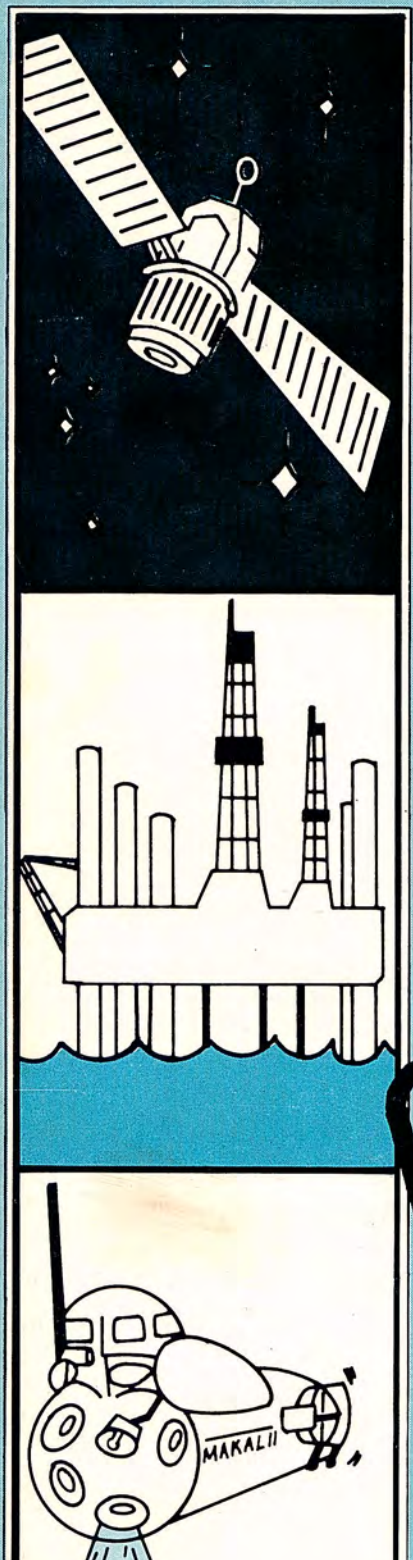

PROCEEDINGS

PACIFIC CONGRESS ON MARINE TECHNOLOGY

PACON 84

MARINE TECHNOLOGY SOCIETY
HAWAII SECTION

HONOLULU, HAWAII APRIL 24-27, 1984

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PACON 84

April 24-27, 1984
Honolulu, Hawaii

Organized by

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PREFACE

The concept of the first Pacific Congress on Marine Technology (PACON 84) was originated in August 1982. The purpose of the Congress was to start a dialogue among the marine technologists and technocrats in the Pacific Basin.

Due to its broad and interdisciplinary scope, the technical sessions of the Congress are grouped under two categories, namely Ocean Sciences & Technology (OST) and Marine Resources Management (MRM). Under nineteen technical sessions, some 95 papers will be presented. Our plan was to have these Proceedings ready before the Congress and hence, with severe time constraints, we did successfully complete these Proceedings which include practically all papers either as a full paper or an extended abstract or a one-page abstract. For obvious reasons, these Proceedings could not include several important papers, such as the keynote speech by Dr. John Byrne, Theme Session presentations under Dr. John Craven, the banquet speech by Dr. Victor Hao Li, Closing Session presentations, and a few other papers which did not reach us in time. Depending upon the availability of funds and other resources, we plan to print a supplement to the Proceedings to include these valuable papers.

We wish to express our thanks to twenty-two sponsors, which include professional/technical societies, federal/state agencies, academic organizations and ocean industry for providing funds, support services and announcements in technical publications. We thank the coordinators and session chairmen for their support, advice and soliciting of papers. The authors deserve a special thanks for submitting their manuscripts in time without which these Proceedings would not be possible.

My special thanks are to the PACON 84 Organizing Committee and the Center for Engineering Research for the untiring support they have given me to make this Congress possible.

Narendra Saxena
Co-chairman, PACON 84
Technical Program Chairman

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OST-1: UNDERSEA VEHICLES & OCEAN ROBOTICS

ADVANCED MARINE VEHICLES - A COMPARATIVE OVERVIEW

J. F. Sladky, Jr.
Department of Mechanical Engineering
University of Washington
Seattle, Washington, U.S.A.

ABSTRACT

The paper is formulated in three parts. The first focuses on the historical developments of the various advanced concepts and traces the key events and benchmarks in each technology. The second phase of the paper is devoted to a qualitative comparison of the different vehicle systems. The last section is more general in nature and addresses the user perspective. Institutional and regulatory aspects are considered. The paper concludes with an examination of the future prospects of advanced marine craft.

Mobility is a vital requirement for man. Whether it is for the obvious military reasons or commercial ones, mobility engenders progress and success. History has shown that societies possessing this capability have grown and prospered, while those devoid of the ease of transportation have withered and collapsed. The degree of mobility is dependent to a large extent on the conditions of the terrain in question. From the earliest times, the water, seas and rivers were the basic transportation routes. These generally did not have elevation obstacles and provided the least resistance to the transfer of goods and commerce. Man, however, continuously demands more from his systems. He needs to move more material and at a faster rate. He himself wants to travel faster and needs to recover natural resources from progressively more remote and hostile areas. All of these factors drive to increase the demand on the capacity of transportation systems. The development of advanced marine vehicles must viewed in this broad perspective.

To increase the capacity of his transportation systems, man has two choices: either increase vehicle size or increase vehicle speed. Each approach, of course, has its advantages and disadvantages. In recent history, it appears that man has opted for the latter--increase vehicle speed. Reasons for this choice may lie in the inherent versatility, flexibility and quick return capabilities associated with high speed systems.

The history of advanced marine craft can be traced through five relatively separate paths. One trend develops in the marine vehicle field. In 1882, efforts of Gustaf de Laval led tot he construction of a ship, the hull of which was "lubricated" by a stream of air bubbles introduced through the hull (Fig. 1). It was hoped that the ship would experience a drag reduction due to the lubricating qualities of the air-water mixture. Developments along this line continued until 1916, when D. Muller von Thomammuhl designed a torpedo boat for the Austrian Navy (Fig. 2). In general appearance, it resembled another attempt at hull lubrication. However, closer examination reveals that for the first time, boundary layer manipulation has been forsaken and an attempt made to physically separate the craft hull from the water surface by an air cushion system. The culmination of the captured bubble or surface effect ship technology is the SES 100 B (Fig. 3) and the demonstrated speeds of this vessel in excess of 100 mph. The current, commercially operating craft are the Bell-Halter 110 (Fig. 4) and the Hovermarine product line (Fig. 5). The key observation to make is that expected speeds have been revised downward and that the technology employed comes from the marine community.

A second historical path can be traced for the air cushion vehicle itself. The air cushion vehicle as we know it today perhaps had its birth in 1716 in the hands of a Swedish minister and inventor, Emanuel Swedenborg (Fig. 6). His proposal consisted of a device resembling an inverted dish which enclosed, over a surface, a volume of air. This volume was to be continuously supplied with air by a man-powered, oar configured fan device. The purpose of the machine was to "fly" and, as such, its connection to the present air cushion vehicle concept may be only through geometric similarity. There were other efforts. However, the key development was marked by a patent issued to C. Cocherelle which covered the peripheral jet or air curtain technique of cushion sealing. Considerable effort was then devoted in England to the development of the peripheral jet seal. The culmination of this undertaking was the English Channel crossing of SR-N1 (Fig. 7).

The present success of air cushion vehicles is largely due to the development in the late 1950's of the flexible seal systems. The flexible seals allow for realistic obstacle clearance capability while retaining minimum aerodynamic daylight gaps, thus minimizing cushion power (Fig. 8). It is the development of these flexible extensions that has made the air cushion vehicle a truly viable transportation alternative. The SR-N1 fitted with fabric seals is shown in (Fig. 9). The technology state of the art is represented by the SR-N4, LACV-30 and the LCAC (Figs. 10, 11, 12). Only the 4 is in commercial operational status at this time.

The third historical path leads us into the wing in ground effect category of surface effect vehicles. Early work by Kaario in Finland focused on the reduced induced drag phenomenon of aerodynamic surfaces in the proximity of an interface. In the early 1920's D. K. Warner was led to the aerodynamic lift concept from experience with hydroplane boat racing. He reasoned that by lifting the craft clear of the water by aerodynamic means he would eliminate the high drag forces of the water and the discomfort of high speed intimate contact with a wavy water surface.

In the U.S., considerable interest existed in the sixties under the Joint Surface Effect Program of the Navy and the Department of Commerce. Ram wing and wing in ground effect craft were constructed and tested. Accidents related to stability and funding problems plagued the programs. Perhaps the most successful craft has been Lippisch's reverse delta (Fig. 13). It is the reverse delta that reduces the center of pressure shift with operating height, and thus minimizes the pitch instability characteristics of WIG craft.

In relatively recent years, the concept of Power Augumented Ram WIG craft has developed. The motivation for ram power augmentation has been the desire to reduce landing and take-off structural loads. The concept provides a capability for the craft to hover on a pressure cushion generated by propulsive jets mounted on the fuselage. Developments in this category include model tests and paper studies. Transoceanic WIG platforms are projected with total displacement of 3 million pounds. Figure 14 depicts one such concept. It is believed that PARWIG prototype designs exist in the Soviet Union. A spin-off from the PARWIG concept is the power augmented landing craft (PARLAC), Fig. 15. This craft used turbo-fan engines to generate a ram cushion under the craft. Propulsion is achieved by bleeding the cushion under the rear seal. Tests appear encouraging.

The fourth advanced marine vehicle concept is the hydrofoil. In its earliest forms the lifting systems were of the surface piercing variety. The lift of this configuration is a function of both the angle of incidence and the immersed area. The surface piercing system is an inexpensive and reliable way to achieve heave and flight control. Perhaps the culmination of surface piercing technology was the Bras d'Or 200-ton hydrofoil (Fig. 16). With the evolution of control technology and the advent of reliable electronics, sensors and minicomputers, it became possible to design and operate fully submerged foil systems. The benchmark for this approach are the Boeing PHM (Fig. 17), the Jet-foil craft (Fig. 18) and the Grumman Mark II Enforcer (Fig. 19).

No overview of advanced marine craft would be complete without examining the small waterplane area concept. While these craft are not high speed platforms, they do exhibit characteristics that are unique. The generic evolution of this concept has its

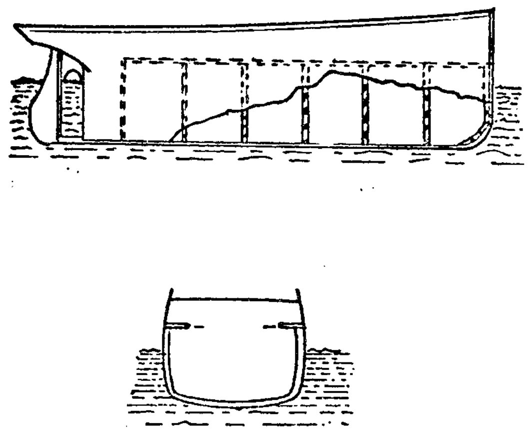


Fig. 1: Hull Air Lubrication

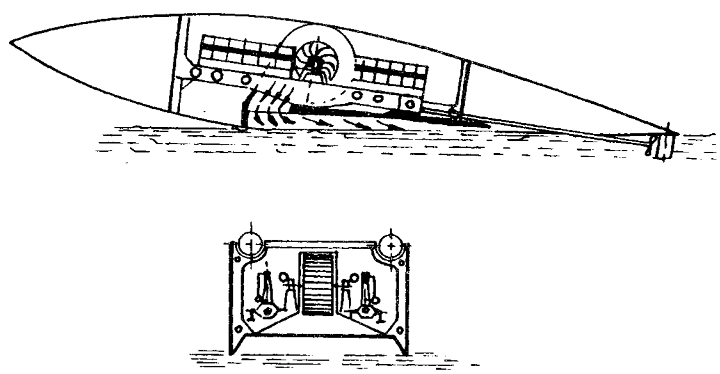


Fig. 2: Austrian Torpedo Boat

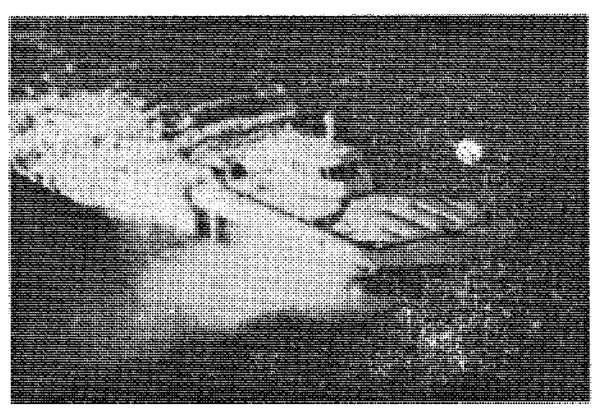


Fig. 3: Bell 100 B Surface Effect Ship (SES)

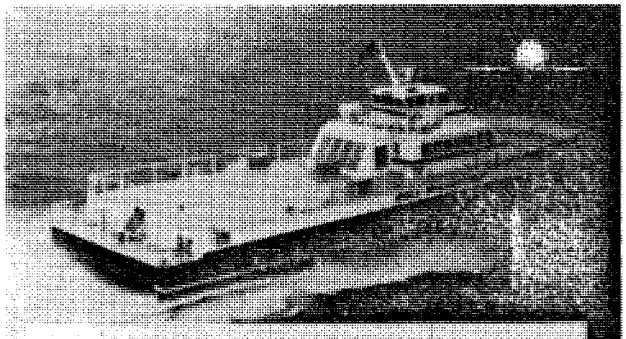


Fig. 4: Bell-Halter Commercial SES (BH110)

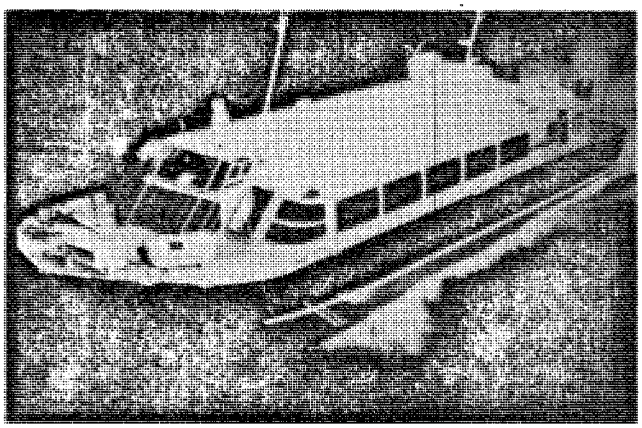


Fig. 5: British Hovermarine HM-2

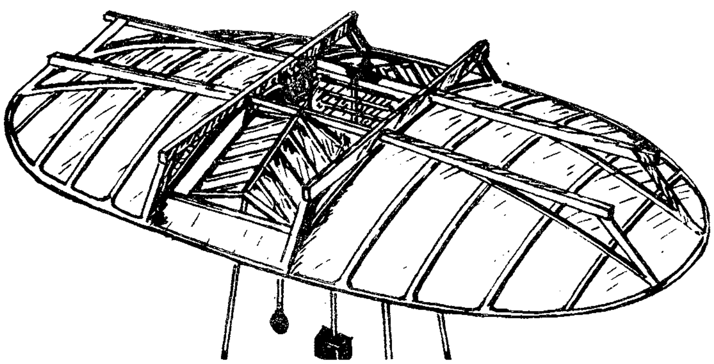


Fig. 6: Swedenborg's Flying Machine

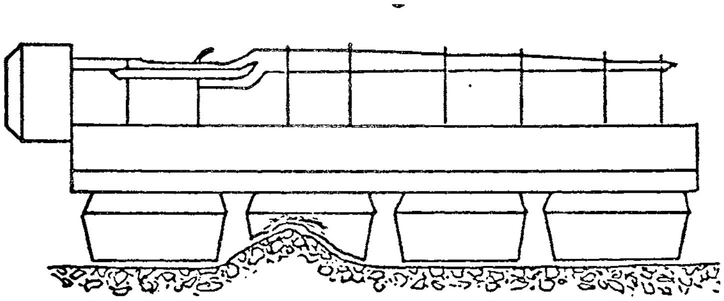


Fig. 8: Flexible Seals

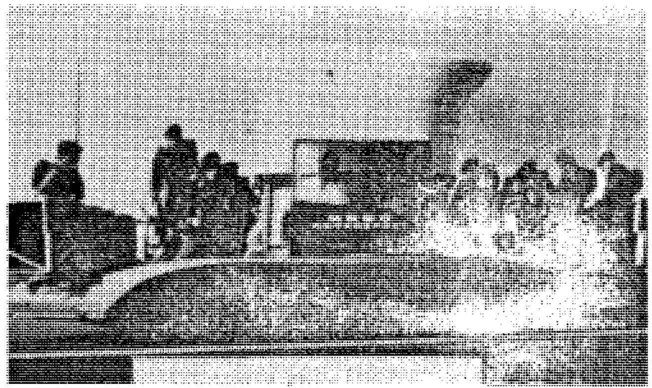


Fig. 7: The SR-N1 Design

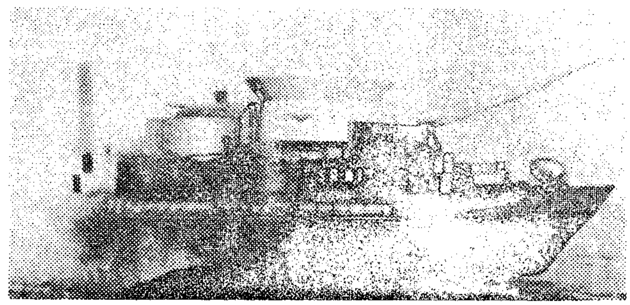


Fig. 9a: SR-N1 Operating Over Significant Obstacles

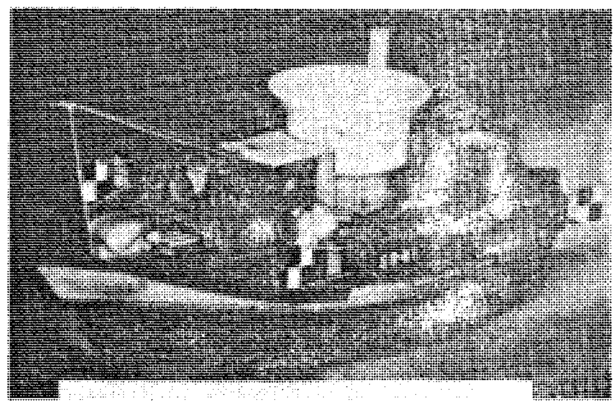


Fig. 9b: SR-N1 Operating Over Water

Fig. 10: Commercial SR-N4

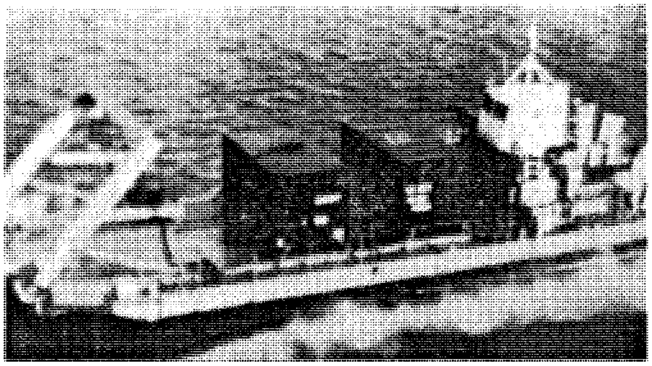


Fig. 11: U.S. Army Lighter LACV-30

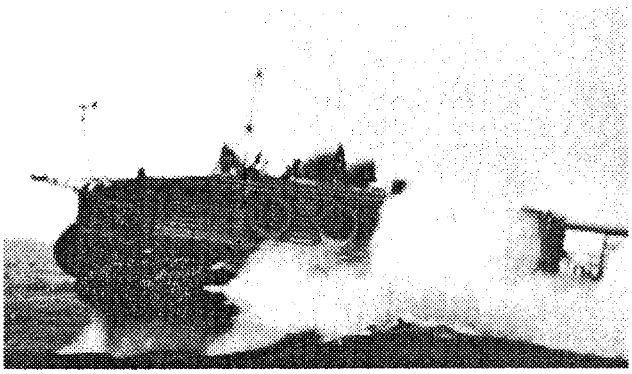


Fig. 12: U.S. Navy Amphibious Assualt Landing Craft

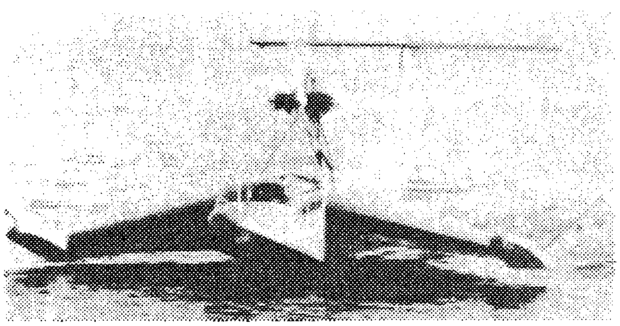


Fig. 13: Lippisch's Reverse Delta Wing in Ground Effect (WIG)

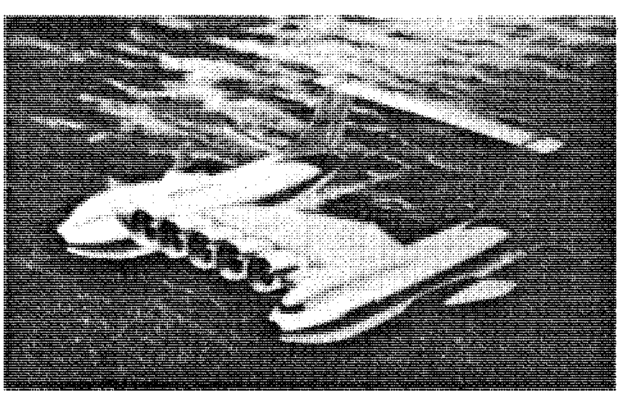


Fig. 14: Power Augmented Ram Wing Concept

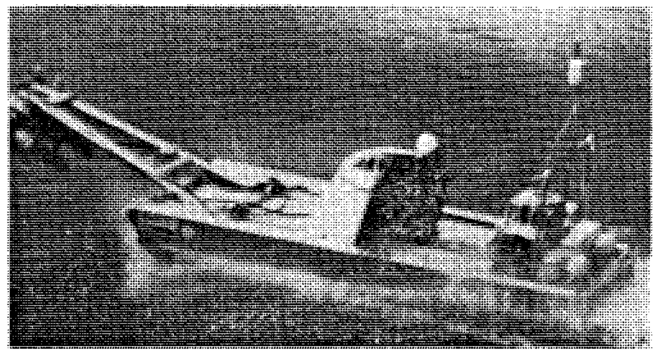


Fig. 15: PARLAC Test Craft

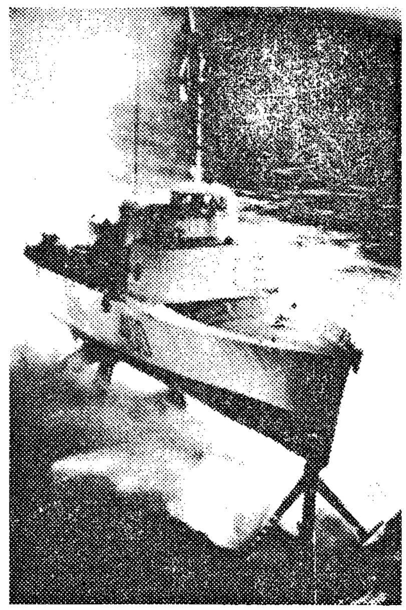


Fig. 16: Bras d'Or Hydrofoil

Fig. 17: Boeing PHM

basis in submarine hull technology. Hull wave-making drag can be significantly reduced or ultimately eliminated if the buoyancy hull is submerged at least one hull diameter below the surface. One type of vehicle employing this concept is the Small Waterplane Area Twin Hull Ship (SWATH). The state-of-the-art in this technology is the Japanese MESA 80-passenger ferry and the KOTOZAKI hydrographic survey vessel (Fig. 20). In the U.S., the Navy is evaluating a SWATH vessel, the KAIMALINO (Fig. 21). Paper studies exist for multi-thousand-ton twin and single hull small waterplane vessels.

In recent years there has been detected a trend in hybridization of advanced marine vehicles (Figs. 22, 23, 24 and 25). Combinations of wings in ground effect, air cushion, hydrofoils, and ram wings have appeared in various proposals. The thrust of hybridization is to eliminate undersirable characteristics of various lift or support systems while retaining their advantageous qualities. It may very well be that the future of advanced marine vehicles lies in the hybrid concept, not only in lift generation, but in propulsion systems as well.

With this breadth of concepts and variety of combinations, can we deduce some commonality in the development of advanced concept marine craft? The first common aspect appears to focus on attempts to achieve high cruise speeds. The problem is to decrease the resistive forces of the media on the hull of the craft. It is apparent, with a few exceptions, that decreased wave making drag is achieved by placing the major part of the marine structure above or below the air water interface. This commonality is evident in air cushion vehicles, hydrofoils, wing-in-ground-effect, and even planning hulls and small waterplane craft.

Unfortunately, the interface seldom assumes a perfectly horizontal line. Surface perturbations--waves--interact with marine structures. This interaction manifests itself in changes in depth of immersion, which leads to changes in buoyancy. This in turn induces vehicle motions and structural loads. There are basically two ways to minimize motions of marine craft: dwarf the interface perturbations or decouple from the interface. Dwarfing the interface is a motions solution of limited applicability: it is often seen in bulk carriers. The similarity of super-tankers and Great Lakes bulkers is an example of this approach. We can thus detect another common feature in the so-called "advanced marine craft," and that is an attempt to reduce the motion as a result of the surface irregularity. It is evident that these craft achieve a degree of "decoupling" from the interface. Air cushions in SES, ACV, and WIG, struts in hydrofoils and small waterplane concepts all serve to mitigate the forcing function of the water surface.

Of the two considerations, the former, speed, may have been the initial driving force for the development of advanced marine craft; however, it probably is the latter--motions--that is and will be the big element in any future utilization and acceptance of advanced marine craft. We may remember that the initiators and proponents in the early years of advanced marine craft were from the aerospace fraternity. It may be interesting to hypothesize about the status of advanced marine vehicles had the development been in the hands of the more tradition-bound naval architects. However, having roots in the aviation industry does not in itself assure success; there are disadvantages as

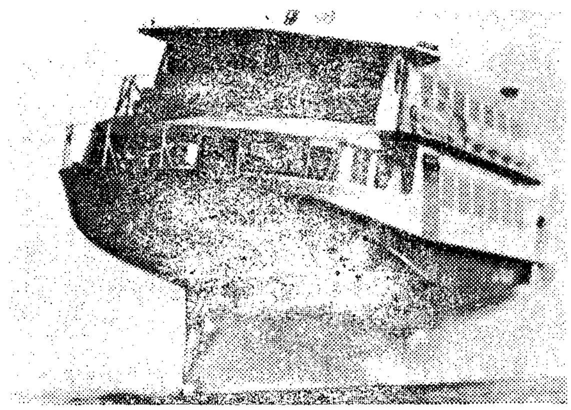


Fig. 18: Boeing Commercial Jet Foil

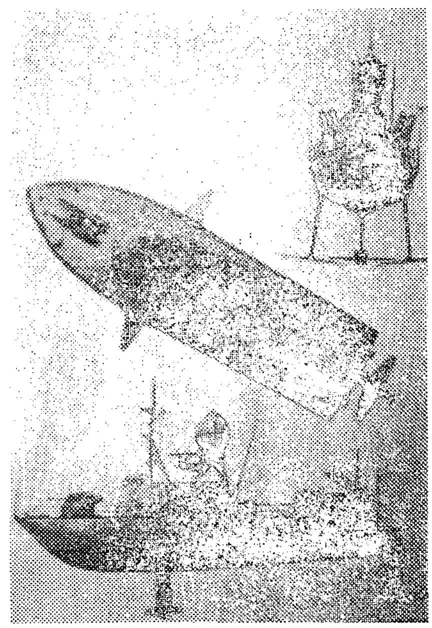


Fig. 19: Grumman Mark II Hydrofoil

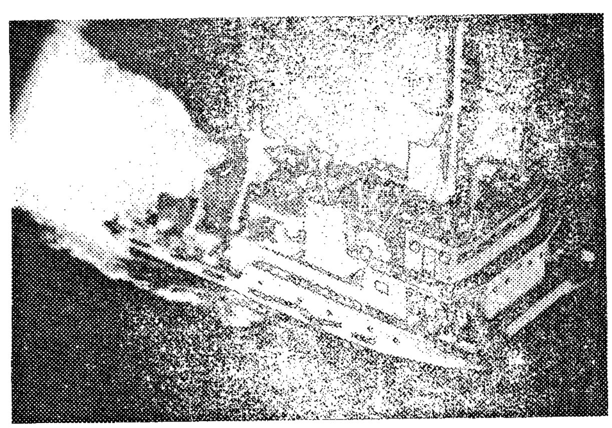


Fig. 20: "KOTOZAKI" Semi-Submerged Ship

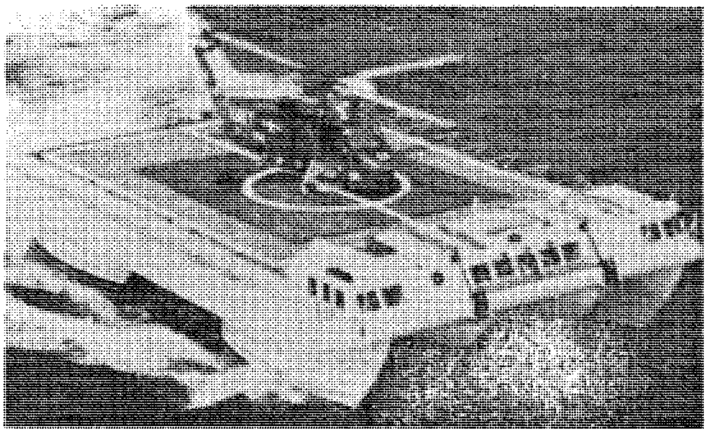


Fig. 21: "KAIMALINO" SWATH Concept

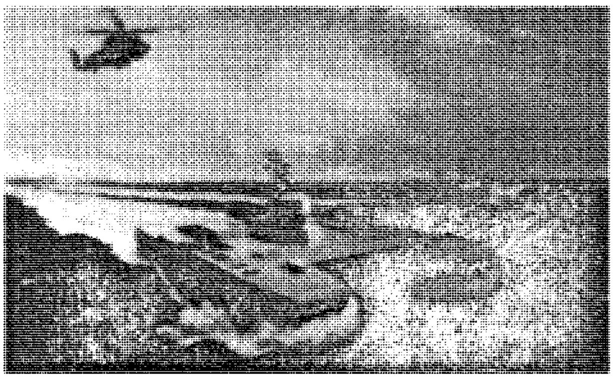


Fig. 22: Catamaran SES Concept

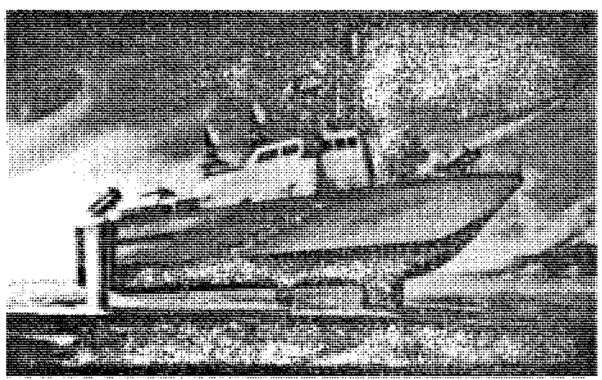


Fig. 23: Combined Semi-Submerged & Hydrofoil Concept

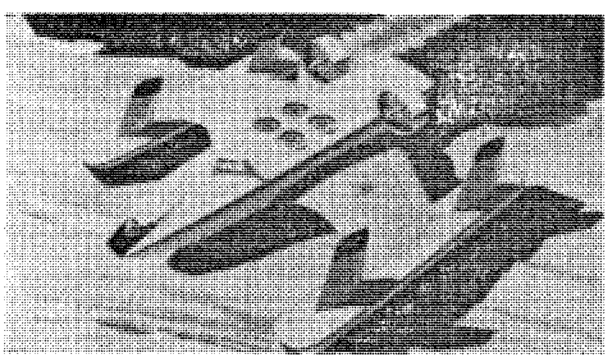


Fig. 24: Wing-Hull Systems

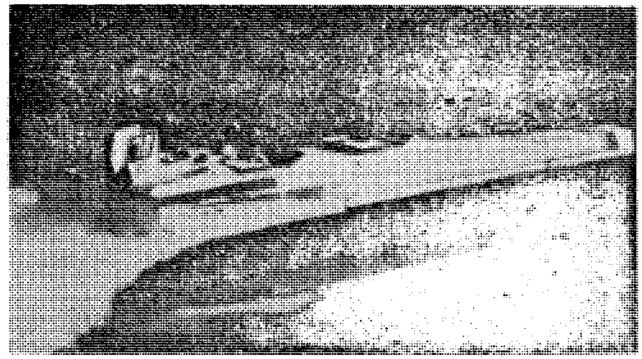


Fig. 25: Seaknife System

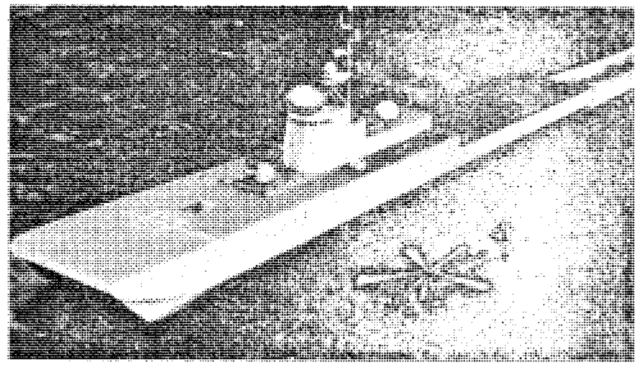


Fig. 26: High L/B Ratio SES

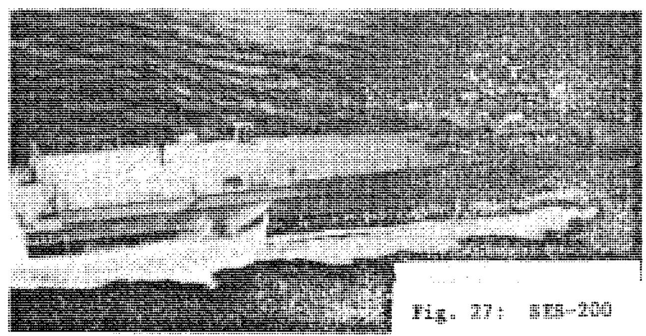


Fig. 27: SES-200

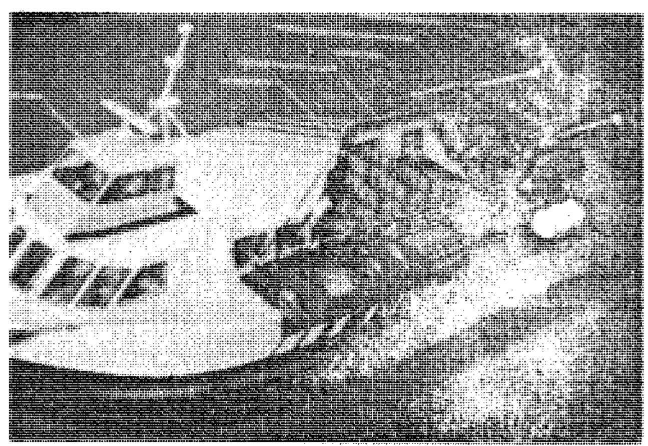


Fig. 28: British Hovercraft Diesel Powered Design

well. Early surface effect vehicles were, for all practical purposes, low flying aircraft, and in many cases powered by unmarinized gas turbines and turning propellers the size of helicopter rotors as thrust generators. And all this in an, at least aviation-wise, extremely hostile environment--salt water, ice, snow, sand, etc. Furthermore, the aviation designer brought with him into the aluminum or steel hull marine practice the dollar per pound attitude characteristics of an aircraft. It is then not surprising that the early craft experienced difficulty establishing an economic position in the transportation spectrum.

The observer today will note that the earlier fervor and belief that the advanced marine craft would perform all missions better than anything in existence has been tempered by realistic technical evaluations and cost considerations. It has been realized that advanced marine craft are specialized vehicles and can perform certain missions exceptionally well. However, pushed "off-design," their once exceptional performance decays rapidly. The situation is analogous to a helicopter. It is the only aircraft capable of sustained hovering flight and thus, in order to justify the high capital and operating costs, vertical or hovering flight must be a stringent mission requirement. So, also, the advanced marine vehicle; its unique capability--be it motion, speed, multi-terrain capability, must be a mission requirement before these craft show an advantage over existing, perhaps more mundane technologies.

What then is in store for the future? Perhaps the most significant general development in the past year has been the degree of dialogue that has evolved between the marine interests and the ex-aero community. There has even been a joint venture or two, Bell-Halter as an example.

In the technology side of the advanced marine vehicles community, there have been subtle but significant trends. Several come to mind:

- In the SES concept there is a trend towards increasing length to beam ratios (Fig. 26, 27). This means that the craft will operate in the sub-critical mode. This yields a positive speed-drag characteristic--a desirable trend at least from the operator's view. It will be interesting to see what length-to-beam values will remain practical. Wave pumping and structural loads in hogging and sagging may establish an upper limit.

- In the propulsion of advanced marine craft there also appears to be a definite trend. The downward revision of expected maximum cruise speed has eased the demand on the propulsion package, so much so that some designs have selected diesel prime movers where before the common fare was a gas turbine (Fig. 28, 29). This yields cascading benefits: lower sfc, lower air rate per horsepower, hence decreased filtration problems, smaller speed difference between the prime mover and the thrust generator, hence lower gear reduction weights and finally, lower initial costs, at least in the smaller horsepower ranges.

- Also, from the thrust generating perspective, the lower speeds introduce interesting possibilities. The air propeller, a common thrust generator for ACVs, must be of low disk loading for acceptable

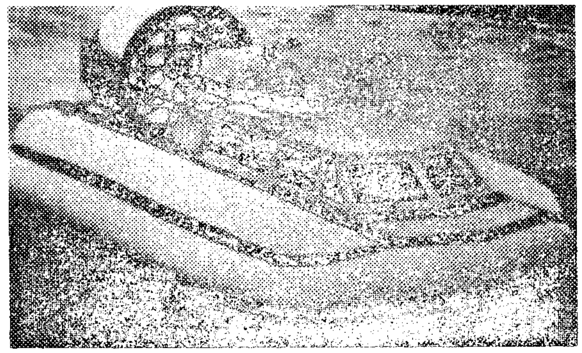


Fig. 29: Small ACV Technology

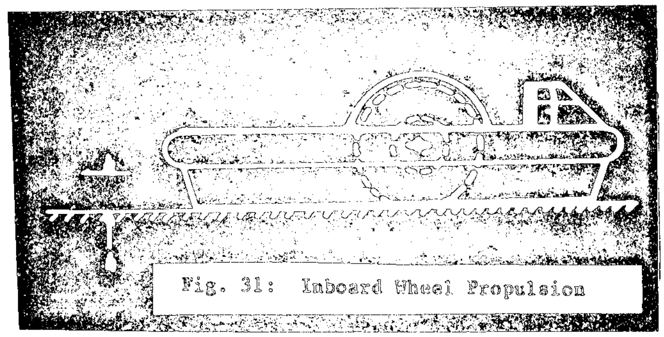


Fig. 31: Inboard Wheel Propulsion

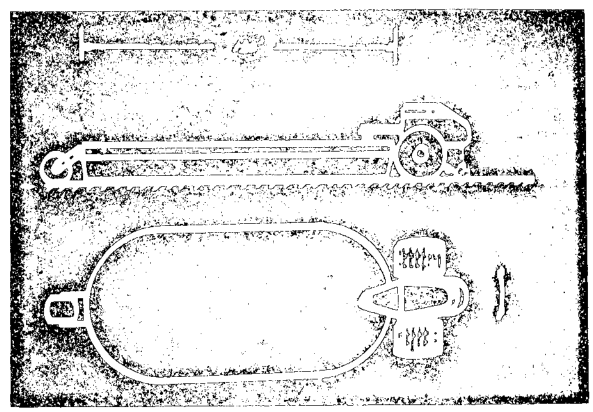


Fig. 32: Tractor-Trailer ACV

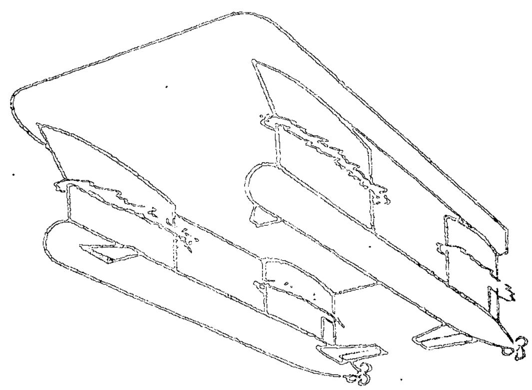


Fig. 33: Present-Day SWATH Geometry

propulsive efficiencies. At low speed the propeller becomes of unacceptable diameter. Alternative propulsors that may appear in the future fall into the surface impulse (wheel) category. Several "wheel" concepts are illustrated in Fig. 30, 31, and 32.

- In the "recent" semi-submerged platform technology, the geometry has largely been set by the "KAIMALINO" layout (Fig. 33). Perhaps the major variation has been the number and location of struts. In the future we may see the hull-strut question addressed synergistically and configurations as in Fig. 34 may evolve. Finally, even greater departures from the norm may yield mission optizmied platforms. Single and triple hull-strut systems (Fig. 35), lifting body hulls (Fig. 36), and low drag configurations (Fig. 37) may develop.

It would be appropriate to make one or two points about institutional aspects or acceptance of advanced marine craft. First, let us consider a passenger ferry system. Here we come up against relatively slow but extremely reliable platforms that plow across waters year in and year out. To enter this market any alternate concept must not only improve on the status quo, but it must also do so with equal if not better reliability. We all have experienced annoyance at cancelled flights; how much more frustrating must it be to be subject to sporadic service on generally only portions of one's journey. The advanced marine vehicle is in a particularly difficult situation in this respect. Unlike the aviation industry, where the technology and the user evolved largely in parallel and unimpeded by existing systems, the high speed marine craft must penetrate a long-standing attitude and mind set, not only in the technology and user, but also in the operator and regulatory agencies. In the U.K. the air cushion vehicle is regulated by the aviation agencies, while in the U.S., marine standards apply. Thus, in order to overcome these hurdles, the craft technical advantages must be significant. Nothing negates a technical advantage as quickly as poor reliability.

From the military perspective, one may develop a platform that performs a specified mission better than any option available. However, once this is demonstrated, numerous other interest groups appear. Choke-point-control will serve as an example. A hydrofoil can perform this task quite well. Suddenly the program feels pressure from the submariners from below, P-3 pilots from above, and surface combatants from the sides--all claiming that the new kid on the block is taking away their missions. The acceptance of advanced marine vehicles by the institutions must be gained by advanced planning and extreme political astuteness.

Advanced concept marine vehicles have proven themselves to be a viable transportation alternative. Their utilization, however, depends on a carefully examined matching question between craft capability and mission requirement. The future will depend on a compromise between technology and institutional acceptance.

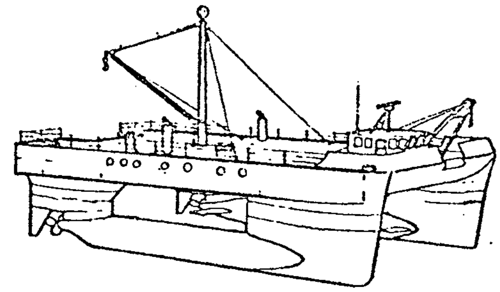


Fig. 34: Hull-Strut Integration

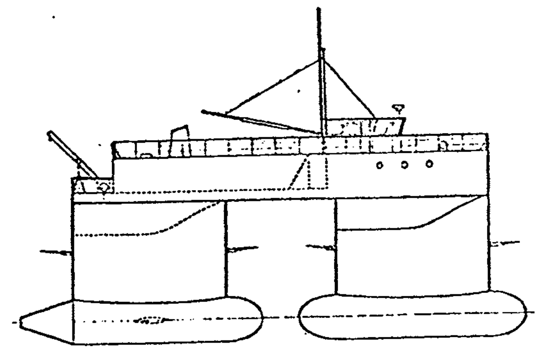


Fig. 35: Multi-Hull SWATH Systems

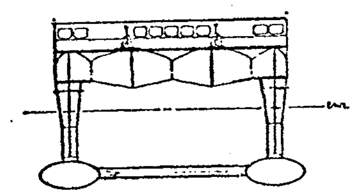


Fig. 36: Lifting Body Hulls

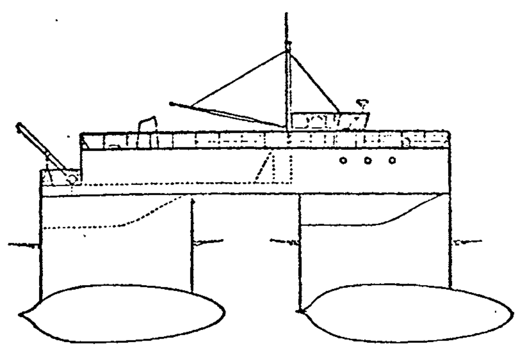


Fig. 37: Low-Drag Hulls

IMPACT OF ADVANCED DIVING SYSTEMS ON DEEPWATER RESOURCE DEVELOPMENT

Steven J. Carnevale
Oceaneering International Inc.
Santa Barbara, California, U.S.A.

Abstract:

Advanced diving systems that have been developed for oil industry requirements can be applied to many different deep water projects. Advanced systems include Atmospheric Diving Suits (ADS), Remote Operated Vehicles (ROV), one man submersibles, and mobile observation bells (MOB). ROVs are excellant observation and light work vehicles. Robotic technology is advancing to the point of giving them complete manipulative capabilities. Manned systems already provide heavy work capability with articulated manipulating arms and the human eyes to observe and make judgements. Yet they keep a person at one atmosphere thereby avoiding psychological complications.

Project applications outside the oil industry include scientific deepwater marine research, underwater cable and pipe laying, deep ocean mining, OTEC, and submarine rescue. These project experiences demonstrate that with proper planning and engineering prior to field operations that advanced diving systems can perform a full range of work tasks that were previously only possible with conventional diving.

Introduction:

Oil and gas discoveries worldwide have created a requirement for sophisticated offshore technology to tap these large reserves. As shallow water resources are depleted, the oil industry is forced to move into much deeper water by using a whole new approach to working underwater.

Traditionally, saturation divers have been used to work subsea. As water depth increases, cost and safety become such important considerations that the oil industry has turned to developing and using advanced diving systems in the form of manned and unmanned vehicles. The equipment involved includes Atmospheric Diving Suits, Remotely Operated Vehicles, one-man submersibles and Mobile Observation Bells. These systems are usually more cost-effective than conventional diving and, in some cases, are the only safe approach to providing underwater intervention.

Each of these alternative diving systems have developed over the last 5 to 10 years and are now considered standard routine operating functions of drilling and production operations. Beyond this application, however, many other fields with underwater interests have been able to take advantage of this new reliable technology and apply it to their own projects. Examples include deep ocean mining, underwater cable laying, OTEC, submarine research, and deepwater scientific marine research.

Manned Submersibles:

The principle advantage of a manned maintenance technique is its visual inspection capability and its responsiveness to unplanned work tasks. The major disadvantage to these systems is their limited manipulative capabilities, which are about equal to that of an ROV. In fact, some one-man submersibles now have ROV operating options because the role of the man inside the suit is minimal.

Although there are a number of submersibles in oilfield service which are operated by two or three-man crews, some of which have diver lockout capability, these are normally assigned to special purpose tasks and are not generally looked upon as cost-effective for most underwater intervention assignments.

The "Mantis" is currently the commercially most popular version of a one-man submersible. It is an elongated pressure vessel with five-function rate-controlled manipulators for performing work, fore and aft-fitted thrusters for propulsion, and variable buoyancy tanks. The vehicle moves in a horizontal posture and has hand controls for propulsion (joysticks) and manipulator operation (push buttons). The major advantage of this vehicle over an ROV is that the man inside the suit can visually observe and has better spatial awareness to co-ordinate manipulator movement. Thus, its manipulative capability is better than that of an ROV with a five-function manipulator. It falls short only when compared to an ROV with a seven-function work system. As with a five-function manipulator-equipped ROV, the tendancy with the "Mantis" is to move the vehicle rather than the manipulator to perform work tasks.

One man submersibles have a large payload, which gives them lifting capability beyond that of smaller vehicles. They do not need to rely as much on lifting devices and tuggers to complete work requirements. This becomes a disadvantage, though, because the larger vehicle requires more access space to the worksite, which is particularly difficult on production wellheads. Likewise, the ROV option on a one-man submersible (unmanned operation ability) gives the client flexibility but creates and extra large ROV.

Manned submersibles borrow the basic design concept of naval submarines. They reduce the submarine down to a 4 man, 2 man and finally a 1 man version. This produces several phenomena. First, these vehicles tend to leave the man in a horizontal position. This forces the operator to strain his neck to view out of the observation dome. It places unnecessary loads on the body, which is uncomfortable and eventually reduces work efficiency. Secondly, there is a tendency for one man submersibles to use joysticks and push buttons for controlling the thruster and manipulator operations. This leads to operator frustration because of the difficulty with maneuvering in midwater while operating rate manipulators. This results in the action previously described where vehicle movement tends to replace four of the five manipulator functions.

The disadvantages of ROVs include high investment cost, special configuration of hardware, limited visual observation and relatively high downtime due to maintenance factors. An ROV with heavy (or intricate) work capabilities requires a seven-function manipulator. This type of system costs 50-100% more than an equivalent manned vehicle. The day rate for a heavy work ROV exceeds other diver alternatives because an ROV still uses a minimum four man crew versus five to six for a manned system (basic manning for drilling support). Therefore, the reduced manning level of an ROV does not offset the large capital investment required to compete with manned systems based on cost.

While society generally expects electronic equipment to fall in price over time, this trend does not appear to be true for ROVs. In order to approach the work capability of manned systems and divers, the ROVs are becoming more sophisticated and in turn more costly. In fact, this holds true for all manipulator-oriented work systems, including manned manipulator-fitted vehicles. This contrasts with saturation systems and atmospheric diving suits (ADS), which are gradually reducing in price as technology improves. The divers are relying on gas reclaim units to reduce gas costs while ADS uses simple mechanical articulated arms providing the ultimate in mechanical dexterity. Maintenance of these mechanical arms is low and they do not require further improvements beyond current designs.

All intervention systems require special attention to the hardware design of subsea equipment. Simple considerations such as valve spacing and fluid control line connection arrangements are important even to conventional divers for quick and reliable tasks completion. ROVs, however, particularly require intervention design considerations because of their limited range of manipulator operation. A seven-function manipulator is used most effectively by parking the vehicle and operating the manipulator. If the arm has good reach, it can perform most tasks with limited tooling requirements (also true for ADS). If only a conventional five-function manipulator is used, the vehicle generally works by opening the manipulator, fixing it, and then driving the vehicle to move the arm's position relative to the subsea equipment. Once the vehicle positions the arm, the jaws are closed on to the specific hardware associated with the task. In effect, the vehicle performs 4 of the 5 functions in the arm. This mode of operation requires large access areas and heavy duty subsea equipment because the vehicle may otherwise cause damage while driving into the hardware. The two-dimensional visual orientation contributes to limiting the manipulator function. The angle of lighting and limited visibility can cause distortion and spatial perception problems, which require the trained eye of an experienced operator. Inspection tasks for large ROVs can be troublesome, especially when visual observation is required to detect leaks or to identify damage and cracking. Finally, ROVs have a high rate of downtime beause of their sophisticated electronic component design. An outstanding ROV operation can be operational 95% of the time with a regular maintenance schedule, a high-reliability vehicle and highly trained personnel. Unfortunately, studies have discovered that most jobs are operational only 75% of the total time. Raising this efficiency level is an industry problem which, of course, requires greater investment in training and vehicle development.

One man submersibles do provide extra payload capacity and have improved observation capabilities over an ROV. However, their larger size and reduced manipulative capablity does not make them as attractive as other manned vehicles.

One Atmosphere Manipulator Bells:

Mobile bells or ARMS bells are one atmosphere diving bells which are fitted with thrusters and have a clump weight anchor system. The bell itself is very positively buoyant but is fixed to the seabed by the adjustable clump weight. The vehicle is raised or lowered in the water by a winch connected to the clump weight system. This provides a very stable platform from which to work when performing tasks and lifting heavy objects.

The ARMS bell operates like an inverted pendulum within a 100 foot radius. It is stationed off to one side of the subsea equipment and drives to it with large, powerful thrusters. This concept was originally designed for drilling rig support, where access is not as critical. Since subsea wellhead access is generally more limiting, the use of an ARMS bell for this type of work requires a more higly modified wellhead design. It is, however, an excellent drilling support tool.

Mobile bells use both five and seven- function manipulators. The commercially most popular, Oceaneering's ARMS Bell, uses a seven-function master/slave system with incorporated force feedback. The use of this type of arm is the major difference bnetween the ARMS bell and a one man submersible (along with the clump weight anchoring). There is sufficient room in an ARMS bell to hold 2 men and a master arm, which controls the slave manipulator. A one-man submersible would not contain the room to house this type of an arm control system. However, several work ROVs are using this system. It is considered the industry standard by which all other manipulators are measured.

Other advantages make the ARMS bell system better than the other alternatives in some respects. First, it has launch and recovery capability in high sea states. It is not as susceptible to damage because of its rugged construction and its negative buoyancy which allows fast movement thrugh the air/water interface. Secondly, a mobile bell offers the opportunity for a client to descend to the work site and personally observe the conditon of the subsea equipment - an attractive feature for many offshore engineers.

Atmospheric Diving Suits (ADS):

ADS combine the safety and cost-effectiveness of the best manipulator work systems, the spatial awareness of manned systems, and have working capability that approaches a conventional diver. They have a perfect safety track record and are designed to be fail-safe, so they are close to ROVs in this respect. They also require the least capital investment. In fact, even with the policy of onsite back-up ahered to by Oceaneering, the main operator of ADS, they remain the least expensive.

The articulated limbs are the key to the unique success of ADS. These arms and legs are designed as a series of ball joints, housed in a fluid-filled cavity which is hydraulically balanced with the ambient pressure of the water. Thus, their easy motion is constant regardless of depth. The articulated limbs are manually controlled by the operator and carefully duplicate the exacting movements of human legs and arms. This makes ADS a far more dexterous and versatile work system than manipulator-fitted submersibles. In fact, even the seven-function force feedback systems cannot compare to ADS articulate arm movement.

The commercially most popular ADS are "Jim" and "Wasp". "Jim" is a fully anthropomorphic suit with both arms and legs while "Wasp" is a legless version of "Jim", (semi-anthropomorphic) which uses thrusters for propulsion. They both have the advantage of the spatial awareness that a manned submersible vehicle offers, except the ADS are smaller and can get in closer for improved visual observation. The system itself is also much easier to control. "Jim" is very stable on the seabed because it has traction and when standing "plants" itself to perform work tasks. "Wasp" maneuvers in midwater but uses foot pedals for thruster control rather than joysticks and push buttons freeing the operator's hands for manipulative tasks. As a team, they are more versatile because "Jim" can perform tasks best on the bottom and "Wasp" in midwater. They also act as an onsite safety back-up for each other.

A disadvantage is their relatively limited payload. ADS generally require assistance for lifting objects in excess of 35 lbs. However, this means they are smaller vehicles and can fit into more restricted areas. The "Jim" system in particular is able to maneuver around a wellhead much more easily than any midwater vehicle.

Design Interface Considerations

With proper planning, alternative diving systems can perform virtually a full range of work tasks. Their capability is dependent on tooling design and intervention design engineering of subsea equipment. If a facility is already built and cannot be modified, then the limiting factor for advanced diving systems is accessibility. If the vehicle or submersible can gain access to a work area, tools can normally be designed to perform most tasks. However, the only reliable way to ensure successful intervention by these alternative diving systems is to perform intervention engineering design work as an integral part of the offshore project design process. Preferably, this parameter will be considered during the early conceptual design stage. Modifications required for vehicle interface do not usually affect the basic project design, particularly if they are integrated early in the process.

Custom tool design can overcome many existing underwater maintenance problems but only proper initial design will ensure that diverless intervention is a 100% reality. Usually, modifications are required to subsea equipment, which do not significantly change the basic design. These are simple changes, such as ensuring access and providing extensions on handles. An important point to recognize is that any modifications which make work easier to perform with vehicles also make is easier for conventional divers. Subsea equipment manufacturers are anxious to provide these alternatives but oil companies, as their customers, must encourage this orientation to subsea design.

The following are general considerations and guidelines for use when designing subsea equipment for vehicle interventions:

- *Vehicles are not as agile as man and are larger, so they need more room when in transit from task to task.
- *All around access to actual "hands-on tasks" of 35 cm (14") is required, more of some kind of tool needs to be manipulated.
- *It should be borne in mind that all types of vehicles have a lifting cable or umbilical attached at all times. Tasks should be clear of overhead obstructions wherever possible.
- *Lift points should be provided on removable equipment so that any workpiece when presented for mating does not need high effort to orientate.
- *Built-in supports for use while dismantling equipment will ensure easier orientations and reduce time required to complete a task.
- *A running tool should be provided for heavy equipment whenever possible.
- *By relieving to core diameter the first two or three threads on any bolt or stud, a more rapid and undamaged make-up can be assured.
- *Permanent and easily definable orientation indications should be provided on any equipment destined for dismantling.
- *Quick connect/disconnects are the most convenient method of making up fluid lines for the vehicle. Male couplings should be mounted rigidly and positioned vertically for easiest operation.
- *Preferably, fluid lines should be mated using quick connect/disconnects. A vehicle cannot generally cope with more than one locking sleeve at a time.
- *Where seals and gaskets are to be placed/replaced, pipework should be designed so that horizontal faces are presented for installing gaskets. It is virtually impossible to maintain a gasket on a vertical face when making up flanges.

New Applications

Many academic and industrial organizations are borrowing this new technology for application to their specific problems. The following projects have already discovered these work systems and may give the reader ideas for other applications.
Deepwater Scientific Marine Research

Under a grant from the National Science Foundation to the University of California at Santa Barbara; six scientists were trained and certified as WASP operators by Oceaneering International, Inc. in August, 1982. The training period covered two weeks and was conducted in a large test-tank facility at the Naval Civil Engineering Laboratory at Port Hueneme, CA. Field diving operations were conducted from the R/V New Horizon which was moored over the Santa Barbara Basin in water 550 m deep. During a 25 day period in September and October, 33 dives were made to depths between 80 m and the bottom (550m). A variety of sampling devices were tested and several video and photographic systems were utilized. Observations were made under three different lighting conditions: white light, red light, no light. Image intensifier (night vision) goggles were used with red and no light and to observe bioluminescence. Both day and night dives were made. Additional surface support was provided by R/V Velero IV which conducted synoptic net tows and hydrocasts to provide comparative and correlative data.

The 1982 dive series clearly demonstrated the value and feasibility of using submersibles such as WASP as an application of advanced technology for in situ mesopelagic research. The suit, is safe, unobstrusive, maneuverable, and easy to operate, thus allowing the scientist/pilot direct access to the midwater habitat for observation, collection, and experimentation. A significant advantage is gained by having the researcher as pilot, not only because it allows the suit to be quite small, but also because it places him or her in direction control of all functions, thus increasing the precision with which operations can be conducted.

Cables and Pipelines:

Between October, 1982 and March, 1983, a large gas pipeline was set from the beach out to the Exxon Hondo Platform (California) in 850 feet of water. Specific project constraints required the pipeline to be installed in three separate pieces. It was connected together on the sea floor with Cameron semi-automatic connection systems. Both the WASP ADS and several Recon J ROVs were used to complete this project which was totally diverless. In fact, this was the largest and most complex project ever undertaken and successfully completed by alternative diving systems anywhere in the world.

Work was performed both from a construction barge and a supply vessel. ADS handled all the heavy work tasks which included:

- Installing screw anchors for a J-tube
- Installing the bell mouth on the J-tube extension
- Positioning and securing 3 spool pieces (105-240 ft long)
- Installing and cutting guide wires
- Retriving equipment lost on the seabed

The ROVs provided the light work tasks and inspection for the pre and post pipelaying operation. Each was outfitted with acoustic positioning systems interfaced with subsea acoustic trisponders to note the exact position of all underwater objects.

For various reasons, not enough pre-planning and engineering occured. While this inhibited the ROV from performing certain work tasks, the ADS had enough flexibility to react to changing project scenarios. Together, they worked as a complimentary team by combining the advantages of each. While such a project approach is not recommended, the results point out the relative advantages of combining both systems.

Deep Ocean Mining:

While this field is many years from actual operations, many consortium's are now working on operational procedures which include aspects of ROV technology. Work tasks range from finding nodules to inspecting operations and even recovering them for field analysis. Several groups are incorporating ROVs into a standard part of their subsea euqipment.

OTEC:

Particularilly relevant to the Pacific Coast Basin, the project has used manned and unmanned vehicles for securing and releasing the main intake. The work tasks are very simplistic compared to oilfield work. Explosives are a good option for severing and recovering the intake tube.

Submarine Rescue:

Several government Navy departments have their own vehicles, as well as, contracts with commercial diving companies for responding to trapped submarines. This primarily involves establishing a lift support line from the surface to the pressure vessel for communication and life support functions. The countries include the USA, Brazil, Britain, and Germany.

Conclusion:

Advanced subsea technology already exists in a reliable and available form. With proper planning and engineering almost any task can be accomplished without conventional diving. A variety of projects outside the normal oil industry scope of work have successfully applied this technology. As the Pacific Basin contemplates its resources developments it should be aware of these develoments and involve them early in basic project planning.

HIGH TECHNOLOGY UNDERSEA RESEARCH AT THE HAWAII UNDERSEA RESEARCH LABORATORY

G.M. McMurtry, E.H. Chave and R.H. Wilson
National Undersea Research Program
at the University of Hawaii
Honolulu, Hawaii, U.S.A.

ABSTRACT

The submersible MAKALI'I is operated by the Hawaii Undersea Research Laboratory (HURL) under a cooperative agreement with the University of Hawaii and the National Oceanographic and Atmospheric Administration (NOAA). The MAKALI'I is a 2-man, battery-powered, 1-atmosphere submersible. It carries a pilot, one observer and a variety of scientific instruments for observing, sensing, recording and sampling the marine environment. The MAKALI'I is transported and deployed by the R/V HOLOKAI and the submersible launch, recovery and transport vehicle (LRT). MAKALI'I dives completed to date include environmental monitoring of oceanic waste disposal sites; geological investigations of nuclear craters and submarine volcanic formations; chemical investigations of gorgonians; fisheries surveys including re-evaluation of precious coral resources, studies of shrimp, grouper and snapper fishing gear; research in the deep waters of atolls; bioturbation; marine biomineralization and community structure of hard substrates. Study areas include Enewetak and Johnston Atolls and the offshore areas of the Hawaiian Islands. As indicated by the scope and variety of dives performed to date, the MAKALI'I is an extremely versatile tool for supporting research in the marine environment. It is anticipated that R/V KILA and ROV SNOOPY will augment and complement the MAKALI'I capabilities in future research investigations.

INTRODUCTION

In July of 1980 the Hawaii Undersea Research Laboratory (HURL) was established by a cooperative agreement between NOAA and the University of Hawaii. HURL is one of the five national laboratories sponsored by NOAA's Undersea Research Program (NURP). The laboratory supports marine research projects that require data acquisition at depths greater than SCUBA limits. The research submersible MAKALI'I is used primarily for projects accepted by a national science review panel which prioritizes solicited proposals for submersible use. To date, the MAKALI'I has completed over 200 NOAA-approved science dives (Table 1).

THE SUBMERSIBLE MAKALI'I

MAKALI'I is a 2-man, battery-powered, 1-atmosphere submersible. It is 4.77 meters (15 feet) long and has a pressurized capsule 1.54 meters (5 feet) in diameter. It carries a pilot, one observer and payload of up to 95 kilograms. Normal operating speeds range from 1 to 3 knots. Dive duration is 4 to 5 hours with life support for 72 hours. Its depth capability is 400 meters.

Table 1 Major MAKALI'I Missions from July 1981 through March 1984

No. Dives	Start/End Date	Min/Max Depth	Project Leader	Purpose	Location
52	-07-13-81 09-17-81	35 to 400 m	Ristvet Noshkin Colin Harrison	Geomorphology Radionuclides Environ. Assess Benthic Metabolism	Enewetak Atoll
10	12-15-81 06-14-82	380 to 400 m	Scheuer	Marine Pharmaceuticals	Makapuu, Oahu
10	01-08-82 10-13-82	100 to 400 m	McMurtry	Geomorphology	East Rift Zone Hawaii
05	01-12-82 01-31-82	350 to 400 m	Wiltshire	Geomorphology	Puna Canyon Hawaii
16	03-29-82 04-29-82	80 m 80 m	Dollar	Benthic Metabolism	Mamala Bay, Oahu Sand Island Outfall
17	04-21-82 05-02-83	250 to 400 m	Maragos	Dredge Spoil Site Transects	Mamala Bay, Oahu Hilo, Hawaii Kahalui, Maui
12	05-14-82 09-20-82	70 to 400 m	Gooding/ Ralston	Benthic Fisheries	Penguin Banks Molokai
15	12-13-82 01-31-83	80 m 80 m	Dollar	Benthic Metabolism	Mamala Bay, Oahu Sand Island Outfall
10	02-14-83 04-12-83	100 to 400 m	Scheuer/ K. Chave	Marine Products Hard Substrates	Makapuu, Oahu
10	06-05-83 06-24-83	30 to 400 m	Fornari	Geomorphology	Kealakekua Bay, Hawaii
20	09-03-83 10-24-83	30 to 400 m	Lobel	JACADS Survey Transects & Measurements	Proposed Disposal Sites Johnston Atoll
10	09-22-83 10-05-83	70 to 400 m	Shomura	Fisheries	Johnston Atoll
06	02-02-84 02-13-84	360 to 400 m	Gooding/ E. Chave	Shrimp Trap Fishing	Mauna Kea Ledge Hawaii
10	03-08-84 03-29-84	70 to 400 m	McMurtry	Geomorphology	East & Southwest Rift Zones, Hawaii

Equipment carried by or used in conjunction with the submersible includes:

1. hydraulic manipulator
2. sample storage baskets
3. color and low-light black and white video cameras, monitors and recorders
4. flood lights and video camera lights
5. 35mm still camera and strobe
6. current and temperature meters
7. environmental monitoring package for continuous recording of temperature, salinity, conductivity, pH, oxygen, solar radiation and depth
8. dictaphone tape recorder
9. water samplers, sediment grab samplers and box corers
10. suction device
11. directional antenna and pingers
12. navigation and submersible tracking system

Various pieces of equipment designed or modified by HURL over the past three years have largely contributed to the success of the missions. For example, a suction device designed by the MAKALI'I chief pilot obtains animals, algae, sediments and small rocks needed for identification or analysis. Other equipment in this category are sediment samplers and the external color camera. The HURL staff also works closely with scientists to modify their instruments or other pieces of equipment for safe and effective use during submersible missions.

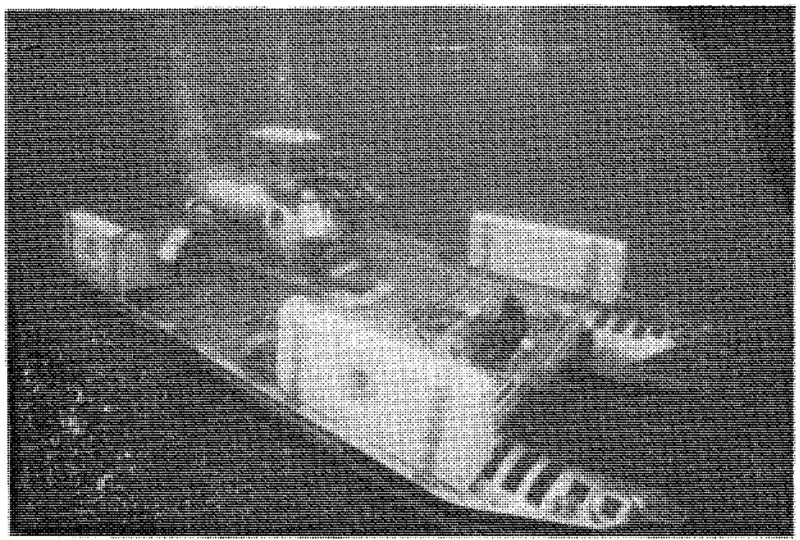


Figure 1. Submersible MAKALI'I being deployed by the diver-operated Launch, Recovery and Transport Vehicle (LRT).

LAUNCH, RECOVERY AND TRANSPORT VEHICLE (LRT)

The LRT was designed specifically to transport and deploy the MAKALI'I in oceanic waters. It is a submersible platform controlled by SCUBA divers and towed to a dive site by a surface support vessel. The LRT submerges with the MAKALI'I to a depth of about 17 meters where the submersible is released by the support divers (Figure 1). The LRT then resurfaces. On completion of a MAKALI'I dive, the LRT resubmerges. The MAKALI'I lands on the LRT deck, and is secured. The LRT and MAKALI'I are then brought back to the surface. This operating procedure ensures a safe subsurface launch and recovery of the MAKALI'I in up to 3.66 meter (12 foot) seas.

THE REMOTELY OPERATED VEHICLE SNOOPY

ROV SNOOPY is a small, tethered, remotely operated vehicle developed primarily for underwater observation. It was recently added to the HURL facilities. Real-time viewing is provided by a black and white video camera with quartz-iodine light source. The vehicle is currently designed for operations to a depth of 400 meters and new designs are being considered to extend this operational depth. Vehicle propulsion is provided by three pressure-compensated electric motors which are proportionally controlled on the surface. Power and control signals for the thrusters, cameras and lights are multiplexed to the vehicle on a single co-axial cable. A second co-axial cable carries the video signal to the surface. To supplement black and white video information, a super 8 color movie camera is provided for limited photographic documentation.

SUPPORT VESSELS

At present, the support vessel for HURL is the research vessel HOLOKAI. The HOLOKAI is 20 meters (65 feet) in length, twin screwed and operates with a crew of two. The vessel is equipped with a towing winch, 50 KW generator, LORAN C receiver, radar, gyro-compass, autopilot, fathometer, high-pressure air compressor and storage bank, VHF and CB communications and 4500 gallon fuel tanks. HURL is currently preparing to use another support vessel, the 34 meter (105 foot) R/V KILA, in future operations. The KILA operates with a crew of seven and has berthing for seventeen persons. It has satellite navigation, a wet laboratory, and ample deck and storage space. HURL anticipates that the KILA will allow extended operations in remote areas.

HURL DATA ARCHIVES

HURL provides a data package which includes a voice tape transcription, environmental data printout, a copy of the videotapes, a videolog, slide duplicates and a data summary listing. It organizes and archives the original data so that any part of the material taken on a dive can be retrieved for the project leader, duplicated and sent to other experts for analysis. The data are also available to individuals who need information for their own research. The project leader may request that permission to use these materials be subject to his or her approval for up to two years after a dive.

MAJOR PROJECTS TO DATE

The first HURL mission at Enewetak in the Marshall Islands used the MAKALI'I to study the Atoll's deep lagoon and outer reef environments, the morphology of large, submerged thermonuclear craters and the distribution, mechanisms and effects of bioturbation on the lagoon floor. The scientific results of the 52 dive mission encompass: outer slope biotic zonation and geomorphology; diversity, abundance and trophic structure of fishes and invertebrates on the Atoll's outer slopes; lagoon sediment community metabolism and nutrient dynamics; callianassid (Crustacea, Thalassinidea) bioturbation and its influence on sediment radionuclide distribution; the distribution and abundance of *Halimeda* sp. on the deep reefs; and geological investigations of the effects of cratering by large thermonuclear blasts. The results of these studies were presented in an Enewetak symposium at the Sixty-third Annual Meeting of the Western Society of Naturalists, and are being submitted to a special issue of the *Bulletin of Marine Science*.

JOHNSTON ATOLL STUDY

Since Enewetak, HURL has conducted multidisciplinary missions around the Hawaiian Islands and at Johnston Atoll. The MAKALI'I was involved in four projects at Johnston Atoll: environmental monitoring, fisheries assessment, island processes and biogeography.

Baseline information required by the EPA was collected at two proposed scrubbed-brine waste disposal sites on the slopes of the Atoll. The results of this mission are now being analyzed by the observer team and indicate that the two areas studied were low in floral and faunal diversity and abundance in comparison to other areas studied by fisheries observers. This was due in part to the zoogeographical isolation of the Atoll and to the steep, smooth, limestone and sediment covered slopes. The submersible was successful in monitoring the disposal of 500 gallons of salt, water and dye of the same density as the proposed scrubbed brine.

Preliminary results of physical oceanographic studies indicate circular and variable current patterns off the leeward side of Johnston Atoll. MAKALI'I observers reported up to seven changes in current direction, including downwelling and upwelling in the same area.

The National Marine Fisheries Service investigated the deep benthic fisheries (mainly snappers, groupers and jacks) at ten localities around the Atoll. The NOAA research vessel, TOWNSEND CROMWELL studied the fisheries in the same locations as the submersible in order to correlate observed abundance of the fisheries with the catch at each station.

The submersible was also used to study the geological evolution of the Atoll. Limestone caves with stalagtites and stalagmites, indicators of dissolution above sea level, were found 400 meters below the surface of the Atoll, indicating that it has submerged at least 400 meters beneath the sea.

The fourth project consisted of two dives to determine deepwater algal diversity and abundance. Algal diversity was low in comparison to Hawaii, although in localized areas above 75 meters algal abundance was extremely high.

HAWAIIAN ISLAND STUDIES

HURL has undertaken several large programs in the Hawaiian Islands. These programs include studies of the effects of dredge spoil on the deep benthos; benthic metabolism around deep sewer outfalls; mapping and exploration for hydrothermal vents on the submarine East Rift Zone of Kilauea Volcano; mapping the Puna Canyon and Kealakekua Bay undersea sites; studies of shrimp, grouper and snapper fisheries and fishing gear; deepwater marine product collections and precious coral surveys; marine biomineralization; and community structure of basalt and limestone substrates.

Two pioneering fisheries projects initiated by the National Marine Fisheries Service have used the submersible to observe deepwater fisheries. During the first project, fisheries scientists observed the behavior of pink snapper (*Pristopomoides filamentosus*) aggregations which were attracted to baits attached to lines from a fishing vessel. On the second project, different kinds of deepwater shrimp traps were set and MAKALI'I observers studied how they were positioned on the bottom and the catch rate of each trap with respect to depth and substrate type. Heterocarpid shrimp distribution and behavior around and at a distance from the traps was also studied.

Submersible studies of the effects of dredge spoil on the deep benthos was initiated by the U.S. Army Corps of Engineers. The Mamala Bay, Oahu; Kahalui, Maui; and Hilo, Hawaii disposal areas were chosen for study. Dredge spoil materials were found at all three sites but the deep benthos was affected only at the Mamala Bay site, where thousands of tons of dredge spoil was disposed. Mamala Bay disposal and control sites were compared and the number of animals associated with eutrophic conditions such as worms, hydroids and sponges were found to be an order of magnitude more numerous at the disposal site. Several species of larger fishes and invertebrates followed the same trend although their distributions were patchy and tended to be substrate dependent.

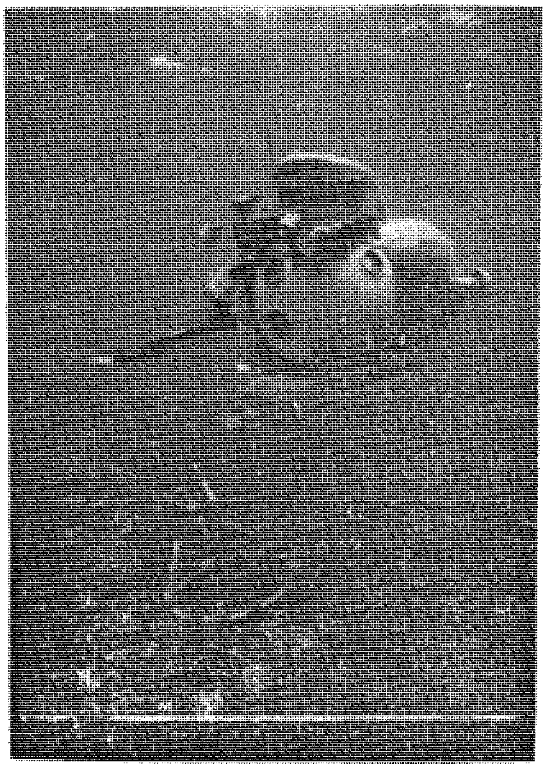


Figure 2. Submersible MAKALI'I deploying dome to monitor the Sand Island outfall.

The Sand Island Sewer Outfall metabolic studies are ongoing. This project uses light and dark domes equipped with recording instruments and deployed by the submersible to record respiration, photosynthesis and nutrient enrichment of the environment (Figure 2). The domes are set in selected locations at various distances from the outfall. Work to date indicates that the microbiota in the vicinity of the outfall effectively recycle the waste material so that the area is surprisingly unpolluted.

Investigators using the MAKALI'I have also studied and collected various organisms in the Makapuu, Oahu gorgonian beds. Most of the material collected was used by organic chemists to isolate possible marine pharmaceuticals. Several previously unknown, promising compounds were discovered from the blue gorgonian Placogorgia sp., the gold zooanthid Gerardia, the mushroom gorgonian Anthomastus fisheri and the sponge-eating nudibranch Tritonia. The precious coral genus Corallium is also being studied to determine their rates of recolonization in the areas of the gorgonian beds.

A multidisciplinary group of scientists has begun to analyze the community structure of hard, basaltic and limestone substrates from 75 to 400 meters in selected Hawaiian localities. The geochemists in the group have dated limestone collected by the submersible and have determined that this material is composed mostly of skeletal remains of Pliocene shallow water organisms. These skeletons have been cemented by calcium carbonate subaerially. Some of the deep limestone terraces are notched, indicating that they were once at sea level.

HAWAII SUBMARINE GEOLOGY PROJECTS

The MAKALI'I was used as part of a major investigation of the origin and sedimentology of the Puna Submarine Canyon off the eastern coast of the Island of Hawaii. Five dives were used to investigate the underwater terrain near the mouth of the canyon, to measure the flow of freshwater into the sea, and to sample sediments and rocks for geochemical and sedimentological studies. The underwater terrain was very irregular with major changes over small distances. The environmental monitoring package was sucessfully used to locate and verify areas where fresh water was flowing into the sea. These data together with aerial infrared surveys suggested a significant process of canyon formation by submarine groundwater sapping.

During mapping of the Kealakekua Bay undersea eruption site of 1877, geologists used the tracking system for precise positioning of the MAKALI'I. This system was accurate enough to relocate and resample a small vent from which a rock sample had been taken on a previous dive. Scientists found that most of the area from which the 1877 flow had emerged was covered with a thick bed of the coral Montipora. Specimens from the Kealakekua Bay lava flows and a 100 meter thick carbonate cliff, discovered at depths of about 150 to 250 meters, are currently being studied.

The MAKALI'I is also being used to map and search for submarine hydrothermal springs on the upper portion of the submarine East Rift Zone of Kilauea Volcano. No active submarine springs have been found to date. However, features such as relatively fresh pillow basalt flows that may represent submarine eruptive activity at a depth of ca. 350 meters have been discovered, and some red-brown coloration in the vicinity of collapsed lava tubes that may be the result of past hydrothermal activity have been noted. Rough topography due to flows parallel to the East Rift Zone was observed, as well as variable bottom types consisting of a'a flows, pahoehoe flows and large sediment fans.

Hawaii Institute of Geophysics Contribution no. 1468.

R.C.V. UTILIZATION IN DEVELOPMENT OF PACIFIC BASIN RESOURCES

Mark D. Iwanowski
Hydro Products
San Diego, California, U.S.A.

ABSTRACT

The role of the remotely operated vehicles in expanding, economically, the resources of the Pacific Basin resources will become increasing evident in the coming years. The exponential growth in the use of ROV's in support of the off-shore oil industry during the seventies will be paralleled by a similar growth in developing Pacific Basin resources.

As is now the case in off-shore oil rig support, the Hydro Products' RCV-225 and RCV-150 will prove to be invaluable tools in maintaining and inspecting the massive Ocean Thermal Energy Conversion structures. Since the commercial usefulness of the ROV's have been proven in off-shore oil, the designers of these structures should consider the adaptability of these vehicles to OTEC support. Because the off-shore oil market was already substantially developed prior to the commercial market introduction of the ROV's, this foresight was not possible in the off-shore oil market and because of this, the usefulness of these vehicles has been somewhat limited.

Some of the recent developments and improvements to the Hydro Products RCV-225, such as higher thrust motors, real-time color capability, microprocessor control, computer image measuring system, etc., will be described and their applications to the OTEC marketplace discussed. Also the expanded capabilities of the RCV-150 and other survey systems developed by Hydro Products will be addressed with respect to both the OTEC market and in manganese nodule mining applications.

Manganese nodule mining could very well play a major role in Pacific Basin economics by the end of this decade if proper commercial emphasis (funding) is placed on the development of advanced undersea remote controlled vehicles to support such operations. Some of the studies Hydro Products has done in this area will be discussed and recommendations made.

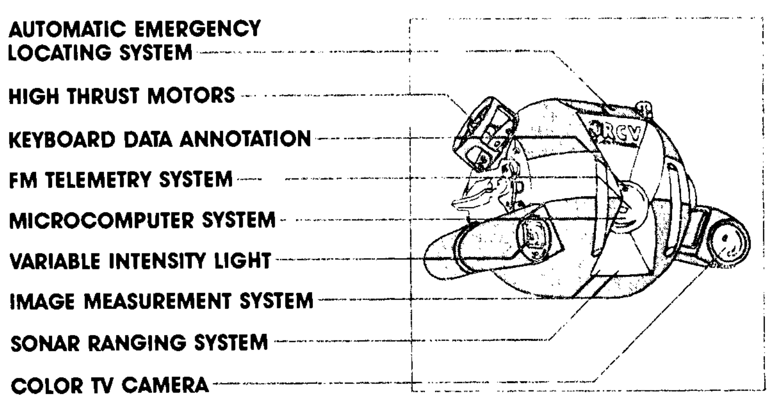
HISTORICAL DEVELOPMENTS

The threefold increase in the cost of production crude oil in the 1973-74 timeframe established the subsequent acute change in the economics of energy production. This sudden increase in the cost of crude was the major influence in the development of off-shore oil resources. The move to subsea oil exploration and production was the principle impetus in the rapid growth of commercial Remotely Operated Vehicles (ROV's). Since the early seventies there were but a handful of commercial ROV's, today this number is approaching six hundred. The technology level of these robotic unmanned tethered vehicles is now moving from the "development" phase of the relatively unreliable, performance-limited vehicles to advanced technology high performance and high reliability work systems.

Hydro Products has been actively involved in commercial and government-funded vehicle developments since the early 1960's. The first commercial vehicle produced by the company was the RCV-125. After some early design improvements, this vehicle evolved into the compact and highly maneuverable RCV-225. There are now approximately 50 systems operational around the world. This vehicle is used principally as a flying eyeball, but recently some new state-of-the-art improvements have been made in the system allowing for greatly enhanced capability.

An improved deployment system has been introduced with 100% active level wind and designed to operate in hazardous environments. In addition, new high power density thrusters have been developed which allow for three times the shaft horsepower of the previous design with no increase in motor size or input power requirement. This threefold increase allows for a greatly enhanced operational envelope. The new DC brushless design also has increased motor life (exhibited by a life cycle test motor with over 6,000 continuous hours - the equivalent of about five operational years) and decreased motor maintenance to an extremely low level.

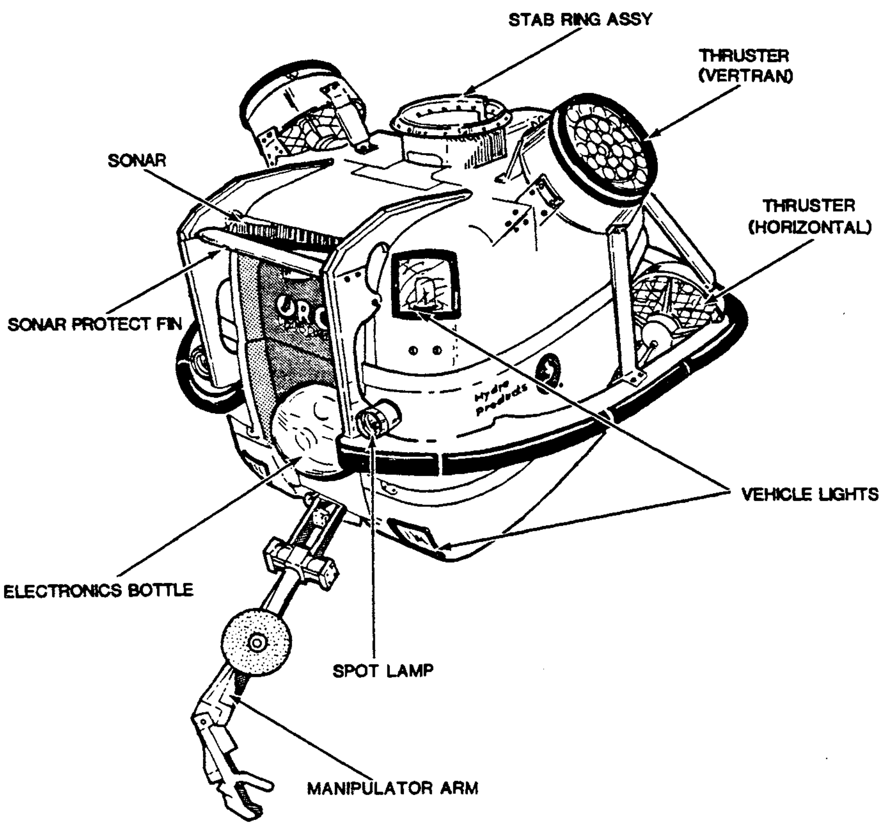
Most recently, the RCV-225 has gone to a microprocessor control and an RF communication link. The RF link permits transmission over a greatly extended cable length and helps to enhance the video signal displayed due to its lower susceptibility to system noise coupling. The microprocessor base has opened up new avenues for vehicle use. For instance, with the microprocessor integration, a sonar ranging system has been developed for use onboard the RCV-225 which supplies range information to the nearest target (up to 30 meters). This information is then processed and an electronically scaled grid pattern is displayed on the system video monitor. The grid is scaled proportional to the range of the object being measured compensating for the parallex viewing effect. This electronic measuring capability allows the operator of the RCV-225 to measure and document specific objects, corrosion or stress cracks in subsea structures. In addition to depth, heading and camera pitch angle information previously displayed on the monitor, both range and vehicle voltage are now also displayed. Any additional information, such as day or structure position, can now be annotated on the screen via a keyboard interface.



RCV-225 SYSTEM ENHANCEMENTS

A real time color viewing capability has also been added to the RCV-225. This color capability has been developed to augment the 35mm still color camera/ strobe capability of the Photosea 1000 System which has been used successfully for years on the RCV-225. The color system also includes an additional variable intensity 250 watt light to augment the standard vehicle lighting which has also been doubled in intensity (from 90 to 200 watts).

The big brother of the RCV-225, the RCV-150 was developed as a highly maneuverable, light-work capable ROV. This vehicle, in addition to being a flying eyeball, has a four function manipulator capability including both a rotary saw, pinching blade and grabber jaw. The RCV-150 has recently been fitted with a second four function arm extending the work capabilities to much more extensive and complex tasks.



RCV-150 SYSTEM

OTEC DEVELOPMENT AND THE ROV

The principal problem commercial ROV manufacturers must contend with in developing work-capable ROV's for the off-shore oil industry has been the fact that the oil platforms are not designed with the ROV in mind. The historical significance of this is that the off-shore oil market was already well underway prior to the advent of the commercial ROV and even today, little emphasis has been placed on the ROV interface in subsea oil production support. This lack of consideration has, substantially, hindered the use of ROV's in platform support. Hydro Products has recently initiated discussions with some of the wellhead fabricators towards resolving this important problem.

With the development of Ocean Thermal Energy Conversion (OTEC) now taking place, a unique opportunity arises to facilitate the eventual production support requirements which will inevitably be placed on the ROV.

OTEC ROV TASK DEFINITION

The principle use of commercial ROV's has been to conduct visual and photographic inspection of the underwater installations. The reason for their popularity is primarily economic. To have a diver perform the same inspection tasks at deep depths requires saturation diving techniques which are both expensive and time consuming. With the initial purchase outlay for the system amortized over many years of operation, the cost savings becomes quite evident. In addition, the obvious hazards associated with platform diving are eliminated and operational insurance costs are also therefore reduced.

While it is not possible to foresee all the areas that the ROV will be called upon in OTEC platform support, it is important to define some of the basic tasks which will be required of the ROV. These areas include:

- Survey of the proposed production site, particularly in shelf-mounted designs
- Site debris clearance
- Visual reference for initial structure placement
- Verification of component alignment and securing
- Corrosion protection verification
- Detailed structural inspection
- Cleaning prior to structural inspection
- Valve opening/closing
- Cold water intake screen cleaning and inspection

Real time and photographic inspection requirements will most assuredly be placed on the OTEC structures just as is now required on oil platforms. The inspection requirements necessitate minimal integration prerequisites with the ROV. Because of this, the ROV has been successfully integrated as the principle oil production inspection device. Hence, if the OTEC designer gives due consideration to accessability to critical structural elements, there should be few difficulties with the integration of ROV's as inspection tools for OTEC use.

Although pre-installation site inspection is not an area requiring ROV integration design techniques, it is an important area presently being accomplished by the ROV in support of off-shore drilling. This is usually done by augmenting visual techniques with a scanning sonar mounted either on the vehicle or its launcher cage. This is an area where the machine is supplanting the diver because of the enhanced capabilities of long range sonar and high resolution, low light level cameras. With the scanning sonar of the RCV-150 and the image measuring system of the RCV-225, coupled with both low light level and color cameras of the vehicles, detailed site inspection can be optimally performed.

Other than inspection tasks, ROV's are demonstrating capabilities in performing work tasks previously performed by divers or manned submersibles. Both the RCV-225 and the RCV-150 have proven to be quite capable in debris removal. Because the RCV-225 is such a small vehicle, it is incapable of reacting large objects. Tag lines have been used here returning such lines to the surface and having a weighted 'go-getter', pulling a heavy lift line from the surface, guided down the messenger line. The RCV-150, being a larger, more powerful vehicle has successfully performed many debris removal tasks under its own power using its built in manipulator(s).

Corrosion protection of the OTEC structures will assuredly follow the evolving guidelines placed on oil platforms. This is an area where proper foresight on the part of the structural designer can play a significant role in lowering maintenance and repair costs of the structure. Typically, sacrificial anodes used on subsea structures have 15 to 20 year life spans. Presently, the replacement of the anodes are done by a team of divers at a very high cost and danger to the divers. Hydro Products has developed a proprietary bouyant anode design to facilitate the exchange of sacrificial anode on subsea structures; it is designed to be used in conjunction with an RCV-150. If such a capability is designed in by the OTEC designer, a significant savings in cost and diver risk will be evident over the life of the structure.

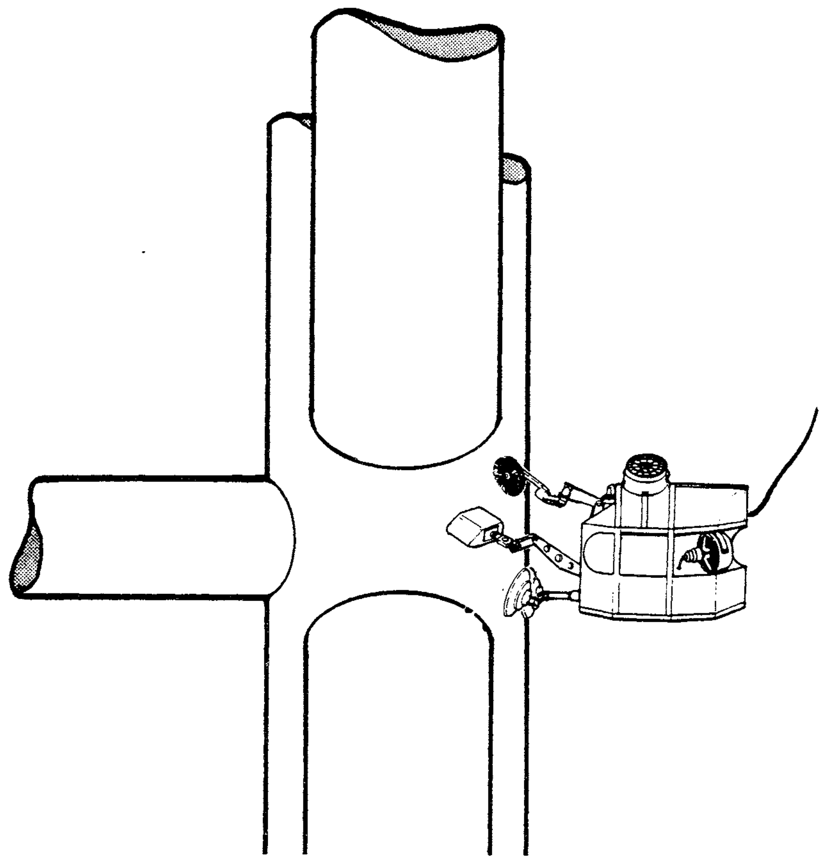
In fairly clean portions of the subsea structure, CP measurements have been successfully performed with the RCV-225 and RCV-150. Other NDT techniques which are being performed routinely by divers at shallow depths, are now being developed and used by ROV's. The major difficulties here are in performing measurements in high stress areas which are difficult to access. Due to the complex shape of many of these critical inspection points, it becomes quite difficult to accurately position the vehicle while cleaning and inspecting the joint.

Since most areas require pre-inspection cleaning of marine growth, built-in vehicle grasping/reaction hardware should be incorporated at key inspection points requiring such cleaning so that the loads caused by manipulator reaction forces and hydrodynamic vehicle loading from vortex shedding and high current conditions can be adequately reacted by attachments to the structure.

Hydro Products has developed a proof of principle work vehicle design which can perform the above tasks efficiently. This vehicle has a proportional rate manipulator arm incorporating a stero camera system, still color camera and lights. A second, spatially correspondent master-slave manipulator performs work tasks such as wire brushing and debris removal. In addition, there are two suction cup devices used to attach the vehicle to the structure rigidly so that hydrodynamic and work related forces will be reacted without requiring vehicle propulsive power. See following page.

Another area where the OTEC designer should consider the ROV is in cleaning and replacement of the cold water pipe (CWP) inlet screens. Because of the depth of these screens, it will be most cost effective to perform this activity subsea and with an ROV. The removal/replacement concept should require minimum complexity of the subsea hardware as the reliability of this hardware is usually directly proportional to its complexity.

Finally, the design of the CWP, itself, should consider ROV utilization. With a 30 year design life goal of the OTEC structure, it is evident that some level of subsea repair capability will be required on the CWP. It is here that the design of such repair patches or sleeves must be designed with ROV capabilities in mind.



WORK VEHICLE MODEL

OCEAN MINING

Two important ROV-capable tasks are required in deep sea "mining": bottom survey and production mining. Hydro Products has many years experience in the deep sea survey field. In 1974 Hydro Products introduced the Deep Sea Survey System which was used to survey 100 nautical miles of the Pacific Basin ocean bottom at depths to 5,000 meters. This system successfully recorded large areas of manganese nodule concentrations. The use of this proven capability would be quite effective in mapping much larger areas of the Pacific Basin for commercial mining exploitation. Subsea resource mining is, like OTEC, in its infant phase. This is a field in which a close working arrangement will be required between the eventual hardware user and the equipment developer. This relationship has proven quite effective in allowing the system designers a better understanding of the operational problems in present ROV development. The result of which has been development of the most useful vehicle enhancements to facilitate the users tasks and therefore increase profitability. The aforementioned RCV-225 and RCV-150 improvements evolved through this process.

Hydro Products' DSS-125 Deep Sea Survey System is an advanced deep ocean television/photographic towed viewing system which incorporates unique design concepts in towed platform stabilization and underwater television viewing to achieve precision visual surveys. Detailed television and photographic survey tracks can be conducted at depths to 6,000 meters.

Key features of the system include:

- Stable towed platform for optical surveys.
- Long range underwater viewing system for surveying 5 to 10 meters off the bottom.
- Remote control and data feedback multiplex telemetry system.
- Complete system operates over single armored coaxial cable.

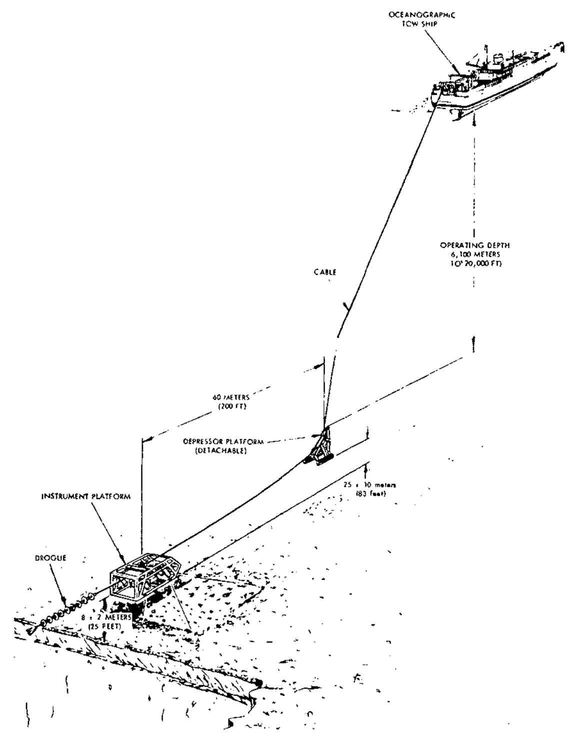
Ship motion is effectively isolated from the viewing instrument platform on the Deep Sea Survey System by means of a unique "tandem" platform system design. The system which employs separate depressor and instrument platforms is shown above and in the system diagram to the right. The depressor platform is easily attached and removed from the cable allowing the system to be readily deployed at sea.

The viewing system employs a Hydro Products' low light level SIT television camera and thallium iodide lamps, with 70mm still camera for permanent high resolution photography. The system, designed for a 10-meter altitude survey, has been used at maximum survey distances of greater than 15 meters off the bottom.

The LLL Television Camera includes a 10:1 zoom lens controlled from the surface. Zoom "reticles" (viewing angle indicators) are "mixed" with the video signal at the bottom and presented directly on the video picture to give the operator a continuous indication of zoom lens position and angle of view of the television system. This information is also recorded on the video tape for later analysis. In addition, two high intensity spot lights are used with the viewing system for scaling and determining height measurement directly from the television picture.

A magnetic compass is located on the instrument platform for heading indications. This compass heading signal is also "mixed" with the video signal and presented directly on the bottom of the video picture from left to right, scaled from 0 to 360° magnetic compass heading.

One of the most important features of the Deep Sea Survey System is the inclusion of Hydro Products' standard DTS-125 Digital Telemetry System which transmits all control and data signals over a single coaxial cable with the video signal. This includes control of lights, zoom lens, camera focus, photo camera, video data, zoom position, and compass heading. In addition, several spare analog and digital channels are available in the telemetry system for additional instrumentation, if desired.



SUMMARY

The capabilities of the Remotely Operated Vehicle, as described in the above developments at Hydro Products, are proceeding at a rapid pace. This, coupled with the fact that the OTEC production model is in its infantile phase, allows a unique opportunity to match ROV capabilities with the OTEC maintenance and repair requirements by incorporating design features into the hardware which will complement one another. The result of which will be lower overall maintenance and repair costs with a reduced human element risk.

Likewise, the development of ocean mining is just beginning and is another important area in which the Ocean Mining Engineer and ROV Designer must work hand-in-hand to develop cost effective systems for resource development.

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THE RCV-150 REMOTELY CONTROLLED VEHICLE IN WORLDWIDE OPERATION

A. B. Billet
Hydro Products, Inc.
San Diego, California, U.S.A.

ABSTRACT

The past decade has shown a dramatic increase in the use of unmanned tethered vehicles in worldwide marine fields. These are used for inspection, debris removal and object retrieval. The RCV-150* system is an example of these advanced technology vehicles. With the requirements of high maneuverability and unusual inspection, a responsive, high performance, compact vehicle was developed.

The RCV-150 vehicle component system consists of the vehicle structure, the vehicle electronics, and hydraulic system which powers the thruster assemblies and the manipulator. For this vehicle, a lightweight, high-response hydraulic system was developed in a very small package. The past approximate two and one-half years of worldwide field activities have resulted in almost 10,000 hours of RCV-150 operations.

INTRODUCTION

Early Remotely Operated Vehicle (ROV) operation was solely for inspection. However, as subsystems were further developed and manipulator arms with advanced robotic technology added, the vehicle now performs jobs previously accomplished by divers.

The use of unmanned, tethered vehicles has increased dramatically over the past ten years. These ROV's are widely used in oil field applications such as search, observation, inspection, debris removal and object retrieval. At the present time, remotely operated vehicles account for a large percentage of all inspection and recovery services for offshore construction projects.

UNDERWATER WORK SYSTEMS

Figure 1 summarizes the methods of diving and performing underwater work. As indicated, these vary from scuba and surface-supplied diving gear in shallow depths, to remotely operated vehicles for depths up to 2,000 feet or greater, to the deep submergence submarine operating at 10,000 to 20,000 feet depths.

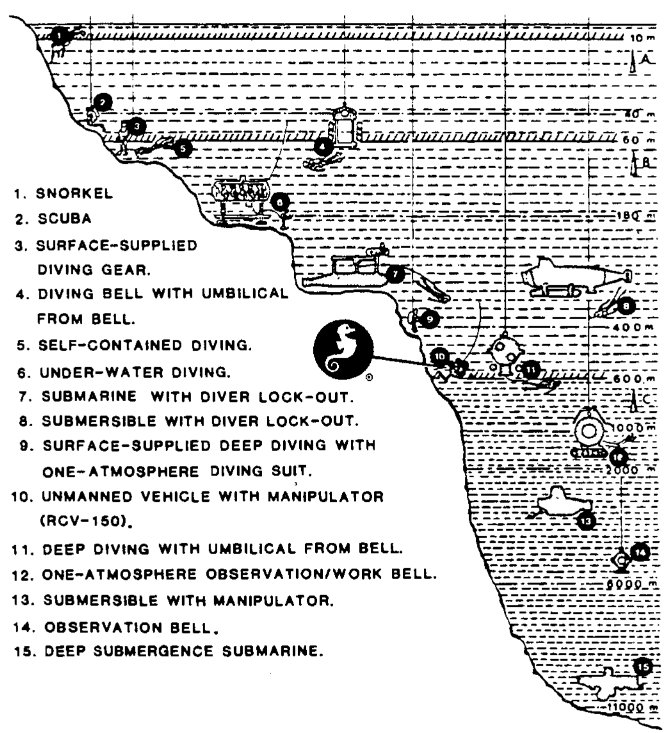

Figure 1. Methods of Diving and Under-Water Working.

*RCV is a registered trademark of Hydro Products, Inc.

Rapid growth in the application of ROV's has resulted in a two-fold benefit to the offshore industry and service companies. First, by using ROV's at greater depths and for riskier jobs, safety to the diver is increased, freeing him for safer, more cost-effective tasks, requiring human capabilities. Second, the ROV operation becomes less expensive to use as the work depth increases. At 1000 feet a diver's 10 minutes of work can cost over $100,000 including support personnel, while an ROV operational cost might be 1/20 of the diver cost per day.

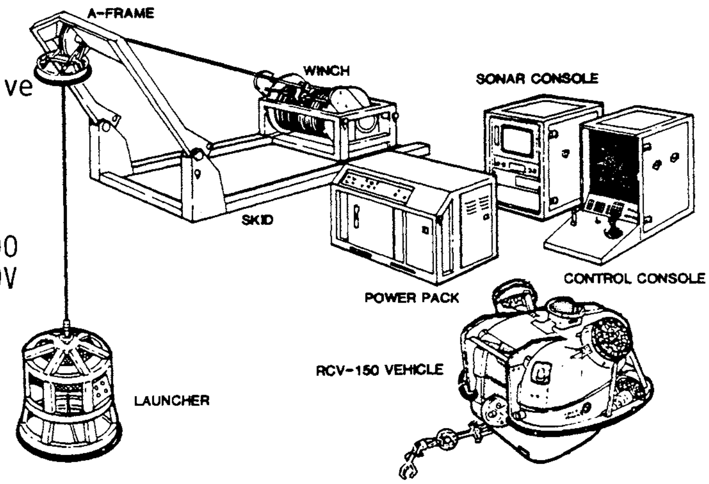

Figure 2.RCV-150 System Major Equipment

An example of these advanced technology vehicles is the RCV-150 system shown in Figure 2. Its major equipment includes the shipboard winch which receives its hydraulic power from the power pack, skid and A-frame, the control console, the sonar console, the launcher and the vehicle.

Figure 3 shows some examples of these robotic type vehicles and some of their missions. These include inspections, repairs, equipment retrieval, and for the large bottom-crawling vehicles, pipeline laying. The RCV-150 vehicle is shown in the upper right-hand part of this figure.


Figure 3. Various Underwater Vehicles

RCV-150 FEATURES

The RCV-150 vehicle as shown in Figure 4 is approximately 4-1/2 feet

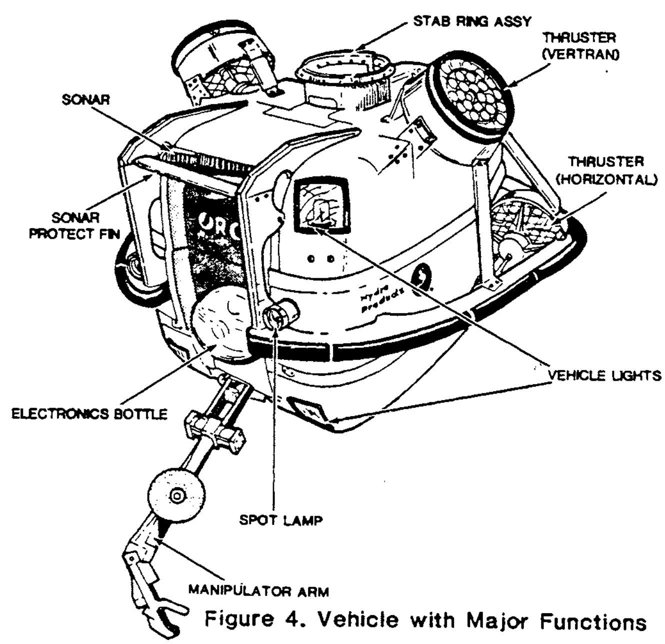

Figure 4. Vehicle with Major Functions

long, 4 feet wide, and 3-1/2 feet high with an approximate weight of 1250 pounds. It is a hydrodynamically designed vehicle with a neutrally buoyant tether cable. The vehicle component system consists of the vehicle structure, the hydraulic system which powers the thruster assemblies and manipulator, and the vehicle electronics. The launcher contains a submersible winch which is used to control the payout of tether to the vehicle during system operation. The winch is driven by a hydraulic motor with power supplied by the launcher hydraulic system.

Upon deployment, the vehicle is housed in the launcher assembly and is positioned to the approximate working depth on the armored cable by winch operation. The vehicle is then deployed from the launcher with the tether cable. The launcher provides a protective housing for the vehicle so it may be lowered safely to the required working depth. The use of the launcher also eliminates the effects of ship heave motions on vehicle performance underwater.

SHIPBOARD MONITORING

Another important feature of the system is the shipboard monitoring capability which allows the operator with the control console, as shown in Figure 5, to perform checkouts of all vehicle systems after deployment underwater and prior to launching and work performance. The major sections of the control console include three nine-inch screens for sonar, video and data display.

ELECTRONICS SYSTEM

All vehicle electronics are contained in the two pressure housings. A pressure-proof housing with a glass dome on one end and an endbell with connectors on the other end encloses the viewing, command/control sensor, and telemetry systems. A second ambient, pressure-compensated power housing contains the AC and DC power supplies for the vehicle electronics and lights. At the front of the electronics bottle the TV camera is mounted in a hemispherical glass dome. Behind the camera are several electronics boards. The vehicle carries a variety of sensors for navigation, servo control, and operator information.

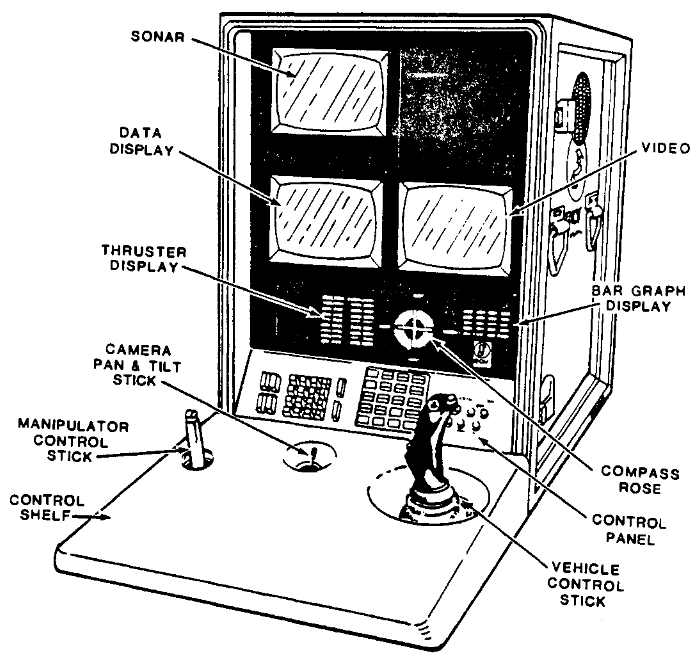

Figure 5. RCV-150 Control Console

HYDRAULIC SYSTEM

Figure 6 shows a simplified block diagram of the vehicle's hydraulic system. The system is powered by a fixed-displacement, internal gear pump driven by an electric motor. The electric motor operates in a sealed motor housing and is rated at 15 HP at 3450 RPM with 880 VAC, 3-phase, 60 Hz power. The motor operates in the same oil as used in the hydraulic system-Shell Tellus 32. The oil-filled case is connected to one of the two pressure compensators. The internal gear pump, driven by the motor, has a displacement of 0.87 cu. in/rev. and delivers approximately 8.3 GPM flow at 2400 PSI system pressure.

SYSTEM FILTRATION

Filter assemblies rated at 3-micron absolute filtration are used in the high pressure filter and the low-pressure filter. This very high degree of filtration results in better system operation, particularly in servo valve usage and in the small component valves of the manipulator.

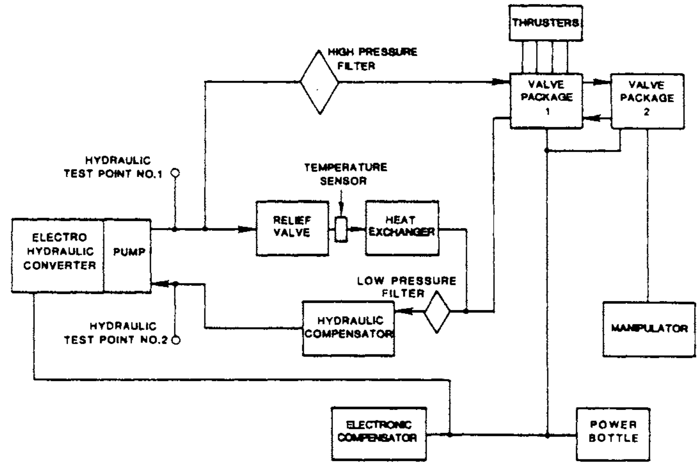

Figure 6. RCV-150 Vehicle Hydraulics (Block Diagram)

VALVE PACKAGES

The pump output flows to two valve packages, Nos 1 and 2. This packaging design ensures system compactness by including a number of valves in each package while maintaining their accessibility. As shown in Figure 7, Valve Package No. 1 (VP-1) contains the four servo valves that control the flow to the four thruster hydraulic motors. Valve Package No. 2 (VP-2), as shown in Figure 8, houses the solenoid valves that control the manipulator arm and the cutting saw. Two spare solenoid valves are provided for add-on components.

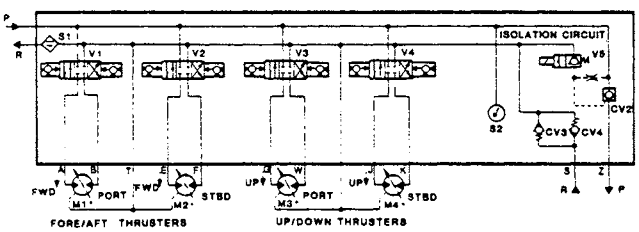

Figure 7. Valve Package No.1

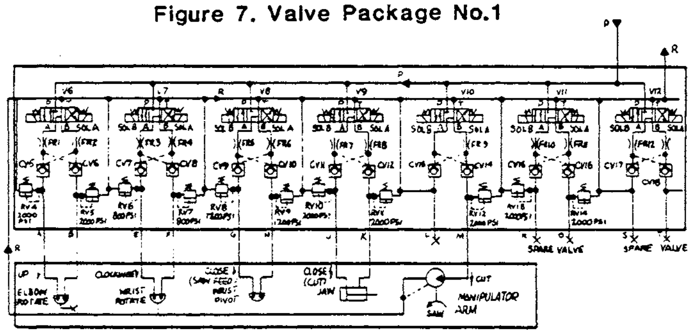

Figure 8. Valve Package No.2 and Manipulator

MANIPULATOR ARM

Figure 9 shows the manipulator assembly. The manipulator is a five-function work arm normally stowed inside the lower framework in the vehicle. A rotary actuator at a "shoulder" joint allows for stow and unstow motion of the arm. An actuator at the "wrist" allows grabber jaws to pivot in a 245-degree arc. The jaws are opened and closed by a linear piston actuator. A pinching blade, capable of cutting 3/4 inch polypropylene line, is actuated simultaneously with the jaws.

THRUSTER ASSEMBLIES

The thruster assembly, as shown in Figure 10, consists of a bidirectional, adjustable, fixed displacement, ball-piston hydraulic motor driving a 10-inch diameter, three-bladed, bidirectionally-pitched propeller. The thrusters are housed within Kort nozzles and are attached to the vehicle framework.

TYPES OF FIELD OPERATIONS

During the past two and one half years, a number of RCV-150 vehicles have been in worldwide operation in such areas as off the southeast and the northwest coasts of Australia, off Brazil, the Gulf of Mexico, the coast of Africa, the North Sea and

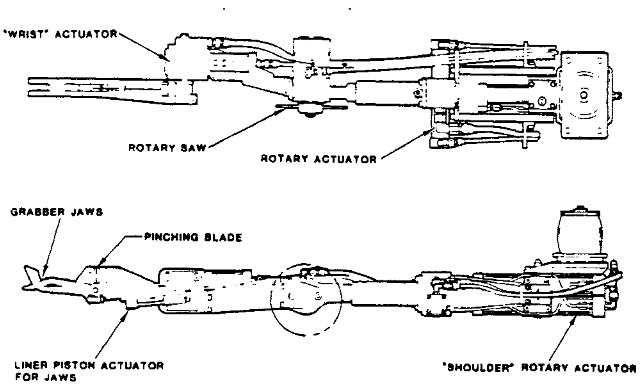

Figure 9. RCV-150 Manipulator

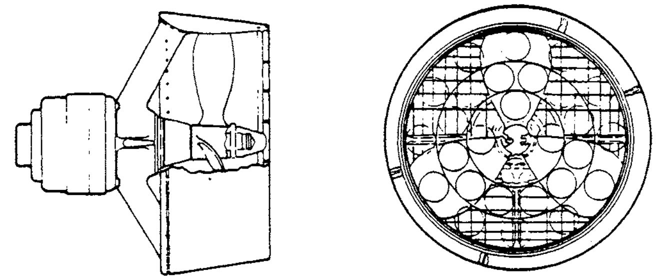
Figure 10. Thruster Assembly

off Ireland. Total operational times are now approaching 10,000 hours. Some of the activities of these operations are as follows:

COAST OF IRELAND

One example (see Figure 11) of the versatility of the vehicle and its hydraulic system is shown in the recovery of the Sea Plow IV cable burying equipment. This $1.7 million, 22-ton piece of equipment was lost off the Irish coast in 800 feet of water. The first salvage efforts were made with a manned submersible vehicle but were called off after six weeks due to threatened entanglement of the submersible's towline with a nearby sunken ship and old fishing nets. A final salvage effort was made using the RCV-150 vehicle. Figure 12 shows shipboard nighttime operation in this recovery. The vehicle first found the lost Sea Plow on the ocean floor with its sonar. After several days of difficulty due to weather and a drifting surface ship, a line was attached by the RCV-150 and recovery was made.

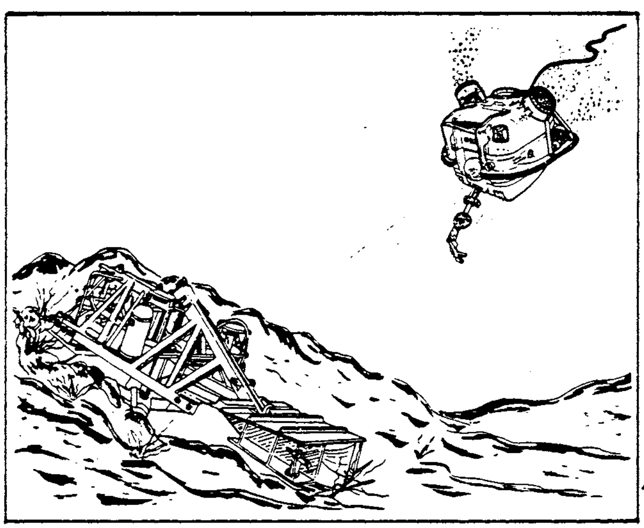
Figure 11. Sea Plow Recovery

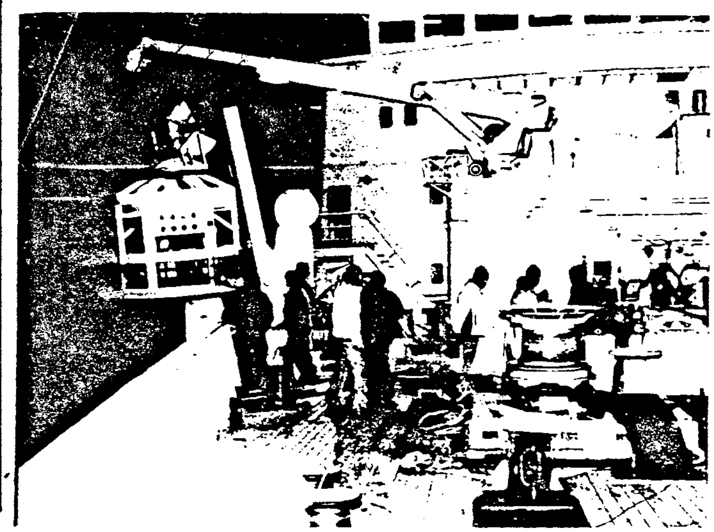
Figure 12. Night Time Operation Sea Plow Recovery

NORTHWEST COAST OF AUSTRALIA

Extensive RCV-150 operations took place off the northwest coast of Australia in connection with pipeline laying from the North Rankin Field to the mainland, and with platform site surveying. The vehicle inspected the laid pipe for proper covering and support. The vehicle was also used in the piling operation for the platform construction.

SOUTHEAST COAST OF AUSTRALIA

In the Bass Strait off the southeast coast of Australia, the vehicle was used in pipeline route surveying and pipeline inspection after installation. This work also included cathodic potential (CP) evaluation and support of the jacket installation. A large number of object retrievals from the bottom were also accomplished.

NORTH SEA

In a North Sea operation, the vehicle was used in transponder location and jacket installation. Inspection work was also accomplished after jacket installation. In this installation, the jacket was positioned within a 2-meter location. The vehicle also monitored piling operations.

GULF OF MEXICO

In the Gulf of Mexico operations off the Mississippi River delta, the vehicle surveyed the Gulf bottom in connection with platform dynamic anchoring. The vehicle also assisted in "clump weight" placement. Also included was the guiding of mooring piles during their installation.

BRAZILIAN COAST

In operation off the Brazilian coast, two RCV-150 vehicles were used in piling operations. One viewed the hydraulic power hammer hitting the piles and the second vehicle viewed the depth that the pile was driven into the ocean floor. A vehicle was also used in jacket placement.

AFRICAN COAST

Off the Ivory Coast of Africa near Abidjan, pipeline route surveying was performed as well as inspection after the line was laid. In this work a bottom profiler was used.

The vehicle was also used in installation of the jacket and in monitoring manned diving operations under hazardous conditions.

FUTURE APPLICATIONS

A number of variations of the RCV-150 type vehicle with the same configuration of hydraulic-driven thrusters is being studied. One of these studies includes a high-speed tethered vehicle that would follow oil field pipelines.

With a vehicle design speed of approximately 5 knots, so that the vehicle and its support ship might "fly" over the subsea pipeline, a larger electrohydraulic transmission system would be required. For this higher speed, the present 15 HP would probably double in output horsepower. Other concepts under study include advanced manipulators with multi-purpose work packages.

As types of applications continue to increase for the RCV's, designs of growth vehicles will use the present baseline systems with their worldwide experience as starting points.

OST-2: REMOTE SENSING & OCEANOGRAPHIC SATELLITES

PLANS FOR OCEANOGRAPHY FROM THE U. S. NAVY GEOSAT

Jim L. Mitchell
Zachariah R. Hallock
Naval Ocean Research and Development Activity
NSTL, Mississippi, U.S.A.

Introduction

Following a planned launch during November, 1984, the altimetric U. S. Navy GEOSAT (Geoid Satellite) will collect topographic, backscattered power (wind), and waveform data from a nominal SEASAT-like, non-repeat orbit (near 3-day repeat) for a period of up to 18-months duration. Doppler tracking via the Defense Mapping Agency's (DMA) TRANET system will provide SEASAT-quality (≈ 1 meter absolute accuracy) orbits. GEOSAT's primary and initial mission is the global collection of sea surface topographic data to be used for computing a high spatial resolution mean sea surface via groundtrack crossover point minimization in order to approximate the marine geoid. The basic approach will be to fill-in the spatial gaps left in global groundtrack coverage by the early demise of SEASAT. The primary objective of these data are to satisfy operational geodetic needs of military inertial and strategic navigation systems. Thus, would be research users of these topographic data are faced with a number of logistical (raw range measurements are classified) and technical (initial orbit lays down non-repeating groundtracks) restrictions. Nevertheless, there are a number of oceanographic research objectives which can be met within these confines, particularly if an extended, exact repeat mission for GEOSAT is realized. In this paper we discuss the on-going altimetric oceanographic research program supported by the Office of Naval Research (ONR) at the Naval Ocean Research and Development Activity (NORDA) and in particular NORDA program objectives and plans for the oceanographic use of GEOSAT altimetric data.

The GEOSAT Satellite

GEOSAT consists of an improved SEASAT, single-frequency (13.5 GHz) radar altimeter mounted on an improved GEOS-C bus. Unlike SEASAT and proposed future oceanographic altimeter systems (e.g., N-ROSS, TOPEX, ERS-1), GEOSAT lacks both a microwave radiometer for water vapor range correction and a laser retroreflector for range calibration. These deficiencies result in both diminished range determination accuracy on longer spatial scales (due to orbit determination error) and some loss of precision on intermediate scales due to water vapor uncertainties. Neither degradation raises critical concern for meeting some intermediate to shorter spatial scale oceanographic objectives. Studies (Born, 1983) indicate that absolute range accuracy of order 50 cm is feasible for GEOSAT, though nominal plans are to provide orbits with accuracy of about 1 meter.

An instrumental noisefloor of approximately $\pm$ 2 cm (1σ) in range is anticipated in a one data point per second average of the 10 points per second raw data stream. This represents a significant enhancement over the approximate $\pm$ 3.5 cm (1_σ) noisefloor in similarly averaged SEASAT altimetry. This enhancement is possible given three modifications of the SEASAT altimeter design (Kilgus and MacArthur, 1984):

(1) Factor of 2 wider gate window for tracking
(2) Diminished time lag for AGC resets
(3) Enhanced instrument range and range rate digitization.

As well, a dual mode tracking strategy is implemented on GEOSAT by which a threshold detector on the leading edge of the return pulse is used in addition to the middle gate SEASAT strategy to reset tracking lock. This allows for an enhanced ability to maintain lock over more rugged terrain and ice than was possible with SEASAT. Total terrain excursions over which lock is maintained are the order of $\pm$ 10 m or somewhat greater.

A key hardware modification on SEASAT design is the use of long pulse, lower power waveforms. This allows for the use of a long-lived, low power 20 watt Traveling Wave Tube Amplifier (TWTA) as opposed to the short-lived 2000 watt SEASAT TWTA. The longer-lived TWTA and the relative simplicity of the overall GEOSAT satellite system result in probabilities of post launch survival which exceed 50% for approximately 3 years (double the required geodetic mission duration).

Oceanographic Limitations and the Extended GEOSAT Exact Repeat Mission

Given limitations on the ultimate obtainable accuracy of GEOSAT's range measurement due to residual orbit error, it is not feasible to pose detailed long spatial scale (> 10^3 - 10^4 km) circulation experiments such as the global mean circulation experiment to be undertaken by TOPEX. On the other hand, on spatial scales of order 10^3 km or less (oceanic mesoscale) residual orbit error will be removed with a precision which allows collection of meaningful topography. The critical limitation on attempts to use GEOSAT altimetry for ocean circulation studies, paticularly for mesoscale oceanography, is the non-repeating nature of the altimeter groundtracks during the nominal 18-month mission. Hence, if oceanographic interpretations of the data are to be made, some reference surface (composed of past altimetry and/or gravimetry) will be necessary. For this purpose DMA has agreed to allow use of a classified blended gravimetric/altimetric surface in the NW Atlantic for the computation of subsequently unclassified residuals.

Gravimetric or mean surfaces with adequate precision and spatial resolution for mesoscale oceanographic interpretation exist in only a few regions. In a vast majority of regions exactly repeating groundtracks which overlap to within a few kilometers or less are essential to meet many oceanographic objectives. Hence, plans are now being formalized within the U. S. Navy to extend GEOSAT's nominal mission for a minimum of roughly 2 years during which time the satellite's groundtracks repeat in a nominal 20 day period (the GEOSAT Exact Repeat Mission or GEOSAT-ERM). In such an orbit crosstrack separations of 140 km equatorial (roughly 100 km at mid-latitudes) allow for minimally adequate spatial coverage with nearly adequate temporal sampling for studying the dynamics of western boundary currents. Studies indicate that stationary ensemble mean topography along each track can be obtained with precisions of 10 cm or better after several months mission duration (Mitchell, 1984), thus allowing for subsequent removal of geoid contamination.

NORDA Oceanographic Plans for GEOSAT Altimetry

NORDA's on-going program in mesoscale dynamics combines the three critical areas of satellite altimetry, regional numerical circulation modeling, and field survey. During an initial Regional Experiment (REX) focused on Gulf Stream and ring dynamics, these three elements will be used to address several critical issues:

(1) What is the relative importance of the barotropic mode (to be uniquely determined by a combination of altimetry and arrayed Inverted Echo Sounders with Microbarographs (IES/MB)) in determining the dynamics of the region on specific space-time scales?

(2) How are fluctuation space and time scales modified by flow through the New England Seamount Chain?

(3) How are fluctuation vertical structure and horizontal exchanges influenced by interaction with topography?

On-going numerical modeling at NORDA (Hurlburt and Thompson, 1984) indicates that many of the characteristic scales and phenomena (e.g., stream bifurcation) associated with Gulf Stream fluctuations arise as a result of the relative importance of the barotropic mode and, in many cases, the subsequent interaction with the strong topography of the New England Seamount Chain. One consequence of this interaction is a greatly enhanced frequency of warm core ring generation over the seamounts themselves.

Of course, any attempt to measure circulation topography in the vicinity of seamounts will be dependent upon the extent to which the seamount geoid effects can be removed. This poses a very difficult problem for the satellite altimeter alone, particularly since some warm-core rings may be quasi-stationary in the region as a result of topographic trapping (Richardson, 1981). Additionally, numerical modeling attempts to parameterize the impact of large amplitude seamounts in quasi-geostrophic (QG) models have not been successful due to violations of the QG-approximation (see Rhines, 1977), making necessary the use of primitive equation models to adequately describe the regional circulation.

One major objective of our supporting field program is to provide topographic intercomparison and possible calibration for the satellite altimeter in two regions. The first region is centered on the mean axis of the Gulf Stream at approximately 65-66^{o}W (upstream of the New England Seamounts), while the second region, centered on approximately 59^{o}W, 39^{o}N, lies immediately downstream of the seamounts. In each region we plan to deploy approximately 10 IES/MB instruments. Supported by periodic regional CTD and AXBT surveys, the moored arrays will allow for in situ computation of both free surface topography and main thermocline undulation (Watts and Wimbush, 1981). Use of the IES/MB thus allows separation of the barotropic mode from low order baroclinic modes. Regional altimetric topography, which responds to the sum of these modes, will be used to extrapolate to the spatial coverage lacking from the moored instrumentation. Correlation space-time scales from the IES/MB arrays, from the altimetry, and from the numerical model results will all be intercompared. Additionally, we plan to assess problems and error budgets associated with possible attempts to use IES/MB data for calibration of the altimeter in an absolute sense. Intercomparisons of absolute values of free surface elevations are possible only to the extent that one has knowledge of:

(1) Location of regional bathymetry (upon which the moored instruments rest) with respect to regional geoid.

(2) IES/MB instrumental biases.

(3) Effects of higher vertical mode structure (as generally neglected or as measured from hydrographic survey).

Any attempt to completely separate the geoid from the free surface topography will depend upon the extent to which the regional mean circulation topography and the geoid can be separated. We anticipate posing the regional inverse problem involving the interrelationship between these variables and associated error budgets (see Wunsch and Gaposchkin, 1980). Possible absolute calibration of the altimeter range measurement would result in diminished residual orbit error and subsequent increase in the spatial scale over which the altimetry may be applied. Redeployment of the IES/MB arrays during the GEOSAT-ERM will concentrate on the relocation of instrumentation at altimeter groundtrack crossover points, allowing for optimized orbit error removal.

Schedules

GEOSAT is scheduled for launch in November, 1984. Following an initial one-month shakedown period, classified topographic data will be available during January, 1985 at which time we plan extensive CTD surveys of regions across the Gulf Stream both up- and downstream of the New England Seamounts. Presently, our initial IES/MB deployment cruise is scheduled for May, 1985 with initial deployment of 12 to 20 instruments and supporting CTD survey planned. Recovery of the moored instruments is planned for March-April, 1986 with their subsequent redeployment and possible augmentation to occur during spring-summer, 1986 at about the time of the beginning of the GEOSAT-ERM. Numerical model studies and data assimilation experiments are planned throughout the period. Additionally, global altimeter crossover point statistics will be used to compile unclassified statistics on global mesoscale variability throughout the nominal GEOSAT and GEOSAT-ERM missions.

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U.S. CONTRIBUTIONS TO TOGA IN THE PACIFIC

Kenneth Mooney
NOAA Office of Oceanic and
Atmospheric Research
Rockville, Maryland, U.S.A.

Robert Cheney
NOAA National Ocean Service
Rockville, Maryland, U.S.A.

ABSTRACT

The Tropical Ocean Global Atmosphere (TOGA) research program now being planned as part of the World Climate Research Program seeks to advance the understanding of events in the atmosphere and the world oceans that significantly influence seasonal to interannual climate variations over much of the globe. The ultimate goal of TOGA is to develop coupled ocean/atmosphere models with predictive capabilities on time scales of months to years. The models, of course, will require a large data base from which to operate and this will in turn require an optimum observing system to collect the data. At present, the U.S. is concentrating its contributions to TOGA in the Pacific where an in-depth investigation of the El Nino/Southern Oscillation (ENSO) phenomenon and its relation to climatic variations will be conducted. The program in the Pacific will be ten years in duration and will be composted of several observing subsystems to monitor specific fields. In the ocean these fields will consist of:

- sea level
- sea surface temperature
- surface wind velocity/stress
- upper ocean thermal structure
- equatorial circulation

There will also be a large program mounted to observe important meteorological fields and vertical heat fluxes. In the beginning years, the observations will be made with classical oceanographic tools (current meters, tide gauges, XBT's, etc.). In the later years, these measurements will hopefully be supplemented by observations from satellites such as TOPEX and NROSS. While the launching of these satellites are several years away, now is the appropriate time to consider how to properly integrate these measurements into the observing system and also how to best deploy the in situ instruments so that they can be advantageously used for ground truthing the satellite measurements.

MESOSCALE OCEAN VARIABILITY IN THE CALIFORNIA CURRENT SYSTEM

Christopher N.K. Mooers
Department of Oceanography
Naval Postgraduate School
Monterey, California, U.S.A.

Allan R. Robinson
Division of Applied Sciences
Harvard University
Cambridge, Massachusetts, U.S.A.

A joint NPS/Harvard investigation of the scientific requirements for, and the limitations of, practical limited-area, open ocean forecasting of the mesoscale ocean eddy field commenced two years ago under ONR sponsorship. The investigation is called the OPTOMA (Ocean Prediction Through Observation, Modeling, and Analysis) Program. Ocean prediction (analysis and forecast) experiments are being undertaken in "test blocks" (ca. 200 x 200 km) of ocean off Northern and Central California. A series of ten week-long, quasi-synoptic shipboard hydrographic XBT and CTD surveys have been conducted, along with some AXBT surveys by aircraft and the acquisition of some satellite IR remote sensing imagery, to develop a statistical (objective analysis) model. The The dynamical model used in the forecasts is a quasi-geostrophic, eddy-resolving numerical model, which is initialized with the aid of observations. The first prototype (real-time) prediction experiment was performed in June/July 1983; the second is planned for the same timeframe in 1984. The first major, comprehensive (i.e., with thermodynamical as well as dynamical models) prediction experiment is planned over a larger space-time domain for 1986.

The initial survey revealed new features in the California Current System (CCS), which were corroborated in the subsequent surveys. The CCS regime is now firmly established as dominated by close-packed, synoptic/mesoscale eddies, intense meandering thermocline jets, and strong surface thermal fronts. It has become clear that the regime had been previously undersampled in space and time; in fact, the instantaneous CCS appears to bear a relationship to the climatological mean CCS analogous to that of the instantaneous Gulf Stream and Kuroshio to their climatological means. Hence, a major issue to be addressed is the role of the mesoscale eddy field in determining the mean CCS. The dynamical model will be useful for this purpose, too, because it is being run in simulations based on observed fields to estimate the energetics of eddy-mean field interactions. (Other uses for the modeling strategy include the conduct of simulations to design an optimal observing system.)

The overall modeling strategy is to use the observations to provide an objective analysis of the initial field, and to update the boundary conditions, for the dynamical model. Both the statistical and dynamical models can be used for making forecasts. The best forecasts will be a linear combination of these dynamical and statistical forecasts, using optimal estimation theory to determine the weighting factors. From a broader perspective, this integration of observations and models to create the optimal predictions (hindcasts, nowcasts, and forecasts) can be recognized as an initial step in developing 4-D data assimilation schemes for oceanography. The first prototype prediction experiment demonstrated the promise of this methodology.

The data assimilation scheme will ingest satellite remote sensing information when suitable quantitative data become available. In the interim, satellite IR imagery has been used (1) to connect the dynamical features of the offshore "test block" to the coastal waters in order to create a more holistic view of the regime; (2) to provide truly synoptic sequences over periods of quasi-synoptic surveys in order to track the fast-changing eddy, jet, and frontal structures; and (3) to calculate the displacement of features in closely spaced images in order to estimate the surface motion field. From these analyses, it has been learned that (1) the turbulent jets meander between close-packed, counter-rotating eddies and propagate with baroclinic Rossby wave phase velocities; (2) they are manifested in satellite IR images by sharp surface thermal fronts on their edges; and (3) they entrain cool coastal waters and advect them a few hundred kilometers offshore within several days. (They also advect warm oceanic water onshore.) Hence, the new information on mesoscale eddies, jets, and fronts in the CCS has strong implications for the cross-shore transport of heat, salt, nutrients, pollutants, biota, and so forth. (The in situ observations also served to more fully interpret the IR images.) Because the surface SST field is variously related to the subsurface mass field, its best uses may be (1) to track the location of major mesoscale features for model verification purposes, (2) to estimate surface velocities, (3) to characterize subgrid scale (relative to models and observing system) processes, and (4) to document changes in the upper ocean thermal field due to horizontal and vertical advection and air-sea interactions. More directly useful dynamical information is expected to be available from the satellite radar altimeters, and other active microwave sensors, of the future.

WAVENUMBER SPECTRA OF PACIFIC WINDS FROM THE SEASAT SCATTEROMETER

Michael H. Freilich
Dudley B. Chelton *
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California, U.S.A.

The spatial variability of oceanic winds is of interest to both meteorologists and oceanographers. This abstract presents preliminary results on one-dimensional spectra of surface winds with wavelengths between 200 km and 2000 km, calculated from data obtained by the SEASAT-A Satellite Scatterometer (SASS) in September, 1978. Comparisons of averaged spectra from ascending and descending passes over the Pacific show that the spectral shape is not a strong function of ground-track angle (in a rectangular coordinate system), thus providing a weak indication that the wind field on these scales is isotropic. Averaged spectral shapes are shown to be consistent with a spectral slope of k^{-3}, as predicted by two-dimensional turbulence theory. Spectral density levels are approximately equal in northern and southern hemisphere mid-latitudes, but levels are significantly lower in the equatorial region.

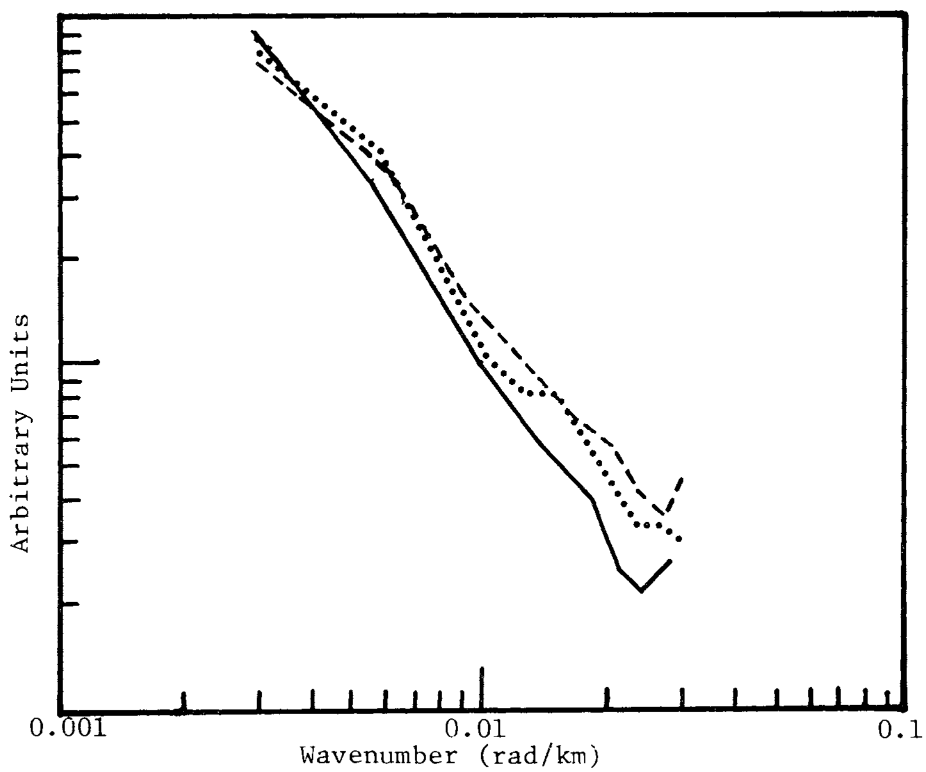
Although historical interest in atmospheric spatial variability has centered on the high energy planetary and synoptic scales (wavelengths greater than 5000 km), attention has recently turned to smaller scale motions with wavelengths from approximately 50 km to 4000 km. From a meteorological standpoint, the detailed shape of the spectra at high wavenumbers has been shown to influence the prediction skill of large scale numerical models (eg. Lorenz, 1969; Leith, 1971). Oceanographic interest results from the possibility that atmospheric motions on these scales may directly force oceanic eddies (Frankignoul and Muller, 1979; Muller and Frankignoul, 1981). Unfortunately, due to their low resolution and unknown degrees of smoothing, standard synoptic weather maps cannot provide the small scale wind information necessary to address these important meteorological and oceanographic questions.

The SASS provided high resolution measurements of surface wind vectors over the ocean. In this study, we use the preliminary de-aliased data set due to Peteherych et. al., with a resolution of approximately 100 km. Initial analysis demonstrated that the sampling characteristics of the SASS precludes the direct use of the data for calculations of 2-D spatial spectra. Large data gaps between the port and starboard swaths, similarly large gaps between swaths from consecutive orbits, and irregular data spacing within the swaths themselves greatly hinders the construction of 2-D covariance matrices which, when Fourier transformed, yield 2-D wavenumber spectra. In particular, it is not possible to obtain accurate estimates of the covariance at large lags in the cross-track direction. However, the high density of data in the along-track direction allows the calculation of 1-D wavenumber spectra. Leith (1971) illustrates the relationships between various 1-D and 2-D wavenumber spectra. Importantly, if the process is isotropic in two dimensions and the 2-D spectra exhibit a k^{-3} power law falloff (as is the case with a 2-D turbulent fluid), then the 1-D spectra of velocity components also exhibit the same k^{-3} falloff.

Spectra were calculated from data obtained in three, 20° latitude bands spanning the width of the Pacific (the bands fall between 25° and 45° latitudes in both the northern and southern hemispheres, and between 10° S and 10° N latitude in the equatorial region). Vector winds were decomposed into zonal and meridional components, binned covariances in the along-track direction were calculated on an orbit-by-orbit basis, and those covariance matrices that were positive-definite were Fourier transformed to yield 1-D spectra. Finally, spectra from different orbits were averaged.

Spectra from ascending and descending orbits were found to have very similar shapes. Such similarity is a necessary (although not sufficient) condition for isotropic wind fields. Figure 1 shows averaged normalized spectra of zonal winds in the three ocean regions examined (... North Pacific; - - - Equatorial Pacific; ---- South Pacific). Spectra were normalized before averaging in order to illustrate spectral shape, independent of the total variance in the wavenumber band of interest. All spectra have similar, nearly linear shape in log-log space, indicating a power-law falloff of spectral density with wavenumber. The spectra as shown fall off like approximately $k^{-1.7}$. However, model testing utilizing synthetic data with a k^{-3} falloff, but sampled using actual scatterometer data locations, yielded 1-D spectra spectra with a nearly identical ($k^{-1.7}$) shape, whereas synthetic data with a $k^{-5/3}$ falloff, when sampled and binned, yielded spectra that fell off like $k^{-1.0}$. Although the 1-D spectra of zonal winds at wavelengths from 200 km to 2000 km are thus consistent with a k^{-3} falloff, as predicted by 2-D turbulence theory, more refined analysis techniques are necessary in order to overcome difficulties imposed by the unique sampling characteristics of the scatterometer.

FIGURE 1



Current work centers on the use of optimal interpolation techniques within swaths, the detailed examination of the spectra of meridional winds and total kinetic energy, and more sensitive tests of isotropy.

Acknowledgements

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* Permanent address: College of Oceanography, Oregon State University, Corvallis, OR 97331.

OPTICAL VARIABILITY IN THE EASTERN NORTH PACIFIC OCEAN
AS MEASURED BY THE NIMBUS-7 COASTAL ZONE COLOR SCANNER

James L. Mueller
Naval Postgraduate School
Monterey, California, U.S.A.

Sequences of Nimbus-7 Coastal Zone Color Scanner (CZCS) images have been processed to map bio-optical variability in the eastern North Pacific Ocean. Phytoplankton pigment concentrations (chlorophyll-a plus phaeopigments-a) and k(490) (the vector irradiance attenuation coefficient at a wavelength of 490 nm) were calculated from the radiances measured in cloud free portions of each available CZCS image. These parameters were then mapped onto a Mercator grid extending from 28 N to 42 N and from 117 W to 143 W at a nominal resolution of 5 km.

Emphasis was placed on October and November of 1979 and 1982 as part of the analysis phase of the ONR sponsored Optical Dynamics Experiment (ODEX). The objective of the ODEX program is to develop a 1-dimensional model for predicting optical propagation in the upper ocean away from coastal current systems. The at-sea observational phase of ODEX took place in October and November 1982. During the experiment, the R/V ACANIA sampled physical, biological, chemical and optical variables at a closely spaced grid of stations surrounding the position of R/P FLIP near 33 N, 142 W. ACANIA also occupied stations along the zonal transect at 35 N from the California coast to 140 W enroute to and from the site.

Optical variability in the transparent water masses of the central gyre and outer reaches of the California Current system are best characterized by optical depth, 1/k(490) in meters. (To the contrary, this representation tends to suppress variability features in turbid water masses over the continental shelf and slope; k(490) in 1/m is more suitable and sensitive a variable here.) A strong optical front separates turbid coastal water from transparent offshore water at a location near the base of the continental slope. Along the zonal transect at 35 N, this front is clearly visible near 123 W in CZCS-derived optical depth (Figure 1a). Also plotted in Figure 1a are in situ observations of optical depth 1/k(488), showing excellent agreement between CZCS estimates and R/V ACANIA measurements (stations 24 & 25 were occuppied within 1.5 hours of the satellite pass, and stations 13 and 19 on the day previous to the pass). The vertical sections of ODEX ACANIA stations along this transect clearly show that the optical front observed in CZCS data is associated with organized features in subsurface optical beam attenuation (Figure 1b) and temperature (Figure 1c).

In the offshore continuation of the 35 N transect, the ACANIA's CTD profiles clearly indicate that the water masses between the optical front at 123 W and beyond 130 W have temperature-salinity characteristics associated with the California Current System. Just west of 130 W, the temperature-salinity characteristics changed abruptly to those of Sub-Arctic North Pacific water (SANP). SANP waters extended to approximately 140 W along this latitude, but changed (again abruptly) to East Central Pacific water just to the south of the sub-tropical front near 32 N.

Vertical profiles of in situ chlorophyll fluorescence also varied systematically over the zonal transect at 35 N. Inshore of the optical front at 123 W, maximum fluorescence values were distributed over the surface mixed layer. In the water masses between the optical front and the transition to SANP near 130 W, a well defined fluorescence maximum was consistently found in the thermocline.

Throughout both ECNP and SANP water masses in the central gyre, a well defined fluorescence maximum was found near a depth of 100 m, which was well below the base of the mixed layer (ranged from 60 to 70 m throughout the experiment).

Extensive cloud cover severely complicates the analysis of optical depth variability from CZCS images of the eastern North Pacific. However, enough cloud free areas were sampled to reasonably characterize the scales of optical variability throughout most of the study region. In general, the strongly turbid band of water adjacent to the California coast extends to the base of the continental slope, with a dominant scale of order 150 km. Optical depth variability in the central gyre and California Current transition region (between the optical front and central gyre) is characterized by organized, eddy-like features with scales ranging up to several hundred km.

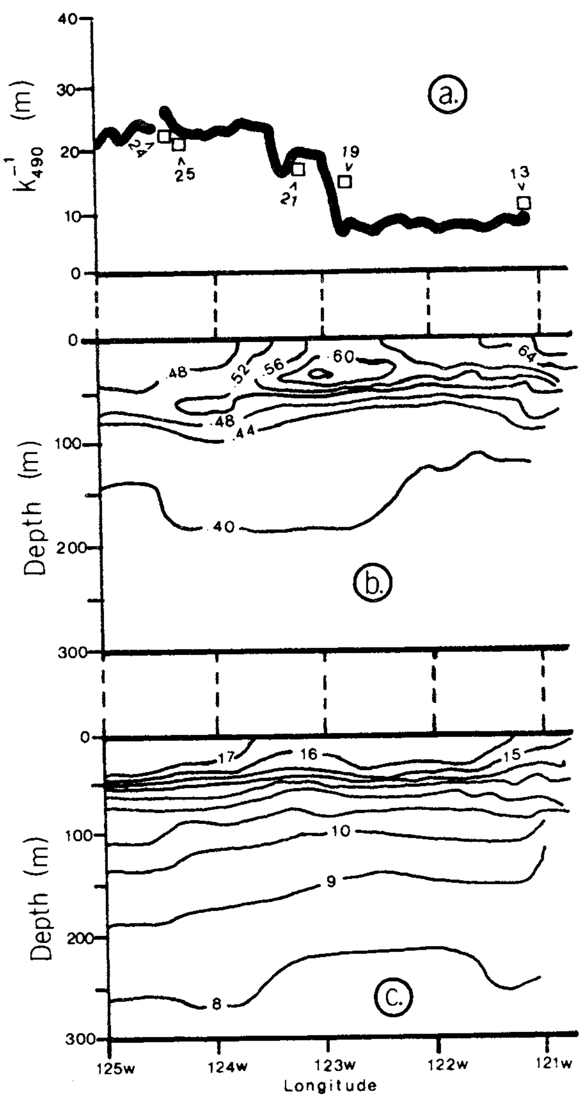

Figure 1: Optical and Temperature Variability Along 35 N.

a) Optical Depth from CZCS ( ) & at ODEX ACANIA Stations ( )

b) Beam Attenuation Coefficient at 660 nm (in 1/m)

c) Temperature (in C).

SATELLITE OBSERVATIONS FOR COMMERCIAL FISHING APPLICATIONS IN THE PACIFIC BASIN

D. R. Montgomery
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California, U.S.A.

ABSTRACT

Commercial fishermen are interested in the safety of their crews, boats and gear, and in making the best catch for their time and money. Rising fuel costs, increased competition from foreign fisheries, improved knowledge about fish habits and the new 200-mile economic zone have all had an impact on the U.S. fishing industry. As a consequence, the modern fisherman, more than ever, requires reliable and timely information about the marine environment.

This paper describes an experimental program to utilize satellite observations of the ocean surface color structure to aid commercial fishing operations in the Eastern Pacific Basin. Ocean color products, in conjunction with conventional observations and products, have been used to depict oceanographic conditions of importance to commercial fishing tactics.

The results of the experimental program to date, have shown that improved safety at sea and decreased fuel costs can be achieved through the applied use of both satellite-derived and conventional environmental products.

INTRODUCTION

Commercial fishing on the high seas continues to be economically risky and physically dangerous. While fishermen are interested in safety at sea and in catching the most fish possible for their time and financial investment, escalating operating costs, especially those associated with fuel, labor and insurance continue to erode the economic viability of the industry. Successful fishermen continue to be those individuals that look for and incorporate the latest and best technology and information to enable their operations to be more efficient. This includes the increasing use of analyses and forecast of oceanographic and meteorological conditions that affect their operations at sea, and application of fisheries research findings to search and fishing efforts. Accordingly, the modern fisherman, more than ever, requires reliable environmental information.

To meet this need, the Jet Propulsion Laboratory, with the cooperation of the Oceanography and Marine Services Division of the National Ocean Service, has sponsored an experimental program involving the preparation and distribution of special environmental products for the U.S. West Coast fishing industry, prepared with the aid of satellite observations of the ocean surface, including ocean color structure.

BACKGROUND

In June 1978 the Seasat satellite was launched by the United States as a "proof-of-concept" mission to obtain measurements of ocean-surface conditions from satellite altitude. This mission proved conclusively that wave heights, surface-wind velocity, and sea-surface temperature measurements can be obtained from space under all-weather, day-night conditions. (1)

Scientific and commercial studies (2) of Seasat data, along with recent fisheries-oriented studies of a Coastal Zone Color Scanner (CZCS) currently in orbit on the Nimbus-7 satellite, have identified promising techniques that may be used to improve the analyses and forecasts of ocean-surface features (i.e., winds, waves, sea-surface temperatures, and color boundaries). These studies have shown that such techniques may well be operationally applicable to commercial fishing activities.

FISHERIES DEMONSTRATION PROGRAM

Data Sources and Distribution

With support from both the National Aeronautics and Space Administration and the NOAA-National Ocean Service, an experimental demonstration program has been conducted on the U.S. West Coast to assess the utility and benefit of specially prepared environmental charts, tailored for commercial fishing operations. These experimental charts, supplemental to the operational charts provided by the National Weather Service, were prepared on a daily basis, utilizing operational products prepared by the Navy-Fleet Numerical Oceanography Center (FNOC), Monterey, CA, and experimental ocean color charts generated by the Scripps Institution of Oceanography - Visibility Laboratory, La Jolla, CA. The products prepared by the FNOC utilize both conventional as well as satellite-derived observations, while the ocean color charts are derived from the Nimbus-7 satellite CZCS. Data from the CZCS are received by the Scripps Institution of Oceanography Satellite Facility whose equipment and personnel have a unique capability to make the color data available on a near real-time basis to preserve its time-critical quality.

A unique data system, developed for use with the data obtained from the Seasat satellite, provides a near real-time access to the operational products of the FNOC by commercial users. This Navy Oceanographic Data Distribution System (NODDS) (3) provides both operational products and selected observations, including observations from the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR).

Figure 1 illustrates the configuration of data sources involved in preparing the experimental fisheries charts. Data from each of these sources was provided each day to a marine forecaster skilled in the preparation of marine analysis and forecast products. From this aggregated set of environmental data, the forecaster prepared a suite of fisheries-oriented charts for distribution to fishing vessels by means of daily radio-facsimile broadcasts supported by both U.S. Coast Guard Stations and radio station WWD operated by the Scripps Institution of Oceanography. Figure 2 depicts the product distribution scheme whereby the charts were made available to fishing vessels operating in the Eastern Pacific Basin from the Bering Sea southward to the Eastern Tropical Pacific.

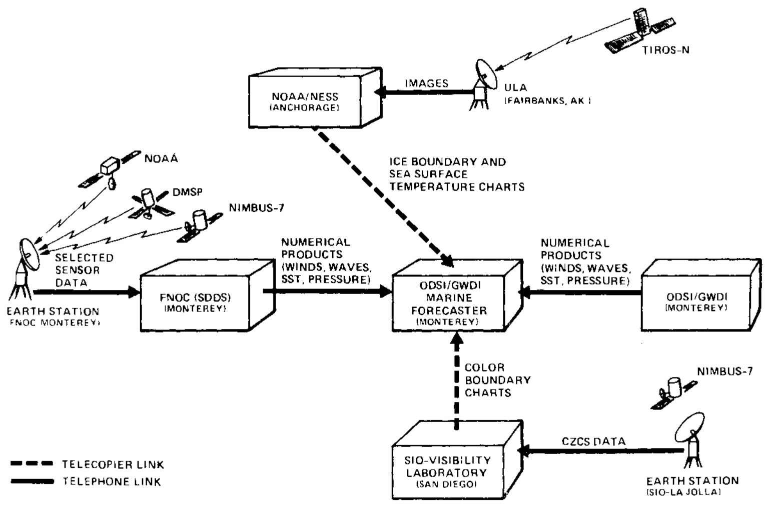

Figure 1. Sources of Data for the Fisheries Demonstration Program

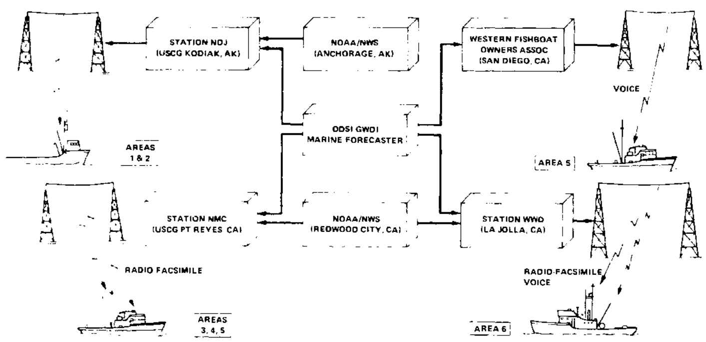

Figure 2. Data Distribution Scheme for the Fisheries Demonstration Program

Ocean Color Observations

The tracking and near real-time data processing capability afforded by the Scripps Satellite Facility and Visibility Laboratory, coupled with the fisheries research of Lasker (9) and Laurs (10), have provided the opportunity to test the utility of satellite-derived ocean surface color observations in commercial fishing operations. With a near real-time capability to handle the Nimbus-7 CZCS data, it is possible to provide perishable ocean color information to fishermen by radio-facsimile in sufficient time to yield a product which has a useful life of two to three days. The work of Austin (4,5), Smith (6), Gordon (7) and Laurs has provided a basis by which these data can be interpreted and correlated with water mass type and aggregation of fish species, especially albacore.

Processing of the CZCS data for fisheries applications involves the use of two CZCS channels, band 1 (443 nm) and band 3 (550 nm). Images showing chlorophyll concentration and water clarity (diffuse attenuation coefficient) can be generated by the use of processing techniques which ratio band 1 and band 3. Atmospheric scattering mechanisms contribute a significant proportion (up to approximately 90 percent) of the signal as detected by the CZCS. To create a useful set of images of the ocean surface, it is necessary to remove that portion of the detected signal which is contributed by the atmosphere. Processing algorithms used by the Scripps Visibility Laboratory (8) have proven to be particularly successful in removing the atmospheric contributions. Figure 3 shows an ocean color image from band 1 data prior to atmospheric correction. Figure 4 shows the same image following atmospheric correction. Figure 5 shows an image proportional to chlorophyll concentration generated from the ratio of the band 1 and band 3 images.

Ocean color has historically been a cue by which fishermen have identified potentially productive fishing areas. Albacore fishermen operating in U.S. West Coast waters key their fishing operations to the "blue" color of the ocean water.

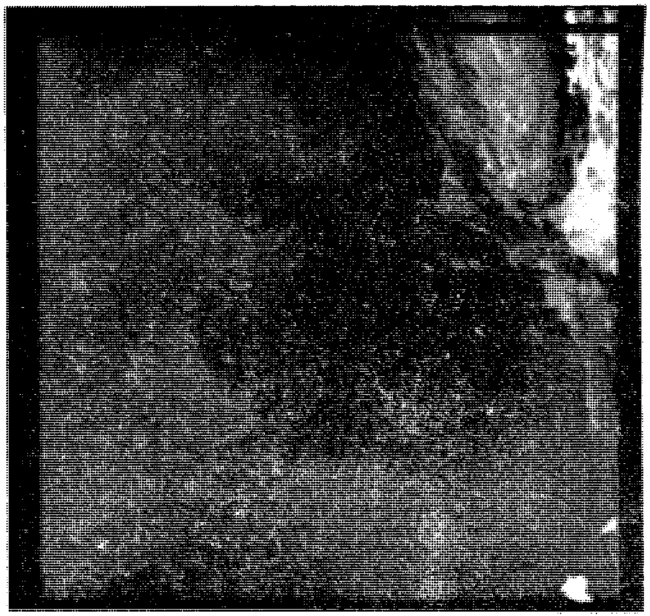

Figure 3. A Band 1 (443 nm) Image from Nimbus-7 CZCS Prior to Atmospheric Correction

Figure 4. A Band 1 CZCS After Atmospheric Correction

Figure 5. An Atmospherically Corrected CZCS Image Depicting the Ratio of Band 1 to Band 3, Which Allows the Identification of Areas of Varying Water Clarity and Chylorophyll Concentrations

Laurs, et al. (10, 11) using both satellite-derived sea surface temperature and ocean color observations, coupled with acoustic tracking data, have begun to correlate the small-scale migration patterns of albacore tuna with ocean color structure and water temperature.

Figure 6 shows a CZCS image of the U.S. West Coast in the region Cape Mendocino, processed to identify color structure proportional to the diffuse attenuation coefficient or water clarity. Warm, clear, oceanic water is shown in blue, while the more cool, turbid coastal water is shown in the yellow to brown color ranges. Also depicted on this CZCS image is catch data for albacore tuna, obtained from logbooks of commercial fishing vessels. The larger the circle, the higher the catch per day for the period September 19-25, 1981. This figure clearly illustrates that albacore tuna aggregate on the clear (and warmer) side of ocean color fronts. While analysis is continuing to explain the role of water clarity and temperature in the mechanisms underlying the preferential aggregation of albacore in certain water masses, it is clear that these satellite derived observations of ocean color can aid both scientific research directed towards fisheries forecasting of the distribution, migration, and availability of the fish stock, and commercial fishing operations.

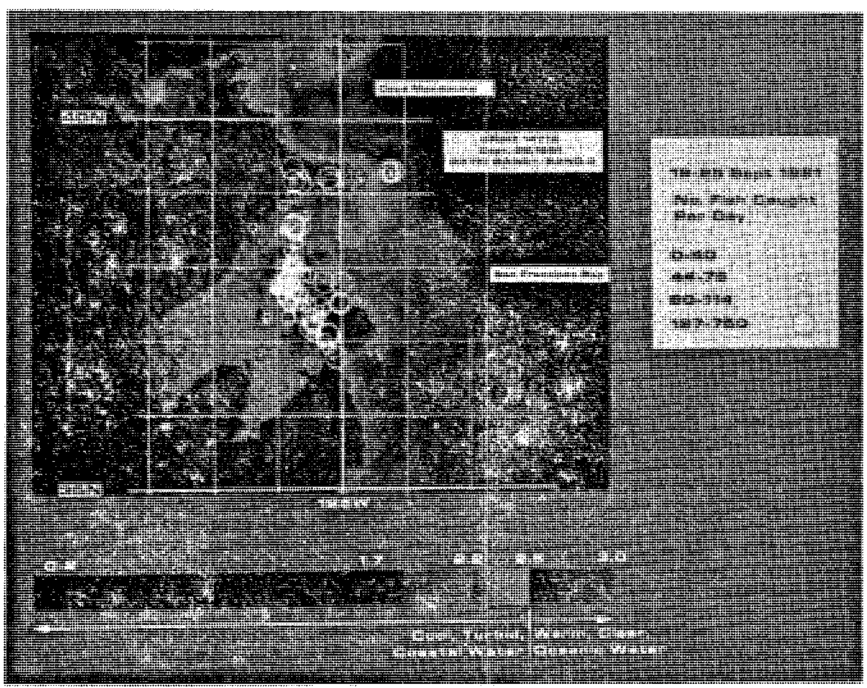

Figure 6. A CZCS image processed using computer enhanced false color to identify water color structure showing areas of varying water clarity. Commercial fish catch data are depicted on the image.

This evidence of fish catch correlation with ocean color structure is sufficient evidence to indicate that an ocean color structure product can be a useful tool to commercial fishermen to aid in the identification of ocean areas with the potential of aggregating quantities of albacore tuna. Based on this knowledge, a color chart is produced as part of the Fisheries Demonstration Program and transmitted to fishermen by radio-facsimile. The radio-facsimile chart, shown in Figure 7, is derived from a computer-generated, false color image processed to highlight ocean regions of high chlorophyll concentrations and water clarity. Based on the false color image, as shown in Figure 8, a chart is drawn to identify the boundaries separating key water masses, based on chlorophyll concentration. Each water mass is identified in terms of its relative color, with the most green water labeled as "number 1 water" and the most blue water labeled as "number 4 water". Water masses of intermediate colors are noted with 2 and 3 labels.

Figure 7. A color boundary chart constructed from a false-color enhanced CZCS image. Key water masses are identified by numbers. Geographic landmarks are added to chart before transmission by radio-facsimile.

Figure 8. A False Color Enhanced CZCS Image Used to Construct Color Boundary Chart as Shown in Figure 7.

Special Environmental Charts

The experimental special environmental charts depict atmospheric and oceanographic properties of particular use by fishermen in selecting fishing areas and fishing tactics. Figures 9, 10, and 11 illustrate three charts representative of the several charts generated as part of the demonstration effort. The chart shown in Figure 9 depicts sea surface temperatures (SST) as well as wave conditions which are noted at the latitude/longitude intersections, or at locations of special interest. Arrows denote wave direction while the number indicates the significant wave-height (H 1/3) in feet. Wave conditions are derived from the FNOC Spectral Ocean Wave Model (SOWM). New SST analyses are made by computer every twelve hours using reports from ships (engine-room injection or bucket temperatures), satellites (infrared) and bathythermograph systems.

The fishing success rate for many species of fish in the Pacific Basin is highest within a relatively narrow range of ocean temperatures. For example, salmon are usually caught at temperatures below 50° F, with the greatest catches occurring between 49° and 51° F. Most albacore are caught at temperatures between 60° and 64° F, while the largest percentage of tropical tuna species are caught in water temperatures between 79° and 81° F. The experimental fisheries charts depict these species-related SST bands. Figure 10 illustrates regions of preferred SST-bands for both albacore (band indicated with A) and

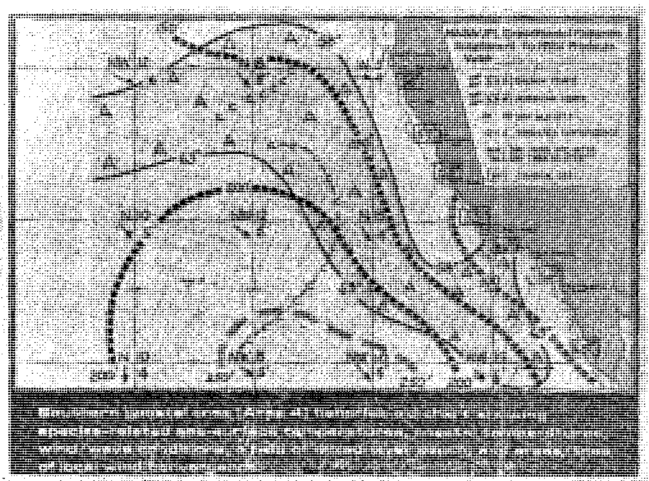

Figure 9. Sample Fisheries Environmental Chart

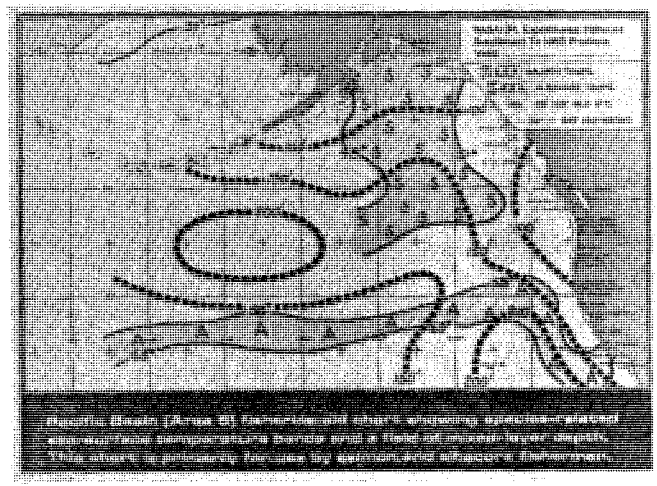

Figure 10. Sample Fisheries Environmental Chart Used by Commercial Fishermen in the Experimental Program

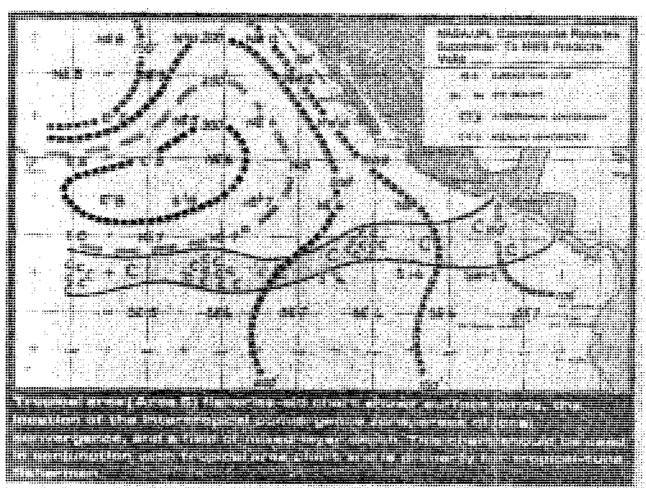

Figure 11. A Fisheries Environmental Chart Prepared for the Tropical Tuna Fishery

tropical tuna (bands indicated with T). The coastal SST values (shown as NUMBER in Figure 9) are derived from the SST analysis and are based on ship reports from vessels operating in coastal waters.

The experimental charts depict key subsurface thermal characteristics. This subsurface thermal information is generated operationally by FNOC utilizing both bathythermograph soundings and climatology, and is selectively available to commercial users through the NODDS. Figures 9 and 10 illustrate, through the use of dashed lines, the depth of the mixed layer, (MLD) which can be a significant parameter for several fish species, including salmon and albacore. Research conducted by Laurs has shown that albacore often tend to experience the MLD as a thermal "ceiling" in their verical feeding excursions. Knowledge of the MLD can aid fishermen in selecting both gear and tactics while fishing for those fish species which exhibit thermal preferences.

On the experimental environmental charts, surface winds are indicated by alphanumeric characters at selected latitude/longitude intersections (see Figures 9 and 10). Selected wind derivatives from basic wind field analyses are of interest to fishermen because they are related to both significant weather and areas where nutrients tend to congregate. Wind derivatives shown on the experimental charts (see Figure 11) include the Intertropical Convergence Zone (ITCZ) and lines of convergence. Typically, a more-or-less continuous zone of wind convergence can be analyzed across the entire Pacific. However, parts of ITCZ are characterized by intense weather - heavy showers and/or thundershowers - while other parts exhibit weaker wind convergence and produce little more than a few cumulus clouds. Since the ITCZ normally lies within the tropical tuna-fishing area, it is shown on the fisheries charts as illustrated in Figure 11. Areas where there are numerous "C's" are the most active and are apt to have heavy showers and wind squalls. The ITCZ is located through numerical wind analyses and satellite derived visible and infrared photographs of clouds.

Local areas and/or lines of wind convergence also represent regions of squalls and wind shifts and possible areas of local nutrient (fish-food) concentration. These areas/lines are also located by means of satellite photographs and are depicted on the experimental charts as illustrated in Figure 9.

<u>Correlation of Environmental Information</u>

To make maximum use of the environmental information available through both the National Weather Service and the experimental fisheries program, fishermen must correlate key meteorological and oceanographic features in order to identify ocean regions most likely to support selected fish species and which permit fishing gear to be deployed. Figure 12 has been developed as a training aid to illustrate the correlation process that will tend to highlight favorable albacore fishing areas. Figure 12 is a composite chart depicting those oceanographic and meteorological parameters shown on NWS and fisheries environmental facsimile charts. Wind and sea conditions denoted above the hash-mark line tend to exceed those limits where troll gear can be effectively deployed, while below this line wind and wave conditions are reasonable. Sea surface temperature conditions are favorable for albacore within the "A" bands and the mixed layer depths levels in the range of 50 to 150 feet are preferred for troll fishing methods. Ocean color boundaries separating warm, clear oceanic water from the colder, more turbid coastal water are highly preferred by albacore and are shown in Figure 12 as boundaries between number 2 water and number 4 water. Significant, but less preferred boundaries exist between number 2 water and number 4 water. Giving consideration to each of these parameters, including the preferred color boundaries, it is apparent from the composite training-aid chart that key ocean areas for albacore exist in the regions of 122° and 123° west longitude and 32° to 34° north latitude.

While this correlation of environmental parameters may not conclusively identify productive fishing areas since non-environmental factors also effect the feeding and migration patterns of fish, it will aid the commercial fishermen in separating those fishing areas with a higher probability of supporting fish concentrations from those with lower probabilities. And, maybe more importantly, the fishermen will be able to identify areas which are most likely <u>not</u> to support fish concentrations, thus allowing the fishermen to avoid selected areas and make more efficient their search operations.

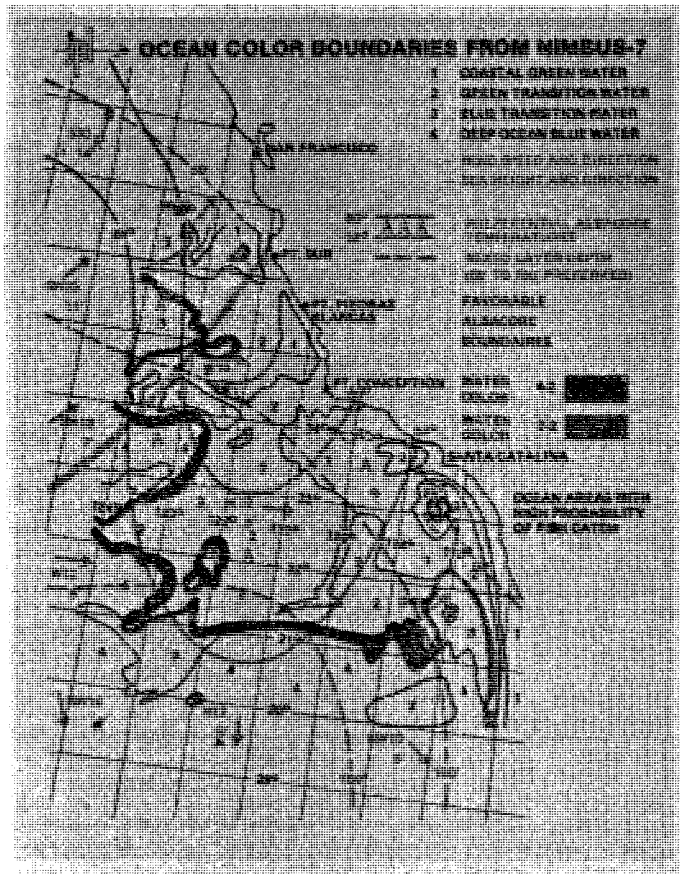

Figure 12. A composite chart showing oceanographic and meteorological features available on various operational and experimental charts transmitted by radio facsimile. The composite shows the use of environmental data in locating productive ocean areas.

Conclusion

The Experimental Fisheries Program has begun to illustrate to the commercial fishing industry the utility and economic viability of satellite observations of the ocean surface in their fishing operations. Assimilation of this NASA-developed satellite technology by the fishing community will be slow, but with continued demonstrations under balanced partnership arrangements between government and industry, the technology will come to play a key role in making the U.S. fishing industry more efficient, safe, cost effective and competitive on the every widening world market.

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APPLICATION OF SATELLITE REMOTE SENSING TO FISHERIES

R. Michael Laurs
National Marine Fisheries Service
Southwest Fisheries Center
La Jolla, California, U.S.A.

Abstract

Satellite oceanic remote sensing is beginning to play important roles in fishery research and fish harvesting. Spaceborne sensors are being used to make synoptic oceanic measurements for use in determining variations in ocean conditions which play key roles in causing fluctuations in stocks of fishes and in their vulnerability to harvesting.

Results from research conducted at the National Marine Fisheries Service, Southwest Fisheries Center (NMFS, SWFC) in La Jolla, California, provide examples of the utility of satellite oceanic remote sensing as a tool in fisheries research. Capabilities have been developed to define the spawning habitat and to describe ocean processes in relation to spawning of the northern anchovy using ocean infrared thermal imagery and ocean color imagery observed by orbiting satellites. Infrared and visible color data from satellites and concurrent albacore catch data have clearly shown that the distribution and catchability of albacore are related to oceanic fronts. Results show that commercially fishable aggregations of albacore are found in warm, blue oceanic waters near temperature and color fronts adjacent to the seaward edge of coastal water masses. Further, studies using satellite imagery in conjunction with field experiments have yielded results suggesting that water clarity as it relates to albacore being able to see food organisms, may be an important mechanism underlying the aggregation of albacore in the warm, blue water associated with oceanic fronts, rather than thermal-physiological reasons as was hitherto believed. In studies underway dealing with the ecology of marine mammals, preliminary results indicate that the distributional patterns of selected marine mammals off the coast of southern California are related to oceanic features detectable in infrared and color imagery from satellites.

THE ACCURACY OF SEASAT SMMR-DERIVED SST*

Cho-Teng Liu
Institute of Oceanography
National Taiwan University
Taipei, Taiwan, R.O.C.

The accuracy of Scanning Multichannel Microwave Radiometer (SMMR) derived sea surface temperature (SST) has been discussed in various published reports and papers, like those in Seasat Special Issue I & II. In many cases, limited number of unscreened expendable bathythermograph (XBT) data are used as reference for comparison, and their conclusions are limited by the reliability of XBT and the incompleteness in XBT's temporal and spatial coverage. In other cases, ship reported SST data and the SST fields derived from them are used as references (Liu, 1983; Bernstein and Morris (B & M), 1983). From these earlier studies, the quality of SMMR SST are proved to be potentially equal to or better than ship SST, but the bias and random error of individual SMMR SST still needs to be determined. A set of bathythermograph (BT) data in the Seasat period (July 1 - October 10 of 1978) is used in this study to determine and to improve the accuracy of SMMR SST through screening out questionable data and through compensating for the systematic errors in the data.

Before being paired with SMMR SST, the BT data are first screened for better accuracy. About 10% of BT data are rejected because they are either redundant, inconsistent with climatological mean SST (also derived from BT data), or inconsistent with other recent reports from the same ship/airplane. The screened BT data are then paired with SMMR SSTs (which are more than 700 km from any continent) if both data are gathered within 100 km and 48 hours from each other. Because of the uneven distribution of BT data, only those in the region of 10°S - 60°N and 130°E - 350°E are used in this study. In addition, because of the complexity in SMMR SSTs of the descending passes (B & M), only those SSTs of ascending passes are used in this study. Total 9867 pairs are found satisfying above requirements. There are 3387 pairs in July, 3131 pairs in August, 2443 pairs in September, and 906 pairs in October 1 - 10 of 1978.

The SMMR antenna was designed to measure both the horizontally and vertically polarized microwave radiation at five frequencies. From these ten simutaneous measurements, the SST, surface wind speed, rain rate, and atmospheric water content can be derived. Since the SMMR-derived SST represents the skin temperature surface and the polarization of surface radiation at 6.6 gHz (used specially for deriving SST) has been rotated by both the earth's ionosphere (Faraday rotation) and the scanning reflector of SMMR's antenna before it arrives at the feed, there are systematic differences between the SMMR-derived SST and the surface observed SST. Following is a short summary on the major causes of this systematic difference between SMMR SST and BT SST:

(1) the difference between skin temperature (SMMR SST) and 1 m depth temperature (BT SST): it depends on both surface heating and surface temperature stratification, which are in turn a function of solar latitude and time of the day (for heating), and wind speed (for mixing);
(2) the difference caused by Faraday rotation: it depends on the electron density in the ionosphere, which is in turn a function of time of the day, solar latitude, and sun spot activity;

* This work is sponsored by the National Science Council, Republic of China.

(3) the difference caused by reflector's scanning motion: it depends on the viewing angle of SMMR, therefore the cell number (from 1 to 4) along a scan line.

The SST retrieval algorithm has accounted for most part of the aforementioned systematic errors through model approximation. The remaining systematic errors still need to identified and compensated if possible. We shall present a pre-processing procedure for using SMMR SST as a data base. This procedure is intended for screening out questionable data and making corrections on them, in order to improve their usefulness.

First, remove those data contaminated by the sun glint. When the sun glint gets within 25° from the beam of SMMR antenna, the derived SST will be biased higher than normal. This is evident from the plot of mean bias against local sun time (LST) in Figure 1, where the light curve is derived from all paired BT and SMMR SST and the dashed curve is derived from those pairs with rain data less than 0.5 mm per hour and sun glint angle larger than 25°. The sun glint problem is more severe in September and October data, especially for cell #3 and #4 because the SMMR antenna has to look southeastward in the morning sun while flying over the northern hemisphere. Both the mean bias and standard deviation of SMMR SST are improved, as shown in Table 1.

Secondly, a small part of the data set deviate unreasonably large from surface observed SST. Before the source of error can be located, these questionable data may be screened out if they deviate from climatological mean SST by certain amount. In our case, this amount equals the square root of $a^2(x,y) + 9$, where "a(x,y)" is the maximal variability index of monthly mean SST field at locatin (x,y). This screening procedure temporarily rejects 366 out of 6183 pairs of SMMR and BT SST, a 6% rejection rate.

Thirdly, deduct cross-track bias from SMMR SST data. The cross-track bias is resulted from imperfect modeling of the polarization-mix of 6.6 gHz signal by the reflector and by the ionosphere. The statistics of SMMR SST from each one of the 4 cells shows similar standard deviation but different bias as seen in Figure 2 (statistics of 100 samples or less are not shown). Corresponding to cell #1, #2, #3, and #4, 0.0°C, -0.327°C, 0.233°C, and 0.865°C are added onto pre-climatologically tested SST data. Then, the climatological test is applied on the corrected SMMR SST. With 5891 data survived the test, the overall bias and standard deviation are changed to 0.144°C and 1.618°C. Most part of the systematic errors will be eliminated by these three steps.

The large change of monthly mean bias from July to August survived all screening processes. B & M (1983) postulated that this monthly difference reflects the true near surface summer temperature gradient. Since the near surface temperature stratification can not withstand wind mixing, the sea should be relatively calm in August than in July if their hypothesis is a valid one . The SMMR-derived monthly mean surface wind speed (associated with each SMMR SST does show a drop from 12 m/s in July to 10 m/s in August. This seems too high for near surface temperature stratification to sustain. After deleting all SMMR SST associated with surface wind speed of 5 m/s or less, the monthly (July, August) mean bias changes from (-0.65°C, 1.03 °C) to (-0.68°C, 0.96°C), a mere 0.02°C improvement in their difference. Before resolving this puzzle, one may use the heavy curve in Figure 1 to remove the remaining mean bias and the resulted SST data will have standard deviation less than 1.5°C.

In summary, the quality of indivisual SMMR SST is equal to or better than the ship SST. SMMR SST is also better than ship SST in constructing ocean-wide SST field because of the evenness of SMMR's spatial coverage. If the shift of monthly mean bias can be removed, the accuracy of SMMR SST can be further improved.

Table 1. Statistics on SMMR SST data of ascending passes, as compared to BT SST. Each block of three numbers are number of comparisons, mean bias (°C), and standard deviation (°C). See text for definitions.

Month	original pairs	no sun glint	screened by climatology	cross-track bias removed
7	3387	3040	2955	2964
	-.81	-.84	-.83	-.65
	1.68	1.48	1.39	1.35
8	3131	2557	2322	2388
	1.08	1.12	.95	1.03
	1.77	1.79	1.48	1.47
9	2443	442	405	410
	1.31	.73	.53	.49
	2.00	1.50	1.34	1.32
10	906	144	135	129
	.90	.42	.31	.74
	1.96	1.79	1.61	1.64
all	9867	6183	5817	5891
	.473	.112	.003	.144
	2.044	1.876	1.663	1.618

References:

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Bernstein, R. L., and J. H. Morris, Tropical and Mid-Latitude North Pacific Sea Surface Temperature Variability from the SEASAT SMMR. JGR, 88, C3, p.1877-1891, 1983.

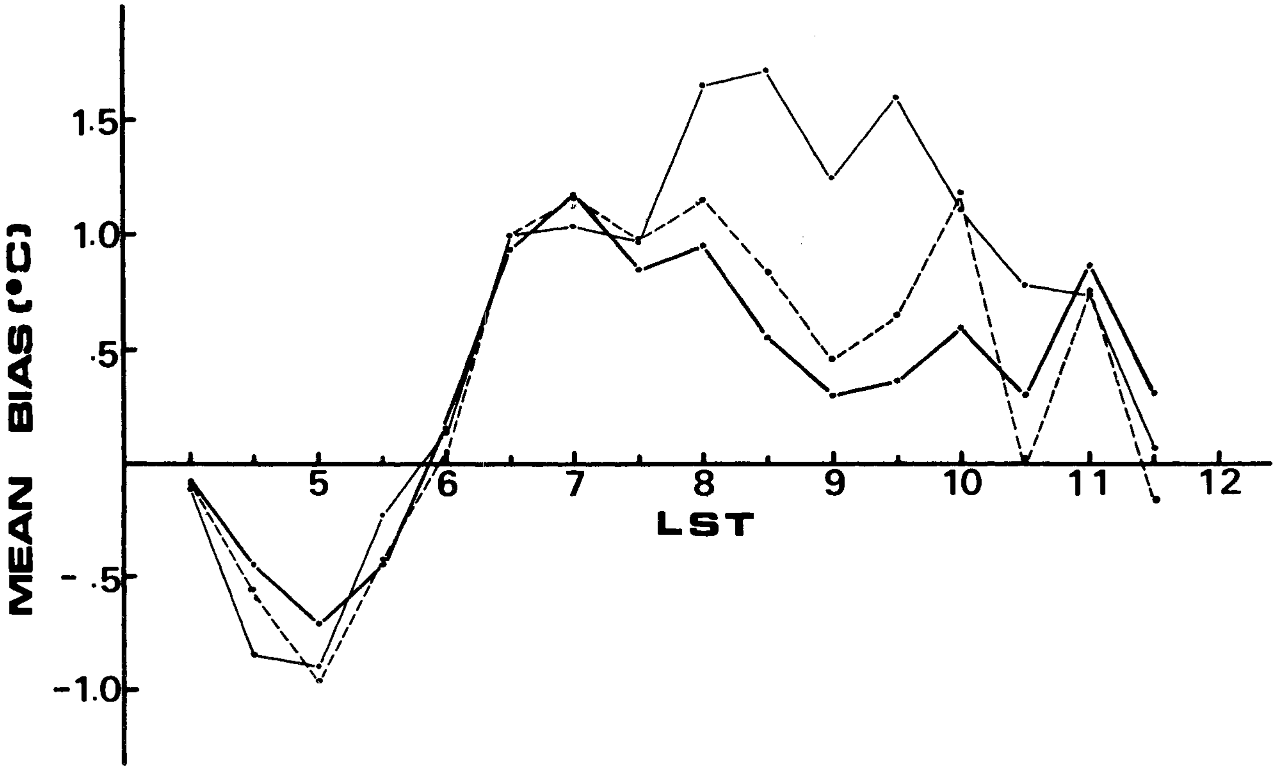


Figure 1. Half-hourly mean SMMR SST bias as a function of local sun time (LST). The light curve is computed from original pairs of SMMR and BT pair of SST, the dashed curve is from those pairs free of sun glint contamination. With further climatological test and cross-bias correction, the heavy curve represents the characteristics of the fully screened SMMR SST.

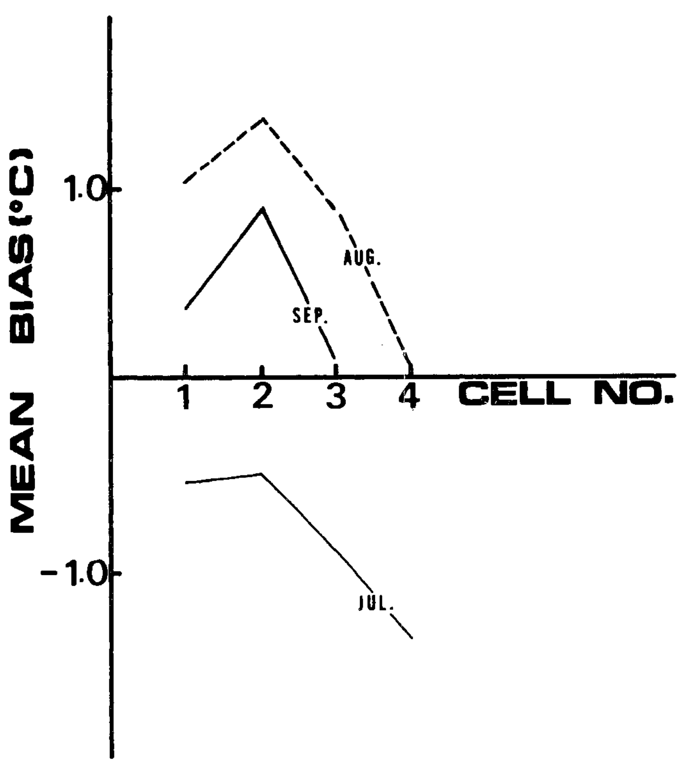


Figure 2. The cross-track bias of each month. Statistics of less than 100 samples are not shown. The mean value for each cell is used for cross track bias correction.

OST-3: GPS: POSITIONING & NAVIGATION

RADIOPOSITIONING SYSTEMS, PRESENT AND FUTURE; THEIR COMPARATIVE CHARACTERISTICS AND APPLICABILITIES.

Allen L. Comstock
Teledyne Hastings-Raydist
Hamptom, Virginia, U.S.A.

Introduction

A brief scanning of the literature by someone tasked with selecting a radiopositioning system for a projected application will quickly reveal that there is a great variety of candidate systems from which to choose. Further investigation will reveal that these various systems, although all are designed to give the user his true position while he is performing whatever his task may be, vary substantially in the manner in which they go about determining that position and their ability to do so under various conditions. In order to select the optimum system for his particular application, one must understand the significant differences among the various candidate systems and how those differences will affect his particular operation.

Before summarizing the characteristics of a few specific radiopositioning systems it will be useful to mention some rather general ways in which these systems differ. This will not only help the prospective user to understand the differences and to evaluate these few specific systems relative to his projected application but will also serve to establish some general guidelines by which he may be able to evaluate other candidate systems not mentioned here.

Frequency

The operating frequency, or that portion of the radiofrequency spectrum in which a particular system operates is one of the most important points to be considered when selecting a radiopositioning system because operating frequency will have a strong influence on operating range and positional accuracy (Table 1).

DESIGNATION	SYMBOL	FREQUENCY
Very low frequency	VLF	10-30 kHz
Low frequency	LF	30-300 kHz
Medium frequency	MF	300-3000 kHz
High frequency	HF	3-30 MHz
Very high frequency	VHF	30-300 MHz
Ultrahigh frequency	UHF	300-3000 MHz
Microwave frequencies	S-band X-band	3-30 GHz

TABLE 1. Designations of Frequency

Without going into the physics of electromagnetic wave propagation through the atmosphere and over the surface of the earth let it be sufficient at this point simply to say that radiopositioning systems operating at LF, MF and HF frequencies will be operable well beyond the horizon, frequently to ranges of several hundred miles, while systems operating at VHF and above in general will be limited to line-of-sight ranges, not very much beyond the optical horizon (Figure 1). On the other hand VHF, UHF and microwave systems are, in general, capable of more precise distance, or position, measurements than are the lower frequency systems. Other important points to be considered regarding operating frequency include (1) the somewhat larger and more cumbersome antennas which are normally required by the lower frequency systems (MF and HF), and (2) the greater susceptibility of the higher frequency systems

(VHF and UHF) to "multipath" problems. Comprehensive discussions of all of these points, as well as many of the points to follow, can be found in References 1 and 2.

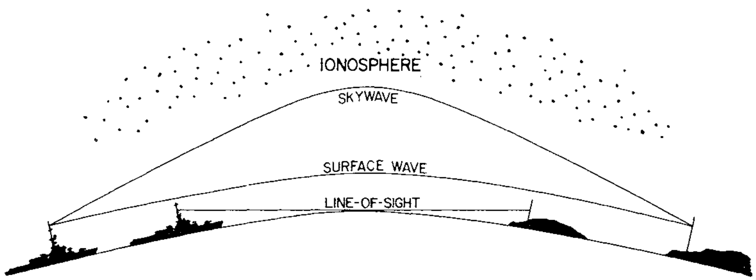
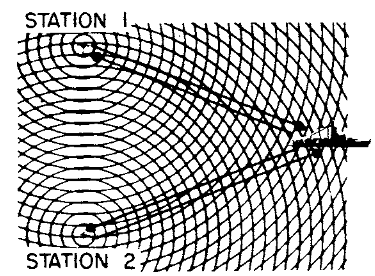


FIGURE 1. Range of MF and HF systems is limited only by signal strength and skywave interference. Range of VHF and UHF systems is restricted by "line-of-sight" limitation.

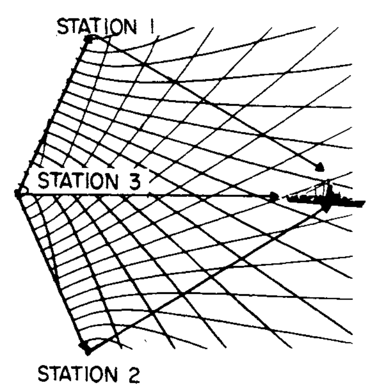
System Geometry

System geometry is another very important consideration when selecting a radiopositioning system (Figure 2). The two most common geometries are "hyperbolic" (range differencing systems) and "circular" (direct ranging systems). Each of these two system geometries has certain advantages over the other under different conditions.

Most hyperbolic arrangements require radio signals to be transmitted along the baseline(s) from one fixed shore station to another. Ranging systems, on the other hand, generally do not require such baseline transmissions. Therefore, in situations where transmissions along the baseline(s) may not be possible, due to intervening mountains or long overland paths, a ranging system arrangement will be advantageous. The freedom from dependence upon baseline transmissions will permit the fixed shore stations of a ranging system to be placed in locations which would not be acceptable in a hyperbolic system arrangement thus permitting wider separation between the base stations and generally better geometry.



RANGING (Circular)



RANGE DIFFERENCING (Hyp)

FIGURE 2. Propagation paths and LOP patterns for ranging and range-differencing systems.

The circular geometry will always yield higher positional accuracy over a larger geographical area than will the hyperbolic geometry (Figure 3). This is due to the "stronger" (more nearly orthogonal) angles of intersection between the circular lines-of-position (LOP's) than is normally possible to achieve in the hyperbolic geometry and to the constant "lane width" (spacing between LOP's) which always exists in the circular geometry, compared to the "weaker" angles of intersection and the ever-expanding lane widths of the hyperbolic geometry. Under some conditions however, such as along a concave coastline or in a nearly enclosed bay or estuary, a hyperbolic system can be arranged in such a way that very good accuracy can be achieved over the area of interest. In such cases consideration should be given to the trade-offs of using only three shore stations to generate two hyperbolic baselines with one station being common as opposed to using four shore stations to generate two completely independent baselines to achieve improved geometry.

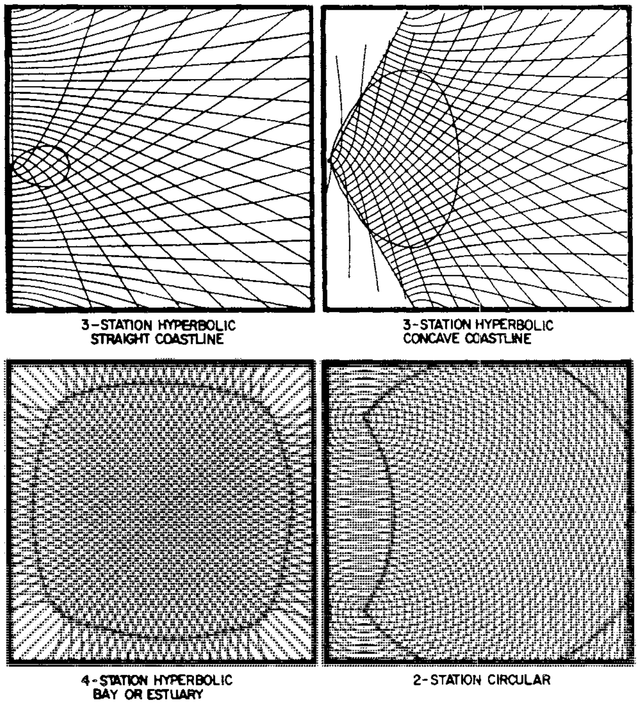


FIGURE 3. Comparative areas of high-accuracy coverage (GDOP <2) for four typical system geometries.

The anticipated number of simultaneous users frequently is a deciding consideration in choosing between circular and hyperbolic system arrangements. As a general rule, any circular, or ranging, system will require two-way transmission, i.e., transmission from the mobile platform (ship or aircraft) to the shore station(s) and transmission from the shore station(s) back to the mobile platform (Figure 2). For this reason practically all ranging systems will be limited to some degree regarding the number of mobile units which can use the system simultaneously. A number of techniques are employed to achieve multiple-user capability in ranging systems such as "time sharing" where each mobile unit utilizes the shore stations for a short period of time while the others wait their turn, and "frequency difference" where each mobile unit is assigned a slightly different operating frequency so that all mobile units can utilize all shore stations all of the time. Under either arrangement, however, the maximum number of simultaneous users varies depending upon the particular system selected and the manner in which it is being used.

Hyperbolic systems, on the other hand, generally require only one-way transmission, from the shore stations to the mobile unit, but not from the mobile unit to the shore stations. Therefore, since the mobile units operating in a hyperbolic system receive signals but do not transmit, such hyperbolic systems can accommodate an unlimited number of simultaneous users. There may be operational considerations other than the unlimited-user requirement which may dictate the selection of a "passive" (hyperbolic) system over an "active" (circular) system such as a requirement that the user(s) maintain "radio silence" for some reason. Futhermore, where such a system is to be used in a "tracking" mode with the position data being generated and utilized at some point other than aboard the mobile unit, it is convenient to place only a small transmitter on the mobile unit and then to receive signals from that transmitter at a number of fixed base stations from whence they are relayed to a centrally located tracking station, or data processing point. The Raydist Type-E configuration is one such arrangement and has been used for tracking free-floating buoys, experimental rockets and small sail-planes studying wind currents over the Sierra Nevada mountains in California. Such a system will, of course, be hyperbolic because transmissions occur only in one direction.

Hyperbolic systems are sometimes linked together in a multi-net arrangement to provide continuous coverage over an extended area. The Chesapeake Bay Raydist-T System in Virginia and the Rio de La Plata Raydist-T System in South America are excellent examples (Figure 4). Both are three-net systems which provide high-accuracy coverage for a large number of users engaged in a variety of activities such as hydrographic surveying, ecological studies, law enforcement, channel surveillance, dredging, maintenance of fixed and floating navigational aids, etc.

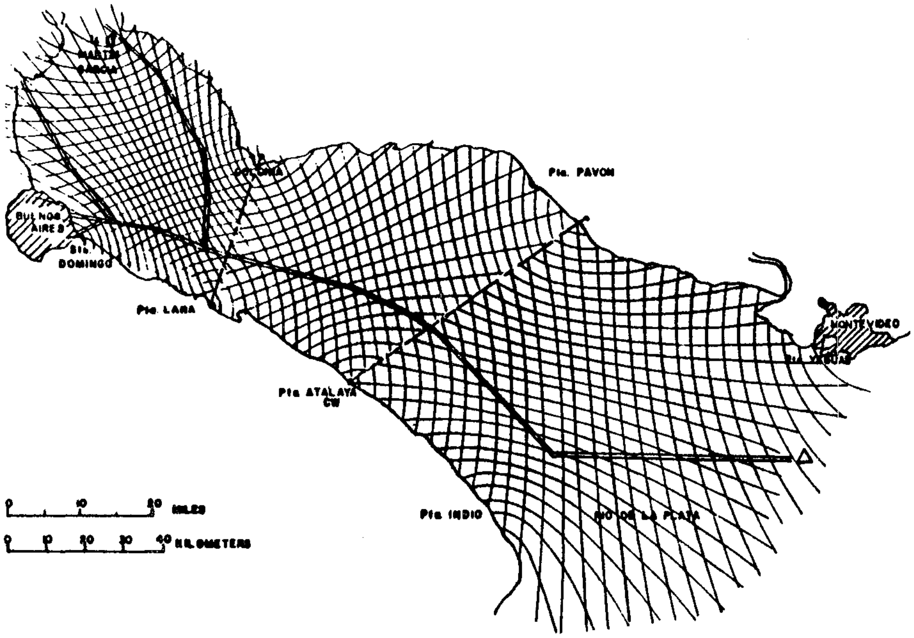


FIGURE 4.

Some radiopositioning systems can be used in either the circular or hyperbolic mode, and in some cases, both modes simultaneously. In general, the same basic elements (transmitters, receivers, clocks, phasemeters, etc.) are present in a radiopositioning system regardless of whether it is a hyperbolic or a circular system. The difference lies in the way these basic elements are grouped and the way in which the phase comparisons (or time measurements) are made. For example, in any Raydist system there are five basic elements involved in the generation of any given LOP whether it be circular or hyperbolic; two CW transmitters, two CW receivers and one phasemeter, plus whatever data links may be necessary to get the information to the phasemeter. These five elements are shown in Figure 5 along with the propagation paths between these elements and a general expression for the phase relationship ψ which will be generated in the phasemeter P. Whether ψ turns out to be a circular or a hyperbolic function depends upon which distances (d) become zero as the various units are grouped together and which terms, therefore, drop out of the general expression. As the Figure shows, if T_1, R_1 and P are grouped together and T_2 is co-located with R_2 then ψ becomes a function of R (the distance between the two sets of equipment) and the result is the DRS-H Raydist ranging system. Either grouping (or both) can be mobile.

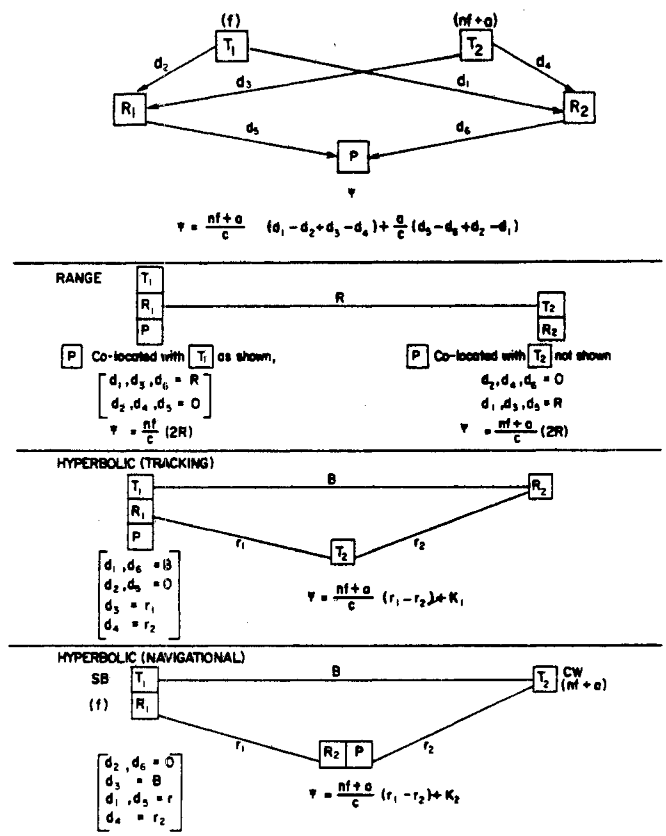


FIGURE 5. Various Raydist arrangements formed by different groupings of five basic system elements.

If, however, R_1 and T_1 are combined at one fixed point, R_2 is placed at a second fixed point and T_2 is placed aboard the mobile unit then ψ becomes a function of the difference between ranges r_1 and r_2 and the resulting LOP will be hyperbolic. The phasemeter P can be co-located with either base station or may be placed at any convenient fixed location. This is the Raydist Type-E "tracking" configuration mentioned above.

The "navigational" hyperbolic configuration is achieved by combining T_1 and R_1 at one fixed base station, locating T_2 at a second fixed point and placing the phasemeter P onboard the mobile unit along with R_2. This arrangement is used in both the hyperbolic mode of the DRS-H Raydist system and in the Raydist-T systems, either three-station or four-station. Variations of the arrangements shown in Figure 5 are possible which permit both ranging and hyperbolic operations in a single network at the same time.

Time Measuring vs. Phase Measuring

From a theoretical point of view, it can be argued that phase measurement is simply a method of measuring time. From a practical point of view, however, there are some important differences. While it is relatively simple to measure phase to something like one degree (which at 3 MHz, for example, represents about 13 cm of distance), it is a bit more complicated to measure time directly to a corresponding accuracy of approximately 0.5 nanosecond. Use of the phase measuring technique, therefore, can result in simpler, less critical and less expensive hardware to achieve a given degree of precision.

The price one pays for utilizing the phase measuring approach is "lane ambiguity". A time difference, theoretically at least, can vary from zero to infinity. Relative phase, on the other hand, can vary only from zero to 360 degrees. All phase measuring systems must contend with the fact that a steadily increasing relative phase angle will become zero again every time it reaches a value of 360 degrees. Such a phasemeter, if put into operation at some arbitrary location in the coverage area, might, for example, register a relative phase angle of 180 degrees. This, of course, would represent a fractional lane value of 0.5 and would indicate an LOP position midway through a lane. But which lane? It would be similar to a clock with only a minute hand indicating half past the hour. Which hour? Hence the problem of lane ambiguity and the need for "lane identification", a process by which the "whole" lane count may be determined so that the 180-degree (0.5 lane) indication mentioned above can be joined to a whole lane count of, say, 1050 to give an actual LOP value of 1050.5 lanes. For this reason, phase comparison systems normally must be "initialized", i.e., the phasemeters must be set to indicate the correct whole lane count (to the left of the decimal) and a fractional value (to the right of the decimal) at some known starting point and then must accumulate changes in phase (changes in LOP's) without interruption as the mobile unit proceeds from that starting, or "initialization", point.

Several lane identification schemes have been devised and are being built into the various phase measuring systems. Most such schemes, however, do not seem to be completely reliable. The "multiple frequency" lane identification method, sometimes used in both circular and hyperbolic systems, (Decca and Argo) utilizes the vernier effect of two LOP patterns, the lane width of one being about 90% of the lane width of the second so that these two patterns, when laid one over the other, go in and out of phase about every ten lanes. This permits a user to determine his actual whole lane count provided he already knows his whole count to something better than ±5 lanes. The problem with this method lies in the unfortunate fact that radiowave propagation on the two slightly different frequencies sometimes varies independently and the two overlaid LOP patterns do not maintain precise registration. One may shift slightly with respect to the other thus blurring the precise interrelationship between the two LOP grids which is vital to successful lane identification.

In hyperbolic systems a "short baseline" method is sometimes used in which a pair of short baselines is established such that their more rapidly expanding hyperbolic lanes (LOP's) will have lane widths about ten times as broad as the lanes of the longer, or "primary", baselines in the area of interest. Obviously, the 10:1 ratio can be made to exist only over a relatively small area. For this reason, the short baseline method of lane identification is of rather limited usefulness.

A third method, one which is employed in the Raydist Director systems, utilizes a redundancy of LOP data and depends upon the solution of a set of simultaneous equations expressing the changes observed in each of the LOP values as the mobile unit moves a short distance through a portion of the operating area. The distance which the mobile unit must travel while gathering the redundant LOP data depends upon the geometry of the LOP patterns but in every case must be sufficient for that geometry to change appreciably. This, of course, is one of the less desirable attributes of this method. A second difficulty lies in the fact that not only must the geographic location of each base station be known very accurately, but the LOP data must remain free from systematic errors, including propagational variations, while the redundant LOP data is being recorded. Given these conditions, the redundant LOP data method works very well. In addition to the lane identification schemes mentioned above, there are a number of operational procedures which can be employed to minimize these inconveniences and phase comparison systems continue to be quite popular due to their ability to produce highly accurate position data with relatively simple, inexpensive and easily maintained circuitry.

Continuous vs. Data Sampling

Time measuring systems are inherently "data sampling" systems; i.e., they measure a time, or time difference, at repeated, discrete intervals. Some phase comparison systems (Decca and Argo) also operate on a data sampling principle while other phase comparison systems (Raydist) employ a continuous, uninterrupted, phase comparison method. The important point to keep in mind is that a "continuous" type system is gathering position information all of the time while a "data sampling" system is gathering data only during those active time intervals. The percentage of time during which such a system is actually gathering phase information can be considered as the "phase-duty-cycle" of the system. For example, Raydist, which measures phase on all LOP's continuously, can be said to have a phase-duty-cycle of 100%. Similarly, a system which measures phase on any given LOP over a period of 50 milliseconds at intervals of once every two seconds would have a phase-duty-cycle of 2.5%. Typically the data sampling systems have relatively low phase-duty-cycles and therefore must depend upon the integration of a large number of data samples to produce a phase measurement (LOP reading). In other words, the position data generated and displayed by a sample data system is actually the average of a sizeable number of the most recent data samples taken over some predetermined period of time and will be correct and current with respect to the mobile unit's present position only under steady state velocity conditions; i.e., movement in a straight line and at a constant speed. Any sudden change in either speed or direction will go undetected until that change has been in existence long enough to have had an appreciable effect on the integrated output. The net effect of low phase-duty-cycle on system operation is an inability to follow accelerations; the lower the phase-duty-cycle, the more severe the deficiency becomes. Conversely, Raydist, which operates with a 100% phase-duty-cycle, is unlimited in its ability to track very high accelerations and velocities and its position data is always current.

New vs. Old

Sometimes there is a tendency for one to feel that any radiopositioning system which has been around for a substantial number of years must be obsolete. This is not a reliable "rule of thumb". Quite frequently the opposite is true. Some of these older systems are based on very sound fundamental concepts and have been continually upgraded through the years as technology has advanced. Through years of usage in the field, the "bugs" will have been worked out, design changes and hardware modifications will have been made, and third and fourth "generations" of the system will have been produced so that the present-day system will be a much-improved version of the original system, still based on the same physics but with the benefit of years of experience and refinement. One thing is certain; the physics has not changed. Sometimes our knowledge of the physics changes, but not the physics itself. Other considerations being equal longevity is a "plus" factor. After all, a system which has been in wide usage for many years must have served its users well.

System Comparisons

Table 2 represents an attempt by the author to condense the essential comparative characteristics of some of the better known radiopositioning systems which are currently available. Much of the data presented in the Table has been taken directly from brochures and descriptive materials prepared and distributed by the manufacturers and the responsibility for the accuracy and reliability of this data must remain with the manufacturers. In most cases little or no documentable data has been available to the author regarding actual operational performance in the field on such points as maximum practical operating ranges, normally achievable positional accuracies, etc. Where such information has been available the author has taken it into consideration. The reader is cautioned that some manufacturers may be less conservative than others in stating their system performance claims and the prospective user of any given system would be wise to seek out actual users of the particular system(s) of interest to get their "first hand" experience.

POSITIONING SYSTEM	FREQUENCY BAND	RANGE(1) (km)	ACCURACY(1) (meters)	SYSTEM(2) GEOMETRY	CONTINUOUS OR SAMPLE
ARGO	MF	450 DAY 250 NITE	2-3	C,H,C/H	SAMPLE
AUTOTAPE	MICRO	150	1-2	C	SAMPLE
HI-FIX-6	MF/HF	300 DAY	2-3	C,H,C/H	SAMPLE
HYDROTRAC	MF/HF	400	2-16	C,H	SAMPLE
HYPER-FIX	MF	450 DAY 250 NITE	50	C,H	SAMPLE
LORAN-C	LF	1600	100	C,H	SAMPLE
MAXIRAN	UHF	500(3)	5-10	C	SAMPLE
MINIRANGER	MICRO	150	1-3	C	SAMPLE
PULSE-8	LF	650	75	C,H	SAMPLE
RAYDIST	MF/HF	450 DAY 250 NITE	2-3	C,H,C/H	CONTINUOUS
SYLEDIS	UHF	100	2-3	C,H,C/H	SAMPLE
TRISPONDER	MICRO	80	1-3	C	SAMPLE

(1) Author's estimate of σ accuracy based upon manufacturers' literature and user reports.
(2) C = Circular
H = Hyperbolic
C/H = Combination
(3) Under favorable "ducting" propagational conditions.

TABLE 2. Comparative Characteristics of a Variety of Radiopositioning Systems.

How About the Future?

One frequently hears reference to the NAVSTAR Global Positioning System (GPS), as "the positioning system of the future" which, it is claimed, will obsolete all other radiopositioning systems sometime within the next decade (Figure 6). Before one embraces such a point of view, there are a number of things which should be considered and which seem to indicate that such a complete "takeover" by GPS is not likely, at least not for quite a few years.

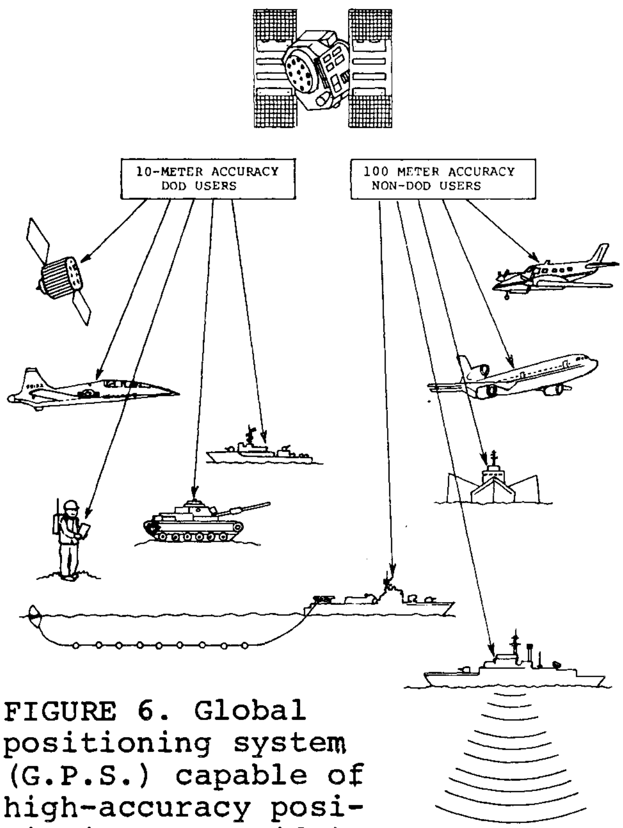


FIGURE 6. Global positioning system (G.P.S.) capable of high-accuracy positioning to a wide variety of users.

Although there seems to be little reason to question the high accuracy of which GPS is said to be capable, there appears to be substantial reason to question the availability of this pinpoint accuracy to anyone other than U.S. Department of Defense (D.O.D.) approved users. Although a very strong lobbying effort is being made by certain civil sector groups to have the full accuracy capability of GPS released, the D.O.D. has indicated, as of the time of this writing, that a degraded accuracy of only ± 100 meters will be released for anything other than the most critical national security applications. And, although the degree of accuracy which will be released to civil users is subject to annual review, it is doubtful that the full P-Code accuracy of the GPS system will be released in the foreseeable future. Secondly, there seems to be a strong reluctance on the part of some civil sector organizations to rely on a system which the D.O.D. could either degrade or make completely unavailable at any moment. Under such conditions all GPS users would be completely "at the mercy" of, and utterly dependent upon, the D.O.D. for their positioning capability. This reluctance to rely on a USA military D.O.D. positioning system is particularly strong among prospective users in other countries. It is more than likely, also, that the D.O.D. would prefer not to be in the position of having to "pull the rug", so to speak, out from under a large non-D.O.D. user population in the event that it should become necessary to degrade or turn off the system for national security reasons. There is much to be said in favor of keeping GPS as a purely military system and letting the civil and civil service communities continue to utilize the commercial radiopositioning systems which are already in service and which will be coming "on line" in the next few years.

One such new system which will become available shortly is the new Raydist TRAK IV system which will bring to the user several new capabilities not heretofore provided by any other radiopositioning system.

TRAK IV Raydist is a four range phase comparison system with 100% phase-duty-cycle, operating on a single frequency assignment in the HF band capable of serving a practically unlimited number of simultaneous users in the ranging (circular) mode. Positional accuracies on the order of 2 to 3 meters will be available at ranges up to several hundred miles. An engineering prototype version of the system is currently undergoing extensive field testing and the market version is expected to be available before the end of this year.

Summary

From the aforegoing it will be seen that one of the VHF, UHF or microwave systems may be the logical choice for a single-user application where the maximum operating range is not expected greatly to exceed the line-of-sight distance and where shielding by ships or other structures in the vicinity of the transmission paths is not to be expected. Where such shielding and/or signal reflection from ships or structures in the area can be expected one should consider one of HF or MF systems, such as Raydist, which are far less susceptible to multipath effects.

In applications where a large number of users will be operating in the system simultaneously a hyperbolic (passive) system usually should be selected in preference to a circular (active) system. Raydist, of course, is available in circular, hyperbolic and compound (circular/hyperbolic) configurations and the circular Raydist configuration can accommodate up to four simultaneous users.

Hyperbolic geometry is best suited to a highly concave shoreline as in a bay or estuary but is not well suited to applications involving a convex coastline or even a straight coastline because the hyperbolic pattern degrades rapidly with distance from the coast under such conditions. In some situations the hyperbolic geometry can be greatly improved by deploying one of the "fixed" shore stations in a buoy specially constructed to maintain a very small watch circle. Where only a limited number of simultaneous users is anticipated, the circular geometry of a ranging system, such as the Raydist DRS-H system, is a better choice for the straight coastline application and, in fact, always will result in a greater area of high-accuracy coverage than will a hyperbolic arrangement in any coastal application regardless of the shape of the coastline. Furthermore, on a mountainous coastline or wherever propagation along a hyperbolic baseline might be difficult or impossible the choice of a ranging type system, in which the base stations do not "communicate" with one another but only with the mobile platform(s), may be the only viable option.

Once again, a high "phase duty cycle" is important in any application and especially where aircraft or highly maneuverable surface craft are involved. Any sample data system will have a relatively slow response to sudden changes in speed and/or direction of the mobile unit and in some cases may be totally incapable of following even moderate accelerations. Some such systems also have an upper tracking velocity limit which must be taken into consideration in high-speed applications. Raydist, of course, enjoys a 100% phase-duty-cycle and, therefore, has no limitations regarding either speed or acceleration.

Finally, don't "write off" the older systems simply because they have been around for quite a few years. Check them out, look into their track records and see what it is that has made them so popular for such a long time.

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NAVSTAR GLOBAL POSITIONING SYSTEM OVERVIEW

William H. Wooden
Defense Mapping Agency
Los Angeles, California, U.S.A.

ABSTRACT

The NAVSTAR Global Positioning System (GPS) is an all-weather, space-based navigation system under development by the Department of Defense (DoD) to enable users to accurately determine their position, velocity, and time in a common reference system, anywhere on or near the Earth on a continuous basis. The GPS program was established in 1973 and was an outgrowth of extensive studies, analyses, tests, and operational demonstrations conducted by the individual military services. The development of GPS is being managed by a Joint Program Office (JPO) at the Air Force Systems Command, Space Division, in Los Angeles. The system is being developed in three phases: Phase I, concept validation; Phase II, full-scale engineering and development; and Phase III, production. Currently, the GPS program is in the full-scale engineering and development phase. During this phase a constellation of five to six satellites is being maintained to support testing so that the operational effectiveness of the GPS concept for both military and civilian users will be verified. The buildup of the operational constellation will begin in late 1986 and will take approximately two years to complete. Even though the system is not fully operational, several potential civilian applications exist. This paper provides an overview of the three segments of the NAVSTAR GPS - satellite, control, and user.

APPLICATIONS OF THE GPS GEODETIC RECEIVER SYSTEM

Bruce Hermann
Alan G. Evans
Robert W. Hill
Stanly Meyerhoff
Michael Sims
Naval Surface Weapons Center
Dahlgren, Virginia, U.S.A.

Patrick J. Fell
Defense Mapping Agency
Hydrographic Topographic Center
Washington, D.C., U.S.A.

ABSTRACT

The Defense Mapping Agency, in cooperation with the United States Geological Survey and the National Oceanic and Atmospheric Administration, is sponsoring the development of a Global Positioning System geodetic receiver (GEOSTAR). The receiver is capable of observing up to four satellites simultaneously by sampling segments of broadcast signals from different satellites in a time-multiplexing sense using a single dual frequency channel. The receiver system was designed to measure the geodetic coordinates of points to an accuracy of one meter and to provide first-order estimates of baselines of up to several hundred kilometers length. In addition, the receiver can support positioning and attitude determination of geophysical survey platforms under low dynamic conditions. Descriptions of these applications are presented.

ERROR ANALYSIS FOR MARINE GEODETIC CONTROL USING THE GLOBAL POSITIONING SYSTEM

Muneendra Kumar
Patrick Fell
Andrew Van Melle
Defense Mapping Agency
Hydrographic Topographic Center
Washington, D.C., U.S.A.

Narendra Saxena
University of Hawaii at Manoa
Honolulu, Hawaii, U.S.A.

ABSTRACT

The Global Positioning System (GPS) provides a new capability for establishing marine control for moored ocean bottom transponders that support precise navigation of ships, instrument packages, and submersibles. Autonomous remotely deployed marine platforms ranging to GPS satellites, which can simultaneously be triggered to measure acoustical ranges to a transponder network, can be used to establish geodetic control for the transponder array. The technique takes advantage of a dynamically changing double pyramid which is formed between GPS satellites and the transponder array linked observationally by the remote platform.

An error analysis is presented for an operational scenario where marine control is established in a deep ocean area. Several designs for this experiment are considered including the effect of constraint conditions. The results indicate that the establishment of precise ocean bottom control is obtainable using the GPS system with this approach.

OST-4: TSUNAMI DETECTION SYSTEMS

TSUNAMI DETECTION SYSTEMS FOR THE PACIFIC OCEAN

T.S. Murty
Institute of Ocean Sciences
Department of Fisheries and Oceans
Sidney, B.C., Canada

Abstract

Present tsunami detection systems for the Pacific Ocean are reviewed. Suggestions are made for future improvements.

1. Introduction

The present tsunami warning system for the Pacific based at the Pacific Tsunami Warning Center (P.T.W.C.) at Honolulu has been in existence since about 1948. This system provides warnings for tsunamis that are generated by seismic sources, and makes use of the data from a number of seismographs and tide gauges distributed around the rim of the Pacific Ocean. This warning system has proved to be very useful for tsunamis of seismic origin. The Tsunami Warning System based at Palmer, Alaska, has the responsibility for warnings for Alaska, Canada and the west coast of the United States. The member nations have also supplementary warning systems for local warnings.

The Pacific Tsunami Warning Center provides information on tsunami arrival times, but not on the amplitude of the tsunami waves. These travel times are precomputed for various locations around the Pacific Rim, using the long wave formula (Murty, 1977). This calculation was based on hydrographic and bathymetric information available some years ago, and does not make use of the more recent and more accurate and detailed data on water depths. Thus the tsunami travel-time charts can be improved by computing the travel times with the new data.

2. Possible Improvements of the System

The improvements suggested below do not imply any criticism of the system, but rather are ideas which can make the system better and more useful. Until recently the knowledge about the deep water signature of a tsunami was of theoretical nature only. However, at present, more observational data is accumulating and new methods making use of geodetical concepts are proposed. One has to consider also the so-called slow (or tsunami) earthquakes and the creep motions associated with them. Through international collaboration channeled through either the P.T.W.C. or the International Tsunami Information Center (I.T.I.C.) also based at Honolulu, one might think of extending the present warning capability to include travel times of the wave with the maximum energy, and providing information on the tsunami amplitudes at various locations at the edge of the continental shelf; other possible extensions are to consider the possibility of using the so-called lateral waves as tsunami forerunners. The I.T.I.C. might consider using the concept of fractal dimension in quantifying the lengths of coastlines damaged by tsunamis (Orford and Whalley, 1983).

The present system is not capable of predicting tsunamis that are volcanically generated, unless the volcanic eruptions are followed by major earthquakes. Two major tsunamis (one due to the eruption of the volcano Tambora in 1815, and the other due to the eruption of the volcano Krakatoa in 1883) generated in Indonesia killed respectively 90,000 and 36,000 people. These tsunamis were observed at several locations around the globe, but they were not generated in the normal manner (i.e. ocean bottom movement). The strong atmospheric pressure waves that were generated following the volcanic eruptions generated tsunamis at distant locations by resonant coupling between the atmosphere and the ocean. If we compute the travel-time of the Krakatoa tsunami to Honolulu, we will need an ocean having an average depth of about 17 km (Francis and Self, 1983). Another situation where the long wave formula is not valid is when the tsunamis travel into shallow coastal inlets and river systems of complex shape. Hence the concepts of diffusive kinetmatic waves are more relevant than hyperbolic long waves (LeBlond, 1978; Murty, 1984).

3. Some Specific Suggestions

The international seismological community has predicted that a very major earthquake is likely to occur within the next two decades in the Shumagin Gap seismic region of the Aleutian Islands. Among other improvements, specifically the following two suggestions might be useful in dealing with a possible major tsunami associated with the predicted Shumagin Gap earthquake: (a) computation of tsunami travel times in shallow costal waters making use of the concept of diffusive kinematic waves, where the standard Lagrangian formula may not be valid; (b) application of the concept of lateral waves for possible tsunami forerunners. We will discuss these now in some detail.

For the Chilean earthquake tsunami of May 1960, the travel times computed from the long wave formula do not agree with observed travel times at some stations in the Queen Charlotte Strait near the west coast of Canada (Loucks, 1962). For these stations there was about two hours of delay in the arrival of the tsunami (i.e. discrepancy between observed travel time and travel time computed from long wave formula). Loucks (1962) showed that the observed travel times at some stations were two hours greater than the computed travel times. Murty (1984) explained this delay in tsunami arrival times by invoking that, in extremely shallow water, the propagation of a long gravity wave is governed predominantly by friction (LeBlond, 1978).

A flow regime that is relevant for tidal propagation was considered by LeBlond (1978), in which the momentum balance of long gravity waves is best described by a set of equations somewhat intermediate between the frictionless long gravity wave equations (hyperbolic waves) and the kinematic wave equations used in the study of flood waves (Whitham, 1974). This intermediate flow regime, referred to as "diffusive kinematic waves" is dominated by frictional terms in its momentum balance, and can account for the long phase lags associated with low water. LeBlond (1978) showed that the most relevant model for a long wave travelling in shallow water is a diffusive model (since the frictionally dominated equations are parabolic) rather than a standard wave propagation model.

Next we will consider the concept of using lateral waves as possible tsunami forerunners. King and LeBlond (1982) introduced the term "lateral wave" to describe a wave that arises at a depth discontinuity in the ocean such as at the boundary between a continental shelf and the deep ocean. They pointed out that the identification of a lateral wave in coastal tsunami records will help in tsunami warning due to the fact that, at sufficiently great distances from the tsunami source, the lateral wave arrives faster than the direct wave. The path taken by the direct wave is entirely in shallow water, whereas for the lateral wave, a substantial part of the travel occurs in deep water. The difference between the arrival time at a coastal location between the lateral wave and the direct wave increases with the distance of the observation point from the tsunami source.

4. Deep Water Signature of Tsunamis

Murty (1977) reviewed the state of art on the deep water tsunami signature, summarizing the knowledge until about 1977. Filloux (1970) described Bourdon-tube, deep-sea tide gauges which have been tested for tides. Vitousek and Miller (1970) described a free drop vibrotron system for measuring tsunamis in the deep ocean up to depth of 6 km. Miller (1976) described a real-time mid-ocean tsunami measurement system, based on the assumption that large oceanographic buoys will be available.

Dykhan et al (1983) and Kulikov et al (1983) discussed tsunami measurements in the open ocean in the northwest part of the Pacific. Saxena (1983) discussed marine geodetic applications for ocean sciences and engineering, including applications to tsunamis. Zielinski and Saxena (1983 A) gave the rationale for measurement of mid-ocean tsunami signature, and suggested that these signatures be measured simultaneously at several locations and correlated with high-accuracy on-shore measurements. Zielinski and Saxena (1983 B) discussed tsunami detectability making use of open-ocean bottom pressure fluctuations.

Zielinski and Saxena (1983 B) proposed models for tsunami signature and background noise for the purpose of synthesizing an optimum tsunami receiver. Making use of these models, the minimum tsunami amplitude (in cm) to give the probability of correct tsunami detection $P_D = 0.999$ and probability of false alarm $P_F = \overline{10}^3$ is deduced to be $0.718\sqrt{bo}$ where b is the tsunami dominant frequency in cycles per hour. These authors proposed a realizable receiver and evaluated its performance using actual tsunami signatures. They considered tidal effects on receiver performance and found that these effects are negligible in certain range of the receiver parameters; this results in considerable reduction of the required signal processing.

The proposed mid-ocean system of Zielinski and Saxena (1983 B) can detect tsunamis with amplitudes as small as 0.7 cm. Figure 1 shows the normalized offshore signatures and figure 2 shows tsunami filter performance.

FIGURE 1 Normalized offshore tsunami signatures as measured by bottom pressure sensors (from Zielinski and Saxena, 1983 B).

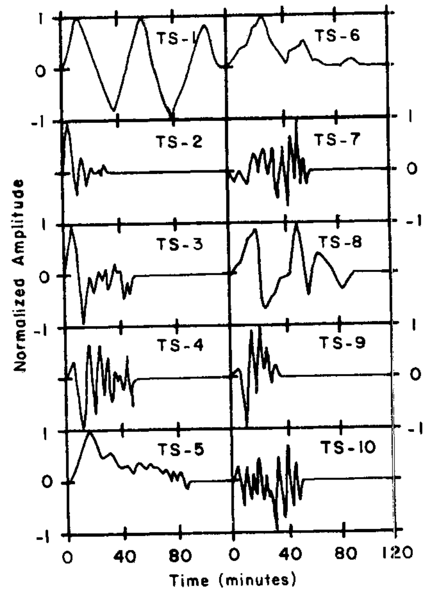
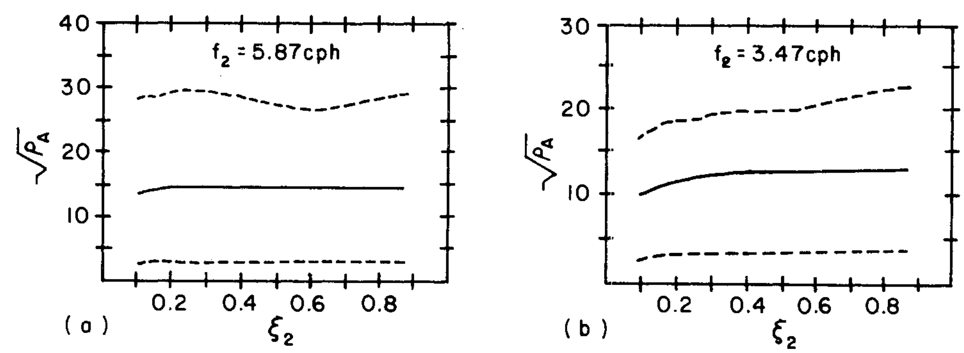


FIGURE 2 Tsunami filter performance for tsunami signals for two different values of filter parameters. Dashed lines indicate upper and lower performance bounds; solid lines denote average performance (from Zielinski and Saxena, 1983 B).



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OPEN OCEAN TSUNAMI DETECTION AND WARNING SYSTEM

Adam Zielinski
Faculty of Engineering
Memorial University
St. John's, Newfoundland, Canada

Narendra Saxena
College of Engineering
University of Hawaii at Manoa
Honolulu, Hawaii, U.S.A.

SUMMARY

To improve the reliability and accuracy of tsunami forecasts, a warning system based on high resolution bottom pressure measurements in mid-ocean is proposed and discussed. The critical question of tsunami detectability is considered using available pertinent data on open-ocean tsunami signatures and background noises. It has been demonstrated that the reliable detection of a tsunami with an average amplitude is as small as 0.7 cm is possible using an appropriate signal processing. Tsunami directionality is considered as it effects the spacial location of monitoring stations. The simple model proposed predicts tsunami beamwidth as small as 16° using realistic tsunami parameters.

INTRODUCTION

"Tsunami" refers to the gravity wave formed in the sea following any large scale, short-duration disturbance of the free surface. Tsunamis are most frequently generated by a certain type of undersea earthquake, although landslides, bottom slumping, and volcanic eruptions can also cause tsunamis (Van-Dorn [28]). The principal source regions for tsunamis are located in the earthquake zones of the Pacific and Indian Oceans, but infrequent tsunamis also occur in the Atlantic Ocean (Murty [18]). Tsunami generation, propagation, and coastal transformations are complex processes that can be treated analytically only after several simplifying assumptions have been made. After generation, a tsunami wave propagates over a complex bottom topography and is subjected to spatial and time evolution as it progresses (Stonely [22]). The far-field tsunami radiation pattern may exhibit remarkable directivity [12, 13, 33], with amplitude variations up to 14:1, depending upon the angular position of an observer with respect to the source (Ben-Menahem and Rosenman [5]). Tsunami energy decay with distance can deviate from simple geometric spreading, depending upon earthquake parameters (Kajiura [14]). The open-ocean tsunami signature is further complicated by interactions with reflected and refracted secondary waves. Its amplitude is believed to be on the order of a few tens of centimeters above average sea level. A coastal area, large in comparison with tsunami wave-length, can drastically change the tsunami character and amplitude. The amplitude may be magnified by a factor of 10 to 20, up to tens of meters in some locations, causing extensive damage and loss of life [27]. The degree of "run up" is a highly localized phenomenon which may result in local amplitude enhancement by a factor of 3 over the mean run up height [27].

It has been observed, however, that on-shore responses to very different tsunamis, although different in amplitude, have remarkably similar spectral characteristics (Miller [17].

To mitigate the damages caused by tsunamis, the Pacific Tsunami Warning Center (headquartered in Honolulu) has been established to issue early warnings to the endangered areas. Such warnings, in principle, can be issued for a tsunami originating at a point distant from the affected coast. Tsunami prediction is based on seismic recordings and observations from coastal tidal stations located on continents and a few islands. After the epicenter of a large, undersea earthquake has been located, the coastal stations near the epicenter are interrogated to confirm the existence of a tsunami wave. This step is required because most of the earthquakes do not generate tsunamis. If station reports indicate the tsunami existence, a general warning is issued to all interested agencies.

The coastal effects, possible tsunami directionality and sparsity of island-based tidal monitoring stations (an ocean sector north of the Hawaiian Islands, for example, facing the seismically active area of Alaska, is unmonitored) create a considerable amount of uncertainty in predictions of tsunami magnitude and the degree of inundation at a specific location. A highly directional tsunami might be overestimated (a false alarm) or underestimated (a miss). The direct cost of false alarms in the state of Hawaii has been appraised (Cox [6])at approximately $770,000 (in 1977 U.S. dollars) per warning. The deferred costs of false alarms can be measured in terms of actual tsunami-caused causalties resulting from the reduced awareness due to previous false alarms.

To improve the reliability and accuracy of tsunami forecasts, several other approaches have been proposed and investigated.

The existence of coupling between tsunami and ionosphere will induce Doppler shift of the reflected radio waves which can be ultilized for warning purposes. (Yuen et al. [31]; Najita [19].

Barrick [4] proposes utilizing Doppler shift from ocean surface reflected radio waves as means of tsunami detection. For the radar system presently in existence, typical warning times exceeding 45 min. are claimed to be possible for Pacific United States coastal locations.

It has been suggested by King and LeBlond [15] that so called lateral waves can be considered as tsunami forerunners and used as a warning.

REAL-TIME OPEN-OCEAN TSUNAMI MEASUREMENT SYSTEM

It has been suggested (Vitousek and Miller [29]), that open-ocean tsunami measurements using bottom pressure fluctuations can improve the reliability and accuracy of the tsunami forecast since those measurements are not distorted by costal effects. Availability of such measurements in few locations will lead to a better understanding of tsunami propagation and the relationship between open-ocean tsunami signature and on-shore responses (Zielinski and Saxena [32]). With this knowledge, the real time measurements will permit highly reliable estimations of coastal vulnerability for warning purposes.

For real time measurements, Saxena and Zielinski [20] suggested using a buoy based system with two-way communication capabilities via a GOES satellite. A more exotic communication link can be considered which utilize ionized meteor trails to reflect radio waves. Systsma and Jolly [23] claimed that using this technique reliable communication can be provided up to 2000 km. Bottom pressure data could be transmitted to the buoy via an acoustic telemetry link or a submarine cable. Present technology makes this concept feasible: deep ocean buoy systems, specifically designed for operations use, have been used since late 1974; systems which provide for the reliable collection of data from remote locations through a stationary satellite are now available; successful acoustic transmissions from 5000 m depth at 4800 bit/sec with an error probability of 10^{-6} have been recently reported (Mackelburg, et al. [16]); systems with lower data rates are commercially available [1, 2, 3]; deep-ocean crystal pressure sensors with extremely high resolution and low noise such as those produced by Hewlett-Packard or Paroscientific are commercially available [9, 30]; other sensors developed and capable of such measurements include Bourdon tube-type transducer [8] and Vibration [21].

Location and number of such open-ocean stations will depend on several factors such as: bottom topography, area to be covered, degree of tsunami vunerability, potential tsunami directionability and others. Zielinski and Saxena [33] have proposed a simple, one dimensional model for tsunami far-field radiation pattern. The leading wave of a tsunami in direction normal to seismic fault ($\alpha = 0$) was approximated by:

$$y_o(t) = A_o \sin(2\pi t/T_o); \quad 0 \leqslant t \leqslant T_o/2 \tag{1}$$

where A_o is the tsunami amplitude and
T_o is the tsunami principle period
The relative reduction of tsunami amplitude in any direction α can be found to be

$$G(r(\alpha)) = \frac{A(\alpha)}{A_o} = \begin{cases} \sin(2\pi r/T_o)/(2\pi r/T_o) & \text{for } r < T_o/4 \\ T_o/2\pi r & \text{for } r > T_o/4 \end{cases} \tag{2a}$$

where

$$r(\alpha) = \left| \frac{L \sin \alpha}{2\ gh} \right| \tag{2b}$$

In the above L denotes fault length, g-gravitational acceleration and h-ocean depth. It if often convenient to characterize the directivity of a tsunami in terms of its half-energy beamwidth Ω. From eqn. (2) one can readily find

$$\Omega = 2 \sin^{-1} \left\{\frac{0.443\ T_o\sqrt{gh}}{L}\right\} \tag{3}$$

Tsunamis with short periods, generated by elongated earthquakes may exhibit a high directivity of energy radiation as illustrated in Fig. 2. For open-ocean depth of 4.5 km, fault length of 200 km, and a tsunami period of 5 min., the tsunami beam width as given by eqn. (3) is found to be only 16° degrees.

TSUNAMI DETECTABILITY

Because of infrequent tsunami occurrences, costs involved, and technical difficulties, and in spite of several attempts which have been made, no true open-ocean tsunami measurements are presently available. THe notable exception is a small tsunami recorded by Filloux [8], 150 km offshore in 3210 m depth using Bourdon tube transducer. Observations of sea pressure variations at 2200 m depth, 110 km offshore, however, are made continuously by the Meterological Research Institute in Japan [10, 24], and the Sakhalin Complex Scientific Research Institute operates a similar installation, at 113 m depth, 8 km offshore Shikotan I., where a small tsunami has been recorded in 1980 [7]. Several tsunamis also have been recorded off small Pacific Islands [11, 26, 28].

The critical question in obtaining tsunami measurements using bottom pressure fluctuations is whether one can successfully discriminate a tsunami signal against background noises from several internal (drift, thermal instability, aging and others) and external (tidal cycle, barometric fronts, wind generated waves, seismic activity and others) sources. This question was addressed recently by Zielinski and Saxena [34]. A deep ocean tsunami signature model has been proposed in the form of a decaying sine waveform with a natural frqequency ω_o and damping factor ξ. Similarly, a ocean ambient noise model has been proposed based on experimental data. These models were used to synthesize an optimum tsunami receiver. It was found that the minimum tsunami amplitude A_{min} (in cm) to yield the probability of correct tsunami detection of $P_D = 0.999$ and probability of false alarm $P_F = 10^{-3}$ is given by a simple formula:

$$A_{min} = 0.718/\sqrt{f_o} \qquad (4)$$

where f_o is the tsunami dominant freqency (expressed in cycles per hour). A realizable receiver was proposed and its performance was evaluated using actual tsunami signatures taken offshore of small islands. These recordings listed in Table 1 are believed to be good approximations of open-ocean signatures. The minimum detectable amplitudes (in cm), A_1 and A_2 for two different receiver parameters are given in column 7 of Table 1. Comparing these minimum amplitudes with actual amplitudes (column 5) we see that all tsunamis listed with the exception of TS-1 can be reliably detected.

Operation of the optimum tsunami receiver for scaled down tsunami TS-4 and simulated ambient noise is illustrated in Fig. 1. The results shown in Fig. 1 indicate that even this hardly recognizable tsunami can be reliably detected (with $P_D = 99.9$ percent and $P_F = 10^{-3}$). In the analysis conducted we have not considered internal noise sources such as temperature sensitivity of a pressure transducer. This effect can produce "tsunami-like" signal in the apparent pressure variations as observed at the monitoring station at Omaezaki (Takohashi [24, 25]). The pressure transducer being used there is a quartz type Model 2813B manufactured by Hewlett Packard Inc. and is deployed at 2,200 m depth. Amplitude of the observed apparent pressure variations sometimes exceeds 25 cm H_2O. This and other effects may trigger a false tsunami alarm at the station. Such an alarm will, however, be correlated with seismic activity at the Tsunami Warning Center and disregarded if no such activity is observed.

CONCLUSIONS

This paper demonstrates the feasibility of tsunami detection based on bottom pressure fluctuation using an appropriate signal processing and available technical means. It is postulated that the gradual implementation of such a system at selected locations should be iniciated in line with recommendations of the NSF-NOAA Tsunami Research Planning Group [26] which have assigned top priority for Tsunami Observation Programs.

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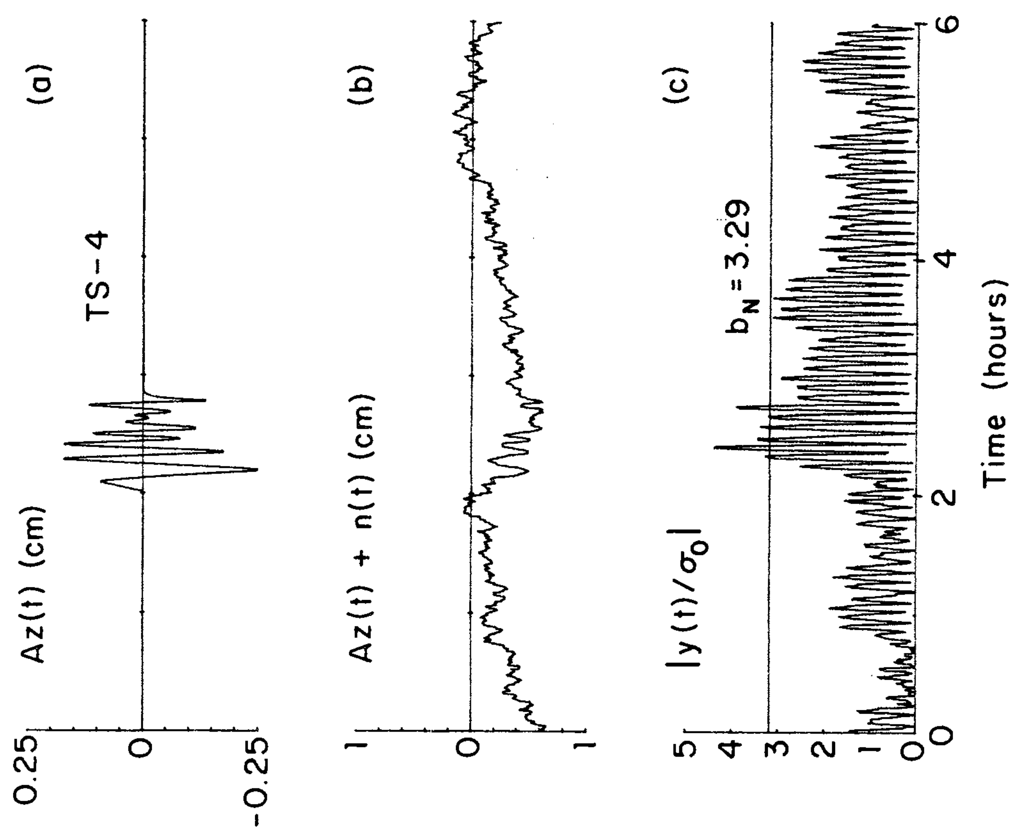

FIG. 1. Simulation of operation of the tsunami receiver: (a) tsunami signal (TS-4); (b) noise plus tsunami; (c) output of the tsunami filter.

Table 1 Summary of Tsunamis

Tsunami No.	Date	Origin	Recorded	Max. amplitude (cm)	Bandwidth (cph)	Min. detectable amplitude (cm)		Ref.
1	2	3	4	5	6	7		8
						A_1	A_2	
TS-1	3/14/79	Petatlan	open ocean	0.47	1.75	2.38	0.96	[8]
TS-2	5/23-24/60	Chile	------	66	7.49	0.38	0.47	[11]
TS-3	10/13/63	S. Kuril	Wake I.	4.1	4.20	0.45	0.42	[28]
TS-4	10/20/63	S. Kuril	Wake I.	3	9.63	0.23	0.34	[28]
TS-5	3/28/64	Alaska	Wake I.	12.5	0.38	1.89	1.67	[28]
TS-6	11/4-5/52	Kamchatka	Johnston I.	37	0.4	1.81	1.57	[11]
TS-7	3/9/57	Aleutian	Wake I.	19.3	11.36	0.41	0.35	[28]
TS-8	2/23/80	S. Kuril	Shikotan I.	3.8	2.54	0.71	0.59	[7]
TS-9	6/10/75	Hokkaido	Markus I.	1.6	10.47	0.24	0.32	[27]
TS-10	6/10/75	Hokkaido	Johnston I.	10	10.49	0.44	0.29	[27]

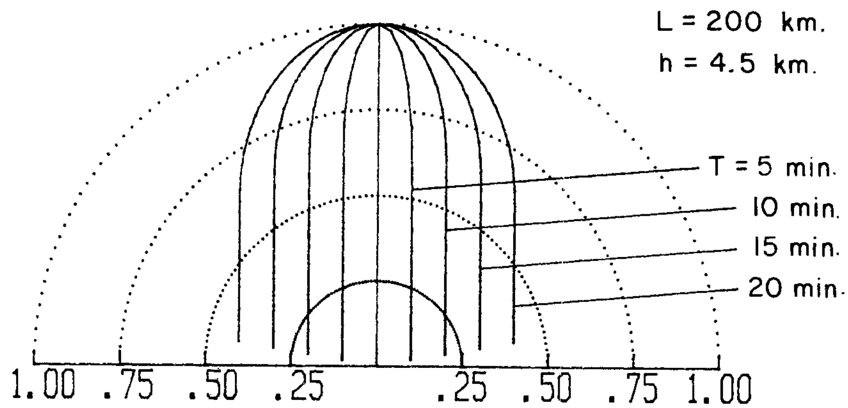

FIG. 2. Tsunami radiation pattern for different wave periods as given by Eq. 2.

OPERATIONAL ASPECTS OF TSUNAMI DETECTION FOR THE PACIFIC TSUNAMI WARNING CENTER

Gordon D. Burton
Pacific Tsunami Warning Center
Ewa Beach, Hawaii, U.S.A.

The operational objective of the Tsunami Warning System (TWS) is to detect tsunamis in the Pacific, predict their arrival and, when possible, run-up on the coasts, and provide timely and effective tsunami information and warnings to the population of the Pacific to minimize the hazards of tsunamis, especially those to human life and welfare. To achieve this objective the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA) operates the Pacific Tsunami Warning Center (PTWC) at Ewa Beach, Hawaii, and the Alaska Tsunami Warning Center (ATWC) at Palmer, Alaska. The responsibility for issuing warnings is divided into a regional and Pacific-wide basis. The ATWC provides regional warning services for Alaska, Canada, Washington, Oregon, and California; the PTWC provides regional warning services for Hawaii. The PTWC also functions as the National Tsunami Warning Center for the United States, and as the operational control center for the Tsunami Warning System of the Pacific (Figure 1).

This paper will address only the primary program objective of tsunami detection. In an operational sense, it is important to make the distinction between tsunami detection and tsunami evaluation. Detection is the earliest recognition of the generation of a tsunami. All data received afterward contribute only to evaluation of the previously detected tsunami. The nominal operational timeframe for tsunami detection by the PTWC is 1 hour after the occurrence of the earthquake associated with tsunami generation.

Figure 2 delineates the potential tsunamigenic source areas for tsunamis impacting the Hawaiian Islands. This does not include all regional tsunamis, but does indicate those most probable source areas for the generation of Pacific-wide tsunamis for which the 1-hour response time is an operational consideration.

Tsunami detection begins with the sounding of the alarm system at the PTWC. This is usually the seismic alarm, but may also be a telephone call or a priority message on the AFTN teletype circuit. It is important to consider the inherent delay involved in the activation of the seismic alarm at the PTWC. Using Hawaii as the center of a coordinate system, the Pacific Basin can be divided into 4 quadrants for evaluation of the PTWC's capabilities. For major earthquakes in the Northeast, Northwest, and Southwest quadrants, the seismic alarm is usually activated by the first arrival of the seismic P-phase. For major earthquakes to the Southeast, the later S-phase more commonly triggers the system due to attenuation of the P-phase. Figure 3 indicates the most probable delay in minutes for each geographic quadrant for activation of the seismic alarm at the

FIGURE 3. ALARM ACTIVATION DELAY

NORTHWEST 9-10 min.	NORTHEAST 7 min.
SOUTHWEST 8-11 min.	SOUTHEAST 23-25 min.

FIGURE 1.

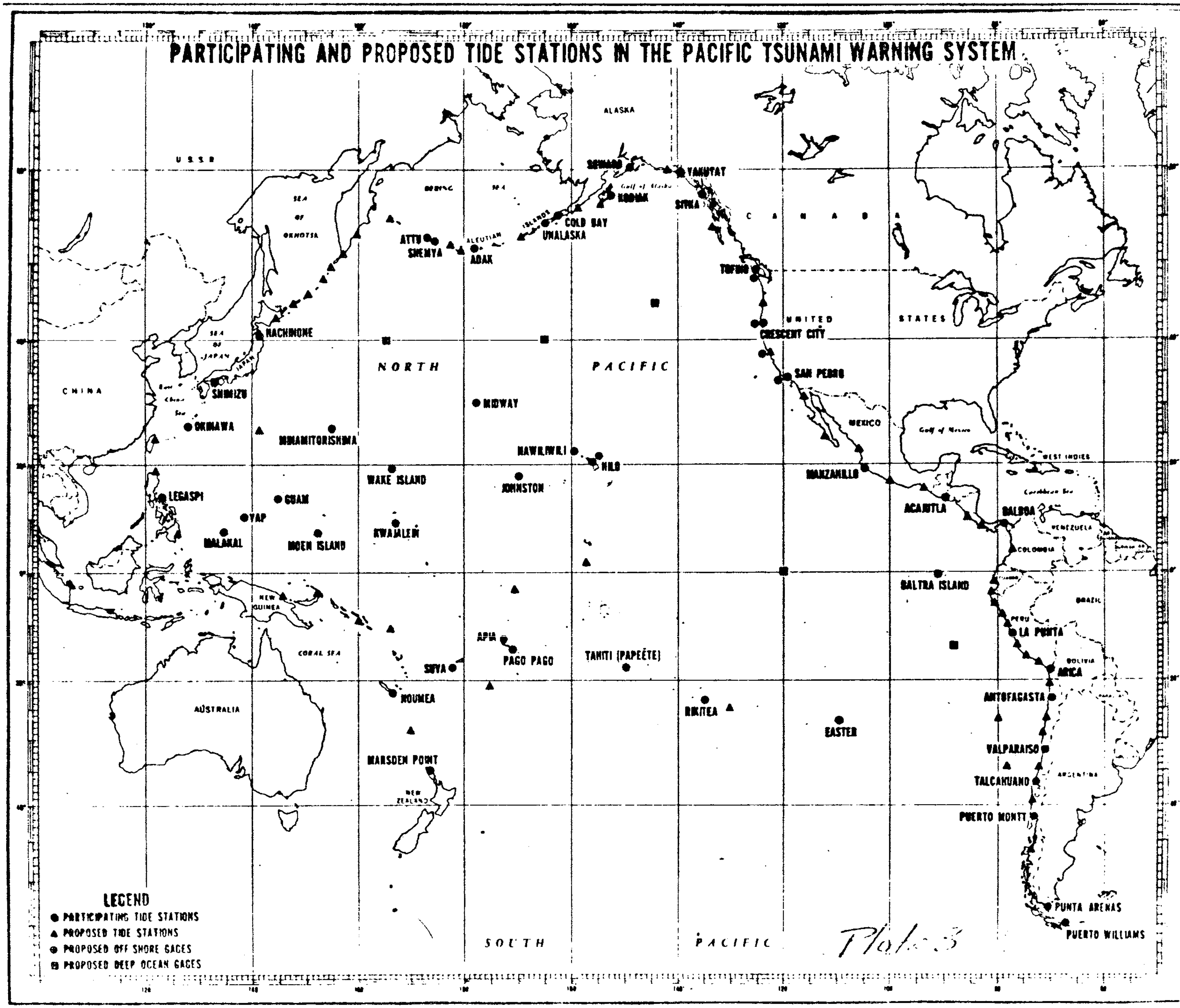

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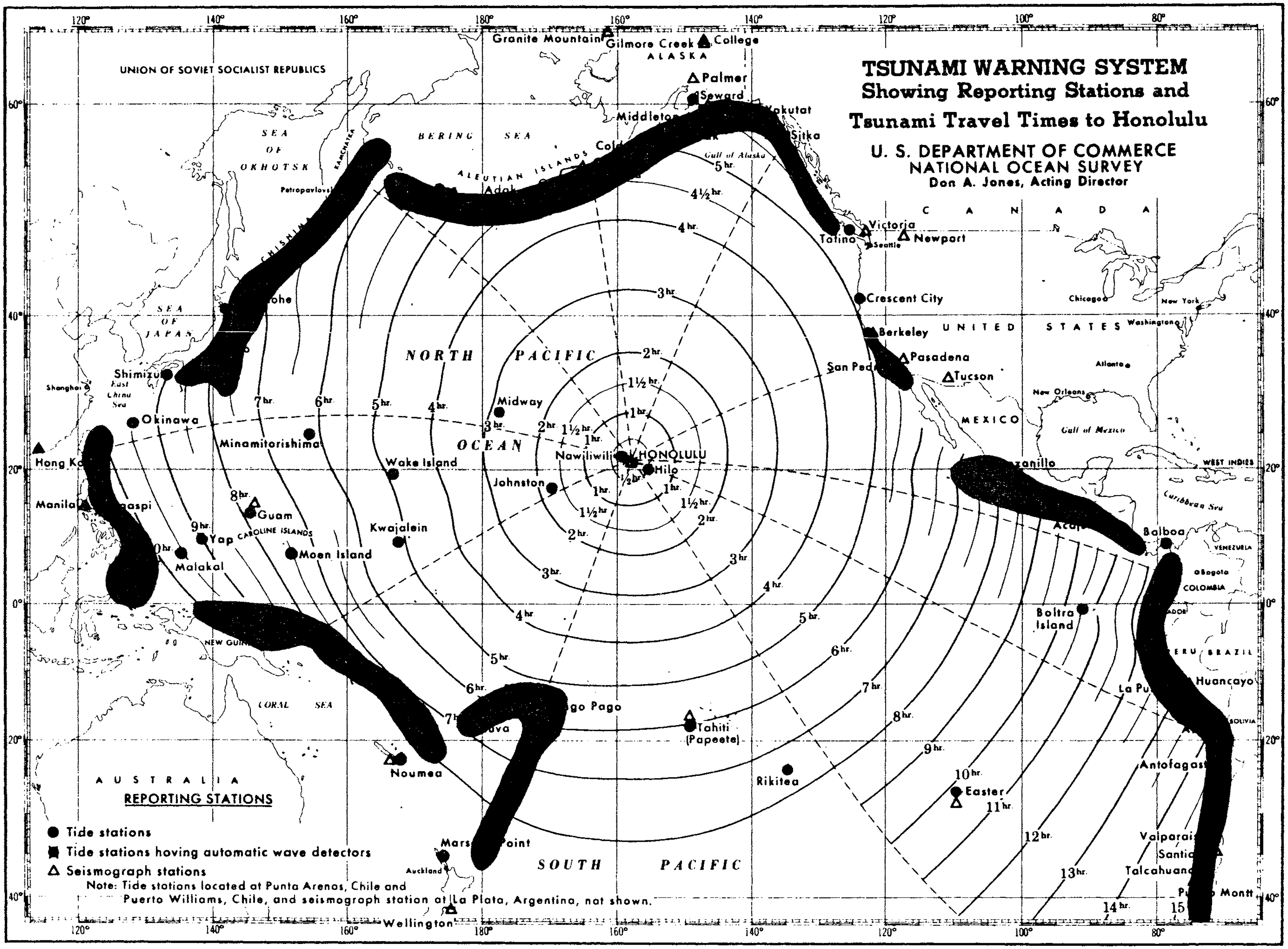
FIGURE 2. IMPACT OF PACIFIC-WIDE TSUNAMIS IN HAWAII



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PTWC. For the northwest quadrant, it is worth noting that for the Sea of Japan tsunami of May 26, 1983, the PTWC alarms were activated by the P-phase 10 minutes after the earthquake origin, but the first waves had already hit the coast of Honshu within 7 minutes.

From its inception in 1948, the Tsunami Warning System has functioned on the premise that seismic wave propagation provides the earliest detection capability, with the earthquake location and magnitude providing the information needed to determine probable tsunamigenesis. Given a coastal location and a magnitude exceeding a threshold value, queries are sent to the nearest tidal stations and a Tsunami Watch is issued to all participants in the Tsunami Warning System. Upon receiving the requested information from tidal stations, the Watch status is either cancelled or a Tsunami Warning is issued, usually based on wave confirmation.

By regarding the issuance of a Tsunami Watch as the earliest notification to participants of the probable detection of a tsunami, we can again analyze the PTWC operational capability in terms of the delay in response after the origin of the earthquake. Figure 4 indicates the most probable delay in minutes for each geographic quadrant of the Pacific for issuance of a Tsunami Watch by the PTWC without tsunami wave confirmation. The major delay experienced is in the time for transmission of seismic surface waves to be recorded at the PTWC for determination of earthquake magnitude on the Richter scale. For instance, seismic Raleigh waves from Chile will not arrive at the PTWC until about 50 minutes after the earthquake's origin.

FIGURE 4. TSUNAMI DETECTION DELAY

NORTHWEST 30 min.	NORTHEAST 25 min.
SOUTHWEST 40 min.	SOUTHEAST 60 min.

To provide wave confirmation of the generation of a tsunami, the Tsunami Warning System is presently composed of 53 participating tidal stations. An analysis of the distribution of these tidal stations indicates that a maximum of 35 stations are located within a 1-hour tsunami travel-time of a possible tsunamigenic source area. When we analyze the communications capabilities to these tidal stations, we are further reduced to only 31 present stations which can provide an achievable detection capability to the PTWC within 1-hour of tsunami generation. For actual operations, these figures are definitely optimistic. For each of the 3 events in 1983 for which tsunami investigations were initiated, the first responses from tidal stations in each case were received more than 2 hours after the earthquake origin.

In addition, the quality of the data provided by the tide observer and the tsunami response characteristics of each tidal station are important factors in evaluating the data to determine if a tsunami has been generated and whether it poses a potential threat to the Pacific community. Tidal stations are usually located within quiet harbors rather than on the open coast. Frequently, stilling wells are used to dampen higher frequency wave action, which further complicates the evaluation of tidal station data for application to the Tsunami Warning System.

We recognize the limitations of using tide data for tsunami detection and evaluation. A tide gauge is not a tsunami gauge. Still it remains the best data available for quantitative measurements of water-level changes associated with tsunami impact. At the same time, it is a cost-effective data acquisition source utilizing existing installations capable of responding on a 24-hour-a-day basis. Tidal stations will undoubtedly continue to provide the primary tsunami data acquisition capability for many years to come.

The National Weather Service is presently in the process of installing GOES Data Collection Platforms at selected tidal stations to transmit tidal data to the PTWC via satellite communications. We are utilizing both Handar DCP's and LaBarge Interrogatable DCP's. The Handar systems can be programmed both as self-timed units for systematic data collection and as event detectors for tsunami detection. The LaBarge systems have the capability of being interrogated on demand. It is anticipated that the initial systems will be deployed for field operations in strategic areas within the next few months.

The previous remarks have been intended to set forth some of the operational aspects and limitations of tsunami detection. The subject of tsunami evaluation is too complex for inclusion in this paper. In closing, I would like to remind the research community that in any evaluation of the operational capabilities of the Tsunami Warning System, the most critical factor is the response time of the PTWC, with a maximum timeframe of 60 minutes established for tsunami detection. Within this timeframe, we must function both with the physical time constraints imposed by Nature as well as the user time constraints imposed by participants. There are many operational areas where improvement is yet to be made, both for earthquake seismology and for tsunami wave confirmation and evaluation. Rapid data acquisition is essential.

It must also be recognized that participants in the Tsunami Warning System have developed their response and evacuation procedures based on the information received from the PTWC. Issuance of any Tsunami Warning by the PTWC sets in motion a series of predetermined actions by participants around the Pacific which are standard for all tsunamigenic events. This will probably remain true until such time that the PTWC can provide a better tsunami evaluation capability. Until that time, the operational requirements for tsunami detection and the establishment of threshold criteria for the issuance of Tsunami Warnings remain a high program priority.

DESIGN AND DEVELOPMENT OF AN INTELLIGENT DIGITAL SYSTEM FOR COMPUTER-AIDED DECISION-MAKING DURING NATURAL HAZARDS

W. M. Adams and G. D. Curtis
University of Hawaii
Honolulu, Hawaii, U.S.A.

ABSTRACT

In 1975, a Tsunami Seismic Trigger was invented by four people working at the Indiana University at Bloomington. Twelve copies were built and installed at various locations in Hawaii. The design utilized hard-wired logic and a mechanical pendulum. The advent of the microprocessor now prompts the design of a new tsunami seismic trigger, using microprocessors and appropriate support chips. In addition to the improved seismic element, the adaptive algorithmic capability of the microprocessor will provide better threshold-setting and better discrimination in favor of tsunamigenic events. Good design should result in both improved reliability and lower cost-per-unit. Such a tsunami seismic-trigger can assist a local public official in making decisions concerning the need for evacuating people from shorelines that may be inundated by a tsunami generated by a nearby underwater earthquake. The need for such decentralized decision-making is evidenced by the difficulty of maintaining real-time communication capability during a large earthquake. The principles involved may have application in other natural hazard warning systems.

II. Background

The need for a system to provide immediate alerting of residents of coastal areas in the event of a local (as opposed to a trans-ocean) tsunami has long been felt; a device to form the basis of such a system was developed in 1975 by a group from Indiana University and the University of Hawaii (Adams et al., 1977). There were two previous efforts, resulting in Mark I and Mark II: this work at Indiana evolved through Mark III to the final Mark IV version. Twelve copies of Mark IV were built and installed at various locations in the Hawaiian Islands--generally in police stations near tsunami-hazard areas.

This instrument was based on an inverted-pendulum system which sensed only motion in the horizontal plane, of about 2 Hz and higher. If this motion exceeded a threshold level (mechanically set), an electrical signal was generated. Straightforward logic circuitry determined the number of pulses in a given time window and set off an alarm if a (settable) rate and number were exceeded.

Note that many significant parameters--frequency response, damping, amplitude threshold, timing, etc.--were predetermined in the design process. The number of pulses required for an alarm (a value set upon installation) is the only variable available, and there is no response to vertical motion. Thus, while the device reliably detected strong earthquakes, it had a high ratio of alarms from any such events to actual tsunamigenic events, i.e., false alarms.

Inevitably, this lack of discriminatory ability eroded its utility as part of a warning system. Equally vital parts of a warning system are a monitor (in this case human) to observe and act on the alarm, and rapid and effective steps to evacuate people in priority hazard areas. Many officers on duty--especially as memory of the 1975 tsunami on the Big Island of Hawaii grew dim--did not feel justified in diverting all available forces to an evacuation effort which turned out to be unnecessary (see Cox and Morgan, 1977).

Clearly, a more intelligent sensing, evaluating, and alarming device was needed to assist the decision-making for a reliable and dependable warning system.

The NWS/Pacific Tsunami Warning System had the University of Hawaii install a network which included both seismic and water-level sensors on three of the islands. The original systems design was developed by one of the present authors (WMA) and Martin Vitousek of the Hawaii Institute of Geophysics (Adams et al., 1971). All information is telemetered to the warning center by telephone and radio links, where it is manually examined to determine an earthquake greater than a given magnitude. While this reduces "false" alarms, it proved to be susceptible to interruptions in the telemetry (sometimes as a result of a seismic event), and too slow in system response; i.e., evaluating the threat and feeding back the decision to officials in the affected locations in a timely manner.

It seems axiomatic that the fastest possible correct evaluation presented to the officer, in the correct locale, capable of effective public action, is required for a local tsunami warning system to be useful. Thus, the need for a more sophisticated and highly reliable warning device is obvious. It is now also possible.

III. Performance Objectives and Specifications

The objectives of this instrumentation may be considered and defined as functions. The Tsunami Trigger (TTT) should:

a. Sense one or more parameters of the ground motion and transduce logarithmically this energy to an electrical signal.

b. Process the inputted electrical signal algorithmically to ascertain, probabilistically, whether or not a large earthquake (greater than threshold magnitude, T), has occurred.

c. Estimate the probable tsunamicity of the source, considering, insofar as feasible:
    1. epicentral distance
    2. focal depth
    3. type of earthquake
    4. dip-slip component

d. Display (list) the estimate for the various parameters.

e. Activate any alarms deemed appropriate to the set of estimated parameter values.

Which parameters, algorithms, and hardware are to actually be implemented require, of course, value judgments. These are best made by experienced, competent, qualified decision-makers, using standard operational research analyses. Naturally, any game theoretic approach must recognize that nature is not malevolent: the personification of "Mother Nature" must be studiously avoided (Adams, 1966).

The foregoing functional specifications constitute an essential set. Other functions may optionally be selected. For example, in addition to distance to the epicenter, the azimuth to the epicenter merits consideration as a parameter. Also, estimation of source magnitude is a possible parameter. The tsunamicity could be indexed--an alternate to GO-NO-GO thresholding.

These and other options may be treated best by the "cost-to-benefit" (or benefit-to-cost) studies.

IV. Physical Objectives and Specifications

There is no demand for portability of the tsunami trigger (TTT), hence size, weight, and appearance are assigned low weights.

The sensor should be electrical (instead of mechanical as in the present Mark IV). This provides the continuous signal required to attain the recording option desired for research purposes and permits better analysis for alarm purposes.

The geophone should sense the vertical component of motion (instead of the horizontal as in the Mark IV). Thus the sensed parameter correlates better with the dip-slip component of the fault motion.

Particle motion in 3-D should also be obtained. A variety of geophone arrays should be evaluated, following standard antennae theory for infinitesimal elements.

Isolation, amplification. and digitization should all be performed at each sensor. This will minimize error growth due to transmission distortion. Error-correcting codes had best be used.

A choice between relative and absolute timing is essential. Optionally, timing can be derived from toroidal crystals, and if temperature independence is considered to be of great importance, then the differencing of two or more toroidal crystals may be used. The output can, of course, be slaved to atomic standards.

Power is supplied from the AC lines, backed up by lithium batteries. These have the advantages of high energy density and long shelf lives. Thus, an uninterruptible power supply (UPS) is provided. Figure 1 depicts the architecture and applicability of the system.

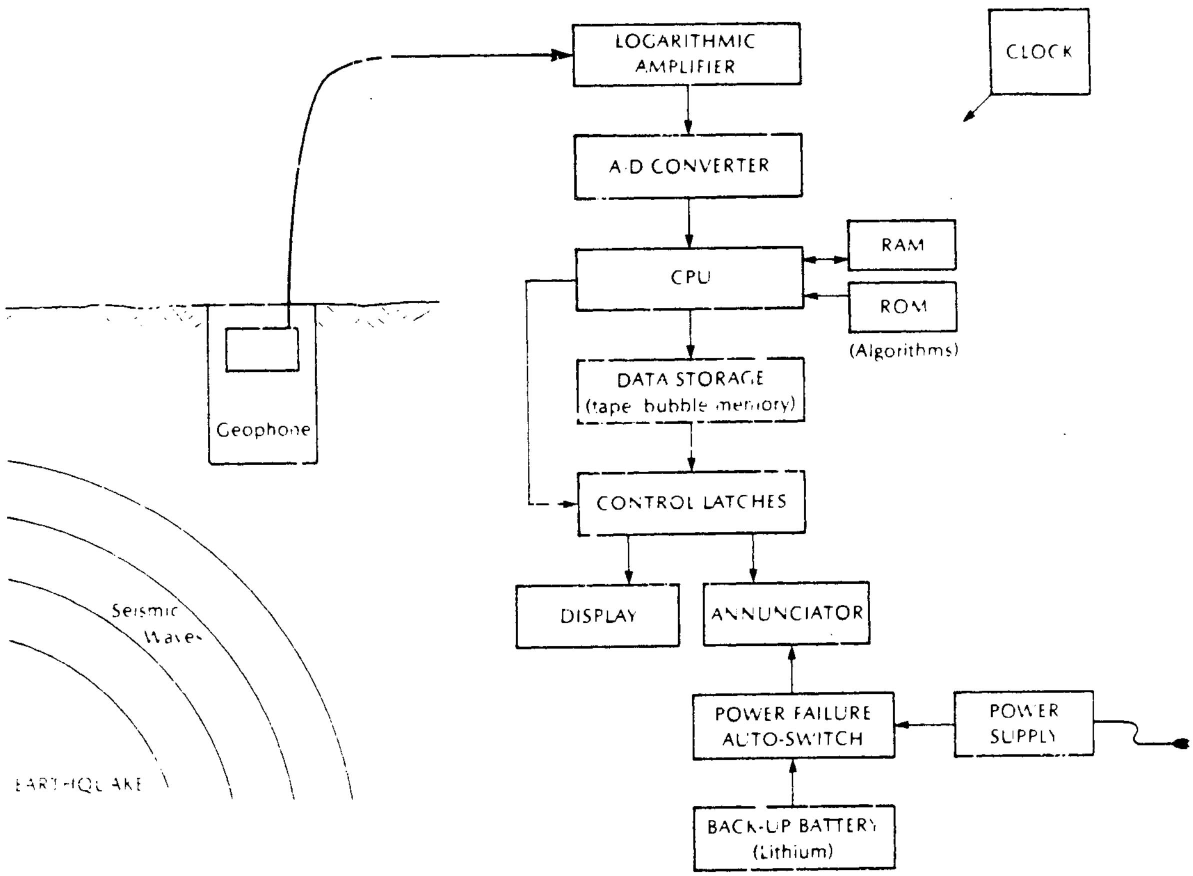

Fig. 1. Information Flow in Mark V Tsunami Seismic Trigger.

The algorithms installed should be subjected to thorough testing by appropriate quality assurance and knowledgable verification processes (see Adams, 1981a). These requirements, although both time-consuming and consequently expensive, provide insurance for credibility and anti-false alarms--features often overlooked in such instrumentation systems.

Displays must be cybernetically adjustable, space-wise and time-wise. The need for daisy-chaining, as to several physical levels in a hardened command-control post, is apparent.

Efectiveness of the alarming, like the displays, is more dependent on the synoptic condition of the monitors than on the physical and financial constraints. An adaptive optimization analysis incorporating the time variations is most appropriate (see Adams, 1966).

V. Design Trade-offs and Reliability Analysis

The most significant choice is the cut between the hard-software and the human monitor. Heretofore the processing by the machine has been termed "analysis" and that by the monitoring person "interpretation." Now that the machines can either learn, or be taught, the "interpretation," i.e., are potentially intelligent, this decision is even more difficult--one may choose to avoid making the monitor seem superfluous (see Adams, 1981b).

Other choices are associated with the reliablity of the system. One way of considering this, assuming perfect hardware, is to designate the variance deemed necessary for the respective parameters. Cost then is weighted inversely with the variance sought.

An example of instrumentation which achieves a MTBF of about 200 years is the Swiss Cesium time base, which also has a precision of 10^{-11}, manufactured by Oscilloquartz. The design consists of three of the Cesium frequency standards phase-lock-looped to one another (Electronics, 1 December 1983, p. 86). Because so much is now technically possible, adherence to achieving specifications derived from users' needs is far more satisfying (and, incidentally, more likely to be competitive in the scramble for funding) than simply listing the state-of-the-art for every specification. (How many A-D converters really <u>need</u> to be 16 bit?)

Best is the practice of breadboarding and developing with a plan of sequential upgrade; this approach minimizes the likelihood of entrepreneuers searching in some blind alley of the maze of routes for possible changes.

VI. Cost-to-Benefit Analysis

Costs can be estimated from those incurred with the Mark IV Tsunami Seismic-Trigger. The entire program, including the preliminary, non-operational prototype Mark III, fifteen copies of Mark IV, and travel for installation cost only $40,000 (1976 dollars). Even then, that seemed fortuitously low. So a comparable estimate in 1985 dollars seems to be about $90,000 for twelve copies of the base model, i.e., options and peripherals extra.

Benefits, on the other hand, necessitate considerably more conjecture. If the value of a life saved be assigned a dollar value of $200,000--a not uncommon value in cost-to-benefit studies--and one life is saved per instrument each time TTT is queried (when the ground shakes noticeably), then a query once per ten years at an annualization of $1,000 <u>per instrument</u> should prompt this capital investment, using discounted present-value theory.

Two things must be recalled: (1) such an instrument can also save a life by preventing chaos unnecessarily, i.e., by indicating to a regional civil-defense officer that a coastal evacuation is <u>not</u> warranted, and (2) this cost/benefit analysis is for the first dozen units; for subsequent production in larger lots, the costs would be significantly lower per unit, thus improving the already favorable ratio.

VII. Summary and Conclusions

The advent of economical, ubiquitous microelectronics permits quantum improvements in existing seismic alarms, based on concepts of threshold switching. These advances will involve both the quality of the association and the reliability (that is, less false alarming) achievable by redundancy.

The trend has been from centralized decision-making to regional decision-making for a variety of reasons reviewed elsewhere. Being now caught up in the tide of "personal computing," we would have but little astonishment to see an advertisement for an upgrade kit that would modify a personal computer so that it could function as a zeroth-order TTT. Can that day be far away?

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REGIONAL EARLY TSUNAMI WARNING SYSTEM UTILIZING SYSTEM TECHNOLOGY

George Pararas-Carayannis
International Tsunami Information Center
Honolulu, Hawaii, U.S.A.

There are areas in the Pacific for which the Pacific Tsunami Warning Center (PTWC) in Honolulu cannot provide suitable warning information within one hour after tsunami generation. A need exists for regional early warning systems which can react within 3-10 minutes after a potentially tsunamigenic event has occurred. The equipment needed to assemble an early warning system, from land and sea based sensors to satellite-based communications links is presently available. Such hardware system can be tailored to the needs of national disaster control authorities and skillfully adopted to their existing response apparatus, to enhance the capability to cope with their tsunami threat. Satellite telemetry can be used, not only for data collection, but also to disseminate, receive and display tsunami warnings utilizing the existing Geostationary Operational Environmental Satellite (GOES), Data Collection Interrogation System (DCIS). The use of satellite telemetry allows the lag between the event and the receipt of initial data to be reduced to the order of a few minutes, thus providing enough time for regional early warnings. Integrating this technology into the infrastructure of an existing Civil Defense response organization is necessary for effective tsunami hazard management during an actual event.

A pilot study named THRUST (Tsunami Hazard Reduction Utilizing System Technology) has been funded by the U.S. Foreign Disaster Assistance (USFDA), Agency for International Development (AID), to determine the feasibility of applying this current technological advances to an early warning system centered on one tsunami susceptible area, both to prove the concept and to develop a prototype for similar early warning systems elsewhere. Valparaiso, Chile was chosen as the site because it represents an urban area with high probability of tsunami occurrence.

A program has been developed along specific elements of data collection and analysis in the pre-event, and in the event phases. In the pre-event phase it is necessary to compile historical and all available information related to tsunami effects in the area under study. The purpose of this data collection is to assemble into forms suitable for use in model studies, emergency preparedness plans, training exercises, etc., as part of a complete package. In the real-time phase, the emphasis shifts to collecting quickly and reporting seismic and water level data which can be used to identify the sudden existence of a tsunami and to assess its potential threat. The use of the satellite-based telemetry reduces the data collection time to a minimum. The real-time analysis of the results of the data collection must be combined with an incoming data stream to provide continuous updating of predictions.

In the information dissemination, complete and thorough knowledge of the host country's tsunami response infrastructure is needed, as well as the development of an educational program. The real-time phase of information dissemination, the actual transmission of the warning information to the threatened population must be interfaced with the automated, satellite-based information gathering network, and the human decision making process. It must be formulated so that the technological hardware merges with the requirements and capabilities of the local disaster response system. Standardization of the procedures must be accomplished and the decision making must be made simplier so that officials would only have one set of procedures to follow and should not find it necessary to improvise responses or evaluate the data. Also because of the public education awareness program the threatened population should know how to respond to ensure their own safety.

The knowledge gained from this study will be applicable to the development of better hazard system management ability and the design of effective regional tsunami warning systems.

OST-5: PACIFIC HYDROGRAPHY/BATHYMETRY

SWATH HYDROGRAPHIC SURVEYS

Scott E. Drummond
SEACO Incorporated
Alexandra, Virginia, U.S.A.

It is fitting that the Pacific Congress on Marine Technology be held in Hawaii. Here we are near the center of our subject, the Pacific Ocean, and can see its major influence on island life - past and present. We can also sense the enormity of our subject. The Pacific Ocean covers one-third of the earth's surface and contains almost 64 million square miles of water. That is 45% of the earth's water. The Atlantic Ocean is a distant second at only one-half the size of the Pacific. The Pacific is the deepest ocean with the Mariana Trench 36,198 feet deep and has the tallest mountain, Mauna Kea, which rises 30,000 feet from the ocean floor to its summit on the neighboring island of Hawaii.

The Pacific Ocean also holds the record for one of the biggest single marine insurance losses which occurred when the new ore ship IGARA stranded on an uncharted rock in the western Pacific in March 1973. The charts of that area were made by the Dutch in 1888 and the British in 1907. This incident helps highlight the problem of outdated and inadequate nautical charts. Before we can have adequate charts, many miles of hydrographic survey and resurvey must be completed. The survey job is enormous and the need is growing each day. The same cannot be said for the resources available to do the job. They are not enormous and not growing.

Faced with this situation it is imperative we get the most for every survey dollar spent. Toward that end I would suggest consideration of the advantages of employing small waterplane area twin hull (SWATH) survey launch and ship, and the multibeam acoustic survey systems.

With SWATH designed survey platforms you will not be as operationally restricted by the sea state, your crews will work better and your data will be of higher quality. All of these benefits come from the better seakeeping qualities of the SWATH as compared to the monohull. With the multibeam acoustic survey systems you will be able to get complete area coverage quickly. Using multibeam equipment and the SWATH platform, data collection rates can increase by a factor of four. First, let's consider the SWATH survey platform.

The small waterplane area twin hull (SWATH) designed boat (Figure 1) has two parallel, submerged, torpedo-like lower hulls which are attached, by hydrofoil-like struts, to a platform or upper hull which is located well above the surface

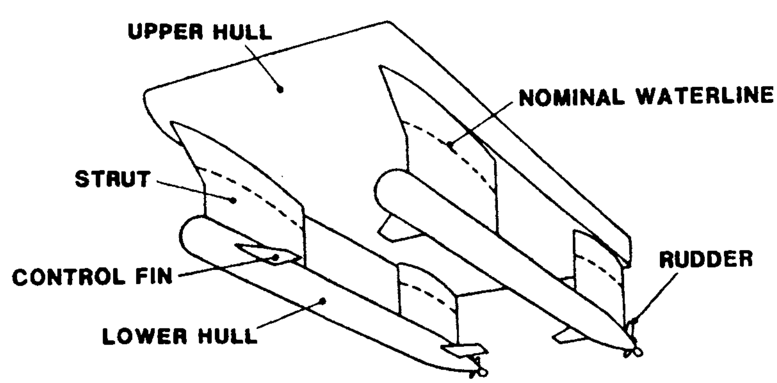


Figure 1. SWATH Design

of the water. Horizontal control fins are attached to the lower hulls for increasing dynamic stability and providing additional control in heave, roll, and pitch under all performance conditions. It should be noted that the SWATH is twin hulled and not a catamaran in the sense that many people think of it. SWATH should not be confused with two monohulls tied together. The monohulls have very different seakeeping qualities.

The SWATH idea has been around for a number of years with the first patents being issued over 100 years ago. The first operational SWATH boat is the U. S. Navy's 90 foot (27.4m) semisubmerged platform KAIMALINO, which was built in the early 70's.

The SWATH boat SUAVE LINO (Figure 2) is the second SWATH boat built in the U. S. Launched in 1981 as a sport fishing boat, the SUAVE LINO is 65 feet (19.8m) long with a beam of 30 feet (9.1m). Normal operating displacement is 46.6 tons, and her maximum load displacement is 52 tons. The normal operating draft is 6 feet (1.8m). Maximum speed is 20 knots and cruising speed is 15 knots. At maximum speed fuel consumption is 42 gallons per hour.

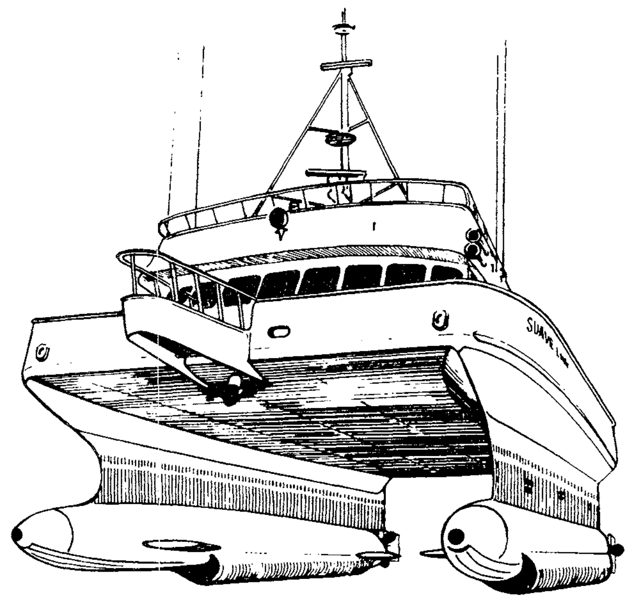
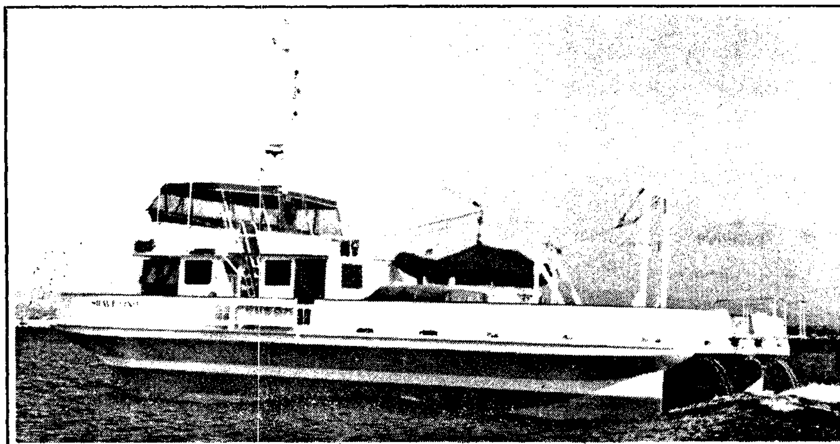


Figure 2. SUAVE LINO

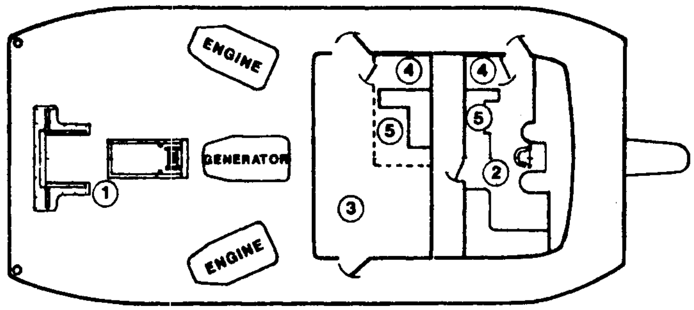
SUAVE LINO is all welded aluminum construction. The vertical struts which give the SUAVE LINO her small waterplane area are 5.6 feet (1.7m) long and about 1 foot (.3m) in thickness. The deck mounted main engines are connected to the propellers by solid shaft "Z" drives using two right angle gear boxes. They are General Motors Detroit Diesels rated at 425 horsepower at 2300 rpm. There are two generators; one 30 kw and one 15 kw. The pilot house has a well laid out control station where everything is at the fingertips of the operator. There is a second control station on the flying bridge, as well as rudder and engine controls at each side of the flying bridge. The lower hulls are 3.8 feet (1.1m) in diameter, and contain both ballast and fuel oil tanks. The total fuel capacity is 3800 gallons. The upper hull holds 500 gallons of potable water, and one reverse osmosis water maker that is rated at 350 gallons a day.

The SUAVE LINO has control fins on the inside of each of the lower hulls. These fins can be controlled by a gyro or manually. The gyro control is more responsive and provides the best ride.

The SUAVE LINO as currently configured is shown in Figure 3. This is a modification from her original design and provides excellent space and arrangement for hydrographic and oceanographic work.



The 19.8 meter Small Waterplane Area Twin Hull (SWATH) ship *Suave Lino*.



(1) "A" FRAME ASSEMBLY
(2) WHEELHOUSE/MESSING
(3) SCIENTIFIC SPACES
(4) HEAD/SHOWER
(5) GALLEY

Figure 3. Current Configuration of SUAVE LINO

Seakeeping tests were conducted with SUAVE LINO soon after she was launched. The reduced pitch and roll data from this test are shown in Table 1. Looking across the top you can see that the SUAVE LINO took the seas from dead ahead, on the bow, beam, quarter, and astern. Wave height ranged from 4.1 (1.2m) to 5.8 (1.8m) feet and the wind averaged 23 knots throughout the test.

Table 1. SUAVE LINO - Seakeeping Summary

Direction of Waves	Head	Bow	Beam	Quarter	Stern	Head
Wave Height (Feet)	4.1	4.4	4.8	5.1	5.4	5.8
(Meters)	1.2	1.3	1.5	1.6	1.6	1.8
Boat Speed (Knots)	15	15	15	15	15	6
Pitch (Degrees)	2.0	2.1	2.0	3.3	3.3	4.7
Roll (Degrees)	1.1	1.4	2.9	2.8	1.7	3.6

Perhaps the most telling information in the table is shown in the BEAM column. With waves of 4.8 feet (1.5m), roll was less than 3 degrees.

The column on the far right is for one run at reduced speed directly into the seas. By that time the seas were almost 6 feet (1.8m) and the wind continued at 23 knots. Under these least desirable conditions with the SUAVE LINO going 6 knots where her control fins are not too effective, roll was limited to 3.6 degrees and pitch to 4.7 degrees.

A limited comparison of the seakeeping capabilities was made between the SWATH hull form, a monohull and a catamaran (Table 2). Due to various constraints the tests were limited to zero speed in head and beam seas. The data for the monohull was obtained from model testing. Corresponding motion characteristics were calculated for the SWATH hull form using computer programs. The motion of the catamaran hull form was estimated using data from previous model tests.

Table 2. Comparison of Motions for SWATH, Monohull, and Catamaran Forms

Hull Description	Monohull	SWATH	Catamaran
Displacement, Long Ton LOA, Ft Maximum Beam, Ft	33.0 56.1 (17.1m) 15.7 (4.9m)	33.0 42.0 (12.8m) 32.1 (9.9m)	33.0 48.6 (14.8m) 18.0 (5.5m)
	SEA STATE		
Sea State Number Significant Wave Height, Ft	2.5 3.5 (1.1m)	2.5 3.5 (1.1m)	2.5 3.5 (1.1m)
	HEAD SEA RESULTS		
Peak Pitch (Bow Up), Deg.	6.6	2.9	12.5
	BEAM SEA RESULTS		
Peak Roll, Deg.	21.8	7.0	18.1

Data was developed for hulls of 33 ton displacement, a little smaller than the SUAVE LINO. At the SEA STATE line we can see that wave height was 3.5 feet (1.1m). Data of special interest is shown in the BEAM SEA RESULTS section, and on the bottom line of the table we can see that the monohull rolled 21.8 degrees, the catamaran 18.1 degrees and the SWATH only 7.0 degrees.

Taking these tests one step further, data was developed for the SWATH in 5 (1.5m) and 10 foot (3.0m) seas. In Table 3 we can see that at 15 knots, in 10 foot (3.0m) seas the SWATH would be rolling some 5.2 degrees. Looking back to Table 2, note that the monohull was rolling 21 degrees in 3-1/2 foot (1.1m) seas.

Table 3. Seakeeping - 42 Foot (12.8m) SWATH

5 Ft. (1.5m) Significant Wave Height		
Pitch	1.8°	2.1°
Roll	1.9°	3.1°
10 Ft. (3.0m) Significant Wave Height		
Pitch	3.2°	3.6°
Roll	3.2°	5.2°

What this tells us is that the SWATH boat will outperform a monohull or a catamaran of the same size. Put another way, the SWATH boat of a given size will turn in the performance of a much larger monohull. For hydrographers it means you will be able to stay on the survey line with a SWATH launch when the monohull launch has had to heave to or seek shelter from the seas. If seeking shelter means that the mother ship has also had to interrupt survey operations to recover boats, combined loss of time can be very costly.

The advantages of the SWATH survey platforms are important in themselves. When combined with the multibeam acoustic survey systems the advantages (and savings) become even more impressive.

Multibeam systems, such as the HYDRO CHART produced by General Instrument Corporation, collect high resolution data from a wide swath of the ocean floor perpendicular to the ship's track. This data is generated by means of soundings from 21 contiguous beams as shown in Figure 4. The multiple beam pattern covers a swath of bottom equal to 2.5 times the water depth to 800 feet (243.8m), and equal to the water depth to 2000 (609.6m) feet. There is also a deep ocean version of this equipment called SEA BEAM which provides coverage equal to 80% of water depth down to 36,000 feet (11,000m).

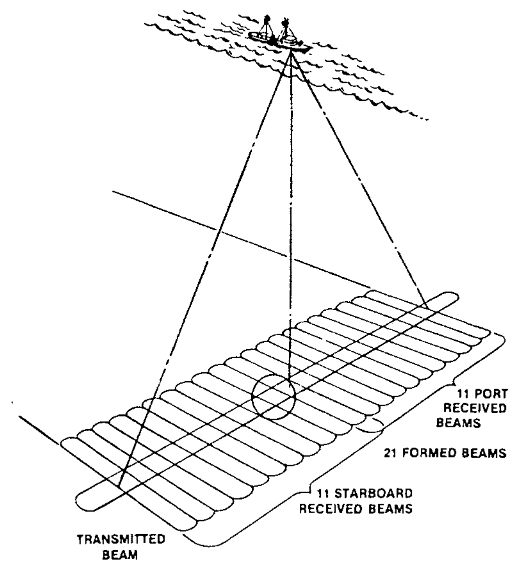


Figure 4. HYDRO CHART Array

When you compare this coverage to what you get from a conventional single 7.5 degree conical beam coverage (Figure 5), the difference is apparent. Where the requirement exists for 100% coverage or identification of all potential dangers to navigation the difference becomes meaningful as well as apparent. The General Instrument Corporation has done a detailed comparison of the efficiencies of the two systems over a hypothetical survey area 10 km by 10 km (6.2 mi x 6.2 mi) with an average depth of 91 meters (approximately 300 feet). Using the single beam sonar and a 30% adjacent track overlap it would take 1171 parallel tracks to get 100% coverage. At a speed of 10 knots it would require 633 hours or 26.3 days of continuous survey. This does not include the time to turn at the end of each line. Just turning would add approximately four more days to the survey.

Using the same survey area and the HYDRO CHART system you would be required to complete 63 parallel tracks for 100% coverage. At 10 knots it would take 34 hours or 1.4 days of continuous survey.

Put another way, if the daily cost of the survey vessel is $10,000 and the survey takes 30 days to complete (includes turning time) a savings of approximately $286,000 would be realized using HYDRO CHART over the single beam system for this survey operation. At that rate, the HYDRO CHART would pay for itself in five days.

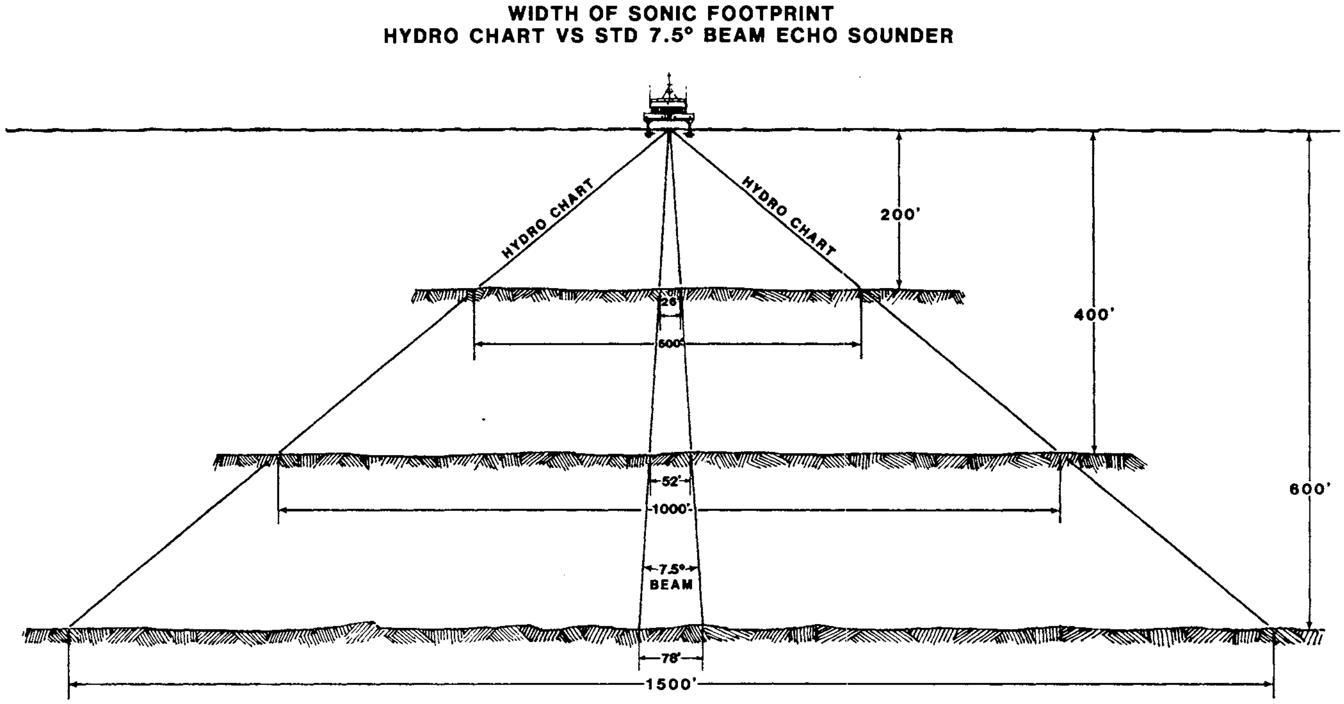


Figure 5. Width of Sonic Footprint

Side scan sonar offers some relief in the single beam survey. You can increase line spacing and "look" between lines for possible dangers to navigation with the side scan equipment. However, the speed of the survey ship must be reduced to accommodate the side scan. It should also be noted you will not get the feature definition or accuracy from side scan that is required for cartographic purposes. An area identified by side scan as a possible danger to navigation must also be surveyed by conventional means.

In summary, using a multibeam survey system aboard a small waterplane area twin hull (SWATH) survey platform places a powerful and economic combination of technologies in the hands of the surveyor. It is encouraging to see SWATH ship design being introduced in Japan and the United States, and multibeam systems in Australia, France, Japan, United States and West Germany. This is a start toward getting the most out of our survey dollars and making the world's oceans safer for navigation.

THE SEMI-SUBMERSIBLE "KAIMALINO": EXPERIENCE IN HAWAIIAN WATERS

J.D. Hightower and G.A. Wilkins
Naval Ocean Systems Center
Hawaii Laboratory
Kailua, Hawaii, U.S.A.

ABSTRACT

The SSP KAIMALINO, a 228-ton semi-submersible craft designed by the Naval Ocean Systems Center, has operated in Hawaiian waters for about 10 years. It consists of two torpedo-shaped hulls which are always submerged, four streamlined struts which pierce the surface, and a boxlike superstructure which stands well out of the water. This configuration results in extremely low motions--at all aspects to the sea, whether stationkeeping or underway. This "seakindly" behavior allows the craft to maintain near-cruising speed in high seas. Other major hallmarks of KAIMALINO's Hawaiian experience include:

- It has carried out routine ocean science and engineering tasks in very high sea states--including storms which have forced companion ships with 10-times higher displacement to cancel ocean operations.

- It is Navy-certified for daylight VFR launches and landings of SH2F helicopters; and has performed such operations in high sea states.

- Its extraordinary stability allows KAIMALINO to come alongside docks and piers in relatively unprotected harbors and roadsteads. Depending on project loading, draft can also be decreased--to about two-thirds of the normal 15 feet. (This feature, for example, could allow transit through a relatively shallow channel into an atoll's deep lagoon.)

These and other capabilities make the KAIMALINO a natural candidate for Hawaiian use--in tasks ranging from ocean science or engineering, to diving support, to search and rescue, to fishing, to interisland transportation. These same features indicate that the concept might be even more valuable in similar roles among the less-developed islands of the central Pacific.

PROJECT SWATHMAP: SIDESCAN SONAR ACROSS THE WESTERN PACIFIC

Peter B. Humphrey
University of Hawaii
Institute of Geophysics
Honolulu, Hawaii, U.S.A.

ABSTRACT: Four long-range sidescan sonar systems operate in the world today: SWATHMAP, GLORIA II, SeaMARC I and the most advanced, SeaMARC II. SWATHMAP is the peacetime application of a combat vessel a.s.w. system utilized on routine ocean-wide transits. Compared to its three brethren, it is a primitive operation justified primarily by its remarkable ease, speed and cost: U.S. Navy cooperation provides what is essentially free science. Despite its limitations, the project has very successfully imaged deepsea trenches, seamounts (many of them newly discovered), deep terraces and vast arrays of seafloor lineaments which are valuable keys to plate tectonic motion (particularly in regions devoid of otherwise essential magnetic clues). While hardly a comprehensive mapping system, these data are proving particularly valuable in two fields of endeavor: (1)pinpointing features (many new) whose gross appearance suggests they are worthy of detailed study, and (2)determining long-range continuity of seafloor patterns and trends (both structural and sedimental).

* * *

Sidescan sonar (along with satellite altimetry and multibeam sonar) is to the seafloor what aerial photography and remote sensing have been to the land--a rapid bathymetric search technique for reconnaisance, survey and mapping of deepsea topography, and discerning changes in the texture and composition of the seabed itself. In its ability to see ridges, seamounts, craters, channels, canyons, faults, fractures, terraces, trenches, slumps, lava flows and sediment structures, sidescan sonar is a most valuable tool with which to study the relief of the seafloor and the shape of the structures thereon.

While a passive sonar system is one which merely listens for environmental or ambient noise, active systems (such as these) force the issue, using their own acoustic energy to 'illuminate', or rather insonify, the seafloor on either side of the ship track. Unlike the more familiar echo-sounder or fathometer whose transducer emits and receives a conical energy pattern, the arrayed transducers of sidescan sonar produce a beam pattern that is fan-shaped: very narrow horizontally (only a couple of degrees) and quite broad vertically. From its high-powered transducers, the array emits short regularly-spaced pulses of low frequency sound in the form of that vertical fan-shaped main beam or "principal lobe" which reaches out at right angles from the ship's course to sweep along the sea bottom: thus the sound will intersect the seafloor only in a long narrow strip that is similarly perpendicular to the ship track (see figure 1). As the sound grazes the bottom and encounters rough features, it is scattered in many directions, but a little bit is reflected back to the transducers from whence it came to let us know something is down there. These echoes are then amplified and transformed electrically into a recordable line of data (one for each sonar pulse) whose darkness depends on the strength of the echo received. As the ship sails along, successive closely-spaced data lines are laid down one-by-one and side-by-side to give a continous map-like 'photographic' image known as a "sonograph".

Currently there are four long-range side-scan sonars operating in the deepsea:

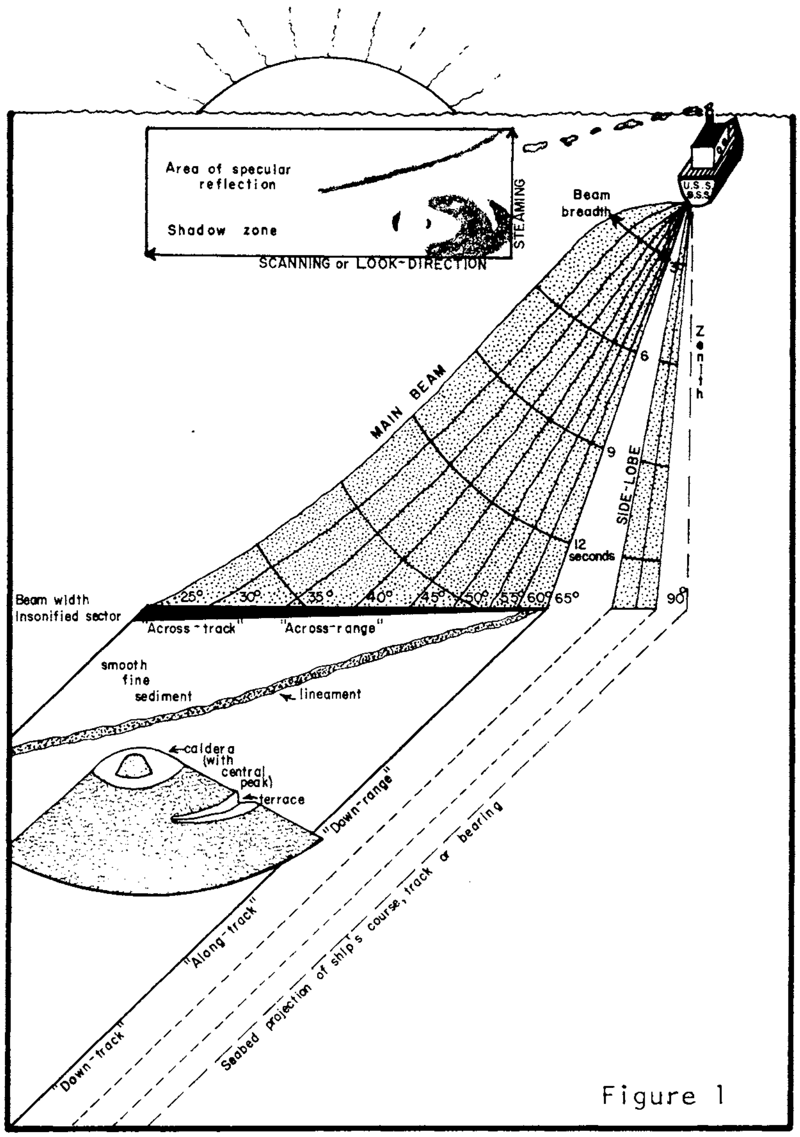


Figure 1

This diagram illustates many of the more important principles of the side-scan sonar technique:

(1) Orientation of the main beam with respect to the ship

(2) Orthogonal nature of sidescan sonar and the terminology most commonly used to describe that nature in the scientific literature

(3) Increasing acoustic refraction with distance due to density changes (generally temperature stratification in the water column)

(4) Uncontrolled spreading of the beam (widening in plan view) across track due to inherent incoherency--this means signal loss resulting from fewer energy 'rays' per unit area

(5) Controlled spreading of the beam (in vertical view) across the track

(6) Change in seabed incidence angle of the beam across the track

(7) Schematic of an imaginary deepsea bottom

(8) Sketch of the sonogram which would result from that same bottom. Note especially the two types of data voids:

--those resulting from "shadowing": areas which never received sound (eg.: behind the seamount or near the crater lip)

--those resulting from "specular reflection": areas which received the sound but reflected it away from the ship (eg.: smooth flat sediments) one on either side of the North Atlantic (SeaMARC 1 and GLORIA 11) and two based in Hawaii (SWATHMAP and SeaMARC 11). All four systems have observed various small sections of the Pacific: SWATHMAP was the first to do so and SeaMARC 11 is the most advanced to do so.

GLORIA 1 & 11

GLORIA (Geologic LOng Range Inclined Asdic) is a somewhat unwieldy towed unit operated by the Institute for Oceanographic Sciences in Surrey, England. After many years of excellent service, the pioneering instrument in this field was cannibalized to provide parts for its greatly-improved second edition. Having served in all oceans and having visited each major tectonic environment, the project as a whole has the greatest mileage and longest publications list. Despite the frequent excellence of its imagery, it has been restricted to the limiting nature of analog output (though steps are now being taken to acquire digital capability).

SeaMARC 1

SeaMARC 1 (Sea Mapping And Remote Characterization), operated by Columbia University's Lamont-Doherty Geological Observatory, represents a leap in image quality due to its ability to manipulate, rectify and enhance its data digitally--even synthetic aperature is possible. Operating rather slowly well-down in the water column with a swath width of only five kilometers, SeaMARC 1 is essentially the middle ground between long-range systems and detail-oriented benthic units such as Scripp's DEEPTOW or Woods Hole's ANGUS.

SeaMARC 11

SeaMARC 11 of the Hawaii Institute of Geophysics is a third system whose resolution and precision are greatly enhanced by sub-surface towing (ie. distant from ship noise, stable in attitude and free from much of the acoustic distortion inherent in pycnocline-rich surface waters). Like its predecessor, its digitized data are electrically corrected for ray-spreading and slant range variations with distance; a geometrically correct image results.

SeaMARC's greatest asset is its ability to generate (HYDROCHART, SEABEAM, SASS) multibeam-like bathymetric contour maps (in addition to its outstanding sonographs) by recording three simultaneous data sets: (1) each echo's amplitude, (2) its acoustic travel time (⇒slant range), and (3) its angle of arrival at the tow body. That all-important last parameter is discernable thanks to the tiny difference in arrival time between the two parallel rows of transducers appearing on each side of the tow body. Unless an echo's wave front arrives at all transducers simultaneously (ie. exactly parallel to the array), the different rows of the array will hear the same echo at very slightly different times, ie. echoes arriving at an angle to the array will enter out of phase--a phase shift appears proportional to this tiny difference in arrival time. This arrival angle is converted to a more easily measurable and recordable electrical angle for later decipherment (essentially interferometry) which allows inference of the reflector's angular position with respect to the tow body (phase angle⇒angle of incidence). The time parameter tells us the distance along this acoustic vector (slant range), and together these values let us plot the reflector's location. The amplitude parameter relates that surface's ability to reflect sound. Amplitude and time together provide the sidescan.

SeaMARC 11's operations have been restricted to Pacific areas. Long-range plans include turning the system into an autonomous kit for greater global mobility. Researchers are also studying the possibility of sediment-typing via seafloor acoustic impedance variations.

	SWATHMAP	GLORIA 11	SeaMARC 11
WAVELENGTH (centimeters)	43	25	13
FREQUENCY (kilohertz)	3.5	6.5(6.3&6.7)	11.5(11.0&12.0)
APPROXIMATE TOW DEPTH (meters)	4	50-100	100
SURVEY SPEED (knots)	up to 20	~7(up to 11)	10
GREATEST POSSIBLE DEEP OCEAN SWATH WIDTH OR MAXIMUM SLANT RANGE IN MINIMALLY STRATIFIED WATERS (kilometers)	65 (less ~10 in center)	60 (less ~10 in center)	10 (less ~ 0.4 in center)
TIME BETWEEN PULSES TWO-WAY TRAVEL TIME (seconds)	40	30	15
RESOLUTION (order of magnitude in meters)	100's	10's	1's
MAXIMUM SURVEY RATE (kilometers^2/day)	58000	30000	4000
MAJOR ADVANTAGES	ease great energy all-weather great rapidity economy	good stability good detail low refraction rapidity	great stability superb detail very low refraction bathymetry&sidescan advanced processing
MAJOR DISADVANTAGES	hazy detail restricted access analog output only	expensive weather-restricted analog output only	expensive weather-restricted slow

Table 1. Specifications of long-range deepsea sidescan sonar systems

SWATHMAP

Project SWATHMAP is sidescan at its simplest. We utilize an EPC 3208 analog recorder plugged into a U.S. Navy SQS-26-CX U.S. Navy sonar system on routine ocean-wide combat vessel transits at times when this apparatus is not serving the function for which it was originally developed: detection of submarines. The hull-mounting of its transducer array accounts for its major advantages (all-weather capability, ease of operation, low price tag and survey rapidity), but the cost in resolution is very high. Nevertheless, the system has excelled at locating new features worthy of study and determining their aerial extent--it works particularly well for quick, comprehensive views of large-scale topographic features such as seamounts, trenches and abyssal plains, examples of which follow. All images arrive with unequal scales only partially corrected photographically--accordingly structures appear elongated on these images.

Figure 2 runs east to west along about 14° 30'N with the Pacific (at two different compressions to the left and the Mariana Trench to the right. The unusual geometry created by foreshortening and proximity to the ship track (at the very top of the image) gives the image's uppermost portion the appearance (and to some degree the function) of a conventional reflection profile while portions immediately below are close to plan view. The 30 km X 900 km image illustrates four Mariana Basin seamounts: two new discoveries (the two smaller ones), one guyot (flat top) and a seamount in the process of entering the Mariana Trench. The sharp edge (arrow), not unlike those on either side of the nearby guyot, suggests break-up of this seamount has already begun, 50 km from the 9000-meter deep trench axis. Current rates of tectonic plate movement will complete the destruction within a million years. The trench itself nicely illustrates the steeper downgoing side to the left and the horst-and graben fault blocks on the forearc side to the right.

Figure 3 runs west to east along about 12° 45'N under the Philippine Sea. The 30 km X 750 km image shows relatively young seafloor south of the Central Basin Fault from whence it probably came. The area is deformed into a regular pattern of linear abyssal hills (the most common structural feature on the face of the earth) which dramatically illustrate (in a manner even superior to the local magnetic anomalies) the evolution of this tectonic plate--note the change in orientation (and hence spreading direction) along the track. Here then, we have a geomorphic tool for inferring spreading directions, even in places where otherwise essential magnetic anomalies are absent. In fact, the number of hills per unit time may allow a rough estimate of spreading rate in regions devoid of these magnetic clues.

Figure 4 illustrates two seamounts along 13° 28'N on either side of 140° 24'E (between Guam and the Palau-Kyushu Ridge). Both are exaggerated across-track, roughly conical in actual appearance (about ten kilometers around) and apically depressed: the left cone is simple with a summit caldera and the right cone is complex with either a central peak (like Crater Lake) or parasitic cone (like Mount Shasta).

One of the most profound discoveries in marine geology is the ever-advancing estimate of the world's seamount population. Seamount distribution is Poisson-like with small mountains far more common than large ones. Satellite altimetry will soon fix the number and location of larger seamounts, but that myriad below about half the ocean depth are undetectable from space, so most seamount detection will continue to depend on the excellence of our acoustic surveys. SWATHMAP routinely finds new peaks on each near-random cruise line over a data base thought reasonably reliable by virtue of its location under common shipping lanes; on four cross-Pacific cruises we've found at least a dozen new peaks. One can surmise that the discoveries awaiting us in the largely unexplored polygons of territory between these well-known strips are very substantial.

Despite our success, we have determined that many of our sonar outputs go unutilized; possible system upgrades include (1) stereo image production, (2) magtape recording for subsequent image manipulation and enhancement, and (3) decipherment of parallax across the array to determine the acoustic arrival angles one utilizes for estimates of bathymetry. Even so, given the extraordinary cost of today's excellent seafloor imaging systems, one does well to utilize such existing systems for low-cost survey, particularly in poorly-known areas.

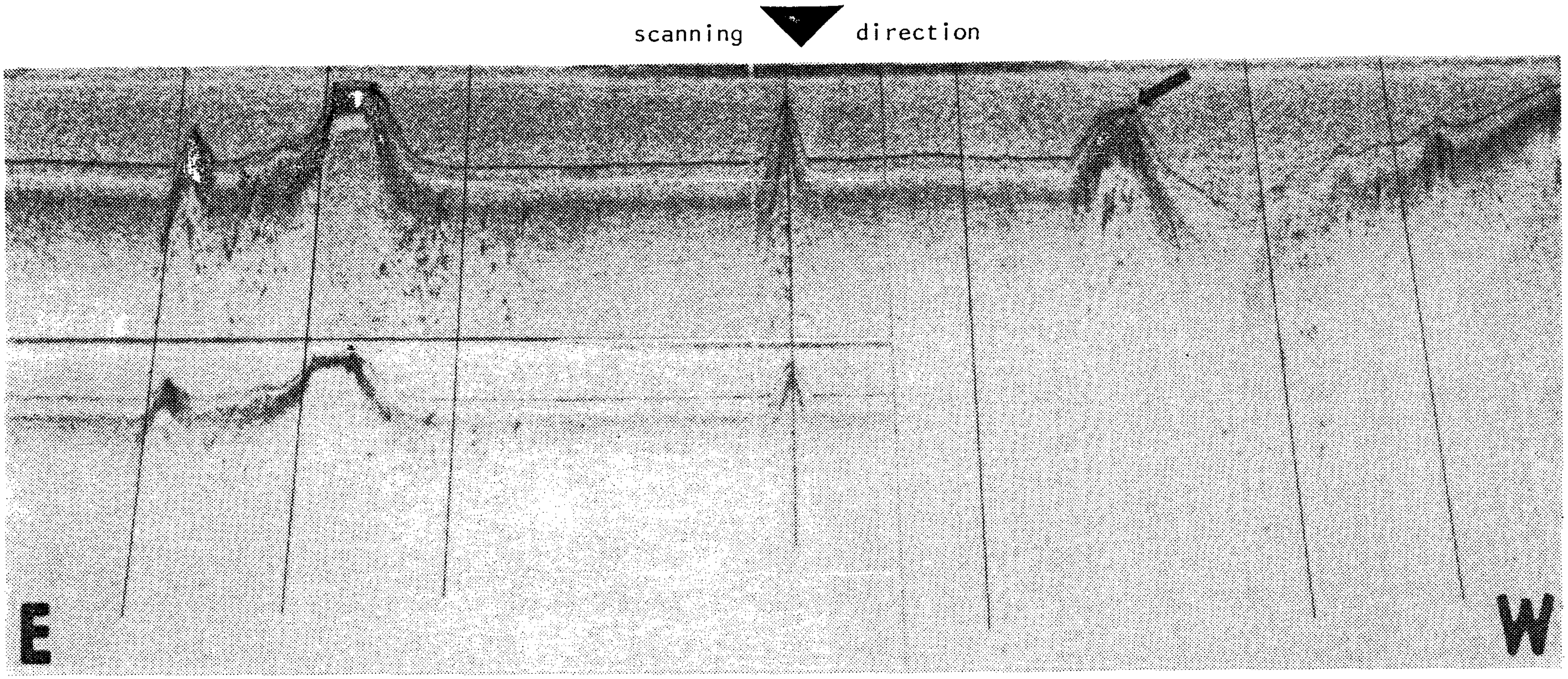


Figure 2. Pacific seamounts adjacent to the Marianas Trench

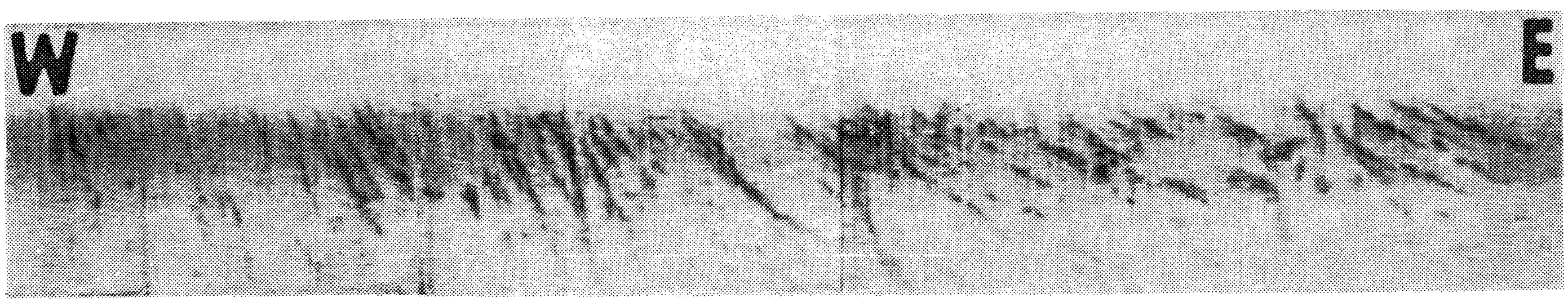


Figure 3. Abyssal hill series under the Phillipine Sea

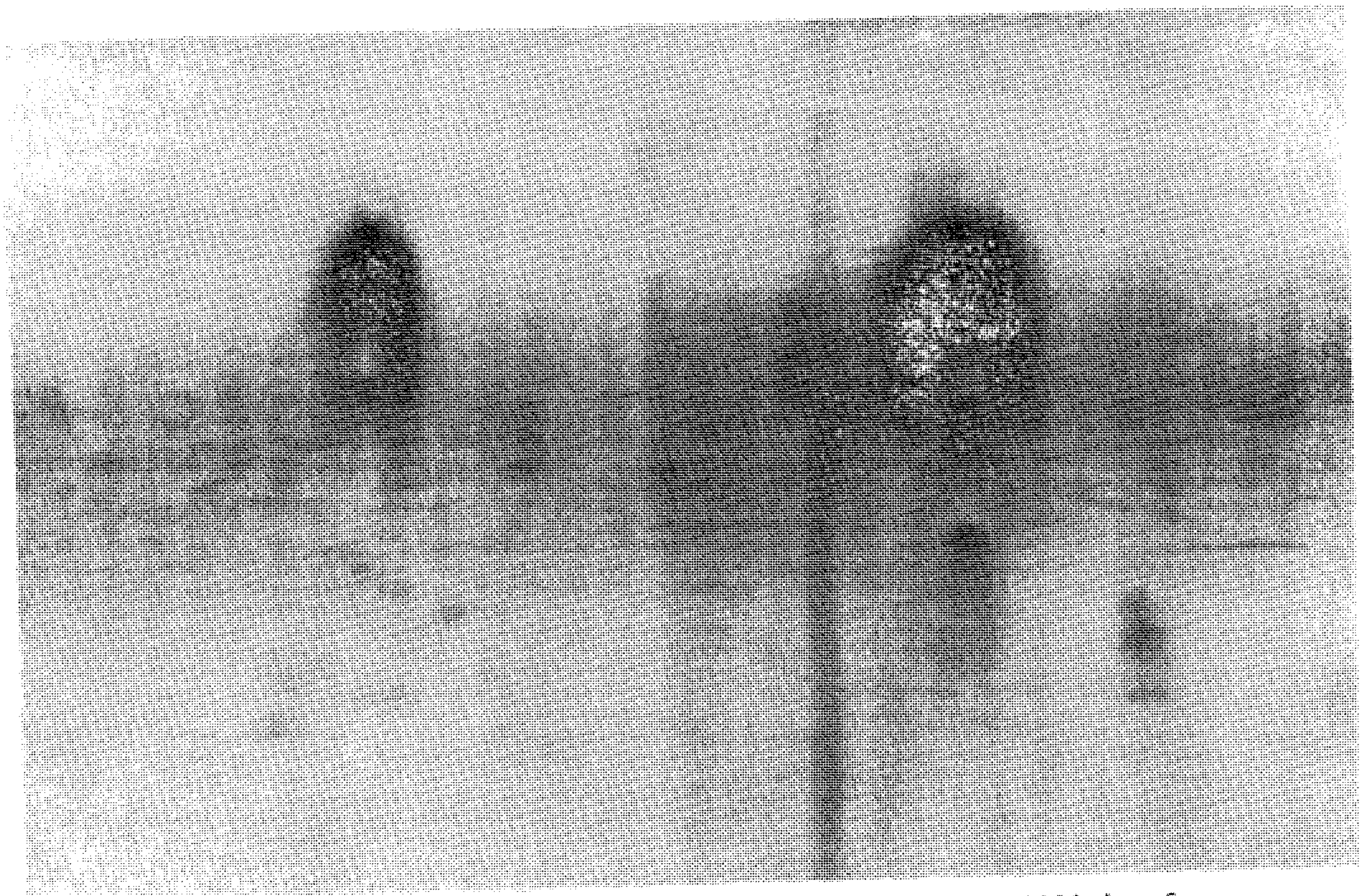


Figure 4. Pair of volcanic cones under the Phillipine Sea

Hawaii Institute of Geophysics Contribution No. 1467.

GUYOTS, SEAMOUNTS, AND TECTONICS OF THE EMPEROR-HAWAIIAN ELBOW BY MULTI-BEAM SONAR

N. Christian Smoot
Bathymetry Division
U.S. Naval Oceanographic Office
NSTL, Mississippi, U.S.A.

ABSTRACT

Five guyots and five seamounts are shown from the last volcanic pulsation of the Emperor Chain, an area called the Hawaiian-Emperor Elbow or the Milwaukee Seamount Group in the north central Pacific Ocean. The data are from the U.S. Naval Oceanographic Office (NAVOCEANO) multi-beam surveys. The bend is shown to occur over an area encompassing 140nm (260km) in steps. Questions are raised as to relative proximity of different flat-top depths and formational possibilities of different geomorphology on the features. Two new features, Taishō and Go-Shirakwa Seamounts, are introduced as are six new names on existing features. The latter are Antoku Guyot, and Genji and Go-Sanjō Seamounts.

OST-6: OFFSHORE ENGINEERING

DATA BASE DESIGN CONSIDERATIONS FOR OCEAN SCIENCE ENGINEERING

M. B. Wagner
Boeing Computer Services Company
Seattle, Washington, U.S.A.

Modern data analysis requires several important considerations when designing a data handling system. First, analysis is frequently multidimensional, that is, more than one discipline is utilized in the overall analysis. An example might be an engineering stress analysis of a proposed structural design plus a statistical model of predicted performance characteristics under different physical oceanographic conditions. Secondly, data for each of the tasks to be analyzed can be fragmented in its completeness with data missing due to collection instrument failure, collection time periods missing due to scheduling constraints, lost historical data, or any number of other reasons for data gaps. Also, as is frequently the case, more than one data set is utilized in the analysis, a data set for which we had little control over the collection, format or content, yet we must utilize it as the best available. A properly designed data base management system (DBMS) provides the tool and the flexibility necessary to organize and extract all data necessary for the desired analysis. The DBMS should be capable of providing data at simplistic levels for basic reports as well as for complex multidimensional models when needed.

This paper builds by examples, concepts necessary for the efficient performance of a data handling system. Concepts from the designer of the system, the computer requirements and the user of the system, will be explored for potential pitfalls and optimization. Many different DBMS systems are available that are ideal for engineering data systems, ranging from hierarchical to networking to relational. Each has its own unique features, strengths and most importantly its weaknesses. Design and implementation of a "Total User Controlled System" has been successfully accomplished, systems that allow a user with little computer knowledge to design, load, extract, and analyze his data, all under his complete control. These systems are commonly referred to as user friendly, menu driven, real time prompting systems. They allow for repeated use of existing data sets using preplanned analysis pathways, the common NOW WHAT IF WE CHANGE...?. In addition they provide the ability to experiment with certain analysis pathways for new data analysis exploration. This is the flexibility that the chosen DMBS and the system design should be able to respond to.

Engineering data, with its large volume, many different types of data elements being collected and utilized, and the large historical data archives available provides an ideal area for productive data analysis and model building. A modern DBMS is an organizational tool that makes the job easier. The current computer science direction of linking different DBMS's into a distributed network will allow even higher levels of multidimensional analyses to take place. For example we can process engineering structural data from a structural DBMS, obtain biological data from a biology DBMS, then build a very complex engineering performance and environmental impact model. These different DBMS's may or may not have been built by us, reside on our computer system, or even be geographically in the same part of the country, yet we can utilize them in our problem analysis. With transportability of data and programs across computer types, ability to utilize different data sets from different sources, and rapid efficient extraction of subsets, the methodology exists for powerful and productive analysis. The well designed system and choice of the DBMS provides all the tools necessary with all the capabilities to process the maximum information from this collected data.

DEVELOPMENTS IN CONCRETE FOR OCEAN ENVIRONMENT

K. Ganesh Babu
Ocean Engineering Centre
Indian Institute of Technology
Madras, India

In recent years the use of concrete as a material for construction of ocean structures like offshore platforms is increasing. However, the inherent property of concrete - of having very low tensile strength compared to its compressive strength has got to be suitably modified by reinforcing and prestressing. Even so these reinforcing and prestressing steels have got to be reasonably protected against corrosion by the available concrete cover and quality. The present paper without going into the mechanisms of corrosion of steels in concrete, presents briefly the various methods available to make concretes of superior quality.

The two basic requirements of concretes for marine environment are, firstly high impermeability to protect the various steel reinforcements from corrosion and stress corrosion and secondly high strength (both in compression and tension) - to facilitate the design of slender and cost effective structures with favourable strength to weight ratios. However, in most cases these two factors are interrelated due to the fact that the higher density required for obtaining the necessary impermeability will also produce improvements in strength.

The basic factors that influence the strength of concrete are the water-cement ratio and workability. Any improvements proposed for a particular mix have to basically look into these two aspects. However, these are two contradicting requirements in the fact that the amount of water required for the total hydration of cement being around 0.25 (w/c ratio), the minimum amount of water required to obtain sufficient workability levels even for a reasonable compaction in concrete by conventional means is around 0.35. The excess water which will occupy the pores reducing the strength of concrete can be minimised by various methods. Some of the methods, with which the author has experience, are high frequency vibration (of the order of 12000 vibrations/min) - imparting higher mechanical energy for better compaction, spinning - imparting a centrifugal force to drive out the excess water, mechanical pressure compaction squeezing out the water in the pores by the impressed force and vacuum dewatering - for removing the excess water by vacuum suction or a combination of the above. However, these techniques are better suited for prefabrication and one should also design the mix, particularly the fines content to avoid segregation and bleeding. In some cases like spinning and vacuum treatment the escaping water forms fine yet continuous channels making the concrete permeable. To avoid this defect spinning or vacuum treatment is done with alternating periods of suitable vibration.

To overcome some of the above difficulties many research workers propose admixtures. Though admixtures by themselves are not new to concrete technology, some of the later inventions particularly polymeric superplacizers, retarders of recent years and latexes (Dow latexes) have been found to solve some of the problems adequately. In the experience of the author superplasticizers like Melment - a sulphonated malamine formaldehyde condensate, Irgament Mighty or Mighty and Lomar-condensate of naphthalene formaldehyde sulphonate offer considerable application possibilities like both for making flowing concrete and water-reduced concretes. By the addition of just 1 to 3% of these materials by weight of cement increases upto 20% in strength due to possible water reduction or completely flowing concretes with minimum requirements in methods of compaction have been obtained. However, it is to be observed that suitable increases in fines in the mix have to be made to avoid segregation and bleeding.

In some cases distributing the tensile reinforcement over the entire concrete-mixture - like in the case of Fibre-reinforced concrete and Ferrocement - impart excellent corrosion, cavitation and spalling resistance by increasing the tensile capacity by distributing the tensile cracks more uniformly. In the author's tests combination of superplasticizers and Fire-reinforcement gave substantial improvements in many of the properties of concrete. In some of the tests of the author the resultant concretes not only showed improvements in tensile and compressive strengths but also good corrosion resistance by the fact that the fibres in the outer layers of concrete are not found to be corroded even after prolonged exposure to chemically aggressive environment.

Finally in the recent years polymer modifications in concrete- in the form of polymer as a binder (polymer concrete) or polymer latex as an admixture (polymer cement concrete), or impregnation of polymer into hardened concrete (polymer impregnated concrete) have shown great possibilities for future. In the experiments conducted by the author polymer concretes are made by a mixture of aggregates with styrene polyester as a binder using catalytic auto curing. The resulting concretes were chemically inert to a high degree to both acids, alkalies and salts apart from having strengths upto about 1000 kg/cm^2. The selection of the mix, monomer, catalyst concentration and promoters are found to be having significant influence on the strength of the resulting concrete. Polymer cement concretes or Latex concretes behaved very similar to superplasticized concretes. The best possibility to modulate both compressive and tensile strengths of concrete were found to be offered by polymer impregnated concretes. The author adopted a vacuum - pressure impregnation using low viscous monomers like Methyl Methacrylate, Styrene and Acrylonetrile or Copolymers of Methyl Methacrylate-Butyl Acrylate and Styrene - Acrylonitrile with Benzol peroxide as catalyst. Improvements in strengths from a normal concrete strength of about 250-350 kg/cm^2 to very high strength concretes of 1300-1600 kg/cm^2 were possible with Methyl Methacrylate, styrene and styrene Acrylonitrile systems. Addition of Butyl Acrylate produced substantial improvement in tensile capacity and the tensile strength could be modulated from the usual 10% of compressive strength to a value of about 30% by varying the proportion of Butyl acrylate. However, the improvements in the tensile strength due to the addition of Butyl Acrylate has a lowering effect on compressive strength. All these impregnated concretes are found to be chemically inert to a very great degree as shown by their resistance to acids, bases and salts.

In conclusion, it can be seen that in the preceding paragraphs the author illustrated a large number of possible concretes having good strength, corrosion and chemical resistance. Many of them are admirably suited for marine environment. However, depending upon the application, suitable modifications regarding mix proportioning or production techniques have to be made for the best possible use of the material. A number of examples of how even the most advanced technology of polymer impregnated concrete has been modified to suit the needs of practice in bridge decks, dam spillways etc. are available in literature.

OCEAN STRUCTURE-SHORELINE INTERACTION

M.R. Pranesh
P. Venugopalan
Ocean Engineering Centre
Indian Institute of Technology
Madras, India

ABSTRACT

The construction of marine structures,both coastal and offshore structures, influences the morphology of the beaches and consequently modifies the shoreline. The impact of the structure on the shoreline can be felt either in the vicinity or at a region away from the structure. Depending on the various factors involved, the changes can occur either immediately or on a long term basis. In this paper the changes on a shoreline caused due to a detached structure, which is constructed parallel to the shoreline, are predicted using a numerical model. The predicted shoreline changes due to a coastal structure of 100 m long and situated 100 m away from the coast is also presented.

INTRODUCTION

The importance of beaches and coasts is well known. Erosion of shorelines downdrift side of man-made littoral barriers has introduced many engineering and economic problems. The construction, improvement and maintenance of beaches by artificial deposition of sand on down coast shoreline are gaining prominence where damage by erosion has occurred.

In recent years it has become imperative to construct structures for preservation of shorelines, maintenance of harbours, reclamation of land etc. Following the present tendency of Coastal Engineering experts, not to construct groins, because of the uncertainities involved, the construction of offshore or detached structures is more in practice. However, even these structures proved to be problematic to the existing shorelines as they obstruct the natural longshore sediment movement. The changes in the natural transport of littoral sediments result in either accretion or erosion.

The shoreline changes due to construction of an offshore structure are controlled mainly by the angle of wave incidence, wave height, the size of the structure, the beach slope, the depth of active sand transport and the regional bathymetry.

In this paper a numerical model is presented to assess the shoreline changes that can take place after the construction of a structure. Hence, it will assist the designer to locate the offshore/coastal structure such that the variation in the shoreline is not of considerable magnitude.

REVIEW OF EXISTING MODELS

The complexity of the processes involved have made formulation of models relating to nearshore regions, a very difficult task. Works regarding this problem has been done only in recent years.

Pelnard-Considere (1956) proposed a mathematical approach for modelling a shoreline on the assumption that the bottom contours are straight and parallel and the longshore transport is linearly related to the incident wave angle. This work seems to be a pioneering attempt in demonstrating the feasibility of modelling of longshore changes.

A two-line model for shoreline evolution due to the construction of groins has been proposed by Bakker (1968) using diffusion equation and accounting for onshore-offshore transport. Bakker et al (1970) included the effect of diffraction also in the model for shoreline evolution.

A more advanced numerical model has been developed by Kraus and Harikai(1983) in an attempt to predict the shoreline changes on Orai beach, Japan, resulted by the construction of a combined groin and breakwater system. Kraus and Harikai had considered the longshore variation of the breaking height also in addition to the effect of refraction and diffraction.

The first model predicting tombolo formation behind a breakwater was presented by Hashimoto (1974). But, in the case of a large incident wave angle, his model could not predict the location where erosion of the shoreline began to occur due to his assumption of a small breaker angle.

A numerical model to predict the shoreline changes was presented by Sasaki (1975). The results simulated by Sasaki's model was compared with results obtained from laboratory experiments and found to agree to a certain extent. But the predicted amounts of both erosion and accretion were much higher than what normally could be. The main reason might be that onshore-offshore transport was neglected in the model.

In comparison with a groin the waves and currents behind a breakwater are very complicated due to diffraction, refraction, and transmission of waves. Behind a breakwater tombolo formation occurs mainly by diffracted waves and resulting currents (Hashimoto, 1974) e.g., on the beach at Santa Monica, California.

BASIC ASSUMPTIONS

The following assumptions are made in the formulation of the model:

1. The littoral drift along the beach is linearly dependent on the angle of wave incidence.
2. The effect of onshore-offshore transport is neglected.
3. The effect of diffraction is felt only on the geometrical shadow zone.

PROPOSED NUMERICAL MODEL

It can be observed that (Pelnard-Considere (1956) and Bakker(1968)) the accretion or erosion of shoreline is linearly dependent on the curvature of the coast and inversely proportional to the depth beyond which there is only negligible sand transport. Hence the diffusion equation viz.

$$\frac{\partial y}{\partial t} = \frac{q}{D} \frac{\partial^2 y}{\partial x^2} \qquad (1)$$

where $q = dQ/d\alpha$, Q is the longshore transport and α is the angle of wave incidence, D is the depth beyond which longshore transport is negligible, y is the distance perpendicular to the shoreline, x is the distance parallel to the shoreline and t is the time.

The equation is solved by numerical methods simulated on a computer. In a numerical simulation model on a computer, the equations of sand transport along a beach and the continuity equation can be solved together to any degree of exactness required with any set of boundary conditions. Time variations are easily introduced; for example, the wave conditions could be changed through time. Longshore variations in the wave energy and deep-water angle of approach can also be included, so that wave refraction and diffraction effects may be considered.

As shown in Fig.1a the shoreline is divided up into a series of cells of uniform width Δx and with individual lengths $y_1 \ldots\ldots y_{i-1}, y_i, y_{i+1}, \ldots y_n$ beyond some base line. The narrower the cells (the smaller Δx), the more nearly the series of cells approximates the true shoreline. Changes in the shoreline configurations are brought about by littoral drift Q_i(cu.m/day) which shifts sand alongshore from one cell to the adjacent cell.

From the continuity relationship, viz.,

$$y_i = (Q_{i-1} - Q_i) \frac{\Delta t}{D \Delta x} \tag{2}$$

for some shoreline advance or retreat Δy_i in cell i, where Q_i is the rate of littoral drift from cell i to cell i+1 (Q_{out}) and Q_{i-1} is the littoral drift from cell i-1 to cell i (Q_{in});Δt is the increment of time (days). A positive Δy denotes net deposition, whereas erosion occurs when Δy has a negative value. It is important that Δy_i values remain relatively small so that there are no sudden jumps in the shoreline position.

As shown in Fig.1b, let H' and α' be the wave height and incident angle outside the geometrical shadow of the structure. The waves inside the region of geometrical shadow are modified by combined refraction and diffraction.

Q' is the rate of longshore transport outside the geometrical shadow and Q is the transport inside the shadow. H' and α' are the wave height and incident wave angle outside the shadow and H and α denote the values inside the shadow.

A computer program has been developed which computes the longshore transport for each cell based on the deep water wave direction and wave height. The breaking wave direction and wave height have been derived using Snell's theory of wave refraction and linear wave theory respectively.

By Snell's theory of wave refraction,

$$\frac{\sin \alpha_o}{\sin \alpha_b} = \frac{c_o}{c_b} \tag{3}$$

where α_o and c_o are the wave incident angle and celerity of the deepwater wave and α_b and c_b are the breaker angle and celerity of the wave at the time of breaking.

The breaker height was computed by the formula given by Munk (1949):

$$\frac{H_b}{H_o} = \frac{1}{3.3(H_o/L_o)^{1/3}} \quad (4)$$

where H_b is the breaker height and H_o and L_o are the height and length of the wave in deepwater respectively.

For the computation of total longshore transport the following formula (Narasimha Rao (1983)) has been used

$$Q = \frac{0.55 \quad g^{1/2} \; H_b^{5/2} \; \sin 2\alpha_b}{(1 - \frac{p}{100}) \; (\rho_s - \rho)} \quad (5)$$

where Q is the total longshore transport, ρ is the specific gravity of sea water, ρ_s is the density of the sediment, p is the porosity of the beach sand, H_b is the height of the breaker, α_b is the angle at which the waves break and g is the acceleration due to gravity.

While computing the longshore transport inside the geometrical shadow the modification of the waves by combined refraction and diffraction has been accounted as given by Wiegel (1962).

RESULTS AND DISCUSSIONS

A typical result obtained by simulation using the numerical model is presented in Fig.2. The effect of a breakwater of length 100 m which is located at a distance of 100 m from an initially straight shoreline has been studied.

The shoreline profile is symmetrical on either side of the assumed structure. In the numerical model, the orientation of the structure is also considered.

CONCLUSIONS

The computer software developed can be used for the prediction of shoreline changes due to the presence of the coastal/offshore structures detached from the shoreline. However, the predicted shoreline changes are to be compared with field observations.

ACKNOWLEDGEMENTS

The authors thank the authorities of the Indian Institute of Technology, Madras for the facilities provided.

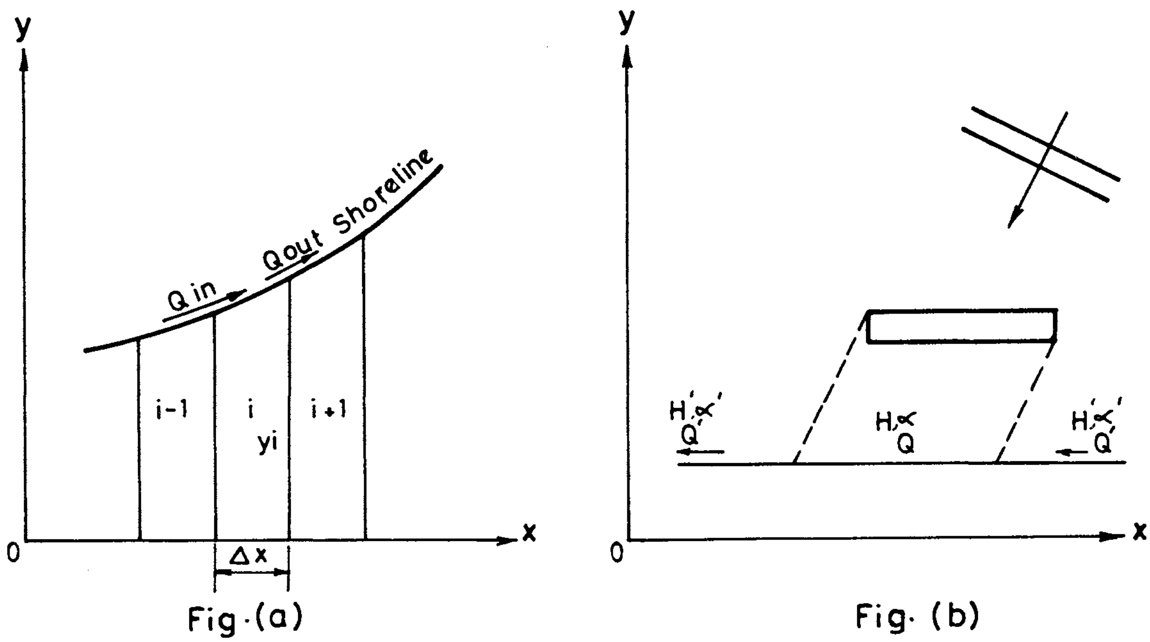


FIG. 1 DEFINITION SKETCH

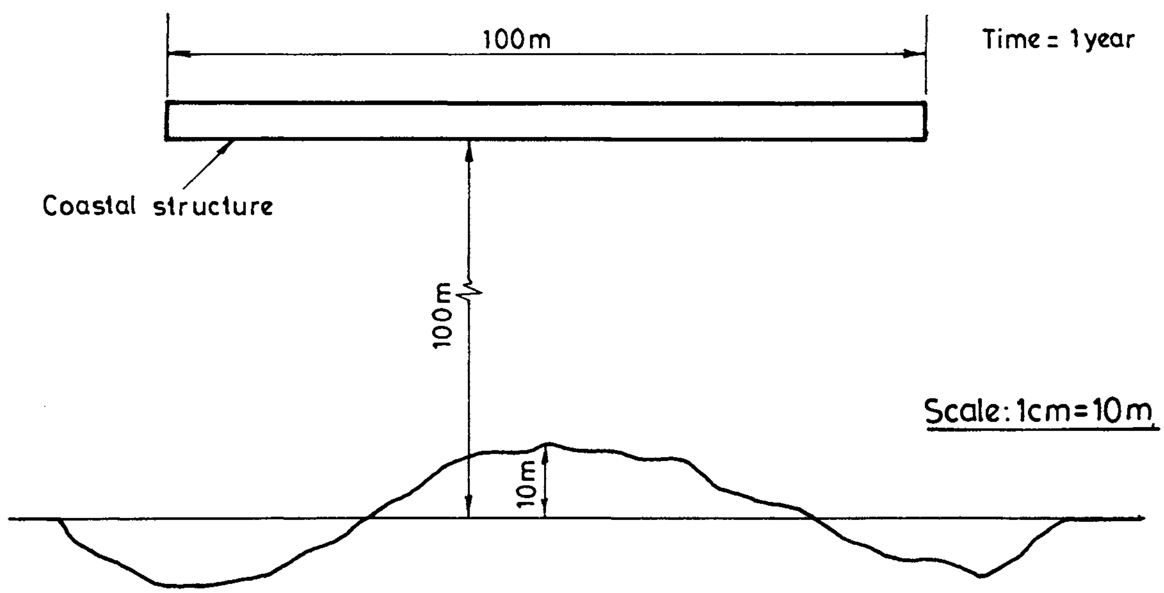


FIG. 2 COMPUTED SHORELINE FORMATION DUE TO COASTAL STRUCTURE

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COASTAL ENGINEERING PROBLEMS IN INDIA - AN OVERVIEW

Narasimha Rao
V. Sundar
Ocean Engineering Centre
Indian Institute of Technology
Madras, India

ABSTRACT

This paper reviews the coastal problems along the Indian coast and presents a detailed discussion on the various physical and environmental factors influencing its shoreline dynamics. Beach erosion and accretion along the coast have been highlighted and the primary causes of these coastal problems have been identified.

INTRODUCTION

Due to the increasing demands on the shorelines of the world for recreation, shipping, industry and marine resources of various kinds, it has become imperative for man to fight and control the short term and long term fluctuations of a natural beach, which are constantly in dynamic equilibrium. In order to control and mitigate the natural problems of erosion and accretion, protective coastal structures like breakwaters, seawalls, jetties, rip rap etc. are constructed. However, paradoxical it may appear, man's battle against nature's incessant forces is not only a futile attempt but also expensive and destroys the aesthetic value of the coast.

India has a vast coastline being bounded on the west by the Arabian Sea and on the east by Bay of Bengal. Since the last 20 years there have been proposals from time to time to establish new harbors or improve the existing harbors or to save vast lengths of coastal strips from erosion by wave action. In evaluating the merits and demerits of such proposals a study of the coastal sediment movement is important since what may be beneficial to a harbor may prove to be detrimental to the preservation of a coastal strip facing erosion. Hence, it is desirable to consider both short and long term effects very carefully before determining the most suitable remedial measures to combat coastal problems.

PHYSICAL AND ENVIRONMENTAL FACTORS AFFECTING THE BEACHES AND COASTS OF INDIA

The interactions of both subaerial and marine processes on materials of widely differing structure, lithology and resistance to erosion, are so variable that the evolution of a coastline in detail is almost infinitely complex. Wave action affects only a narrow littoral zone at any moment of geological time, but fluctuations in sea level extending throughout the Pleistocene and Holocene periods have left evidences of marine processes over a much wider belt (Fairbridge,1968). The important physical and environmental factors which affect the broad shore features of India are discussed below.

GEOMORPHOLOGY OF THE INDIAN COAST

Extremely gentle, even and uniform offshore submarine slopes and surface prevail around Indian Coast, except in limited stretches, near Cape Comorin, off some parts of Konkan Coast, Malabar Coast and the Andamans and Nicobars. Fig.1 shows the location map for the various coasts, places and rivers in India.

Such an even, gently sloping submarine floor gives rise to an even unindented shoreline because the most dominant latest tectonic phase of peninsular India is emergence. The shallow shelf also assures the common growth of offshore bars which play an important role in determining India's shore features. The beach sediment is partly marine, churned up from the submarine floor due to the shallowness of the shelf.

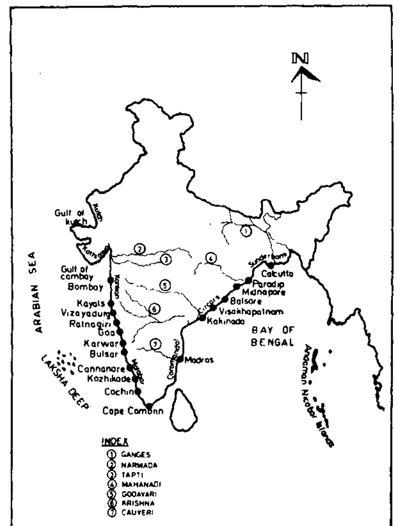

FIG.1 LOCATION MAP

The terrain, altitude and level of the land behind the shore is one of the major determinants of the shore characteristics, particularly when submergence is dominant as on the west coast (north of Karwar) and around the Andamans and Nicobars. At Visakhapatnam, Ratnagiri, Goa, Karwar and Bulsar, the shore is cliffed, crenulate and indented, where hilly and rugged terrains exist. The shore is characterised by large scale embayments (at Kayals), estuaries (Gulf of Cambay), Marshes (South eastern Kathiawar), high promonotories (Moplabay and Visakhapatnam), where the land is marked by great relief. In Tamil Nadu the shore is even and marked by lagoons and marshes (Ahmad, 1972).

WINDS

The monsoons are a great force in shaping India's shore features. India experiences two monsoons, the South West monsoon (June to September) and the North East monsoon (October to December). The South West monsoon strikes the Western Coast almost orthogonally and is particularly of great strength towards the southern half of the peninsula. The constant and high winds generate waves which build offshore bars and drive them towards the mainland. These winds are responsible for beach erosion and formation of cliffs in clay occuring on the beachless shores of Kerala and Bulsar.

WAVE CHARACTERISTICS AND WAVE ENERGY POTENTIAL

It is well known that the littoral transport rate is strongly influenced by the wave characteristics and wave energy. Narasimha Rao and Sundar (1982) observed that the mean wave height and the period off the east cost ranges from 1.1 to 2.0 m and 5.5 to 8.3 sec. respectively. Off the west coast, the mean wave height ranges from 1.0 to 2.6 m and the mean wave period ranges from 5 to 7 sec. The deepwater wave energy potential along the west coast during the monsoonal period varies from 5 to 47 kW/m and during the non-monsoonal period varies from 5 to 9 kW/m. Off the east coast it ranges from 13 to 34 kW/m during monsoons and from 7 to 19 kW/m during the non-monsoonal period.

TIDES

Tides in India are predominantly semidiurnal. The highest tides are observed at the Gulf of Kutch and Gulf of Cambay on the west coast of India and here the maximum spring tide ranges are about 6.5 and 9 m respectively. As the distance south from the Gulf of Cambay increases, the semi-diurnal tide decreases until about 15^{o} latitude, the diurnal tide again predominates and the range is about 1 m off Cochin. At Lakshadweep and Maldives there is a strong diurnal influence but the range is less than 1 m. On the east coast, the semi-diurnal tide prevails, the range of tides increasing with the increase in the distance north of Madras where its average range is about 1 m. The range of tides at Paradeep and Diamond Harbour (Calcutta) are about 2 and 5 m respectively.

CURRENTS

The annual reversal of winds causes a corresponding change in the flow of surface water in the Bay of Bengal. During the spring, there is an anti-cyclonic circulation of this water, which combines with the eastward moving North equatorial current. The swiftest flow is close to the central Indian continental shelf,where the speed reaches 3 to 5 knots. In autumn, the surface circulation is reversed and gives rise to cyclonic circulation with lesser speeds in central and eastern parts. The lack of close relationship between winds and currents applies particularly to the Arabian Sea. The Indian south west monsoon current (May to September) refers to the monsoon, not the direction of current and primarily affects the Arabian Sea though, the waters farther south are influenced to some extent. This current is an extension of north east setting Somali current, curving to the east over the central part of the Arabian Sea and to the south east towards the coast of India. Thus during the south west monsoon, the flow of surface waters of the Arabian Sea turns in a clockwise manner. To the south of the Arabian Sea, there is a major current associated with the north east monsoon and flows strongly to west or west-southwest.

DELTAIC SEDIMENTATION

A considerable part of the Indian shore is occupied by the deltaic regions of Ganges, Mahanadi, Godavari, Krishna and Cauvery rivers. The shore features in these areas are directly affected by delta formation. The greater part of the Indian drainage finds its exit through the delta mouths. The accumulated discharge of sediments causes land building towards the sea as protuberant shore.

BEACH EROSION AND ACCRETION ALONG THE INDIAN COASTLINE

Most of the beaches along the Indian coasts are sandy intercepted by rocks or shingle at some places. Almost all the shores of India erode 1 to 2 mm per year, due to the rise of sea level (Per Bruun, 1972). Erosion experienced is seasonal in character, being severe during south west monsoon. During the fine weather season the beaches begin to build up. Natural and Manmade erosion is observed on the south west coast of India (Per Bruun and Nayak, 1980). The natural inlets act as littoral barriers at various places along the coast. The construction of 5 km long approach channel for the development of Cochin Port, the breakwaters at Neendakara and Mopla Bay, have contributed to the disturbance of equilibrium conditions of the coast on either side of them. The unimproved inlets in the region and the sand spits at Periyar river outlet have the tendency to migrate to the south. These indicate southerly movement of the drift. The curvature of the coastline of Kerala, tending to form a line in NNW and SSE direction is conducive to the southward drift as the dominant waves are from the west during the monsoons. The predominant wind direction during the south west monsoon being from the west and north west, for most part of Kerala coast aids southerly drift. Most shores of south west coast have low backshore levels of less than 1.5 m above MSL which enables severe tidal over-flow during storms and monsoons. A historical survey of bathymetry charts reveal the continuous shoreline regression of about 2 to 5.5 m/year. Fig.2 illustrates the most severely eroding factors along the south west coast of India.

The most severely eroding sectors here, are situated south of two major mud banks, which act as littoral barriers.(Alleppey mud bank and Narakkal mud bank in Kerala). The mud banks produce regions of calm water even during the rough monsoon seasons due to their property of dissipation of wave energy in the large quantity of colloidal suspension.

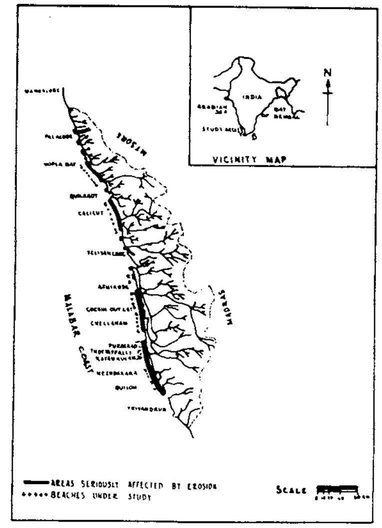

FIG.2 LOCALITY MAP SOUTH WEST COAST OF INDIA (AFTER MONI,1972)

Contrary to the rate of longshore transport on the south west coast which is 1.5 lakh tonnes/year, the rate of transport on the east coast is 1 million tonnes/year. While severe land erosion is prevalent on the west coast in general and south west in particular, the east coast is subjected to the perennial problem of accretion which manifests in silting up of navigational channels of harbors at Madras, Visakhapatnam and Paradeep. The cause of erosion on the south west coast and accretion on the south east coast of India may be due to the curvature of the Indian peninsula. The littoral drift on the east coast is towards north east or head of the Bay of Bengal. The surface currents flow north easterly for 7 to 12 months and their velocities are greater than when flowing in the southerly direction. Also the waves which approach from the south are higher during the northerly flowing current. This enables the suspension and agitation of sand that is easily transported by longshore currents. The presence of sand bars which lay partially across the small river mouths may be attributable to the littoral drift of sand in a northerly direction.

At Visakhapatnam and Mopla bay a promonotory or headland acts as the littoral barrier causing the updrift coast to accrete and the downdrift coast to erode. At Cannanore, Cape Comorin and Pudimadaka, rock or reef outcrops act as littoral barriers. At Malpe and Tuticorin tombolo formation is observed due to the existence of a rock island parallel to the shore. The wide Marina beach at Madras is a result of sand accretion due to the construction of the harbor. Fig.3 shows the shoreline advance, south of the harbor since its construction. The dredged entrance channels of Cochin, Madras and Visakhapatnam habors caused severe downdrift erosion. A study of the Naval Hydrographic Charts of 1893 and 1955 indicates that there had been considerable shore erosion in the northern side upto a distance of 7.5 m north of the Madras harbor (Fig.4). At Mamallapuram, near Madras the construction of an offshore breakwater in order to save the shore temple from wave action resulted in downdrift erosion which reached alarming proportions threatening to wash away a Tourist Complex located

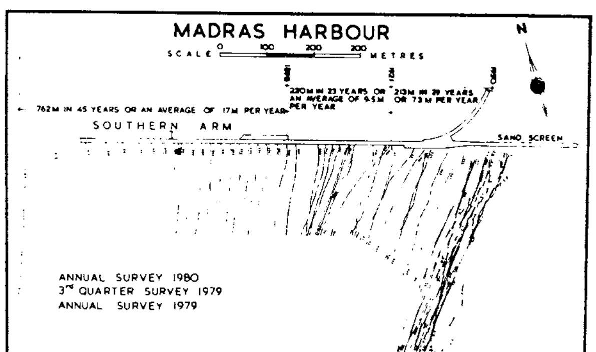

FIG.3 CHART SHOWING THE POSITION OF SHORELINE(I.S.L.W.) SOUTH OF HARBOUR SINCE THE YEAR 1876.

nearby. To the south at a distance of 3 kms from the Madras harbor lies the mouth of river Cooum which flows through the city of Madras before entering the sea. The construction of breakwaters of Madras harbor is now resulting in closing the river mouth for 8-10 months in a year, thus causing the water to stagnate.

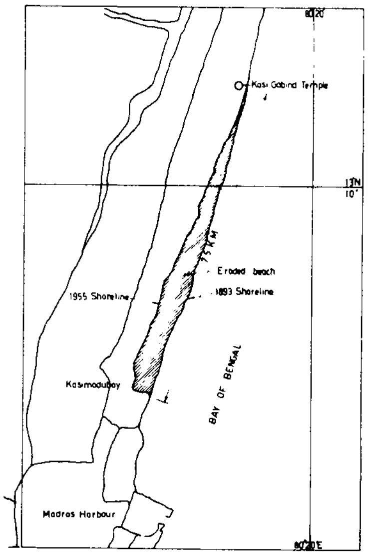

FIG.4 COASTLINE NORTH OF MADRAS HARBOUR

At Kakinada (Andhra Pradesh), the Godavari spit was caused by a northerly drift and deposition of sand due to flood discharges. The growth of Godavari spit resulted in erosion at Uppada (Fig.5). The natural inlets at Devgarh, Vijaya Durg (Maharashtra) cause downdrift erosion owing to their large tidal prisms which push the littoral drift material far out into the ocean or into the bay where it is deposited in shoals. The inlets with smaller tidal prisms cause less or no erosion downdrift as material drifts across the channel on an ocean bar as is evident at Baypore (Kerala), Honnavar, Coondapur (Karnataka), Krishnapatnam, Machilipatnam (Andhra Pradesh) Chilka Lake (Orissa). Malpe (Karnataka), Neendakara (Kerala) and Paradeep (Orissa) are examples of tidal inlets which were improved by the construction of jetties on both sides of the inlet. This led to accretion on the upcoast side and downdrift erosion.

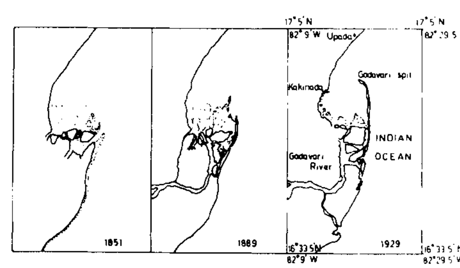

FIG.5 THE DEVELOPMENT OF THE GODAVARI SPIT ON THE EAST COAST OF INDIA

SUMMARY

Though the wave energy potential along the west coast during monsoons is greater than that of the east coast, the littoral transport is more along the east coast, because, most of the major rivers drain into Bay of Bengal discharging large quantities of sediments.

The shorelines of India are presently undergoing changes which are attributable to man and nature. The prediction of shoreline dynamics requires a more comprehensive base for field measurements and an improved understanding of the accretion and erosion process associated with waves and storms. Before remeial measures to counter severe erosion and accretion are taken, it would be beneficial to carry out extensive field measurements especially during premonsoon and postmonsoon periods in order to ascertain the exact causes of the problem.

Data pertaining to the shoreline changes of the Indian Coast are rather scanty. Hence, a critical assessment of the pattern and quantity of sediment transport could not be made. In this paper, the authors were more concerned in reviewing the problems pertaining to the shoreline changes, and not to attempt for solutions to derive conclusions.

The most important criteria for planning any coastal protective measure is to look at the problem on a broader scale and to be farsighted. Depending on the specific need, the protective measures should be considered. As most of the coasts are sandy coupled with high rates of littoral transport, it is suggested that groynes should not constitute remedial measures. Instead artificial beach nourishment schemes should be considered. Systematic study including model studies in some cases must be given to hydraulic, navigation, control structures, sedimentation and maintenance factors. Beach protection by a mechanical technique such as a sub-sand filtering system allows selective protection i.e. the system can be operated during periods of storm degradation and shut off during periods of normal accretion. This technique has a great advantage over classical beach protection methods, in that it does not permanently modify sand movement patterns along a beach (Machemehl et al.,1975). However, in planning any remedial measure it is attractive to consider the systems which would be operative within a reasonable cost, which may be entirely submerged and which are capable of operating without regard to surface sea keeping problems.

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WAVE FORCES ON PARALLEL PIPELINES

M.R. Pranesh
Indian Institute of Technology
Madras, India

G.S. Somanatha
K.R. Engineering College
Surathkal, India

ABSTRACT

Experimental investigations have been carried out on 16 cm diameter parallel pipelines in a newly built, well controlled two dimensional flume of width 2 m. The effect of spacing between the parallel pipes (W) and the proximity of the solid boundary are investigated. The maximum negative horizontal forces are analysed. The results show that the proximity of the boundary has effect on the inertia coefficient. The inertia coefficient increases as the relative clearance, (E/D), is decreased. The shielding effect due to the proximity of the neighbouring pipe is found to decrease the inertia coefficient of both the u/s and d/s pipes. It was observed from the wave force records that the maximum positive horizontal force is considerably less compared to the negative horizontal forces.

INTRODUCTION

The adaptability of submarine pipelines for transportation of oil and gas, in addition to several other purposes, and use of pipelines in more hostile environment has provided a major impetus to the study of wave forces on submarine pipelines. The accuracy of wave force estimation using the well known Morison equation (1950), depends on the accuracy of fluid kinematics for a given wave field and the accuracy of hydrodynamic coefficients used in the wave force equation.

Several methods have been used for the determination of C_D and C_M from both laboratory and field experiments. But, all these analyses show that there is considerable scatter in the values of C_D and C_M and hence cannot be expressed as functions of parameters such as Reynolds number, or the Keulegan-Carpenter number. The possible reasons for the discrepancies are (Dattatri, 1982):

1. The determination of C_D and C_M by linear addition of forces, using Morison's equation is questionable.
2. Lack of understanding of interdependence of the coefficients and the assumption that they are constant over a wave cycle.
3. The effect of flow reversal on the anatomy of the wake formed behind the pipe.
4. Neglecting the convective acceleration terms while evaluating the inertia force (Wiegal, 1964) and
5. Inability of the wave theories to describe the actual water particle kinematics.

Hogben (1976) observed that the values of C_D and C_M are interdependent due to the fact that the wake structure is affected due to flow reversal. Keulagan and Carpenter (1958) have shown that the values of C_D and C_M vary considerably during a wave cycle, while Evans (1969) observed that they vary with distance from the still water level.

Several investigators (Grace and Nicinski, 1976; Wright and Yamamoto, 1979; Johansson, 1968) have reported that the coefficients are sensitive to relative clearance and that the unsymmetric flow due to the solid boundary causes lift forces on the pipeline. Ippen (1966) has suggested that large lift forces on pipelines resting on seabed can be avoided or reduced by supporting the pipe at regular intervals along its length such that it remains a short distance away from the seabed boundary.

But, there is very little information reported regarding the interference (shielding) effects due to neighbouring pipeline. Wilson and Caldwell (1970) report that the shielding effects of the upstream cylinder are considerably larger. It was reported that the closeness of the pipes has decreased the C_D of the downstream pipe but increased the C_L of the u/s pipe.

Dalton and Helfinstine (1971) assuming potential flow theory, have reported that for parallel cylinders the inertia coefficient reduces for the d/s cylinder as the relative spacing (W/D) is reduced. But the effect of the solid boundary near the cylinders have not been considered.

This paper presents the laboratory results of maximum horizontal forces on parallel pipelines near a solid boundary due to regular waves. The maximum horizontal wave force on 16 cm diameter pipelines are analysed to find the inertia coefficient. The variation of inertia coefficients due to shielding effects are presented with respect to the relative spacing between the cylinders.

Fig.1 shows the definition sketch of the idealised two dimensional wave problem on parallel pipelines near the solid boundary.

ANALYSIS

The Morison equation was used to analyse the forces on the pipelines near the solid boundary, from which horizontal force is given as:

$$F_H = C_M \rho \frac{\pi D^2}{4} \frac{\partial u}{\partial t} + \frac{1}{2} C_D \rho D u|u| \quad \ldots \qquad \text{Eq.(1)}$$

in which F_H is the horizontal force per unit length of the pipe, u is the horizontal water particle velocity, $\partial u/\partial t$ is the horizontal particle acceleration, D is the diameter of the pipe, C_M is the inertia coefficient, C_D is the drag coefficient and ρ is the mass density of the fluid.

For the experimental results reported herein, the convective component of horizontal accelerations were very small when compared to the local accelerations calculated using linear wave theory and hence were ignored. Further, as the horizontal component of velocities at the centreline of the pipe were very small for the tests conducted (d = 80 - 100 cm) it was observed that the drag force was very small compared to the inertial forces. Linear wave theory was used in the analysis because of its simplicity and also it predicts correct fluid kinematics near the ocean bottom. Maximum negative horizontal forces are analysed and reported herein for a single pipe and parallel pipelines at different spacings between them.

EXPERIMENTATION

The experimental study was conducted in a two dimensional wave flume facility newly developed at the Ocean Engineering Centre, I.I.T., Madras. The wave flume has R.C.C. side walls finished with plaster and measures 30 m long, 2.0 m wide and 3.9 m deep. 2 m x 1 m R.C.C. slabs are used to provide a false flooring at a height of 2.3 m from the flume bed with provision for developing currents. The investigations were restricted to 80-100 cm depth since at 70 cm depth of water above the false floor, secondary waves of other harmonics were developed. The minimum and maximum depths at which regular sinusoidal waves generated in this flume are 80 cm and 110 cm respectively. The range of wave periods is 1.0 to 1.9 seconds. The waves are filtered through a wire mesh filter near the generator and are absorbed by a rubble stone beach at the end of the flume. The water level fluctuations over each pipe were recorded by capacitance type sensing elements fabricated and calibrated at the Centre. The force variations were sensed by strain gauge bridges each consisting of four strain-gauges pasted on cantilever beams. All the strain gauges were balanced through an amplifier bridge and connected to a six channel strip chart recorder.

EXPERIMENTAL RESULTS

The experiments were conducted for different relative spacings and relative gaps in the following ranges:

(1) H = 4.0 cm to 14.7 cm
(2) T = 1.2 to 1.8 secs
(3) L = 2.22 to 4.35 m
(4) W/D = 2.0, 4.0, 6.0 and 10.0
(5) E/D = 0.1, 0.2
(6) $R_e = 4.74 \times 10^3 - 28.51 \times 10^3$
(7) K = 0.17 to 1.55.

Here, W/D is the relative spacing, E/D is the relative gap, R_e is the Reynold's number, H is the wave height, T is the wave period, K is Keulegan-Carpenter number.

Fig.2 shows a sample record of water level fluctuations and the corresponding forces (horizontal and vertical) on parallel pipelines. Fig.3 is a graphical representation of the horizontal force peaks (-ve) located near the nodes and behind the wave crest against the maximum horizontal local accelerations for single, u/s and d/s parallel pipes (for E/D = 0.1, W/D = 2.0, T = 1.2 to 1.8 secs). Fig.4 shows the effect of relative spacing on the inertia coefficients.

DISCUSSIONS

The simultaneous records of wave heights and forces showed that for a single pipe line the +ve horizontal inertia forces were about 5-12% less than the -ve maximum inertia forces while for u/s pipe of parallel pipes they differ considerably depending on the closeness of the pipes (W/D ratio). Hence, only maximum -ve horizontal inertia forces are reported in this analysis. Another phenomena observed is, that in all runs on parallel pipes, the wave probe on the d/s pipe recorded a slightly greater wave heights than that compared to the wave height on the u/s pipe, the difference between H_2 and H_1 being larger for low frequency waves. This may be due to wave build-up (runup) because of the u/s pipe.

The values of inertial coefficient computed for each case are presented in Table 1. The results of single pipe are compared with those of other investigators and given in the same table.

Table 1 : Summary of force coefficients (C_M) for $\frac{d}{D}$ = 5.65

W/D	E/D = 0.1		E/D = 0.2		Range of	
	u/s pipe	d/s pipe	u/s pipe	d/s pipe	Reynolds number x 10^3	Keulegan-Carpenter Number
2.0	2.310	2.156	2.156	2.014	6.32-28.5	0.23-1.55
4.0	2.350	2.25	2.194	2.100	4.74-22.8	0.17-1.24
6.0	2.380	2.314	2.220	2.160	6.32-26.6	0.23-1.45
10.0	2.400	2.394	2.248	2.245	5.66-26.4	0.21-1.44
Single pipe	2.414		2.28		-	-

C_M = 2.5 for E/D - 0.104 d/D = 5.32 (Wright & Yamamoto, 1979)

C_M = 2.3 to 2.5 for E/D = 0.1 (Grace and Nicinski, 1976)

C_M = 2.3 to 2.45 at E/D = 0.15 (Grace and Nicinski, 1976).

The results indicate that the shielding effects are found to be effective in reducing the inertial coefficients of both u/s and d/s pipes, but is more predominant on the d/s pipe. In most of the cases reported, A/D ratios (ratio of maximum horizontal particle displacement to pipe diameter) is less than 0.2, the wake effects are insignificant. Though, the magnitudes of lift forces were negligible compared to horizontal inertia forces, it could be observed from records that there is a significant increase in lift forces. However the same are not presented in this report.

CONCLUSIONS

The inertia coefficient varied according to the proximity of the boundary and the relative water depth. Values of C_M increased as the relative gap between the pipe and the boundary decreased.

The inertia coefficient of the parallel pipes decreased due to shielding effects. The d/s pipe coefficients were comparitively lesser than those of u/s pipe. Further it is observed that the -ve maximum horizontal forces are much larger (about $1\frac{1}{4}$-$1\frac{1}{2}$ times) than the +ve maximum horizontal forces depending on the relative spacing. The records indicated that the wave heights on the d/s pipe were larger than that of the u/s pipe due to wave buildup caused by the presence of the u/s pipe.

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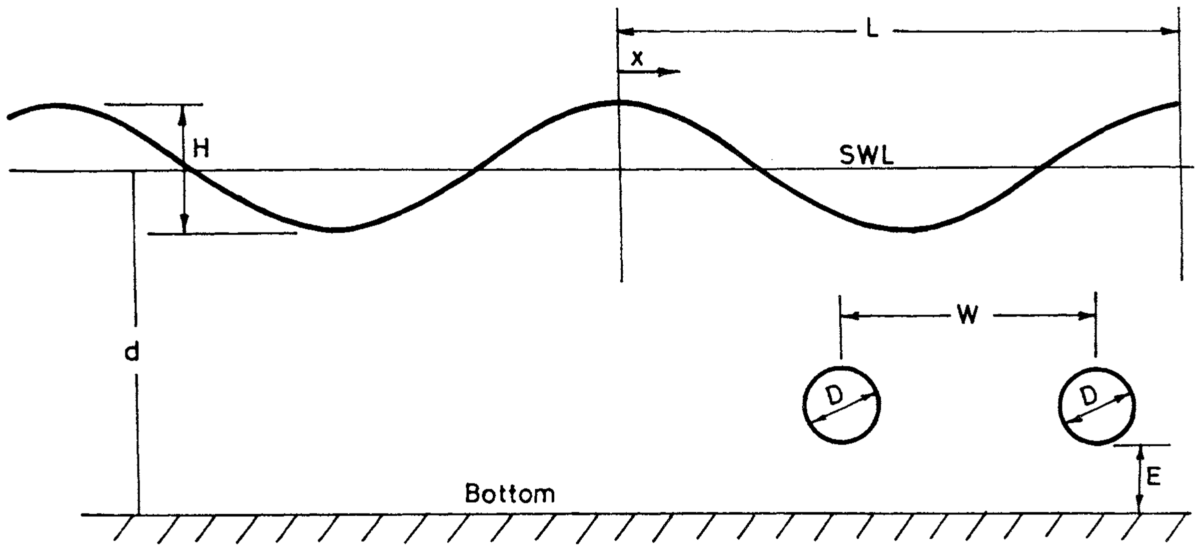

FIG·1 DEFINITION SKETCH

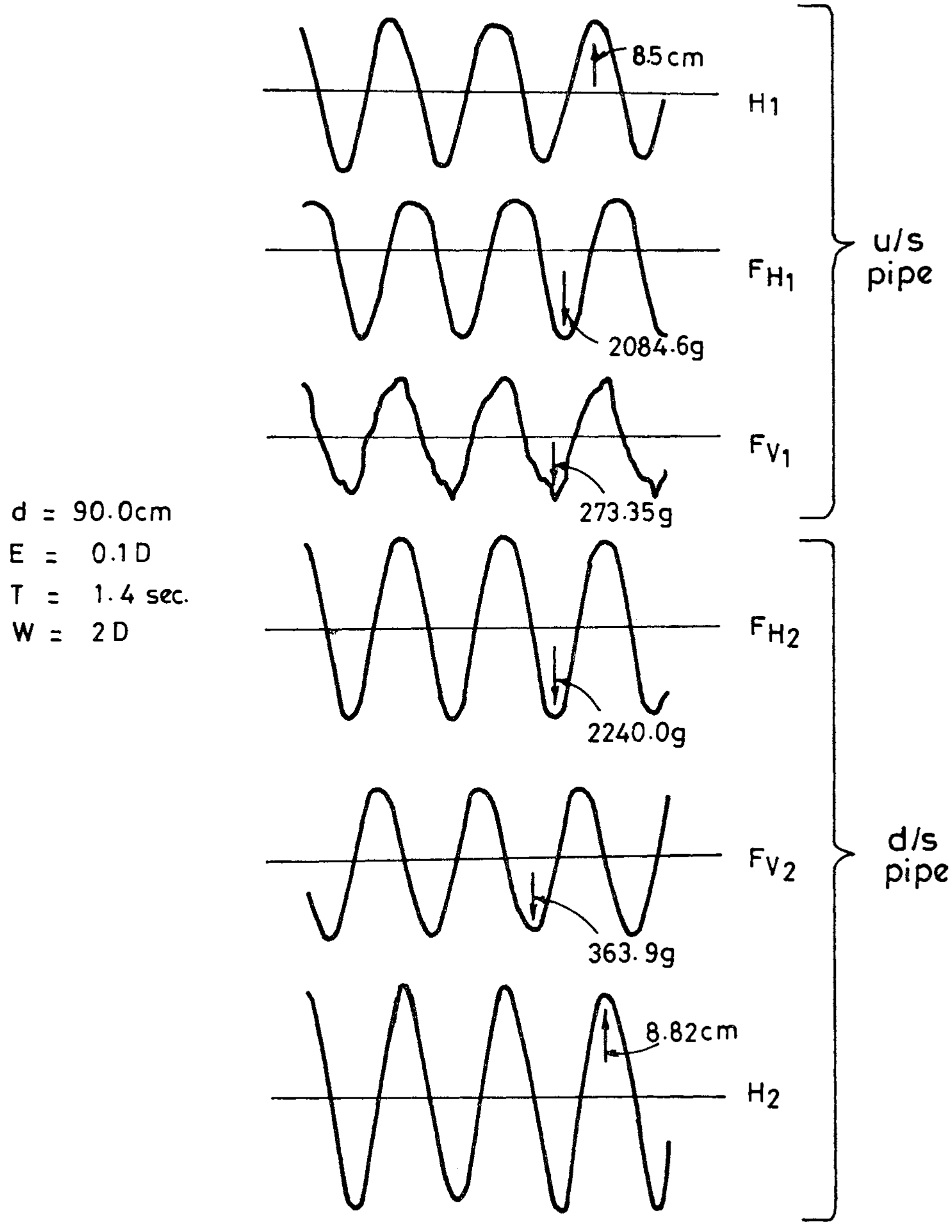

FIG. 2 SAMPLE RECORD

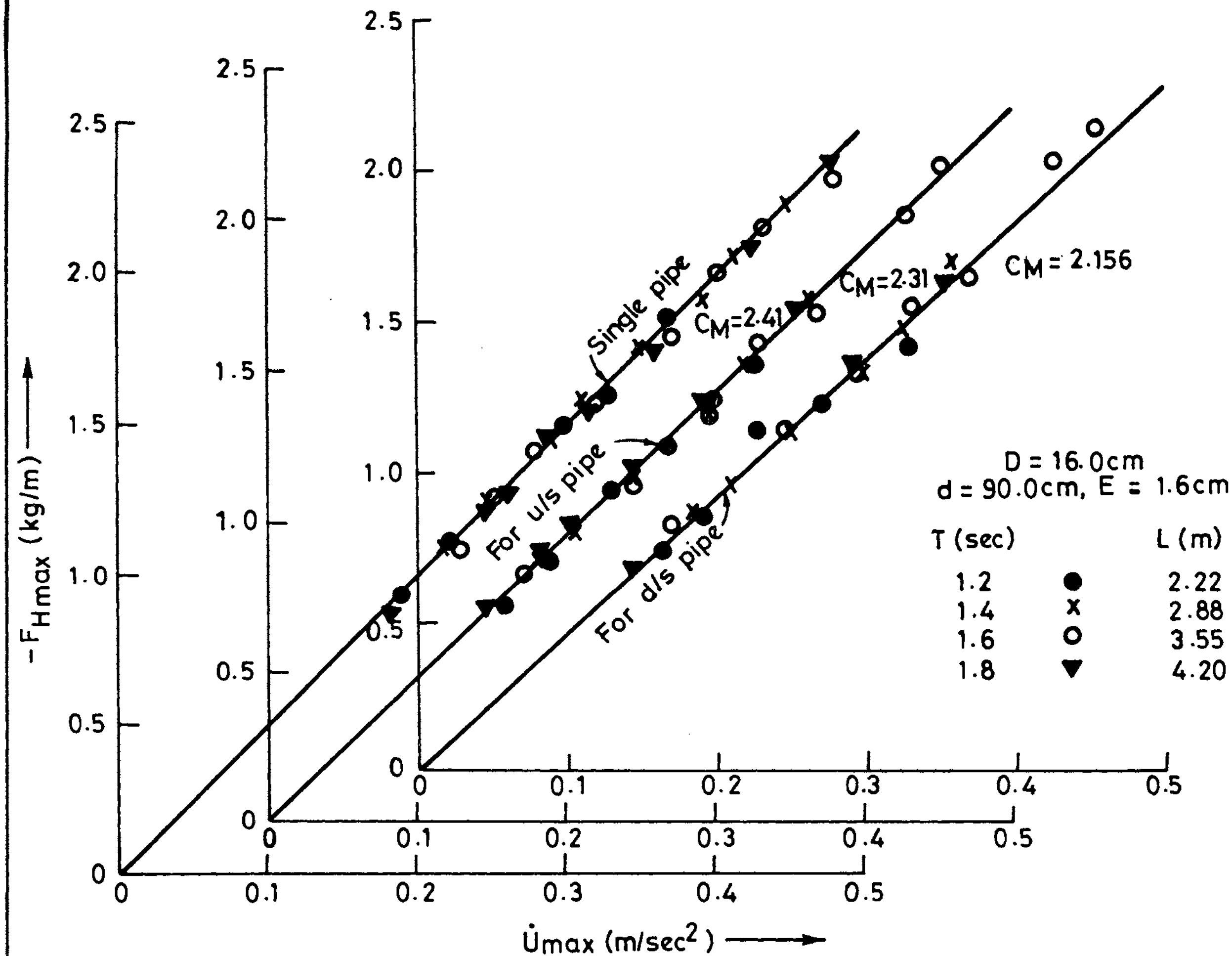

FIG. 3 NEGATIVE HOR. FORCE V/S MAX. HORIZONTAL ACCELERATION

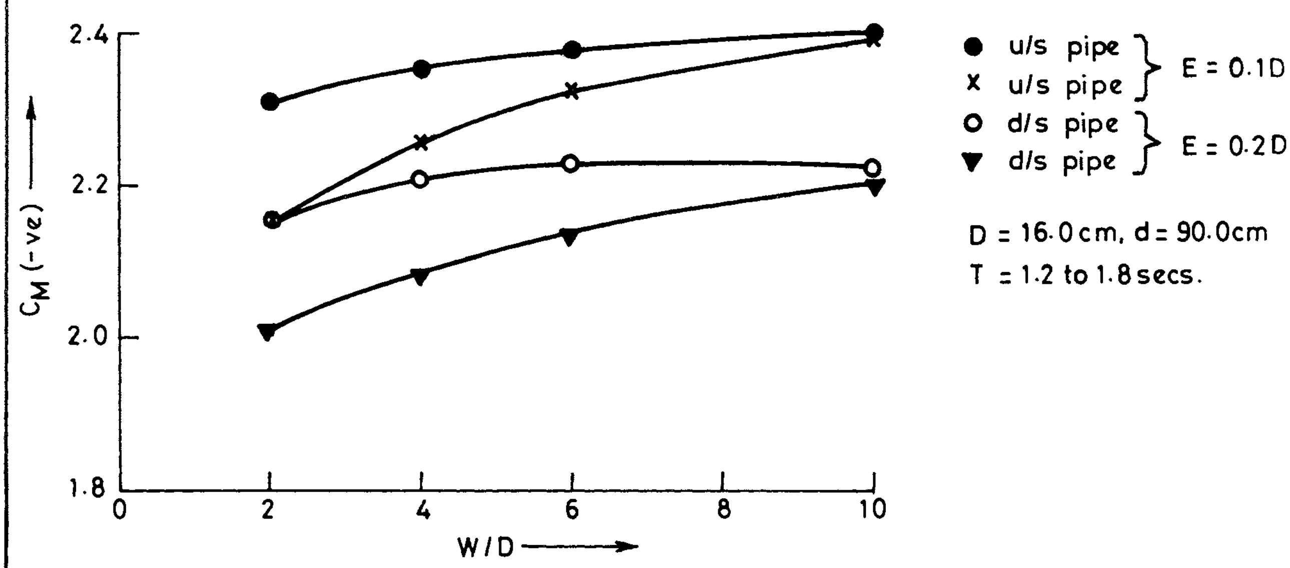

FIG. 4 EFFECT OF W/D ON INERTIAL COEFFICIENT

STORM CONDITIONS AT THE MONTEREY BAY REGIONAL SEWER OUTFALL DURING THE FALL/WINTER CLIMATOLOGICAL SEASON OF 1982-1983

Sheldon M. Lazanoff
Science Applications, Inc.
Monterey, California, U.S.A.

C. Gene Courtney
Morrison-Knudsen
Boise, Idaho, U.S.A.

A Monterey Bay regional sewer outfall is being constructed north of the city of Marina, California as shown in Figure 1. The project began in 1982. The offshore sewer outfall line was designed, at the recommendation of the California Caostal Commission, to extend 2000 feet in a westerly direction from the coast, make a 45° jog to the right (northwesterly) for 6500 feet and then bend back to the westerly direction for 1400 feet. The outfall line, starting 2000 feet from the onshore junction box to Station 34+7, Figure 2, was installed first. A trestle extended approximately 1500 feet from the coast. The submerged outfall line which was oriented in a southeasterly to northwesterly direction was completed on 19 November 1982. All of the submerged pipeline was placed on top of bedrock and then covered by ballast and armor rock. The rock extended approximately 4 1/2 feet about the reinforced concrete pipe.

A storm occurred on 30 November and 1 December 1982 and the combination of high tides, wind waves, and swell damaged 375 feet of the trestle section but did not damage the outfall line or covering rock.

Another storm began on 16 December 1982 and continued through 18 December. Long period swell with measured heights greater than 40 feet along the west and high tides greater than 6 feet demolished over 750 feet of the trestle.

Severe storms continued throughout the 1982-83 winter season. Visual inspection of the pipeline which began on 25 July 1983 determined that the ballast and armor rock had been displaced in the 6500 foot section. The portions of the pipe which extends in a westerly direction did not suffer the rock damage of the dog-leg section.

Coastal waves in Monterey Bay are a result of waves propagating from North Pacific deep-ocean storms, locally-generated wind storms and coastal bathymetry. The propagation of deep- water waves into Monterey Bay is strongly influenced by an underwater canyon.

SAI reviewed hindcasts and analyses from the FNOC deep-water Spectral Ocean Water Model (SOWM) for the time period of September 1964 to April 1983. The SOWM is the present official U.S. Navy wave forecast model and was used to generate a Northern Hemisphere wave spectral climatology

(Lazanoff, and Stevenson, 1977). The SOWM climatology, analyses, and forecasts are used by private industry as well as government users. The model is well documented (Lazanoff and Stevenson, 1975). The hindcasts and analyses are saved on a 6-hourly basis by the U.S. Navy's Fleet Numerical Oceanography Center.

The fifty highest wave heights by storm events for the closest SOWM grid point (36.08°N, 123.81°W) to the Monterey Bay is shown in Table 1. Table 1 contains the year, month, day, and hour (Greenwich Mean Time, GMT) of the event; wind speed in knots; the wind direction; SWH ($H_{1/3}$); the average height of the highest one-tenth waves ($H_{1/10}$); the maximum wave height for the time period (H_{max}); the wave period which contains the most energy (modal period); and the direction from which the predominant wave energy is propagating (modal direction). If more than one wave period is presented, then the waves have more than one peak. The first period listed is the more dominant period. If more than two modal directions are listed and separated by commas, then there is more than one wave train at the grid point. If the wave directions are separated by a hyphen, then the wave energy is distributed over several directions. The storms are listed in descending order by the largest analyzed wave height within the storm.

Thornton (1978), using several sources, compiled a list of severe storms from 1910 to 1964. The wave heights of the first 12 storms in Table 1 were larger than all but two of the storms compiled by Thornton. The three 1982/83 storms would have ranked in the top five storms of Thornton's table.

The largest significant wave height (SWH) of 36 feet for the nineteen-year period occurred at 2100 GMT 26 January 1983. Thornton (1978) estimated the return for a 37-foot wave height to be 68 years. The storm began on 24 January and continued through 27 January even though the wave height on part of the 24th and 25th of January dropped below 29.8 feet. The principal differences between the 9 February 1960 storm cited by Thornton and the January 1983 storms are the directions and periods of the waves. The February 1960 wave direction was 280° while the January 1983 storm had a directional spread of 185° to 215°. The modal period of the 1960 storm was 15 seconds and the modal period of the 1983 storm ranged from 15 to 20 seconds. Shallow-water waves are directly influenced by deep-water wave periods and directions.

The January 1983 storm ranks as one of the top two storms in the past 73 years. The 16-18 December 1982 storm which had documented 40-foot waves at the sewer outfall did not even make the worst storm list. The measured waves at two deep-water NDBC buoys (34.9°N, 120.9°W and 37.4°N, 122.7°W) did not exceed 20 feet for the entire storm period. The modal wave periods were 16.7 seconds.

The reason for the severe 1982/83 climatological year off the California coast is quite evident after reviewing past climatological charts from the <u>U.S. Navy Climatic Atlas of the World, Volume II</u> (1977) and 1982/83 storm tracks for November, December, and January. The normal winter storms that affect California develop in the Gulf of Alaska and move in a sinusoidal easterly direction, depending on the location of the upper atmosphere jet stream which controls storm tracks. Because the jet stream shifted position, the 1982/83 low pressure systems developed south of the Gulf of Alaska and moved in an easterly or northeasterly direction. Thus, California felt the full impact of the winter storms.

Many other large storms occurred during the 1982/83 fall/winter season. Large waves occurred during January through mid-April 1983. As mentioned earlier, many oceanographers and meteorologists believe that the abnormal weather is related to the arrival of El Nino current off the South American coast. El Nino events occur periodically. The duration of the El Nino can last from one to several years. Since the 1982 El Nino was rather severe, it would appear that its influence will last for several years. As of 13 November 1983, two major storms had occurred during the 1983/84 fall/winter season. The abnormal weather may remain normal for at least one more season.

Waves with periods near twenty seconds from the west-southwest focus in the area of the sewer outfall and waves may be at or near the breaking point. Review of meteorological records led to the selection of waves most likely to have damaged the outfall covering rock. These waves with heights of 40 feet and periods of 20 seconds have been used to calculate conditions on the bottom in 58 feet of water at station 34+7 and in 92 feet of water at station 98+92.

Maximum wave caused velocities were calculated using Stokes' progressive, second-order wave theory (U.S. Army Coastal Engineering Research Center 1975, Section 2.252). Wave celerity (the speed of the individual wave crest) was 41.9 ft/sec in 58 feet of water and 51.9 ft/sec in 92 feet of water. Maximum wave particle velocity at the bottom in 58 feet of water was 31.4 ft/sec and in 92 feet of water it was 15.5 ft/sec.

The most significant forces on the stone were lift and drag and these vary with the direction of the pipeline relative to the waves. The rock which had little opportunity to settle and interlock after its recent installation was generally exposed to drag forces nearly perpendicular to the pipeline axis. A lesser exposure to drag forces occurred when particle flows were more parallel to the pipeline axis. Drag forces (F_D) are determined with the following relation:

$$F_D = C_D \ 1/2 \quad A \ U^2_{max}$$

where C_D = drag coefficient (0.7)
Θ = Fluid density (2 slugs/ft^3)
A = Cross-sectional area of rock exposed to flow
U_{max} = Maximum particle velocity at the bottom due to wave passage

The value of C_D was selected in accordance with Reynolds Number criteria given by Allen (1969) and U.S. Army (1975). Dividing the F_D equation by area gives a pressure due to the drag force. Drag pressure in the 58 ft water was 690 PSF (pounds per square foot) and in the 92 ft water it was 168 PSF.

Lift forces can be calculated by a similar equation with the replacement of C_D with C_L, the coefficient of lift. Brown (1967) conducted full-scale tests by inserting piezometers in a pipe on the bottom subjected to a unidirectional current. Suction forces were experienced over the top two quadrants plus the leeward lower quadrant. The coefficient of lift was found to be greater than that of drag. However, with the designed rock cover, flow above the pipeline should be accelerated less as it flows over the mound than it would flowing over a naked pipeline (Silvester, 1974). Thus, a combination of lift and drag forces, which are in phase, have the combined capability to roll the rock away from the pipeline.

Additionally, the angle that the pipeline makes with the waves has a second role to play. The distance that that rolling rock will move away from the pipeline is proportional to the sine of the angle between the wave propagation direction and the pipeline axis. If we use a sine function as representative of the variation of rock exposure to lift and drag pressures between the wave to pipe angles of 15° and 65°, the following results are obtained.

1. Damaged pipeline at station 34+7 F/A of (690 PSF) $(\sin^2 65°)$ = 567 PSF
2. Damaged pipeline at station 98+92 F/A of (168 PSF) $(\sin^2 65°)$ = 138 PSF
3. Undamaged pipeline seaward of station 98+92 F/A of (168 PSF)$(\sin^2 37°)$ = 61 PSF
4. Undamaged pipeline landward of station 34+7 F/A of (690 PSF)$(\sin^2 15°)$ = 46 PSF

Thus it is probable that the portions of the pipeline cover damaged were subjected to higher lift and drag forces from the long period (20 sec) waves and that the cover rock was moved away from the pipeline before setting into stable locations due to the relative orientation between the waves and the pipeline.

Liquefaction is another likely factor in the disappearance of pipeline cover rock under conditions of strong wave action. It has been reported in a number of pipeline cases (Strating, 1981; Lambe and Whitman, 1969; and Miller, 1965).

Liquefaction is likely in well-sorted sands which have uniform size or in sensitive clays. Liquefaction is a loss of shear strength and here, where wave forces can disturb the bottom, it could result in the pipeline covering rock sinking into the sand which could no longer support it. The grain size analysis done by PSC Associates, Inc. for samples along the outfall show well-sorted fine sand or silts along the damaged portion of the pipeline. Whether or not liquefaction will occur in a sand is related to whether the sand tends to expand or to decrease in volume during shear. If the volume decreases during shearing, most of the load will be borne by pore water pressure. Loss of intergranular contact means that the sand can no longer support the rock.

If liquefaction is the cause, the first coating of rock should be beneath the sand supporting the pipeline rather than transported away by rolling under storm waves.

The 1982/83 fall/winter produced the worst storms for at least the last 73 years. Individual storms produced extremely high wind wave heights within Monterey Bay as well as swell propagating from the deep water. Because so many storms occurred from the same direction, wave energy persistence probably played an important role in baring the sewer pipeline. Unusually high tides helped bring deep-water waves closer to the shore line. There is no question that long-period swell, particularly from the southwest quadrant, could move the rock away from the pipeline. Liquefaction could also cause the disappearance of cover rock under strong wave action.

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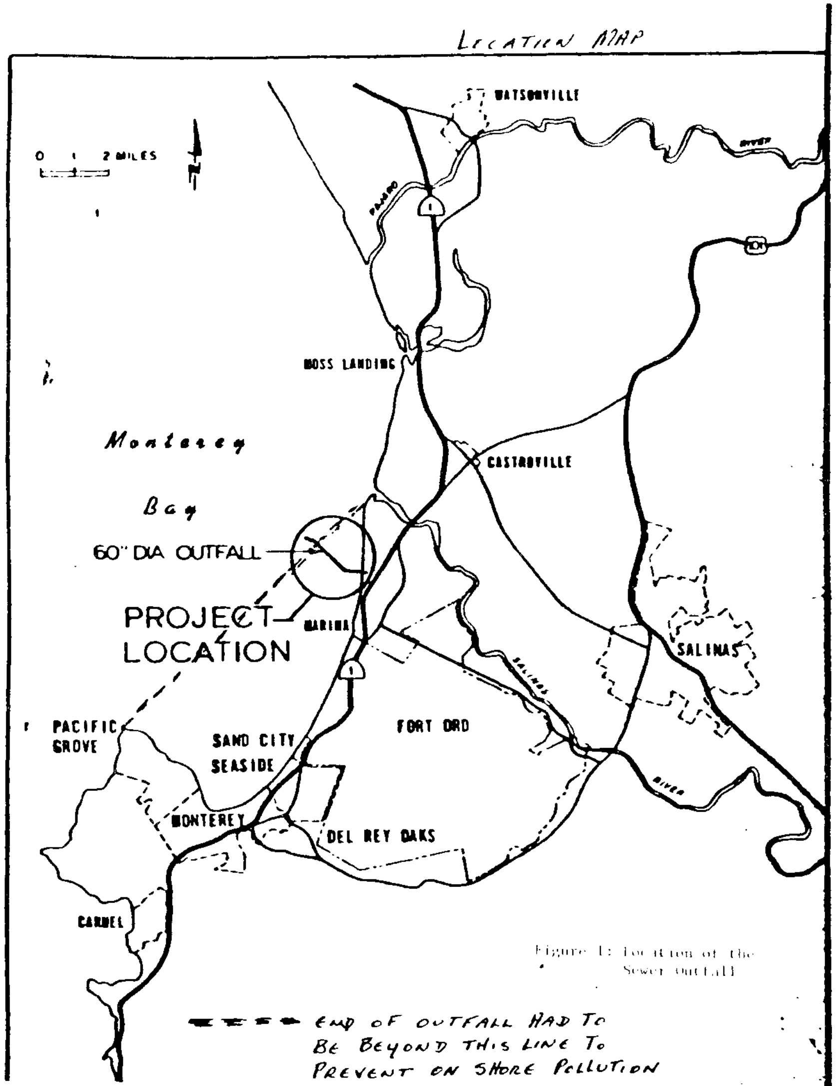

Figure 1: Location of the Sewer Outfall

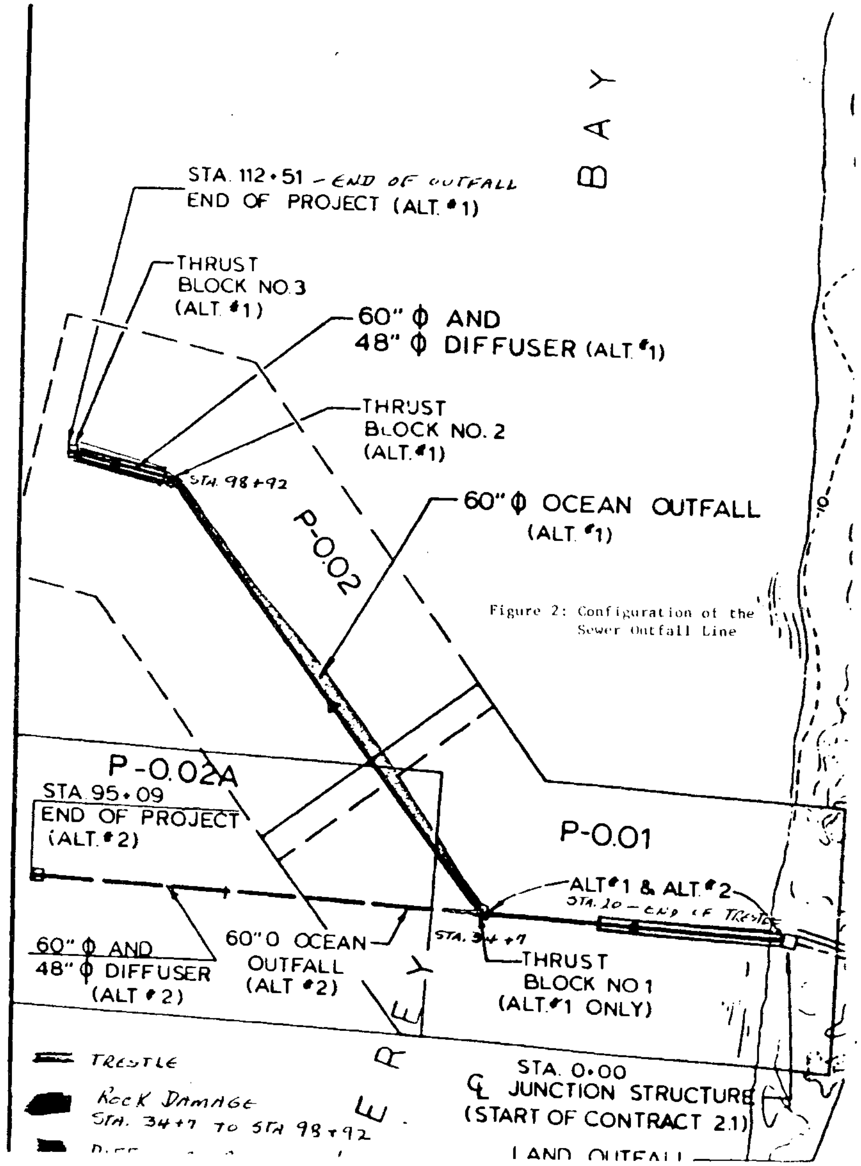

Figure 2: Configuration of the Sewer Outfall Line

DTG yr.mo. da.hr.	Wind Speed (knots)	Wind Dir	$H_{1/3}$ (feet)	$H_{1/10}$ (feet)	H_{max} (feet)	Wave Modal Period (sec)	Wave Modal Dir (from)
83012403	42	186	27.7	35.2	51.5	14.9	185-215
83012609	35	192	28.4	36.1	52.9	20,12	275
83012615	42	192	33.9	43.2	63.1	17.8,14.9	185,275
83012621	49	194	36.0	45.9	67.0	16.3	215(155-275)
83012703	42	205	32.6	41.4	60.6	16.3	270,215
83012708	30	216	30.1	38.3	56.0	16.3	275,215
83012715	18	232	27.3	34.8	50.9	14.9,17.9	275
81111403	missing	missing	32.4	41.2	60.3	14.9	245(185-275)
81111409	missing	missing	29.5	37.5	54.9	13.9	245,155
81111415	missing	missing	26.1	33.3	48.6	14.9	275
82113015	30	259	27.3	34.7	50.7	16.3,13.9	275
82113021	41	290	32.3	41.1	60.1	16.3	305
82120103	39	298	29.4	37.5	54.7	16.7	305
82120109	33	302	25.5	32.4	47.4	12.4	305
73022409	42	162	25.3	32.2	47.1	13.9	165-195
82041115	40	208	25.1	32.0	46.7	14.9,12.4	215
73011615	40	196	24.4	31.0	45.3	13.9	195
67012409	40	195	23.8	30.5	44.5	12.4	195
65122815	41	174	23.8	30.3	44.3	13.9	165-195
73120103	44	187	23.5	29.9	43.7	13.9	195

Table 1 Extreme Waves 1964 to 1983

DYNAMIC RESPONSE OF SUBMARINE POWER CABLES DURING LAYING OPERATIONS

Frank A. McHale
Hawaiian Dredging &
Construction Co.
Honolulu, Hawaii, USA

Joe C. Van Ryzin
Makai Ocean Engineering
Kailua, Oahu, Hawaii, USA

Luis A. Vega
EG&G Ocean Systems
Berkeley, Calif., USA

Introduction

The Hawaii Deep Water Cable (HDWC) Program was established to determine the technical feasibility of an electrical transmission cable system in underwater depths ranging from shallow waters to 7000 feet and over a distance of more than 150 miles between Oahu and the Big Island of Hawaii. The Alenuihaha Channel, between the islands of Maui and Hawaii, is considered to represent the most adverse conditions and constraints to the establishment of such a system.

The conditions in the Alenuihaha Channel are well beyond the present state of knowledge and practice in the design and laying of submarine cables. The maximum depth of installation is four times as great as that of any existing system and the most probable wave conditions correspond to significant heights three times as great as those considered operational by present experience.

This article summarizes an analytical study performed for the HDWC program on the subject of dynamic response of submarine power cables during laying operations from a surface vessel in the Alenuihaha Channel (Ref. 1). The principal aim was to determine cable loads and motions as a function of environmental, vessel, and cable parameters by simulating the response of the overall system. The state of practice and knowledge in the simulation and analysis of submarine power cable laying operations was established. There was hardly any information regarding the dynamic response of submarine cables during laying operations. Moreover, rules-of-thumb expressing dynamic loading as a percentage of static/equilibrium loading were not properly documented and appeared to be based solely upon casual observations during actual operations.

The computer-aided analysis methodology selected to simulate the overall system and utilized in the parametric analysis performed to characterize system response is described in detail in Reference 1.

Analysis Parameters

A range of environmental and structural parameters was selected as input to the sensitivity analysis. The wave environment was modeled with a two-parameter spectrum based on significant wave height and mean wave period. The wind and current fields were modeled considering their influence on surface vessel loading as well as current loading on the cable. Laying vessels were represented by their displacement RAOs as a function of heading and speed and their windage and current drag areas. The cable/vessel attachment point was modeled as a fixed point. The multi-layered cables were represented by homogenous cables of equivalent axial stiffness with hydrodynamic loading corresponding to the actual cable geometry.

The analysis parameters are reproduced in Table 1. The median or baseline for each parameter and the range to be considered are given. Only one parameter at a time was varied about the baseline. Firstly, only the maximum and minimum values were considered. Secondly, if resulting cable motions and loads variations were relatively significant, intermediate values were considered. Engineering judgment was observed at all times to avoid combinations of parameters that were unrealistic.

TABLE 1 Sensitivity Analysis Parameters

Environment (Ref. 2)	
• Wind: - Speed	< 35 knots
- Direction	60° ± 30°
• Wave Spectrum:	Seas:
- Sig. Ht. H_S	8 ft.
- Mean Period $\bar{T}$	5.53 sec.
- Direction (see vessel heading)	69° ± 22°
• Current Distribution:	
- Speed	2.9 kts @ surface; 2.2 kts @ 700'; 1.2 kts @ > 1300'; 1.2 kt tidal component
- Direction	50° ± 15°
• Waterdepth	3000' to 7000'
Laying Vessel	
• Two Generic Barges	400' x 76' x 20' and 250' x 76' x 20'
• Heading	340° and 160°
• Speed	0 and 2 knots
Cable Handling System	
• Payout	0 and 1.7 fps
• Attachment Point (Cable/Barge interface modeled as a fixed point.)	C.g. and stern of vessel
Cable	
• Outer Diameter	5.25" ± 1.78"
• Axial Stiffness (EA)	54 ± 25 x 10^6 lbs
• Unit Dry Weight	31.2 ± 17.2 lbs/ft
• Tensile Strength	220 ± 20 ksi
• Normal and Tangential Drag Reynolds Number dependent.	

Cable properties considered apply to contrahelically armored power cables in the 200 KV to 300 KV range utilizing steel as armor material. No assumptions were made as to design and layout of cable components relating to its electrical function. Therefore, at this point it is implied that the load will be carried by its armor and that the cable behaves like a linearly elastic material (i.e., an axial member with constant modulus of elasticity).

Under the modeling considered herein, for example, a representative axial stiffness (EA) is 54 x 10^6 lbs corresponding to an elastic modulus (E) of 27 x 10^6

psi and cross-sectional area (armor area) of 2 in^2, while the hydrodynamic diameter is about 5 in, corresponding to a cross-sectional area ten times larger.

Cable Model and Simulation Methodology

The complete global motions and stresses of a submarine power cable during laying operations are represented by a set of differential equations. The multilayer cable is modeled as a homogeneous cable of equivalent axial stiffness (EA) and bonding stiffness (EI) with hydrodynamic loading corresponding to the actual cable geometry. Loads acting in the cable axial and two orthogonal directions in the horizontal plane are modeled by a set of three differential equations including the effects of axial extensibility, bending and torsion. Boundary conditions at the top and the bottom of the cable are also modeled as appropriate.

The equation modeling effects on the axial direction basically equates the tension and weight components with the external hydrodynamic loading including the effects of virtual or added mass. The two equations for the horizontal plane include additional components representing the cable bending and rotary inertial effects. By comparing the order of magnitude of the different terms in the equations, it was found appropriate to model HDWC generic cables as a traditional cable or line (an axial element) loaded at the cable/vessel connection by the wave and current induced vessel motions and by the wave and current induced velocity field throughout the water column. For example, the relative importance between tension and bending effects can be determined by the ratio of TL^2 to EI where T is the tension, L the cable length, and EI the flexural rigidity or bending stiffness. This ratio indicates that tnesion effects are at least seven orders of magnitude larger than bending effects for the cables and scenarios considered in this study. Therefore, only effects in the axial direction were analyzed.

In this fashion, the total tension and motions experienced by the cable or axial element during simulated laying operations are generated by three sets of forcing functions. Firstly, the effects of time-invariant loading due to winds and currents acting on the surface vessel and current loading on the cable throughout the water column are modeled as drag forces. Secondly, the time dependent wave induced motions and loads in the cable/vessel system were modeled in the frequency domain utilizing a spectral representative for the sea surface variance, $S(\omega)$, and determining the system Response Amplitude Operators, $RAO(\omega)$, or transfer functions and henceforth the standard deviation of system response,

$$R_\sigma^2 = \int S(\omega) \left| RAO(\omega) \right|^2 .$$

The most probable extreme value in 1000 cycles was selected to determine maximum response in terms of the standard deviation obtained from the frequency domain analysis and assuming a Rayleigh Distribution for cable motions and loads. A time domain analysis taking into consideration the nonlinear nature of the loading was also performed to assess the frequency domain analysis and the estimates for maximum tensions.

Thirdly, the potential for cable strumming was evaluated. For the cables and laying scenarios considered, the range of Reynolds Number is from 0.3×10^5 to 1.3×10^5; therefore, the Strouhal Number (S) can be taken as 0.2 such that matching the shedding frequency ($F_S = (SU)/D$) with natural frequencies of cables is only probable at flow velocities of between 0.25 to 0.5 knots corresponding to shedding frequencies between 1 and 2.5 rad/sec and cable transverse fluctuations in the 3rd to 8th modes. Because cable laying considered herein is performed at speeds of at least

1 to 2 knots, the loading due to cable strumming was not considered further in the study. Moreover, even under lock-on conditions (matching of frequencies), the maximum expected peak-to-peak displacement would be two (2) diameters corresponding to a cable loading of no more than 20% maximum dynamic loading.

Equilibrium Analysis

The computer-aided equilibrium analysis was performed using a three-dimensional cable model. The aim was to assess the influence of the quasistatic or time invariant environment, represented by currents and winds, upon the cable top-tension, cable configuration and excursion of the ship from a prescribed laying route.

The following summarizes knowledge acquired from this analysis:

- The equilibrium or quasistatic tension at the top of the cable may be obtained within 2% with the formula:

$$T_{equilibrium} = T_{bottom} + wh$$

where T_{bottom} is the tension at cable seafloor interface and

h is the water depth and

w the wet weight per foot of cable.

This deceptively simple result remains valid for all directions of current. $T_{equilibrium}$ is not significantly affected by current intensity or cable characteristics (other than the cable unit weight in water). In other words, the relatively high weights of generic HDWC cables dominate other forms of static loading. As a point of reference, consider that for this structure the wet weight per unit length is about one order of magnitude larger than the compounded drag force per unit length.

- The current (relative to cable) affects the excursion of the ship with respect to laying route as well as the angle of attack of the cable.

- Bottom tension, aside from its contribution to the tension all along the cable in the form of an additive constant, determines the distance between barge and touchdown point in the laying direction.

To determine the maximum bottom tension, the cable/vessel system was allowed free to drift with surface-current and wind loads on the barge. This situation generates the highest equilibirum tensions with the cable acting as an anchor and mooring line system. The resulting bottom tension for the cases reported herein was in the range of 30,000 to 40,000 lbs.

Dynamic Analysis, Frequency Domain

The dynamic analysis was performed utilizing a computer model that considers a fully coupled solution. That is, the barge and cable motion and loads are determined simultaneously. Two surface vessels were selected using information available about generic barges (i.e., 250' long and 400' long barges). In both cases, the beam is 76' whereas draught was as given in Table 2. The attachment of the cable was either at the stern of the barge, the most likely situation, or at the center of gravity (CG). The barge was subjected to wind and surface-current loads. In most cases, except #5 and #6, the barge was ballasted, which accounts for higher values of the draught. Three cables are considered herein with properties corresponding to baseline and extreme values given in Table 1.

For this parametric analysis, it was found necessary to utilize a frequency increment ($d\omega$) of 0.06 rad/sec and to consider the range of frequencies between 0.578 and 3.098 rad/sec to determine tension RAOs (TRAO(ω)).

Assuming a Rayleigh distribution for the responses, one can express expected highest values in N cycles in terms of the standard deviation. N = 1000 was chosen for the tension responses, so that $T_{1000} = 3.72\ T_\sigma$ where T_σ is determined from the integral given above evaluated between 0.578 and 3.098 rad/sec.

Wave spectra were defined with two parameters, the significant wave height, H_S, and the mean period, $\overline{T}$, i.e.,

$$S(\omega) = 174 \frac{H_S^2}{\omega^5 \overline{T}^4} \exp\left(-\frac{694}{\overline{T}^4 \omega^4}\right)$$

TABLE 2 Summary of Dynamic Analysis in Frequency Domain for H_S = 8'

Case Number	Barge Length	Draught (as computed)	Cable	Water Depth	Attach-ment	T_{1000} (lbs)	$\eta = \frac{T_{1000}}{wh}$
1	250'	7.97'	Baseline	7000'	Stern	59,663	0.40
2	250'	7.93'	Baseline	5000'	Stern	48,069	0.45
3	250'	7.89'	Baseline	3300'	Stern	34,109	0.48
4	250'	7.87'	Baseline	2000'	Stern	23,895	0.55
5	250'	5.60'	Baseline	7000'	Stern	94,654	0.60
6	250'	5.54'	Baseline	5000'	Stern	79,606	0.75
7	250'	7.91'	Baseline	3300'	CG	7,461	0.11
8	250'	7.97'	Heavy	5000'	Stern	74,179	0.48
9	250'	8.35'	Light	5000'	Stern	20,051	0.40
10	400'	10.29'	Baseline	7000'	Stern	44,041	0.30
11	400'	10.26'	Baseline	5000'	Stern	40,356	0.37
12	400'	10.24'	Baseline	3300'	Stern	28,562	0.40
13	400'	11.15'	Light	3300'	CG	3,726	0.12
14	400'	10.26'	Heavy	3300'	Stern	46,792	0.45
15	400'	10.21'	Light	3300'	Stern	17,584	0.54

The time history of cable tension at the vessel/cable interface was defined as follows:

$$T(t) = wh + T_{bottom} + T_{dynamic}(t)$$

Under the frequency domain analysis, we obtained the standard deviation of tension about the time invariant term ($wh + T_{bottom}$) as given by tension response spectra. Furthermore, an upper bound for total tension has been defined as follows:

$$T_{peak} = wh + T_{bottom} + T_{1000}$$

For convenience, the dynamic amplification factor (η) is defined as the ratio of T_{1000} to wh such that

$$T_{peak} = (1 + \eta)\ wh + T_{bottom}$$

where η is given in the summary table.

The knowledge acquired from sensitivity analysis in frequency domain can be summarized as follows for the range of parameters given in the summary table:

- Under head seas conditions, deploying the cable from the center of gravity of the barge reduces dynamic tensions by as much as a factor of 5.
- Shallow draught (5.6') barges induce dynamic tension peak amplitudes about 60% higher than those with larger draughts (8').
- Dynamic amplification factors η associated with a 400' barge are between 17% to 25% less than those corresponding to a 250' barge.

Dynamic Analysis, Time Domain

The computer-aided analysis of cable motions and tension in the time domain was performed with a model that requires as input motions generated at the top end of the cable by the barge. The 400' barge with conditions from Case 11 were considered to generate motions at the cable attachment in the stern of the barge. The baseline cable, with a wet weight of 21.6 lbs/ft, was deployed at a payout speed corresponding to the barge forward speed. The barge speed was taken as either 2 knots or zero.

The main objective for the time domain simulation was to assess the frequency domain analysis for at least one cable/barge/environment combination. In addition to the somewhat extensive modeling of Case 11 corresponding to 5000' depth, a 60-second record of tension corresponding to Case 12 was also obtained. In summary, the time domain simulation yields maximum values in agreement with those obtained in frequency domain by assuming a model for maximum dynamic tensions as a function of standard deviation (T_{1000}). The shallower water simulation (3300') yields higher dynamic amplifications than the baseline case (5000') in agreement with frequency domain analysis.

Conclusions

The knowledge acquired regarding submarine power cable response to environmental and surface vessel loading during laying operations can be summarized as follows for the range of parameters reported herein:

- The generic cables considered in this study respond at frequencies that are high in relation to those of interest to traditional marine structures. Considerable motions and loads are excited in the cables at frequencies in the range of 1 to 3 rad/sec. For example, for some cases 50% of the contribution to dynamic tension is from frequencies larger than 1.4 rad/sec (periods smaller than about 4.5 sec).

- Cable response is excited via wave induced barge motions. Therefore, the barge motions must be modeled for frequencies beyond the standard 1 rad/sec and as high as 3 rad/sec. The same comment is applicable to the determination of wave spectra energy levels.

- Cable tension at the barge/cable interface is given by:

  $T(t) = wh + T_{bottom} + T_{dynamic}(t)$

APPLICATION OF JAPANESE TECHNOLOGY TO ARTIFICIAL REEF DESIGN IN SOUTHERN CALIFORNIA

Robert S. Grove
Southern California Edison Co.
Rosemead, California, U.S.A.

Choule J. Sonu
Tekmarine, Inc.
Sierra Madre, California, U.S.A.

ABSTRACT

Artificial reef technology is still essentially an empirical art. New reef development relies heavily on the performance assessment of existing artificial reefs. Within the last decade, Japan has made a major commitment to the development of artificial fishery reefs and is now amassing valuable experimental information. This paper focuses on the Japanese experience and reviews the present state-of-the-art of reef design for possible application in the Southern California nearshore environment.

Engineering design of artificial reefs is coupled primarily with the behavior and response patterns of selected target marine organisms. For example, the physical parameters which can influence fish in an artificial reef include; shape, size, color, light, currents and eddies, sound, and reef material type. The space of reef modules is also important in maximizing reef effectiveness while minimizing reef materials.

Of the design considerations discussed, the following were chosen as foremost in developing a new fish attracting reef; maximize vertical excitation surfaces and minimize horizontal components while ensuring structural integrity; provide an axiometric shape to make installation easier and allow omni-directional response to water currents; include interior tilted panels that deflect upward the ambient currents and create a variety of shadows and chambers within the reef to harbor and protect various fishes. These factors could be applied to Southern California waters in building reef modules out of steel or concrete.

HAWAII'S ARTIFICIAL REEF PROGRAM

Eric W. Onizuka
Division of Aquatic Resources
Department of Land and Natural Resources
Honolulu, Hawaii, U.S.A.

ABSTRACT

The State of Hawaii began in 1957 to work with artificial structures to increase reef and nearshore fish species. To date, four artificial reefs have been maintained on barren ocean bottoms off Oahu and Maui. The reefs have increased fish populations, both in biomass and species diversity, thus helping us meet the increasing demand for improved and additional fishing opportunities.

Introduction

The Division of Aquatic Resources of Hawaii's Department of Land and Natural Resources (formerly the Division of Fish and Game), is actively involved in programs to improve public fishing opportunities. Fishery resources are managed with laws and rules, stocking, by installation of ocean buoys to aggregate pelagic species, and by other means. As early as 1957, the Division began to experiment with artificial structures to increase and sustain reef and nearshore fishes sought by fishermen. Hawaii's artificial reef program was initiated formally in 1961 on the basis of these early studies.

We acknowledge the support provided to Hawaii's artificial reef program by fishermen, private organizations, and various County, State and Federal agencies. The program receives financial support from the Federal Aid in Sport Fish Restoration (Dingell-Johnson) Program, administered by the U.S. Fish and Wildlife Service, Department of the Interior.

Nearshore Environment

Among the factors which limit nearshore fishing in the main Hawaiian Islands are the relatively narrow extent of shallow waters surrounding each island. Steep submarine slopes drop rapidly to the ocean floor, 12,000 to 18,000 feet below sea level. Further, a large proportion of the shallow nearshore bottom is sandy, flat or barren, and largely devoid of such bathymetric features as coral reefs, rock formations, ledges, crevices and drop-offs necessary to provide vertical relief suitable for most of the nearshore marine species which fishermen seek. The relative scarcity of nutrients in the warm oceanic waters surrounding the State also limits the availability of fishery resources.

In addition to limitations imposed by Hawaii's natural environment, the availability of the resources is further influenced by man's activities, such as pollution, landfills and other shoreline developments, or other uncontrollable and conflicting activities causing destruction to reef and nearshore areas. The State's population continues to increase. With it, the efforts of both commercial and recreational fishermen have intensified, exerting ever-increasing pressure on our limited fishery resources. Improving unproductive, "flat" habitat, by adding structures to provide vertical relief, has proven to be a viable means of accommodating the growing demand.

Early Studies

Aware of reports from other states and foreign countries (especially Japan), the State of Hawaii began to investigate the effects of artificial structures on fish communities in Hawaiian waters. Between 1957 and 1959, specially fabricated reinforced concrete "boxes" (48"x48"x17") were installed off Oahu. Various designs were used to test effects of numbers and locations of openings on capacity to attract and sustain reef fishes. Structures were placed in sets of four designs at three experimental sites--"Yokohama Bay," Keaau and "Brown's Camp" off the leeward coast (Figure 1).

Structures placed at a depth of 35 feet off Keaau were destroyed by a storm before conclusive data could be collected; the "Yokohama Bay" and "Brown's Camp" sites were deeper than 70 feet, so structures here were not damaged by storm waves and surge. At "Yokohama Bay" and "Brown's Camp," the experimental structures succeeded in attracting and sustaining reef fish populations. On a barren site at "Yokohama Bay," the standing crop of fishes increased by a factor of 16 after structures were installed; structures placed during the same time near a natural coral reef at "Brown's Camp" attracted only a very small increase in the standing crop. The number and design of openings in the structures appeared to have no significance.

Existing Artificial Reefs

To date, the State has established four artificial reefs in nearshore waters off Oahu (Maunalua Bay, Waianae and Kualoa Artificial Reefs), and off Maui (Keawakapu Artificial Reef). Approximate locations are shown in Figure 1. Fish populations in all of these areas were surveyed prior to establishment; the bottoms were all flat with little relief, and standing crops were low. Various materials have been placed at these artificial reef sites: derelict cars, stripped car bodies, concrete pipes, tires, and derelict hulls of a ship, barges and rafts. Effectiveness at attracting and sustaining fishes has varied among sites and materials used.

Maunalua Bay Artificial Reef

The first artificial reef officially designated for Hawaiian waters is the 74-acre Maunalua Bay Artificial Reef, situated about one and one-half miles offshore of Kahala, Honolulu, Oahu. The ocean bottom in this area is primarily consolidated rock under a thin layer of sand, devoid of depressions and crevices. Corals are small and sparse. Car bodies first were installed at Maunalua Artificial Reef beginning in 1961. More recently concrete pipes have been added. In all, 1,593 car bodies and 2,331 tons of concrete pipe have been deployed at the site. At present only the concrete pipes remain, with a few larger parts from the car bodies installed in the 1970s.

Estimates of the standing crop of fishes have increased nearly 18-fold (averaging 651 pounds per acre), and the average number of fish species (56) is nearly 3 times higher than the respective "pre-reef" values of 37 pounds of fishes per acre and 20 fish species. As shown in Figure 2, post-construction values for number of species and estimated biomass have varied considerably between 1961 and 1983, ranging between 37 (in 1965) and 72 (1973, 1982 and 1983) species, and from 213 (1976) to 1,370 (1965) pounds per acre. Overall, 138 different species of fishes have been observed at the Maunalua Artificial Reef since establishment. Large schools of goatfishes, damselfishes, surgeonfishes, squirrelfishes, and snappers frequently congregate here.

Keawakapu Artificial Reef

The State's second, Keawakapu Artificial Reef, was established in Maalaea Bay, off the southern coast of the island of Maui. It occupies 52 acres of flat, sandy, limestone bottom, approximately 400 yards offshore of Keawakapu. About 150 car bodies were installed during 1962. During 1979, 80 bundles of weighted automobile tires were added by students in a Federally-funded Young Adult Conservation Corps.

The estimated standing crop at Keawakapu increased by a factor of about 63 (from 3 to an average of 195 pounds per acre) and the number of fish species by 6 (from 6 to 38 species). Figure 2 presents the annual average numbers of species and estimates of standing crop recorded between 1963 and 1966, which show a steady climb from 24 species and 93 pounds per acre in 1963 to high values of 47 species and 276 pounds per acre in 1966. Unfortunately, no surveys were made thereafter. Overall, 68 different species of fishes were recorded at Keawakapu Artificial Reef during the four-year period, with goatfishes and damselfishes predominating.

The reef is deteriorated, largely covered by sand which has drifted from surrounding areas.

Waianae Artificial Reef

Construction began on the Waianae Artificial Reef in 1963, on 141 acres of sandy and limestone bottom with a few large coral mounds. The site is about one mile offshore of Maile Point on the western coast of Oahu. Waters here are generally calm. Proximity to convenient boat launching facilities affords to small boats easy access to the Waianae Artificial Reef; it is fished heavily. Waianae Artificial Reef contains a large quantity of concrete pipes, some weighted automobile tires, the steel hulls of two barges (171 feet and 110 feet long), six 30-foot steel rafts, and the hull of a 165-foot former minesweeper.

Prior to construction the site supported 23 species comprising a standing crop estimated as 100 pounds of fishes per acre. Subsequently, the average standing crop has risen by a factor of 6 (to 628 pounds per acre) and the diversity by a factor of 2 (to 55 species). As at Maunalua Bay, annual averages of numbers of species and standing crop estimates have varied widely, ranging from 24 (1963) to 75 (1966) species and 45 (1982) to 1,475 (1963) pounds per acre (Figure 2). One hundred twenty-one different species of fishes have been recorded over 21 years of observation. Surgeonfishes, goatfishes, snappers, damselfishes and squirrelfishes dominate the fish fauna at the Waianae Artificial Reef.

Kualoa Artificial Reef

Largest and most recently established, the Kualoa Artificial Reef was started during 1972 as part of a State-County derelict auto cleanup campaign in Honolulu. It encompasses about 1,727 acres of hard, flat rock, interspersed with sand patches and coral rubble offshore of Kualoa and Kaaawa on the northeastern (windward) coast of Oahu. It was not possible to assess the effects of the reef on standing crop or species diversity since by mid-1973 strong currents had swept virtually all the car bodies offshore into very deep waters. No other materials have been placed at this site.

Status of the Artificial Reef Program

The State's artificial reef program has continued since 1961. In recent years, budgetary restraints coupled with increasing cost to assemble, load, and haul the material by tug and barge have caused reduction in the effort allocated to the artificial reef program, but Hawaii's artificial reefs continue to attract fish and fishermen.

Recently the State has initiated an experiment using mid-water attractants (buoys) to enhance fishing opportunities by attracting semi-pelagic and mid-water fishes to artificial reefs. Fifteen buoys were deployed in mid-December, 1983, at the Waianae Artificial Reef. Preliminary monitoring data are inconclusive.

Currently with a low profile, the State's program is far from ended.

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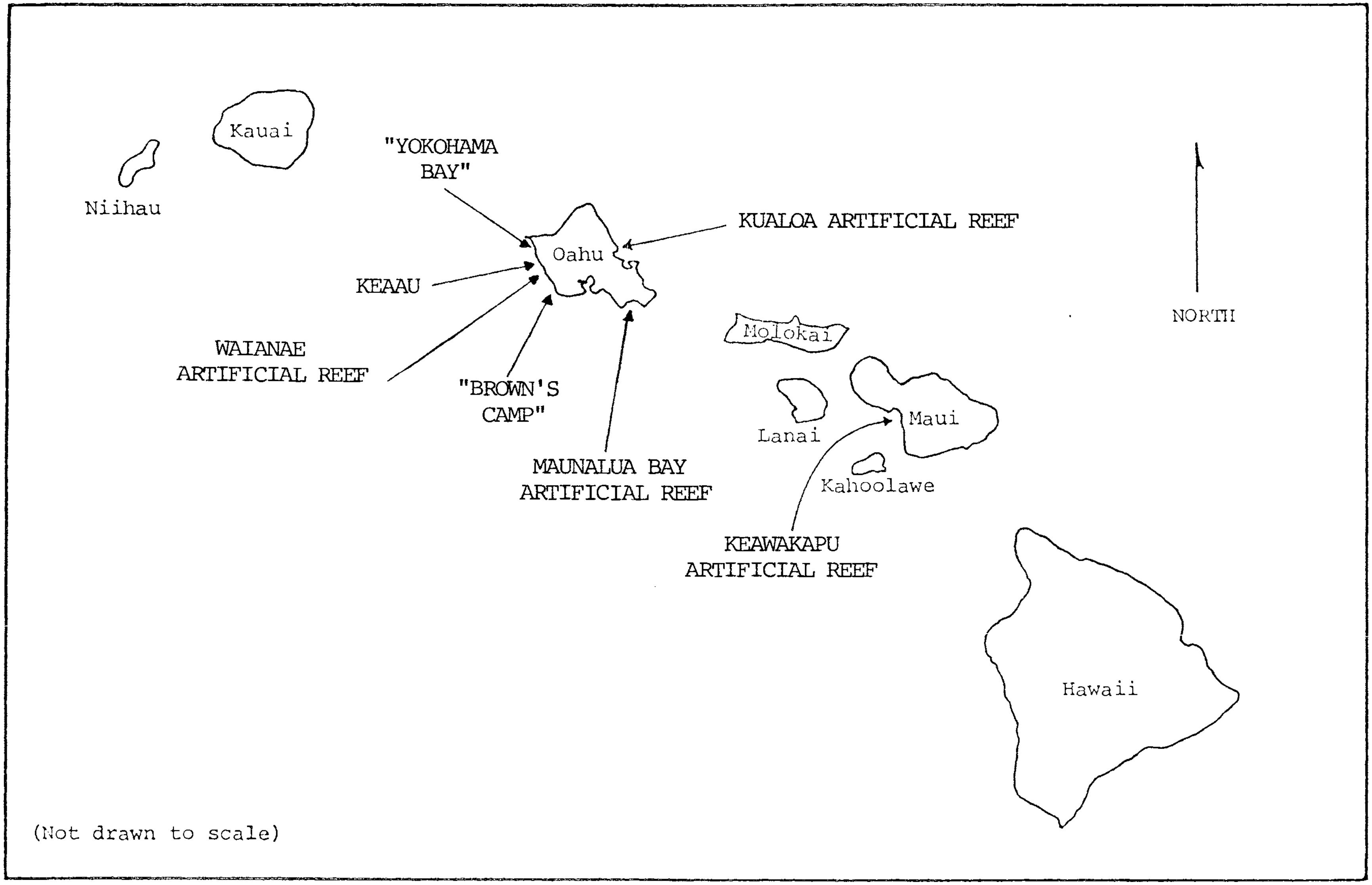
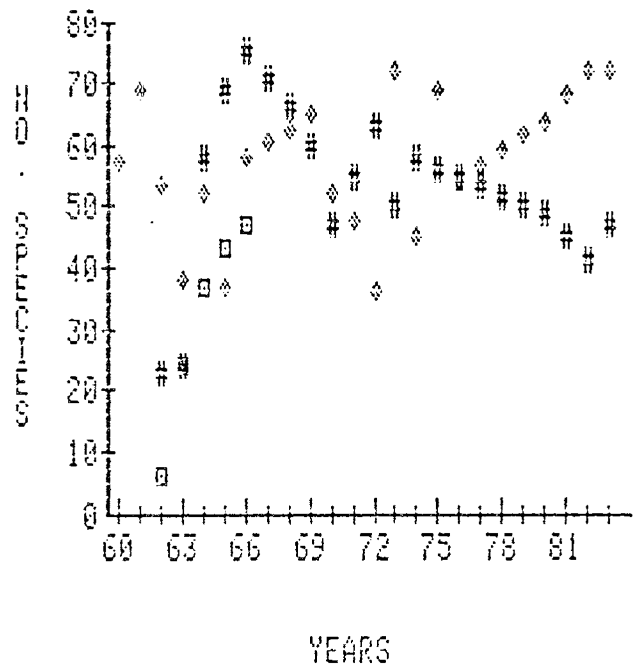


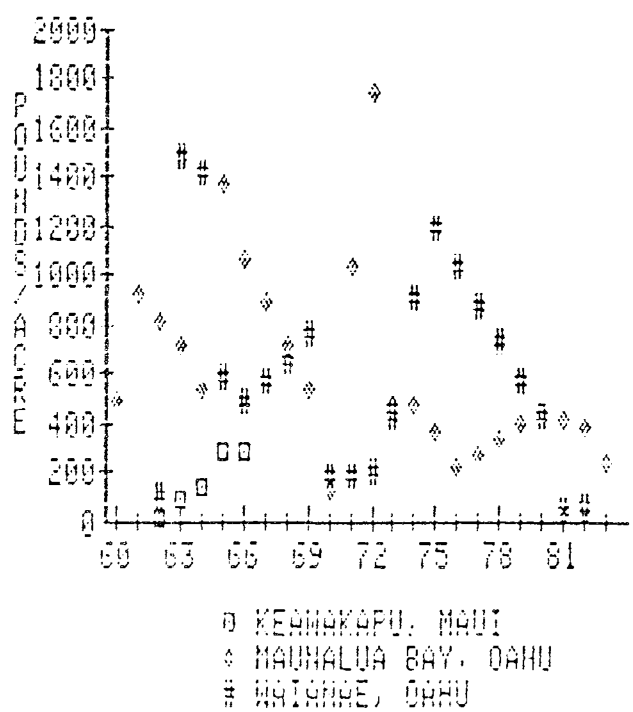
Figure 1. Approximate locations of the experimental sites and existing artificial reefs.

Figure 2

a. Annual averages of numbers of species.



b. Annual averages of biomass estimates.



ENGINEERING ASPECTS OF ARTIFICIAL REEF DESIGN

Choule J. Sonu
Tekmarine, Inc.
Sierra Madre, California, U.S.A.

Robert S. Grove
Southern California Edison Co.
Rosemead, California, U.S.A.

ABSTRACT

Extensive use of artificial fishing reefs during the past decade in Japan has brought to light an assortment of engineering problems which may be broadly classified into three categories: operational, functional and structural. The purpose of this paper is to review these problems in the hope of extricating the lessons with potential relevance to our future use of the technology. The operational problems related to the strategy and the act of deploying the reefs on the sea floor. Much of the functional problems appeared to stem from the scour of the sea floor, which would lead to burial of reef structures, instability (i.e., tilting and toppling), excessive sediment suspension. Structural problems were frequently related to free-fall impact on the sea floor during installation, excessive stresses caused by the scoured uneven sea floor, impact associated with toppling under wave and current drag, failure due to corrosion, fatigue, and aging.

DEVELOPMENT OF BIG-SIZED ARTIFICIAL FISHING REEFS UTILIZING FLY ASH

Yoshihira Shimomura
Tatsuo Suzuki
Hazama-Gumi, Ltd.
Minato-ku, Tokyo, Japan

1. Background in Japan

1.1 Present State of the Fisheries Industry

Japan has a long coast line of 34 million meters, with many excellent fishing grounds. Therefore, Japanese people tend to consume considerable amounts of animal protein from marine products. In this connection, it is not too much to say that the fisheries industry is a sector of vital importance for the Japanese people.

The coast lines of Japan have many excellent fishing grounds, but on the other hand there are also other areas whose potentialities have not been fully exploited. Under the circumstances, the Japanese Government is taking positive measures to create large-scale fishing grounds along the coast line of the country under strict quality control, in order to secure a stable supply of indispensable marine products.

The Projects for the Construction and Development of Coastal Fishing Grounds, with a budget of US$1,600 million alloted for the 6-year period commencing in 1982, has been prepared in this connection, with expectations of further financial support in the future.

1.2 Present State of the Power Industry

Japan is the second largest energy consumer in the world after the USA. The risk of relying too much on petroleum as an energy source has been mentioned before, and in this connection Japan is attempting to convert the fuel of many thermal power stations from petroleum to coal in order to free the country from excessive dependence on petroleum.

At the same time, with the construction of coal fired power plants, the disposal of the huge volumes of coal ash resulting from the combustion of coal is becoming a serious problem.

At the present time, the coal fired power plants of Japan have a capacity of approximately 6 million kW, and the volume of coal ash they generate is approximately 2.5 million tons per year. Of that total approximately 30% is used in an effective way, and the remaining 70% is used in the reclamation of coastal areas.

The capacity of the coal fired power plants of Japan is increasing rapidly, and concurrently the disposal of coal ash is expected to become increasingly serious. Under the circumstances, active research and development are being carried out with the purpose of devising effective ways of utilising the coal ash generated by the thermal power plants. In this connection, we have succeeded in developing a cheap and high-strength hardened material using coal ash, cement, water and a newly developed admixture.

This paper introduces one of the ways of using this hardened material, which is for the construction of large-sized artificial fishing reefs weighing 52 tons each.

2. Characteristics of the New Hardened Product Using Coal Ash

2.1 General Characteristics

The use of the newly developed admixture makes a very great improvement in the strength of the hardened product. We came to the conclusion that it is impossible to achieve the economic production of hardened products consisting principally of coal ash without using this admixture.

The general characteristics of this hardened product are as follows.

(1) The specific gravity is of the order of 1.7 ~ 1.8, which is much lighter than the specific gravity of ordinary concrete.

(2) The strength can be readily changed from a minimum of 5 kg/cm^2 to a maximum of 500 kg/cm^2.

(3) The increase in the strength of the product during ageing, particularly after 28 days, is much greater than that of ordinary concrete.

(4) The results of the elusion tests of harmful substances from the hardened material meet perfectly the "Standard Values of Environmental Pollution" of Japan.

(5) If coal ash is assumed to be available free, the cost of the product required to make a product with a compressive strength of 200 kg/cm^2 is extremely cheap, i.e., approximately 30% of that of an equivalent product made of ordinary concrete.

2.2 Details of the Strength

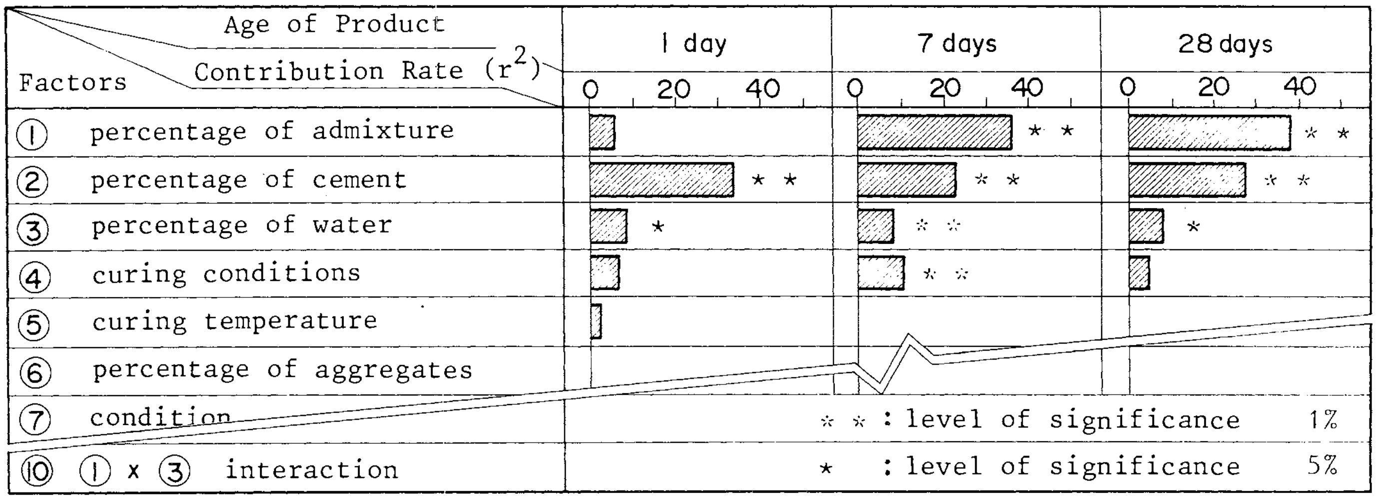
i) Factors contributing to the strength of the new hardened product

The factors that presumably effect the compressive strength of this hardened product are the percentage of admixture, percentage of cement, percentage of water, curing temperature, percentage of aggregates, etc. The extent of the contribution of each one of these factors to the compressive strength of the hardened product at various ages is examined by using the experimental planning method.

Figure 1 summarizes the results. As can be seen from the figure, the percentage of cement has a predominant influence on the strength in the first day after moulding the hardened product. However, as the age of the product progresses, i.e., 7th day, 28th day, etc., the influence of the admixture becomes more pronounced than the percentage of cement.

The figure indicates that the curing temperature, the type of aggregate and the interaction between percentage of admixture and the percentage of cement does not exert so much effect on the compressive strength at any age of the material.

FIGURE 1 Factors Contributing to the Strength of the New Product



ii) Relation between the percentage of addition of admixture and the compressive strength

Figure 2 shows the unconfined compressive strength of the hardened sample at ages of 7 days and 28 days with the parameter x/C varying from 0.0 to 0.24 and the other parameters fixed at C/(F+C)=0.15 and W/(F+C)=0.3, where F is the weight of fly ash, C is the weight of cement, W is the weight of water and x is the weight of admixture. As can be seen from the figure, at the beginning the compressive strength increases rapidly with amounts of admixture, but when the parameter x/C exceeds 0.12, the rate of increase of strength slows down considerably. Therefore, we came to the conclusion that the proportion of admixture x/C of approximately 0.1 brings about the most effective results.

FIGURE 2 Relation Between the Percentage of Admixture and the Compressive Strength

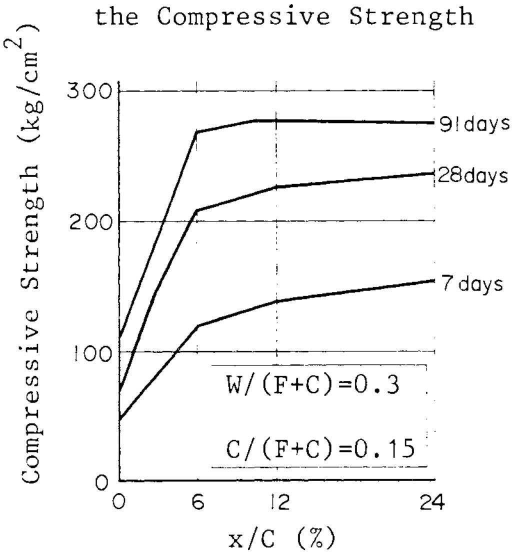
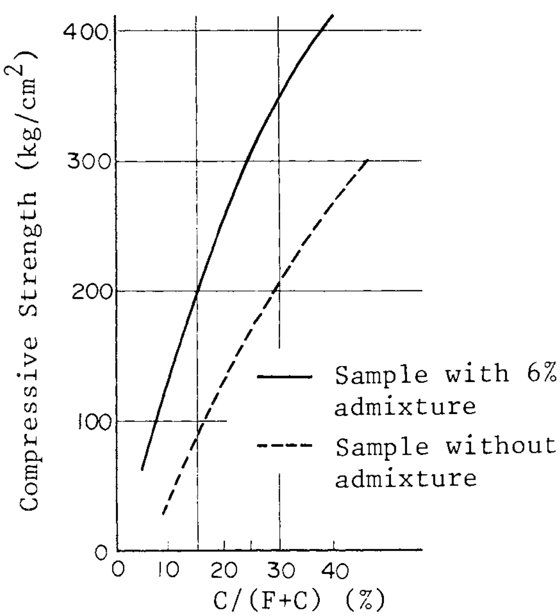


FIGURE 3 Relation Between the Percentage of Cement and the Compressive Strength



iii) Relation between the percentage of cement and the compressive strength

The relation between the compressive strength of the hardened product and the percentage of cement is shown in Figure 3.

In this figure the solid line indicates the strength of the sample when the percentage of admixture x/C is 0.06 and the broken line indicates the strength of the sample when the percentage of admixture x/C is 0.0. When the proportion of cement is changed from 0.0 to 0.4, the compressive strength increases continuously.

On the other hand, in terms of samples of the same age, the solid line is always above the broken line for any percentage of cement, proving that the strength of the sample containing admixture far exceeds the strength of the sample without admixture.

iv) Relation between the strength of the hardened product and the age of the material

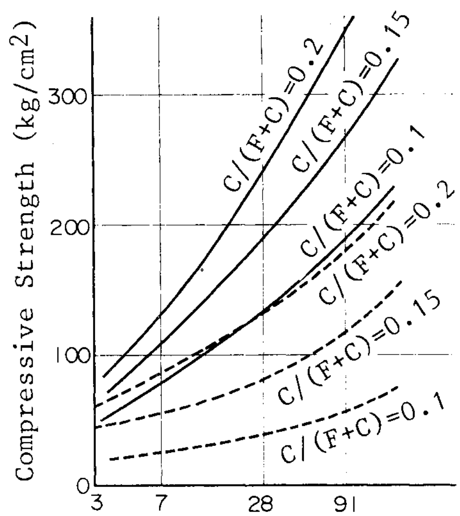
The relation between the age of the hardened product and its strength is shown in Figure 4.

In this figure the solid line indicates the sample whose proportion of admixture x/C is 0.06 and the broken line the sample containing no admixture. As can be seen from the figure, the use of the admixture exerts a pronounced influence on the strength of the sample at any age.

As can be seen from Figure 4, the strength of the hardened product continues to increase even when the age of the material passes 28 days. This is an interesting tendency compared with ordinary concrete, because in this case the increase of strength becomes very slow after 28 days.

FIGURE 4 Relation Between the Strength of the Hardened Product and Age

sample with 6% admixture
sample without admixture



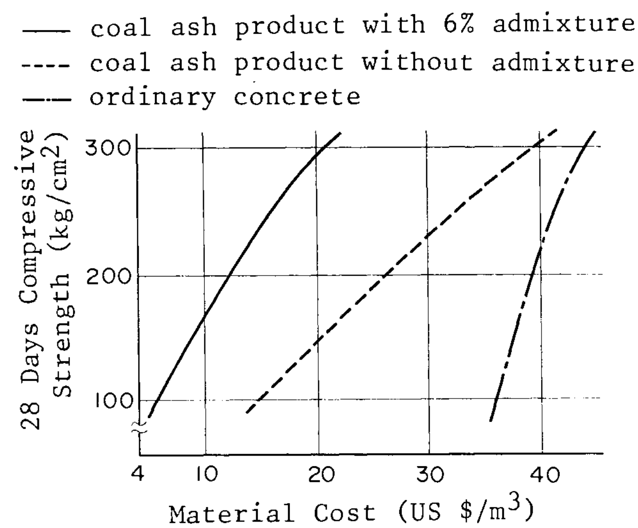
2.3 Cost of Materials

Coal ash is an industrial waste material and under present conditions its disposal requires considerable cost. Therefore, it is difficult to set an appropriate price for coal ash as a construction material. In this paper the calculations of cost are carried out assuming that coal ash is available free of charge.

The relation between the compressive strength of the product and the cost of raw materials per cubic meter is shown in Figure 5. The cost of materials for ordinary concrete and coal ash product without admixture are shown separately for the sake of reference.

As can be seen from the figure, the cost of materials for a product with 200 kg/cm^2 compressive strength made of ordinary concrete is US$43/$m^3$, compared with US$13/m^3 of the same kind of product made of coal ash, proving that this is an extremely cheap material.

FIGURE 5 Cost of Raw Materials



3. Artificial Reef for Fish Made from Hardened Coal Ash Material

3.1 Objectives of the Development

The development of an artificial fishing reef using hardened material made of coal ash was carried out for the benefit of fishermen interested in using this kind of structure. The fishing reef is required to be easy to use, able to attract large quantities of fish, simple to assemble and have a low construction cost.

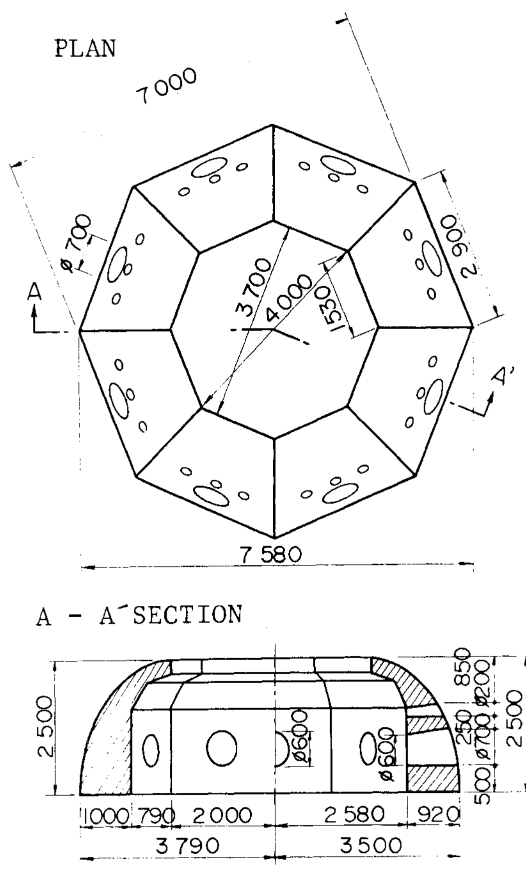
3.2 Design of the Newly Developed Fishing Reef

Each one of the newly developed fishing reefs weighs 52 tons, including 33 tons of fly ash. Each fishing reef consists of 8 blocks of the same shape that are assembled into a structure with a maximum width of 7.6 m and a maximum height of 2.5 m. A sketch of the fishing reef is shown in Figure 6.

3.3 Features of the Newly Developed Fishing Reef

This fishing reef has the shape of a bowl upside-down, and it does not damage the fishing nets of trawling boats because it does not have projections on the surface. This advantage has been confirmed in experiments carried out in tanks using 1 : 50 scale models.

FIGURE 6 Sketch of the Circle Reef



Theoretical calculations have demonstrated that this fishing reef does not move even when exposed to a 6 knot-tide, and therefore it is the most stable one among over 150 kinds of fishing reefs presently existing in Japan.

An appropriate analysis using a the three-dimensional FEM technique was carried out, because this is a large-sized structure made of a new material and using no steel components such as reinforcing bars, etc. The results of these analyses have demonstrated that the strength of the material used to construct this fishing reef is required to be 150 kg/cm^2 or more.

3.4 Construction of the Fishing Reef

The various steps in the procedure for constructing of the newly developed fishing reef consist of the design of the mix proportions for the material, construction of the blocks, transportation of the blocks, assembly of the fishing reef and installation at the bottom of the sea. The flowchart of this process is shown in Figure 7.

Photograph 1 shows the installation of the fishing reef. A derrick barge with a lifting capacity of 150 tons was used to install 4 fishing reefs at the bottom of the sea at a depth of 43 meters.

The place where these fishing reefs were installed is located on the Pacific Coast of Japan, at a distance of approximately 3 km from the shore and the surface of the bottom of the sea consists of sand covered with silt. The name given to this design of reef is the "Circle Reef".

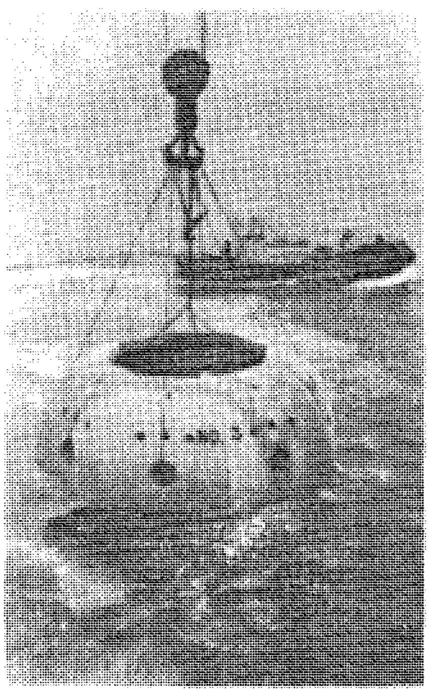
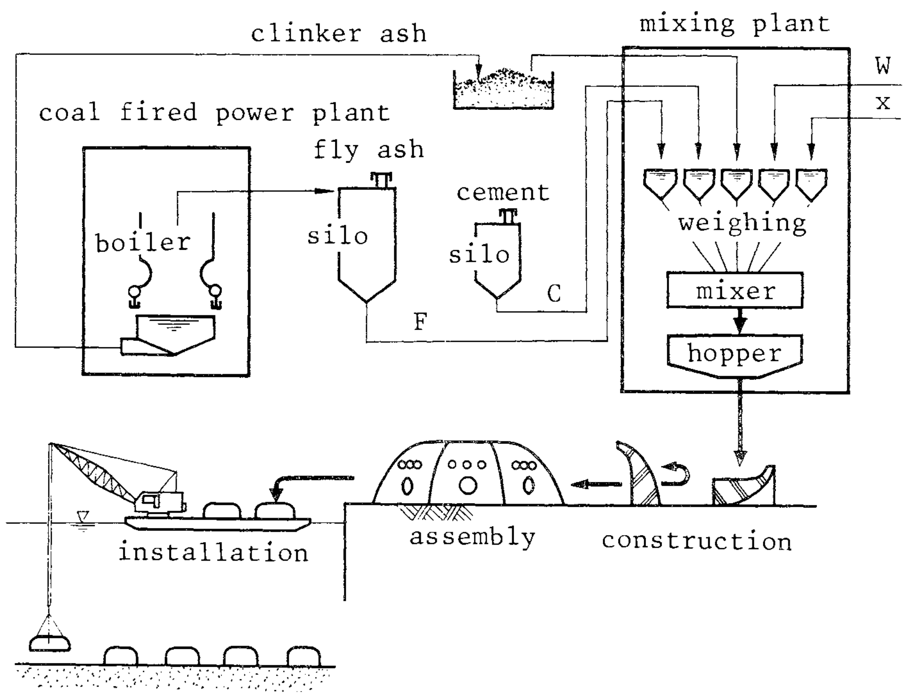


Photo 1 Installation of the Circle Reef

FIGURE 7 Flowchart of the Construction Process



3.5 Effects of the Fishing Reef

The conditions at the site where the 4 fishing reefs were installed in June 1983 were investigated by divers 2 months and 4 months after their installation. There was no indication of the presence of fishes before the installation of the fishing reefs, but the 2 surveys carried out after their installation indicated the presence of many kinds of fishes. Photograph 2 shows fish gathered together near the reef. The survey carried out 4 months after the installation of the fishing reefs proved that both the variety and quantity of fish had increased since the 2-month survey.

The periphery of the place where these fishing reefs are installed is scoured by the waves and/or by the tide, because the bottom of the sea consists of sandy mud. The conditions at the periphery of the place where these fishing reefs are installed are shown in Figure 8.

As can be seen from Figure 8, the scouring process has developed up to 1.5 ~ 2 m from the edge all around the fishing reefs, and the scouring depth is 0.5 ~ 0.8 m. Large quantities of shells which were deposited in the mud are now visible in the new sea bottom where it has been subjected to scouring.

FIGURE 8 Conditions at the Periphery of the Circle Reefs

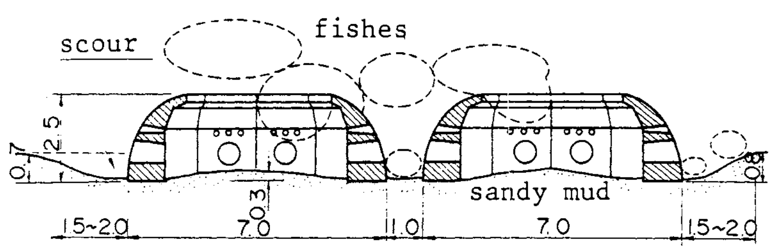


Photo 2 Fish Gathered around the Reef

4. Points for Further Development

It is widely known that the quality of coal ash differs considerably depending on the type of coal, boiler, burning conditions, etc.

Therefore, it is essential to develop an appropriate process for the design of the mix proportions to produce the hardened product with the required strength.

Furthermore, it is necessary to develop mixers able to mix fine fly ash, small amounts of fine cement, admixture and water in an efficient way, as well as a plant able to carry out the automatic weighing of these materials without polluting the environment with dust.

In addition, it is necessary to develop other applications besides artificial fishing reefs , in order to make effective use of the coal ash produced in coal fired power plants.

MRM-5: MARINE ECONOMICS & PLANNING

THE COUNTY'S ROLE IN PLANNING FOR THE NORTHWESTERN HAWAIIAN ISLANDS

Leigh-Wai Doo
Honolulu City Council
Honolulu, Hawaii, U.S.A.

Jan Naoe Sullivan
Roy Takeyama, Attorney at Law
Honolulu, Hawaii, U.S.A.

ABSTRACT

The City and County of Honolulu extends 1800 miles into the Pacific Ocean northwest of Kauai to include the chain of islets and atolls known as the Northwestern Hawaiian Islands (NWHI). The significance of county jurisdiction in the NWHI has not been addressed to date. However, the possibility of increased activities on some of these islands indicates that it is an appropriate time for the City and County of Honolulu to determine what its role in planning for the future of the NWHI should encompass.

Jurisdiction in the NWHI

The NWHI, with the exception of Midway which was annexed by the United States, were admitted into the Union as part of the State of Hawaii. The Admissions Act of 1959 included "all of the islands in the Territory of Hawaii". The territory, pursuant to the Organic Act of 1900, encompassed the NWHI (1).

Although the NWHI are part of the state, the federal government has extensive jurisdiction over a large number of islands. This jurisdiction stems from Executive Order 1019 which was issued by President Theodore Roosevelt to establish the Hawaiian Islands Reservation in specified areas of the NWHI. The purpose of the Order was to prevent the depletion of birds on the islands due to poaching. The Order therefore sought to maintain the NWHI "as a preserve and breeding ground for native birds". In 1940 the reservation was redesignated the Hawaiian Islands National Wildlife Refuge by presidential proclamation (2).

The Fish & Wildlife Service (FWS) manages the islands pursuant to numerous laws, among which include the Migratory Bird Treaty Act and the Endangered Species Act. A second federal agency, the National Marine Fisheries Service has the dual responsibility of developing underutilized fisheries and conserving the endangered monk seal and threatened green sea turtle that are present in the NWHI. The Western Pacific Fisheries Management Council, a regional agency, has the responsibility of regulating fisheries within the 197-mile fishery conservation zone that is adjacent to the territorial sea surrounding the NWHI. The responsibilities of these agencies overlap in areas, and further coincide with state agencies involved in managing resources in the NWHI (3).

Recognizing that the federal agencies responsible for administration of the refuge were experiencing difficulties in managing the refuge, agreement was reached in 1951 for joint federal-state administration. The state agency that has taken the most active role in the management of the NWHI has been the Division of Aquatic Resources in the Department of Land and Natural Resources (DLNR). The Department of Planning and Economic Development (DPED) is also involved through its role in the implementation of Hawaii's Coastal Zone Management (CZM) program (4).

County authority in the NWHI arises from state statute and county charter. Hawaii Revised Statutes (H.R.S.) section 4-1 divides the state into districts "[f]or election, taxation, education, city, county and all other purposes". Oahu is further divided into seven districts, including the Honolulu district which encompasses "the islands not included in any other district". Section 1-102 of the Revised Charter of the City and County of Honolulu also provides that Honolulu's geographical limits include "[t]he island of Oahu and all other islands in the State of Hawaii, not included in any other county and the waters adjacent thereto..." These provisions place the NWHI under the jurisdiction of the City and County of Honolulu as the islands are not included in any other district or county (5).

County Regulatory Powers In The NWHI

The county does not presently assert a role in resource management and does not participate in administration of the refuge. The County of Honolulu does, however, play a significant part in the land use regulatory process in Honolulu. In the case of the NWHI this role may presently be minimal, but if activities other than the present conservation uses were to take place, the county could have a major role.

H.R.S. section 205-5 states that county zoning power governs the zoning within all districts except conservation districts. This provision generally allows counties to assert an important role in land use regulatory processes. Pursuant to the H.R.S., land use regulation in the NWHI would be vested in the DLNR because the islands have been placed in the conservation district.

Activities in the conservation district are regulated by the DLNR through its Regulation No. 4 (6). Any activity in a conservation district, by either governmental or private action, requires a conservation district use permit (CDUP). The Board of Land and Natural Resources is the permit-granting authority. CDUP applications are sent to the counties for comments. However, the county's input is minimal as the Board is not required to take the county's comments into consideration when deciding to grant a CDUP application.

Any proposed activity in the conservation district may require a state environmental impact statement pursuant to chapter 343, H.R.S. The county could comment on a project at this level. However, the purpose of the EIS procedure is limited as it is generally concerned with disclosure to insure that appropriate information is made public and does not allow for county vetoing of a particular proposal.

The NWHI are located in the state's designated coastal zone management (CZM) area. The county's CZM power is embodied in its shoreline management area (SMA) permit which is required for activities located in the SMA zone (7). The SMA is statutorily defined as extending from the certified shoreline to a minimum of 100 yards inland. The county could therefore regulate the development of shoreline areas in the NWHI under its CZM power regardless of the fact that the land is in conservation. However, the SMA permit is not applicable to the NWHI at the present time because no SMA has been mapped or designated for the NWHI.

A land use regulation that could presently be enforced by the county in the NWHI is the shoreline setback law. This law essentially prohibits the commercial removal of sand or beach material and the placement of structures within the "shoreline area" without a shoreline setback variance (8). The setback area is statutorily defined as extending "not less than twenty feet and not more than forty feet inland from the upper reaches of the wash of waves other than storm and tidal waves." Although the setback area overlaps with the SMA, the setback law is not part of the CZM legislation and is contained in Hawaii's land use law, chapter 205, H.R.S.

Although the county's land use regulatory control is presently limited in the NWHI, other county regulations may apply. For example, the county has the power to issue building permits to insure building specifications are up to county standards. Grading, grubbing and stockpiling permits can also be required depending on the amount of work that needs to be done. Honolulu county would also require a well permit to be issued by the Board of Water Supply for the excavation of any fresh, brackish or salt water wells.

Planning for the Future of the NWHI

The various county regulations that have been outlined above would take on significance if activities other than conservation uses were proposed for the NWHI. An example of such an activity would be the fisheries support station that the state has previously considered for the NWHI(9).

Land use regulations would apply if a fisheries base or support station were to be constructed on state land. The applicant could seek administrative approval of a project by obtaining either a land use district boundary amendment or a CDUP. The requirements of chapter 205, H.R.S. would have to be complied with in the case of a district boundary amendment. However, H.R.S. section 205-1 which allows for county input by requiring the Land Use Commission to consider the county general plan in establishing district boundaries may not presently apply in the case of the NWHI as there is no general plan or development plan for the islands. If a general plan were adopted for the NWHI, a land use district boundary amendment would have to consider the county's general plan designation. If a development plan which placed the NWHI in preservation was adopted, an applicant would be required to obtain a development plan amendment - a procedure which requires a legislative mandate and detailed public review.

If an applicant sought to obtain a CDUP from the DLNR instead of obtaining a district boundary amendment, a public hearing would be required if the proposed fisheries base was considered to be a "use of land for commercial purposes". Even if a use is not commercial, a public hearing is required if the application involves a conditional use in the protective subzone(10). Section 13-2-11 of Regulation No. 4 places "all land encompassing the Northwestern Hawaiian islands except Midway island" in the protective subzone. The only permissible use that a fisheries base could fall under in the protective subzone is the catch-all provision allowing governmental uses in cases where the public benefit outweighs any impacts in the conservation district(11). If the use did not fulfill this definition, or if it were considered to be a commercial use, the regulation would require a public hearing. An exception to this requirement could found in the case where the applicant has undergone a public hearing by a federal, state or county agency for the same purpose and use as is being requested in the CDUP application. The DLNR would then review the previous public hearing and if it were determined to be sufficient the applicant would be considered to have met the public hearing requirement.

The County could allow for greater public participation in the regulatory process by designating a SMA around the shorelines or perhaps over the entire land masses of the islets and atolls contained in the NWHI subject to its jurisdiction. If a SMA was established, a SMA permit would be required for a fisheries base placed in the SMA. This permit would be required regardless of whether the land remained in conservation or whether it was redesignated. To obtain a SMA permit an applicant must present sufficient data to demonstrate that the project will not have "any substantial adverse environmental or ecological effect". The SMA permit is generally processed along with the shoreline setback variance and a public hearing is normally required. The permit and the variance are processed prior to the CDUP application. Therefore, although the state has the final say in approving a project in the conservation district, the county could deny a SMA permit or a shoreline setback variance and the project could not proceed until state and county agencies came to an agreement.

The establishment of an SMA could also lead to greater county input in development in the oceans adjacent to the NWHI that could occur in the distant future. Manganese nodule mining, polymetallic sulfide mining, Ocean Thermal Energy Conversion plants or other ocean-related activities could seriously affect the CZM area. The county's role in the regulation of any proposed activities in the waters adjacent to the NWHI is presently limited. The coastal waters that have been placed under state jurisdiction are in the conservation district. Although the federal CZM act places waters out to the territorial sea in the CZM area, Hawaii has statutorily limited its SMA to the land extending inland from the certified shoreline(12). Therefore, the County of Honolulu presently has no CZM regulatory power in coastal waters - its jurisdiction effectively stops at the shoreline.

The federal CZM act contains a consistency provision that requires federal actions which "directly affect" the coastal zone to be consistent with the state's coastal zone management policies(13). In Hawaii, consistancy determinations are made by the DPED(14). H.R.S. section 205A-6 allows a county to bring suit against the DPED if that agency fails to follow the objectives and policies of the CZM act by improperly approving the consistency of a federal action "directly affecting" the CZM area. By establishing a SMA and by setting forth a coastal zone management program for the NWHI, the county would have a solid position on which to challenge an improper consistency determination.

In a recent case the state of California and various environmental groups sued the Secretary of the Interior for violation of the federal CZM act in refusing to submit its action in granting Outer Continental Shelf oil and gas leases through the federal consistency procedures(15). Numerous California counties intervened in that suit. Without a designated SMA area it may be difficult to assert, as was done in this case, that any action in or affecting the waters adjacent to the NWHI violate the state and county's objectives and policies in that CZM area.

<u>The Significance of County Planning</u>

By adopting a general plan, development plan and shoreline management area for the NWHI, the City and County of Honolulu could ensure that extensive public input and county legislative mandate would be required before any changes that were proposed for the islands could be effectuated. County planning at this point in time is not premature and would present a concrete safeguard to protect the pristine environment of the NWHI.

If the county implemented these plans and if activities other than conservation uses were to be proposed for the NWHI, the county would have to develop its resources to deal with the potential problems of enforcement of regulations, resource expertise and staffing. A collaborative federal, state and county effort would aid in coordinating planning and administration of the NWHI. Responsible planning could allow for a balancing of competing interests and for public participation in guiding the future of the NWHI.

FOOTNOTES

(1) Kurata, Colin, Analysis of Northwestern Hawaiian Islands Jurisdictional Issues. Unpublished paper (1978).

(2) Twelve of the islets and reefs in the NWHI were specifically covered by the executive order. However, the federal government only manages eight of the islands as a wildlife refuge. Dowsetts Reef, Frost Shoal and Two Brothers Reef were included in the Order but are presently submerged and are no longer designated on marine charts. Kure island, the last and most northerly island in the NWHI chain, was originally included in the executive order but in 1936 was placed under the jurisdiction of the Navy. In 1952, President Truman subsequently restored jurisdiction over Kure to the territory of Hawaii. Yamase, Dennis, State-Federal Jurisdictional Conflict Over the Internal Waters and Submerged Lands of the Northwestern Hawaiian Islands. 4 U.Hawaii L.Rev. 139 (1982).

(3) Harrison, Craig, A Marine Sanctuary In The Northwestern Hawaiian Islands: An Idea Whose Time Has Come. Unpublished paper (1983).

(4) Id.

(5) HAWAII REV. STAT. section 4-3 (Supp. 1983) states that archipelagic waters are also included in each of the districts. There is therefore a basis for the county to assert its authority over coastal waters. This issue, however, goes beyond the scope of this paper and will not be addressed herein.

(6) State of Hawaii, Department of Land and Natural Resources, Honolulu, Hawaii. Title 13, Chapter 2. May 29, 1981.

(7) HAWAII REV. STAT. ch. 205A (1976 and Supp. 1983).

(8) HAWAII REV. STAT. section 205-33 (1976 and Supp. 1983)

(9) The state has in the past requested the use of Tern island as a fisheries base and has been denied that

request by FWS. The DLNR is currently drafting another request for Tern island to be resubmitted. The state has also looked to Midway as a potential site for an albacore base. A study is being completed to determine the economic feasibility of establishing such a support station on Midway. The draft of that study ultimately recommends the establishment of such a base. Review Draft, Midway Islands Albacore Fishery Feasibility Study. Department of Land and Natural Resources, Division of Aquatic Resources, State of Hawaii (October, 1983).

(10) Regulation No. 4, supra note 6, section 13-2-23.

(11) Id., section 13-2-11(c)(8).

(12) HAWAII REV. STAT. section 205A-22(4) (1976 and Supp. 1983)

(13) 16 U.S.C. Section 1456(c)(1).

(14) HAWAII REV. STAT. section 205A-3(3) (1976 and Supp. 1983).

(15) Sect'y of the Interior v. California, 52 Law Week 4063 (January 11, 1984).

RISK FACTORS IN MARINE RESOURCE EXPLOITATION

Njoman Suwidjana
ASEAN Finance Corporation
Singapore

In the past decade there has been a remarkable increase in marine resource exploitation activities. Inspite of this, however, marine resources are still largely underexploited. As we know, the sea covers about seventy percent of the surface of this earth, and it has enormous resource potential.

Various factors all closely intertwine contribute to this underexploitation. Among the more important are: a) lack of government incentives; b) technology intensity of marine resource projects; c) capital intensity of marine resource projects; d) rate of return on investment; and perhaps most important of all, e) the high risk. Marine resource exploitation projects are among the most risky undertakings. Investors have often been forced to think twice or thrice before reaching a decision. Many had been discouraged because they were unsure of having sufficient information on the risks involved.

This paper attempts to throw some light on the questions surrounding risks in marine resource investments. In doing so it shall, firstly, identify the risk factors, examine their nature and operation, and further discuss how they affect investment decisions. Secondly, it shall identify methods currently employed to avoid or overcome these risks. These will include both internal business policies/strategies as well as the availability of external facilities. It will discuss their nature, operation, advantages and disadvantages. Finally, as part of the conclusion, it will suggest an alternative method for investors to avoid the above risks.

The paper will approach the subject from the investors' point of view, and will put emphasis on aspects with direct policy relevance. Inspite of their importance, capital and technology intensity, return on investment, and government policies will not be discussed in this paper.

The paper shall also argue that it is important for policy makers in both developed and developing countries alike to keep in mind that this earth has limited resources. Therefore we must exploit them optimally. That it is in the long term interest of all for all countries to have balanced resource exploitation strategies, taking into account renewability and accessibility of these resources. Most of the nonrenewable resources are on land and more easily accessible whereas most of the renewable resources are offshore and therefore less accessible. If initiatives to exploit these resources are left solely to the private sector, there is a good chance that onshore resources will be depleted much too soon and marine resources, inspite of their renewability, will continue to be underexploited. Governments therefore have a crucial role to play in protecting the long term interests of their citizens. They should consider treating these vital, easily accessible, but nonrenewable resources as emergency reserves, and place more emphasis on exploitation of less accessible but renewable marine resources.

ECONOMIC AND FINANCIAL INFLUENCES CAUSED FROM THE CONSTRUCTION OF OFF-SHORE MAN-MADE ISLAND

Kenji Hotta
College of Science and Technology
Tokyo, Japan

Abstract

The purpose of this study is 1) research of possible economic and finantial influences casued from the construction of off-shore man-made island - 2) analysis past data on land-fill type and its review for as the future reference.

For an island nation, like Japan, utility of off-shore space offers her an enormous potentiality for the creation of new land. Its first step is seen in the cases of Port Island, Nagasaki Airport and Gobo Power Plant ie land-fill type.

After four years of investigation done by the Ministry of Transportation, Ministry of International Trade and Industry and Kozai Club, they came out with two final figures for its cost - floating and land-fill. Therefore, in this time, using this estimated cost, simulation of economic influences on the hinter-land of island were made. Input-Output Analysis by W. Leontief was selected as its method. This quantitive method makes seperate analysis possible for each prefecture ie with its unique industrial structure; human and natural resources; hinter-land ecinomic influences. In the process for the land-fill type, actual figures of already existing island were taken into consideration. From four-points of view, the study was researched;

1) Public investiment - ie off-shore island itself
2) activation of local economy
3) constructing plan and its method
4) coastal zone management.

Its placement in which location is yet undecided. Several prefectures have shown interest in this venture. We hope, no matter where it would be a factor to ameriolate local and social environment of the area.

MARINE INTENSIVE TOURISM IN ASEAN COUNTRIES

Md. Habibullah Khan
Department of Economics and Statistics
National University of Singapore

Tourism is a composite product which enters into international trade flows as an invisible item. The potential development of the industry depends largely on the effective utilisation of marine resources. Beaches, reefs, sport fishing, interisland cruises, surfing, water skiing, seafood restaurants, etc., help significantly in promoting a country's tourist industry. This study intends to make a survey of the various tourist resorts in the coastal areas of ASEAN countries with particular attention to Sentosa and St. John's islands in Singapore, Phuket, Samui and Pattaya in Thailand, Penang in Malaysia, Sombrero Park in the Philippines, and Bali in Indonesia. Demand for marine-based tourism in this region depends on a number of factors. These include tourist's income, volume of sea-borne trade in relation to total trade, cost of travel by sea in relation to airfare, relative prices in different countries, degree of marine pollution, etc., as well as various other social, political and demographic factors. An econometric analysis of the marine intensity in tourism will be made for Singapore. The various price and income elasticities will be estimated by using regression analysis. Such an analysis will have important policy implications and can easily be extended to other ASEAN countries. The various aspects of supply and marketing of the tourist industry in the region will also be examined.

A marine intensive tourist industry depends on a well-preserved environment and is therefore often in conflict with other marine resource users. The introduction of pollutants into seas by petroleum hydrocarbons and other sources is disastrous for water-based tourist resorts. On the other hand, the recreational activities (sports diving, collection or aquarium fish, shells, corals, etc., dumping of non-biodegradable rubbish) of tourists have caused ecological damage in many countries. Expanding tourist centers in coastal belts have had adverse effects on fisheries, aquaculture, mariculture and mangroves as well. The proposed study will attempt to uncover these conflicting uses of marine resources with special reference to ASEAN countries. Finally, policies will be suggested for the harmonious development of the marine sector.

THE USE OF SYSTEMS ANALYSIS TECHNIQUES IN MARINE RESOURCES DEVELOPMENT

Milton G. Johnson
Economic Consultant
Silver Spring, Maryland, U.S.A.

Abstract

There is a growing need for the engineer, scientist, and administrator to better understand the kinds of overall, across-the-board planning problems involved in the development of coastal and off-shore resources. Of primary concern is the awesome problem of maintaining, even improving the quality of the marine environment. The waters that ripple and break on any shore are part of vast regimes which are international, yes global in character, covering about 70% of the world and touching countless lands. The bigness of this water phenomenon for countries with extensive coast lines calls for an overall perspective that must meet the challenge of size and complexity. It is important that countries such as in South Asia, which have hundreds of miles of shorelines and many international commitments, should approach water questions with the kind of analytical and managerial knowledge that can cope with these large, interacting problems. Governmental bodies as well as private industries are finding that the use of systems analysis techniques can lead to sounder decisions.

Principles will be set forth on maintaining and improving the quality of the marine environment, with considerations of cost in so doing. In making the analysis, an early step is to identify specific needs and appropriate roles. A next step is to lay out alternatives for achieving objectives both within a given organization and external to it. The alternatives may be appraised through their costs and benefits. But, how do you make choices between goals when resources are limited? Each proponent of an aspect of water technology usually believes that his field must be greatly enlarged in the near future. How can we gather the data, accomplish the evaluation, and do the planning that will make rational choices possible?

Management by Objectives

More recently this process is being called "Management by Objectives" and today is probably the most widely accepted management system. Why? Because MBO gets results! Today, more than ever before, managers are being judged by the results they achieve. MBO is a systems approach to management that focuses on growth opportunities. It aligns a manager's need for self-development with corporate goals so that teamwork replaces the divergent activities that often characterize the operations of an industrial or governmental organization. Managing for results is organized around three basic elements:

1. A clear statement of objectives that are verifiable and can be achieved.
2. A plan to achieve these objectives, including the individual steps required and when each step will be taken.
3. A method for keeping account of these plans and steps to make certain that they are being followed and, if not, what corrective actions should be taken.

The key to MBO's operation is verification. The objectives as well as the steps leading to their achievement must be clearly verifiable. Wherever possible, objectives should include quantitative measures of achievement. Also, an objective should be expressive of its direct impact on the public. But deciding what the objectives are is only half the battle. The plans for achieving these objectives must be developed as well as a method for checking progress. It must be understood that MBO involves people-to-people communication. Objectives are not imposed from above. Rather, they are developed at the working levels through personal consultation with the individuals responsible for their achievement. (For further discussion see section below; "Selecting Meaningful Objectives.")

The Relevance of Zero-Base Budgeting

In the strategy for linking MBO into detailed action, a recent technique has become recognized as "Zero-Base Budgeting." At the Federal level it has moved so swiftly and all-consuming as to subsume the language of MBO. Thus, it has become a management process that provides for systematic consideration of all programs of a given agency in the formulation of budget requests. The central concept or key to ZBB's full utilization is that this management tool requires the participation of managers at all levels in the planning and evaluation processes. As with MBO, we could say that ZBB's objective is to compare alternative uses of scarce resources. In a real sense, the job of an executive is to make these comparisons in order to decide how best to exploit them, then to move forward in implementing the best alternatives. Thus, ZBB can be combined with MBO and become an important component of systems analysis for improving the decision-making process.

The Intergovernmental Interface

With respect to intergovernmental relations, actions would be taken to formalize the framework so that well-controlled exploitation may take place. The term "intergovernmental" is used here because the rules must be laid down for various levels of jurisdictions from local or metropolitan through state (or province) and regional to national and international. Among the coastal districts there is growing concern over jurisdiction of the sea floor along the coastlines and out onto the continental shelves. Boundary problems are increasing, particularly in areas of higher population and resource use.

There are some fears that rapidly advancing technology in the ocean may result in anarchy unless the serious questions of jurisdiction can be resolved. Apparently laws may not exist at present by which questions of ownership and jurisdiction in the sea areas beyond the territorial limits and the continental shelves can be resolved. This raises serious questions since our sea technology is bringing us closer to total undersea capability at various depths of the world ocean. It is important to increase our knowledge and develop the roles of regimes for governing the exploitation of resources in off-shore areas that are beyond present national jurisdiction. The complex problems of these vast areas are being studied by lawyers, diplomats, engineers, geographers, economists, and others, under the subjet known as "Law of the Sea."

Representative Problems Impeding Exploration

One of the purposes herein is to identify some of the contributions that can be made to the analysis of coastal and ocean exploration problems by scientists and engineers within the current state-of-the-art. In setting forth these critical questions the following might be included:

1. Storms at sea and along the coastline, including hurricanes, typhoons, and other types of storm surges.
2. The movement of waste products through the waterways of the coastal belt into the ocean which becomes the sink for all pollutants.
3. Damaging and costly interference with ecological balance from unwise exploitation of resources of the coastline and adjoining areas. Here, estuaries and salt marshes become critically important.

4. As aforementioned, the improper and inefficient use of coastal space through inadequate boundary demarcation. At one end of the spectrum this creates problems between nations while at the other end, disputes between shell fishermen often result in costly law suits.

In evaluating the existing situation it is well to search out and delineate the specific problems which obstruct the achievement of objectives.

Selecting Meaningful Objectives

As discussed above, under "Management by Objectives," an essential first step in the analysis of coastal problems is the formulation of a set of goals and objectives. But in dynamic economic development, what types of statements can be made concerning them? Listed below are some objectives which would have general, if not unanimous acceptability:

1. Developing ways of opening up the coastal areas for exploration and development, such as improved maps, charts, and geodetic control.
2. Maintaining and improving the quality of the coastal environment in order to promote and protect the ecological balance.
3. Clarifying the problem of jurisdiction in increasingly complex boundary situations which will become more prevalent on local, state, regional, national, and international bases. (Boundaries between claims, leases, etc., of competing companies will need ever sharper and more accurate delineation.)
4. Protection of life and property from coastal storms and storms at sea through improved marine environment prediction and knowledge.

In proposing progress in coastal development, systems analysis would help to make specific and quantitative the objectives the program is to attain through measuring the dimensions of relevant national needs and estimating the cost of meeting them in various ways. In particular, the analysis helps to find out exactly what may be accomplished, to identify alternatives and provide a basis for choosing among them. Stating the objectives in meaningful terms may be extremely difficult for this may question the very existence of an activity. The value of agreed upon, clearly-stated objectives is that techniques can then concentrate on the relatively straightforward effort required for achieving the objectives.

Although the above discussion may seem detailed, it cannot be over-emphasized that if objectives are not correct, subsequent analyses will almost certainly be fruitless. If wrong objectives are specified, then the most ingenious selection of sophisticated techniques and criteria or measures of effectiveness coupled with mountains of data processed on the most advanced computers will all be wasted. Specific, realistic objectives for coastal programs may be difficult to formulate but the efforts made in this direction will certainly lead to improvements and a better look into the future.

Criteria or Measures of Effectiveness

The next, or intermediate step is to analyze, insofar as possible, the output of a given program in terms of the objectives initially specified. In other words, there would be a reasonable description of outputs underlying the objectives, that is, services and products emanating from the program. In considering both "objectives" and "criteria" it is important to understand that these terms are to be concerned with "ends" rather than "means." That is, they are intended to reflect what ultimately is to be accomplished and for whom, not the ways to accomplish such objectives. The establishing of objectives and criteria are interacting processes; the selecting of criteria may even suggest the need for revision of the objectives. These criteria may be referred to as measures for determining effectiveness or simply, measures of effectiveness.

Criteria as explained above should have the following general properties:

1. Each criterion should be relevant and important to the specific problem for which it is to be used.
2. The criteria so used should consider all major effects relative to the objectives. A sufficient number of criteria should be included to cover all major effects.
3. Ideally, each of the criteria should be capable of meaningful quantification.

The Selection of Alternatives

The next and crucial step has to do with the subject of program alternatives or what may be considered as the best methods of accomplishing an agreed set of objectives. In this step we analyze alternatives seeking those which have the greatest effectiveness in achieving the objectives specified in the step described above or which achieve those objectives with the least cost. In this process, the programs are considered not as ends in themselves, but rather as means to higher objectives and in competition with other and possibly more effective programs. It is this competition among alternatives which is a crucial device for testing the effectiveness and economy of existing and proposed programs.

Emphasis on Supportive Analysis

The next step has to do with the analysis process which is in support of the objectives and alternatives described above. Although many different kinds of analyses may be performed, it is useful to distinguish two levels; one which may be considered as preliminary or an early, less-rigorous analysis, while the latter would be a more refined, detailed type of analysis.

A less-rigorous analysis can be carried out where the more detailed studies are not possible. Much of the relevant analytical work done thus far has resulted not from the various kinds of sophisticated technical analyses but from penetrating questions. Much can be derived from the dialogue, or questioning and response among the decision-makers, the proposal-makers, and the analysts. Where appropriate factual data are not available, one has to rely on whatever analyses can be found.

Program analysis is not easy, whether it is done at the less rigorous level or using the more refined methodology. Some of the most important limitations on the carrying out of these analyses are: (1) The problem of defining the real objectives; (2) the presence of multiple benefits; (3) inadequacies of data relevant to the analysis; and (4) difficulties in considering costs and benefits over a long period as well as a single point in time.

It should be clearly understood that quantitative estimates are not the only elements of systematic analysis. Human factors and intangible elements in a decision must not be ignored. Systematic analysis is designed to: (1) Uncover the relevant issues; (2) identify the specific assumptions, and factual bases upon which alternative recommendations rest; and (3) trace out the normal consequences and costs of each alternative.

These analyses are designed to provide information that is vital to decision-making in a complex structure. They are primarily a tool for high-level decision-making and will not be worthwhile unless high-level management understands them, wants them, uses them.

The Systems Approach and Socio-Economic Evaluation

The systems approach should be addressed not only to the furtherance of scientific and engineering efforts but to analyze the effects of coastal exploitation upon society. Thus, before we embark upon scientific efforts in the coastal zone we would be well-advised to make analyses of their anticipated costs, together with social and economic benefits. This admonition applies particularly to competing programs. Systematic commitment of resources depends upon a balanced program of: (1) Science, engineering, and technology; (2) services; and (3) socio-economic evaluation. We have consistently downgraded the last, yet without analysis of human impacts we risk developing service without focus or with potentially dangerous results.

Government agencies produce and disseminate products and services which are designed to improve the public welfare and safety and to encourage commerce and trade. Thus, an early task of socio-economic evaluation would be to identify specific users and their needs, then determine the extent to which various combinations of products and services can meet those needs. This would be related to an analysis of costs and benefits from various combinations of products and services. General studies in economic regions can play a significant role in providing valuable analytical data.

Conclusion

Through systems analysis or similar orderly and rational approaches to decision-making, we are able to assess the costs of achieving objectives against the benefits to be expected, thereby making possible a more intelligent, efficient use of the resources available. This process should be viewed in the wider context of the coastal environment which is at once urban and non-urban in character yet encompassing much wider regimes.

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THE DEMAND FOR MARINE RESOURCES

James Barney Marsh
University of Hawaii and
East-West Center
Honolulu, Hawaii, USA

Increasing exploitation of marine resources creates a pressing need for clear analysis to ensure that management policies will be sound. However, vast changes have made the analysis seem monumentally difficult, if not impossible. It suffices to name just a few of the changes to demonstrate the resulting complexity. Ownership patterns of known and expected resources have been irreversibly altered through the extension of maritime and exclusive economic zones, the establishment of the archipelagic principle and the conception of the common heritage thesis. The accessibility and potential exhaustibility of resources has been advanced through the rapid introduction of high technology into fishing and offshore platform activity. Finally, rapid economic growth in such highly maritime regions as East and Southeast Asia has induced growing needs for all resources, the marine being no exception.

In the face of such complexity it is vital to keep in close touch with the basics of analysis. Hence, the objective of this paper is humble: it is a restatement of the economic theory of demand in the context of several specific marine based resources as they are found off the shores of Asian countries. Due account will be taken of the interaction that may exist between the markets for the resources and those of similar or related resources produced on land based sites. We will also look into the impact of rising income and production cost factors on the demand for the marine resources.

The resources in question are hydrocarbons, shipping lanes, waste disposal sites and fish. The study is to be basically theoretical, although many known and suspected statistical inferences about these four economic activities will be used for illustrative and heueristic purposes.

Clearly, the resources in question must be defined with some care. We are dealing in all cases with derived demand, that is, demand that is derived from larger world wide markets. For example, the demand in the world economy for energy gives rise to the need to produce it in a variety of locations. But to produce energy, it is necessary for firms to demand productive inputs such as labor, capital equipment and geographical space characterized by the presence of hydrocarbon reserves. Hence, the resource is proven reserves, the demand for which is derived from the demand for energy in the world economy, Similarly, in the fisheries, the resource demanded is geographical area (or volume in the water column) containing reserves or stocks of fish. In waste disposal it is geographical sites containing desirable properties of isolation and assimilative capacity. Finally, in shipping it is surface area of marine space containing desirable properties of location and navigability. Respectively, these demands are derived from the demand for food, for the products of waste producing industries, and for the goods involved in international trade.

The theory of derived demand is well established in microeconomic literature. It is our objective to apply this theory to the resources mentioned above. In particular, we will be interested in the probable magnitude of the elasticities of derived demand, i.e., of the degree of responsiveness of quantity demanded to price level changes. Because of the known theoretical relationships between these elasticities and other closely related elasticity coefficients, and because of known empirical estimates of the other elasticity coefficients, it is possible to make educated guesses as to the range of values into which they fall. The resulting estimates will be strictly preliminary, but will point the way toward other needed research.

MRM-6: MARINE TRANSPORTATION

THE CASE FOR A SWATH INTERISLAND FERRY SYSTEM

J. B. Harmon
and
S. A. Nicinski
SEACO, Incorporated
Honolulu, Hawaii, U. S. A.

THE FERRY HISTORY

One form or another of interisland ferry transport has existed in Hawaii almost since its discovery by Captain Cook. In the late 1940's the Interisland Steamship Company pulled up its gangplank and slowly faded into the west. Its demise was caused largely by the aging, Navy-converted vessels it was using and the arrival of efficient airline transportation.

In the last serious attempt to establish a full-service ferry system in 1962, State Senator John Hulten managed to get the Legislature to authorize twelve million dollars for its support. The funds were to be raised through the sale of revenue bonds, but problems with bond experts delayed the process until 1964 when the proposal was resubmitted to the legislature for a fourteen-million dollar package that failed to get sufficient votes. In 1967, Hulten devised a plan for a four-ship ferry system similar to those used in Alaska. The cost of each was figured at eight million dollars. Again a series of delays occurred with the various investment schemes that were attempted and by 1976 his 460-ft monohull vessels (Figure 1) were programmed at sixty-five million dollars each. They could haul a thousand passengers and two hundred or so cars, considerably more than the programmed need at that time, or even well into the future. The demise of the Hulten plan occurred when Hulten's corporate investors required the State to guarantee their investment, an act the Legislature was unwilling to accept. About the same time, however, the SEAFLITE passenger ferry was announced, requiring no such guarantee from the State. The Navy's Semi-submerged Platform (SSP) KAIMALINO, also began operating successfully in Hawaiian waters, demonstrating the tremendous seakindly advantages of the SWATH concept for passenger comfort.

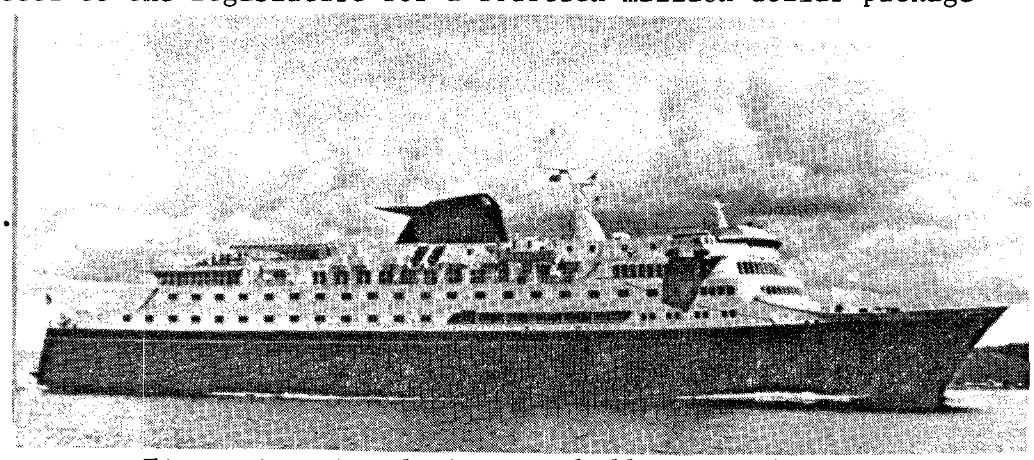


Figure 1. The Alaskan monohull COLUMBIA

THE NEED TODAY

The citizens of Hawaii who travel from one island to another must pack suitcases for the trip, and, like any tourist, take an airplane, rent automobiles, and frequent the hotels. A Honolulu family cannot visit Grandma on Molokai (less than 100 miles away) without packing up tourist-fashion and expending a great amount of money. No other state has the transportation obstacles that are presented in this island-state situation. A good interisland ferry system has long been considered a valuable asset. With the closing of much of our sugar and pineapple plantations, the State's outerisland citizens greatly need the flexibility of the small farm to keep employment stable. The Honolulu marketplace is ideally situated for an effective self-help program provided there is a way of getting produce there in a timely manner.

Since the closing of the Interisland Steamship Company, bulk goods have had to be transported on an inexpensive but very slow barge system operated by Dillingham's Young Brothers subsidiary. While the barges are effective for hauling heavy goods, they have proven to be very poor distributors for the outer islands' personal goods and farm produce. The Dole Company operates its own barges for pineapple shipments. More recently, Matson has introduced a barge system of its own.

However, none of these systems offers the frequency of service that will enable the small farmer to put his goods on the table in Honolulu. As a result, most of the produce that is utilized in the major marketplace, Honolulu, is flown in from California. In fact, because of the transportation problem, our out-state farmers and ranchers cannot compete effectively with the mainland or even with other nations around the Pacific for the Honolulu marketplace. Imagine that. Moreover, each island produces exquisite products: Waimea butter lettuce and celery are among the world's finest; there are gourmet coffee beans from Kona as well as macadamia nuts; large sweet papayas and flowers and foliage from Kauai, our garden isle.

While it is expected that tourists would make wide use of an effective ferry system, the system's success should in no way be dependent on tourist travel. In fact, from 1976 to 1979 the State had an interisland hydrofoil system, SEAFLITE, operated by LTV's Kentron division. SEAFLITE used the sophisticated Boeing 929 hydrofoil as presented in Figure 2. SEAFLITE attempted to compete with the airlines; it even charged the same rates and offered airline transfer rates just as the inter-island commuters do. Unfortunately, the local citizens still couldn't collectively take their automobiles, family and produce so the venture failed to serve local needs; later it failed altogether when the tourist industry regressed.

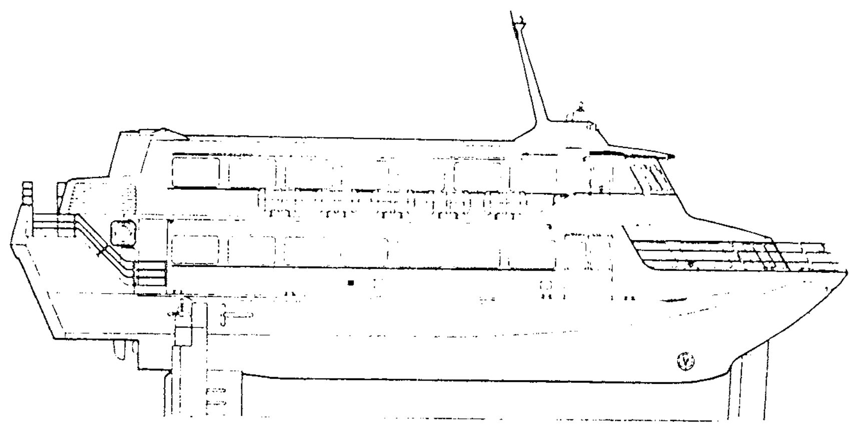


Figure 2. Boeing 929 Jetfoil used by SEAFLITE

THE ALTERNATIVES

The State of Hawaii has conducted numerous studies since the early 1970's aimed at the establishment of a State-owned ferry system. The demise of the Great Society, which had been asked to consider the Hawaii Interisland Ferry as a form of interstate freeway, has doomed recent attempts by the State to pursue a Federally-funded system. However, the results of their studies provide a wealth of data that is useful in the design and operation of a commercial ferry system. The data is also particularly supportive of the SWATH concept, mostly because of the projected customer acceptance of a vessel that is luxuriously spacious, and comfortable.

The proposed vehicle/passenger ferry would not compete with business travel on the airlines nor, for that matter with a hydrofoil system. Rather it would be a permanent alternative that will enable the family to pack up kids in the family car, spend the day at another island, and return home for the evening, very much like the Seattle ferries and those along the East Coast. As in the other states, business travel and time-critical cargo and personal transportation still will constitute the bulk of the interisland airline business.

If we are to restore a cargo/passenger ferry service, then what type is best suited to the task? Senator Hulten's Seattle-type ferry certainly would provide the comfort, luxury and capacity required. Unfortunately, its breakeven is projected to be about twice the maximum market and might require heavy subsidization in its early development. Do we resurrect SEAFLITE? The vessels were costly to maintain and if the vessel failed to remain aloft at-sea, the passengers were in for a rough ride. Do we become innovative...introduce a SWATH vessel which can maintain high speeds and passenger comfort in high sea states?

There are several critical technological factors that must be considered. The channels between the islands are frequently the roughest stretches of open ocean in the world. The Molokai channel between Oahu and Molokai is reknowned for its heavy sea states even on nice balmy days. So the vessel must be sized to provide passenger comfort in heavy seas. Figure 3 presents a chart of the minimum size of vessel that can provide the necessary level of comfort to attract passengers. This is the factor that shows why the SWATH concept is so strong a contender. Incidentally, the hydrofoil and air-cushion vehicles both offer superior speed and excellent passenger comfort qualities, but as anyone who experienced SEAFLITE's mid-channel power-outages knows, they are sickening when dead-in-the-water in rough seas. SWATH, in the same situation, is very nearly as stable as it is traveling at cruise speeds.

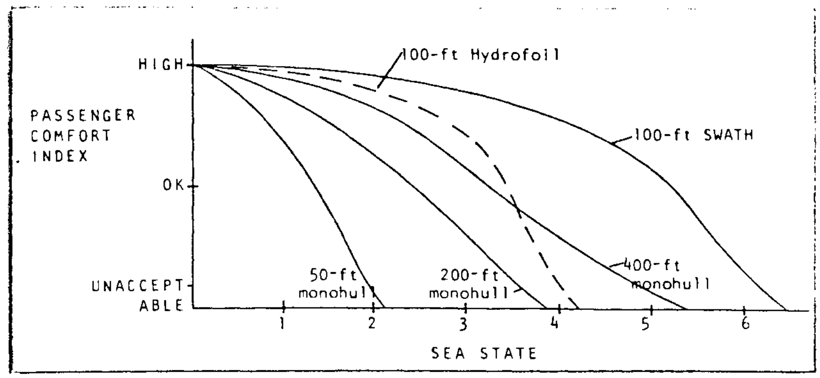


Figure 3. Passenger Comfort Index Comparison

From the standpoint of power needs during Hawaiian channel crossings, the SWATH again is the pick of the lot. Only a sailing vessel can beat it for rough ocean runs, and some of the advanced SWATH concepts adapt mechanical computer-controlled sails to alleviate power cost.

In smooth seas below sea state 3, the SWATH's greater hull surface area (therefore greater skin friction) consumes about 10% more fuel than a comparable monohull. Above sea state 3, the SWATH design and form generate less drag than the comparable monohull. The SWATH vessel can then maintain its cruise speed at a power consumption level below the monohull. Figure 4 graphically represents this significant SWATH feature at elevated sea states. The fuel factor along the West Coast might not favor SWATH. Most other places it does; and in the Hawaiian channels, there's no comparison, as anyone knows who has ridden the Navy's KAIMALINO.

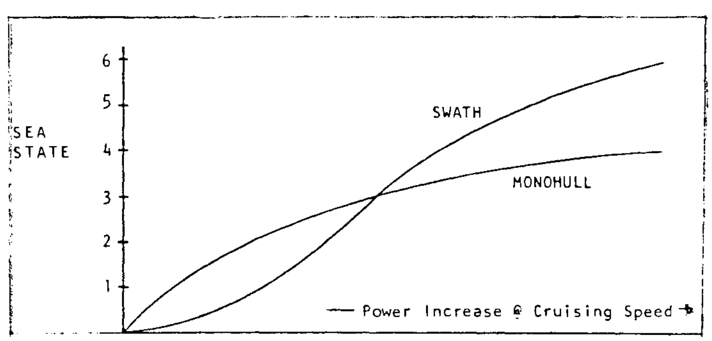


Figure 4. SWATH vs Monohull Power Curve

THE SWATH FERRY

The SWATH concept was first conceived in the late 1800's and has resulted in a number of patents dating that far back. By 1969, the U.S. Navy became interested in the concept, principally for use as a high-speed stable platform for launching research submersibles, and perhaps for ASW interdiction, salvage, and a host of other applications. The Naval Ocean Systems Center (NOSC) designed the KAIMALINO which was constructed in 1973-75 at the Coast Guard's Curtis Bay Shipyard in Maryland. KAIMALINO was transported to Hawaii where whe has been operated in a wide variety of range support and research activities. The 90-ft vessel is known for its ability to perform work in heavy seas. So successful was the KAIMALINO that the Japanese Mitsui Shipbuilding is offering its own version for a wide variety of applications, and has a larger 150-ft SWATH under construction for hydrographic surveys.

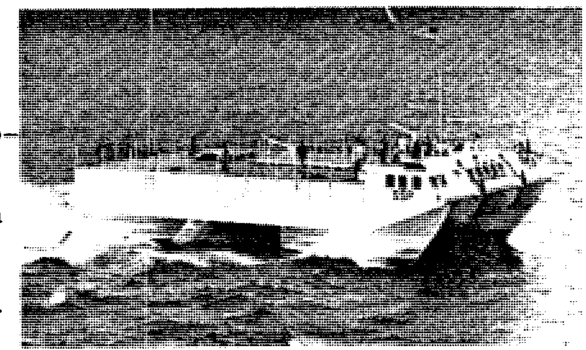


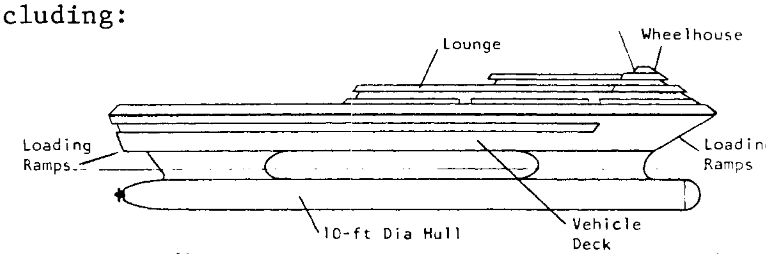
Figure 5. SSP KAIMALINO
(Official U.S. Navy Photo)

Because of the SWATH's stable ride in rough waters, seasickness is virtually nil. The vessel's design is ideally suited for high-speed applications. Perhaps the greatest advantage for the SWATH concept, aside from its seakindliness, is the usable space it provides. The large rectangular cargo space is structurally positioned above the rough seawater interface astride two submarine-like submerged buoyancy hulls. The thin, streamlined struts offer minimal resistance to the rough waters at the interface, hence the acronym for the Small Waterplane Area Twin Hull, or SWATH.

There are already several alternative SWATH concepts for Hawaii. Mitsui has one based on its survey vessel design that is well along in construction and certification. Unitek's Pacific Marine acquisition in Honolulu has one. Several designs exist at the University, and the State Department of Transportation has a half-dozen proposed designs based on a competitive design solicitation they issued in 1975. But the subject of this paper is the SEACO concept which embodies some of the best qualities of the SWATH concept with advanced architectural design to offer an exciting alternative for a critical need of the State of Hawaii.

SEACO participated in a proposal for the State-owned system which resulted in a preliminary design of a 3,000-Ton SWATH-type ferry system. However, it is planned to utilize a smaller vessel with fore and aft loading capability as a more appropriate concept for projected needs (see Figure 6). The use of smaller vessels offers the economic advantage of higher load factors, increasing the number of vessels as the market grows. In off-hours, fewer vessels would be used, like bus scheduling, and service to smaller harbors is easily accommodated. While the vessel's basic design is based on tried and proven technology, the development will embody a number of innovations, including:

- Diesel engines in the lower hulls
- Fore and aft loading schemes
- Draft-adjustment thru deballasting



Length:	180 ft	Displacement:	900 Tons
Beam:	100 ft	Cruise Speed:	18 knots
Draft:	16 ft		

Figure 6. Proposed SWATH Ferry

The initial schedule will most likely accommodate the existing port facilities at Kauai (Nawiliwili), Oahu (Honolulu), Maui (Kahului), and Hawaii (Kawaihae); later, service will be added to Hilo. And once the needed harbor facilities are constructed at Molokai (Kaunakakai), it will be added right away. The vessel's end-loading ramps readily accommodate to simple road-pier construction techniques as depicted in Figure 7.

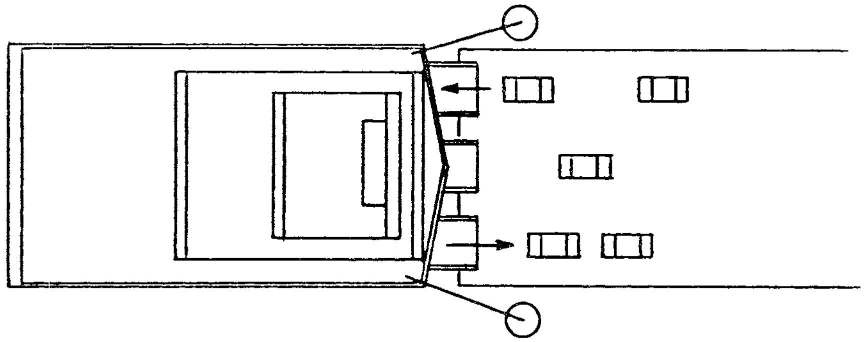


Figure 7. Loading/Unloading

The planned route for ferry operations is shown in Figure 8.

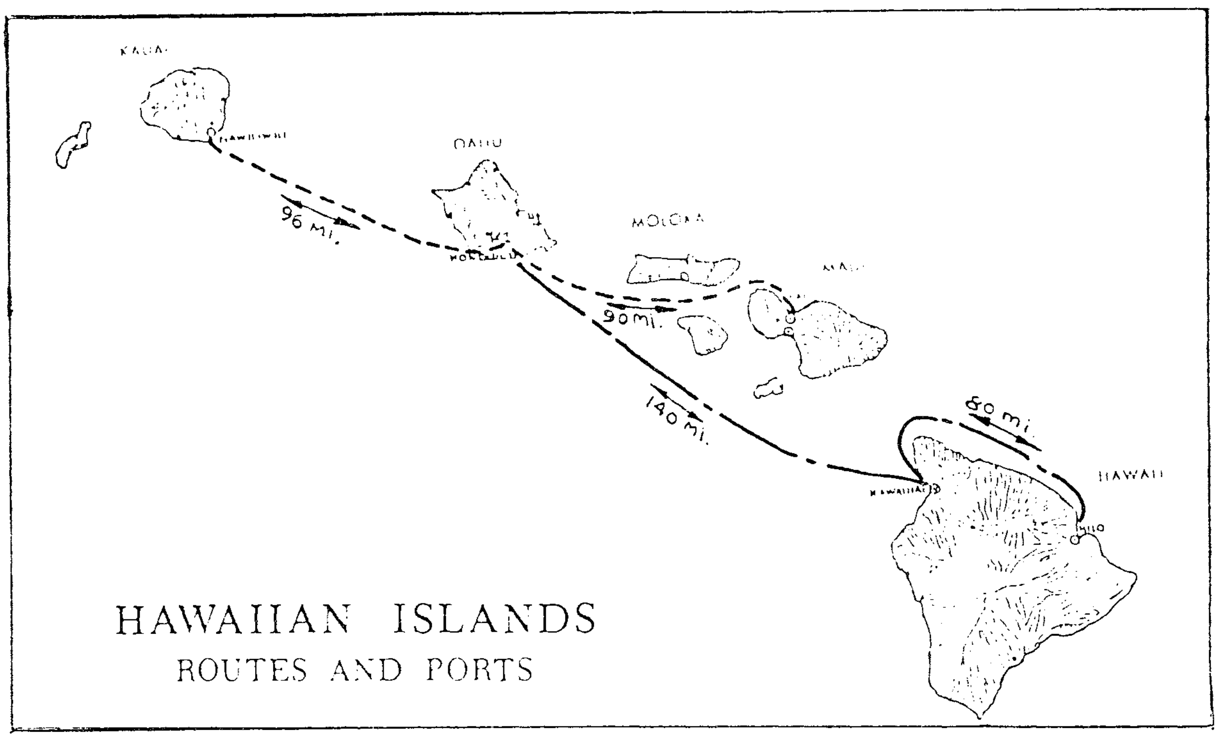


Figure 8. Planned Route for Interisland Ferry

The route schedule and distances are shown below.

TERMINALS	STATUTE MILES	TIME ENROUTE
Honolulu	0	-
Kauai	96	4 hrs 40 min
Honolulu	0	-
Molokai	52	2 hrs 30 min
Maui	38	1 hr 50 min
Honolulu	0	-
Kawaihae	140	6 hrs 45 min
Hilo	80	3 hrs 50 min

Imagine the convenience of packing the kids and a picnic in the family van for a day on Molokai. You already have reservations, so you arrive at the ramp area 20 minutes before departure time, about 7:30 A.M. Drive aboard and lock the van. The kids can spend the 2 ½ hours in the TV lounge or the game room; you can have breakfast in the lounge and stroll around the main deck. At 10:00 A.M., you're back in the car and headed for the State Park at Kokee for a full afternoon of hiking and sightseeing.

At 7:30 P.M., you board the ferry for the trip home. You can eat dinner in the restaurant or the gourmet lounge, or just enjoy the slowly expanding panorama of Honolulu. You're back in Honolulu at 10:00 P.M. The cost? For a family of four, figure on $52, plus meals and the game room, of course. $96 to Kauai and $90 to Maui, but you'll probably want to stay overnite to have more time to visit. By comparison, a roundtrip for four to Molokai by air costs $160, exclusive of auto rental, etc. To Kauai, it's $250, and Maui is $250. So while the ferry's cost isn't incidental, it certainly opens up affordable opportunities to visit relatives or just to see the other islands.

More important to the island's economy are the opportunities for the small truck farmer in Molokai to pack his truck and be in Honolulu in the late evening to market his produce to the wholesalers, or to participate in the farmer's market on Oahu.

The ferry is coming. Sooner or later. The ferry is coming to Hawaii.

SEMI-SUBMERGED CATAMARAN (SSC) APPLICATION IN MARINE TRANSPORT AND OCEAN DEVELOPMENT

M. Oshima, H. Narita, Y. Kunitake and H. Nakamura
Mitsui Engineering & Shipbuilding Co., Ltd.
Tokyo, Japan

ABSTRACT

The Semi-Submerged Catamaran (SSC) or Small Waterplane Area Twin Hull (SWATH) is the ideal design concept for variety of ship applications in marine transportation and ocean development, where good seakeeping and ample deck space as well as sustaining speed in waves are required with a modest-sized ship.

This paper presents an example concept design of the passenger/car ferry as well as the design and performance data of various SSCs constructed and under construction including the passenger ferry SEAGULL, the hydrographic survey vessel KOTOZAKI and the 2,800 gross ton support vessel for underwater work. As application to the field of marine recreation, designs of a small prototype SSC leisure boat and a larger version are briefly described.

1. INTRODUCTION

Several SSC type ships have been developed and built for marine transportation and ocean development during the past decade as a new type of ship which can provide good seakeeping and spacious deck space within modest-size.

In the United State the SSP KAIMALINO was built in 1973 and was followed by the 19.5 meter demonstrator SWATH boat SUAVE LINO built in 1981. (1) (2) In Japan, Mitsui Engineering & Shipbuilding Co., Ltd. (Hereinafter called Mitsui) completed the high speed SSC ferry SEAGULL in 1979 after construction and testing of the 12 meter experimental craft SSC MARINE ACE, the 250 gross ton (G/T) hydrographic survey vessel KOTOZAKI in 1981 and is presently constructing a 2,800 G/T large SSC support vessel for underwater work. (3)

The SSC consists of a pair of submerged main hulls or lowerhulls, an above-water platform structure, and streamlined surface-piercing struts which connect lowerhulls to the upper structure. Because of this unique hull shape, the SSC is less susceptible to the wave forces in a seaway and has longer natural periods of motion than a conventional monohull ship, while it can provide greater effective deck space and less speed loss in waves, in addition to good stability.

Several years ago the State of Hawaii showed much interest in adopting the SSC passenger/car ferry for the Hawaiian inter-island marine transportation in view of the wave conditions, the size of transportation demand and the SSC's advantagerous features. At that time Mitsui conducted some conceptual design studies and since then much additional experiences including the operation of the SSC type passenger ferry SEAGULL have been accumulated to confirm the suitability of the SSC for Hawaiian inter-island passenger/car ferry service. Therefore, an example concept design of the SSC type passenger/car ferry is briefly presented in Chapter 2.

The first SSC type passenger ferry SEAGULL has provided much technical information through the extensive sea trials and service experiences of successful commercial operation, and some of the results are described in Chapter 3.

In the field of ocean development, the KOTOZAKI was delivered to the Japanese Ministry of Transport in 1981. The larger SSC support vessel will be delivered to JAMSTEC (Japan Marine Science and Technology Center) in 1985. The outline of these designs and comparison of these vessels' performance with those of other ship types are described in Chapters 4 and 5.

Because of comfortable ride attained by SSC's good motion characteristics SSC has a good potential for marine recreation as leisure boats. Therefore Mitsui has built some prototypes in order to ascertain their performance in real sea conditions. Chapter 6 will present a design of 12 meter long SSC Cruiser SEA SALON as well as a smaller version.

2. SSC CONCEPT DESIGN FOR HAWAIIAN INTER-ISLAND MARINE TRANSPORTATION

It appears that there is a need to develop the inter-island passenger/car ferry system as a transportation network within the Hawaiian Islands.

Considering the transportation demand, a relatively small, fast and comfortable passenger/car ferry appears to be necessary for generally rough seas between the islands. The SSC type ferry is a primary contender among various ship types in satisfying these requirements.

During the preliminary discussions between the State of Hawaii and the Mitsui some basic requirements for the subject ferry were assumed as follows:

Service speed .... 25 to 35 knots

Range .... Approximately 320 n.m. (Corresponding to a round trip between the Oahu and the Hawaii Island.)

Payload .... 25 to 50 cars
90 to 175 passengers
(Each car weighing 2 tons, 3.5 passengers being assumed for each car)

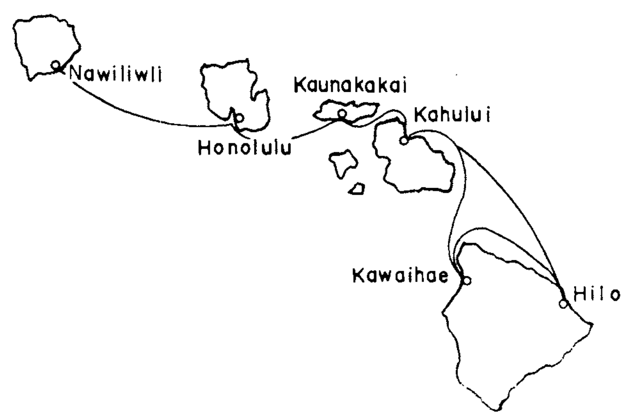


Fig. 1 The State of Hawaii and Example Routes of the Ferry Service

Operational routes were considered as shown in Fig. 1. Wave conditions in the vicinity of those routes were assumed as 8 feet waves for normal operation and 15 feet high waves for the severest operating condition.

Based on the above design requirements, Mitsui conducted conceptual design of various alternatives to be used for a feasibility study. The feasibility study included the basic model tank tests and studies on machinery selection and engine room arrangement, hull material selection and structural arrangement, etc.

Principal particulars of an example among those alternatives are shown in Table 1 and its artist's impression is shown in Fig. 2.

Table 1. Principle Particulars of Hawaii an Passenger/car ferry

Length overall	39.6 M
Length of lower hull	35.0 M
Breadth overall	18.0 M
Depth to car deck	7.3 M
Draft, full load	4.4 M
Pay load	25 cars and 90 passengers
Main engine (Gas turbine)	
CSO	10,000 ps
Speed at CSO	26.5 knots
Tank capacity	
Fuel oil	40 m^3
Ballast	abt. 120 m^3

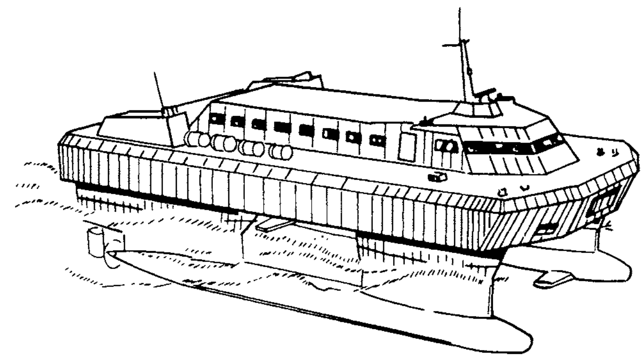


Fig. 2 Artist's Impression of SSC Passenger/Car Ferry

These design studies showed that this type of ferry is technically feasible and the unique advantageous features of the SSC can successfully be realized in the Hawaiian ferry system. Excellent performance in waves and the relatively large deck space attained by this SSC ferry will provide the comfortable and economical transportation of the passengers/cars which neither any other types of ships nor the aeroplane can realize for the Hawaiian inter-island transportation network.

3. OPERATIONAL EXPERIENCES OF THE SSC FERRY SEAGUALL

One of the domestic shipping companies in Japan, which operates many ferries on the routes between our main island of Honshu and the seven remote islands near Tokyo, had been concerned about passenger complaints of poor ride quality and resultant seasickness. Therefore, the company considered enlarging the size of their ferries or adopting a relatively small-sized new type of ship capable of carrying large number of passengers at high speed with good seakeeping characteristics, in order to improve their ferry service with regard to passenger comfort.

They compared various ship types including hydrofoils, hovercraft, etc; however, they noticed some disadvantages such as limitation of the number of passengers, high initial cost, and high maintenance cost. Mitsui proposed an SSC passenger ferry design which was just following the design experiences on the Hawaiian passenger/car ferry and construction and sea trial experiences of the 12 meter long experimental SSC MARINE ACE. Consequently, they found the SSC to be the most suitable ship to meet their demands from various viewpoints of ship motion, speed in waves, economy, etc.

The basic design requirements for the SEAGULL were the capacity to carry 446 passengers at a service speed of 23 knots and the ability to run comfortably even in rough seas with a significant wave height of up to 3.5 meters (11.5 feet).

Accordingly, the main particulars of the SEAGULL were decided as shown in Table 2.

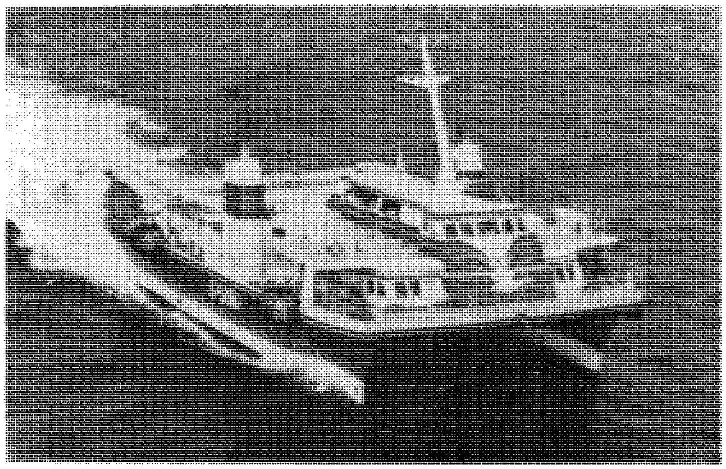


Photo 1 SEAGULL in Operation

Table 2 Main Particulars of SEAGULL

Length b.p	31.5 m
Breadth, max.	17.1 m
Depth	5.845 m
Draft, full	3.15 m
Draft, max.	3.8 m
Displacement, full......	343 tons
Main Engine ...	High speed diesel 4,050 PS X 2 sets
Speed, max.	27.1 knots

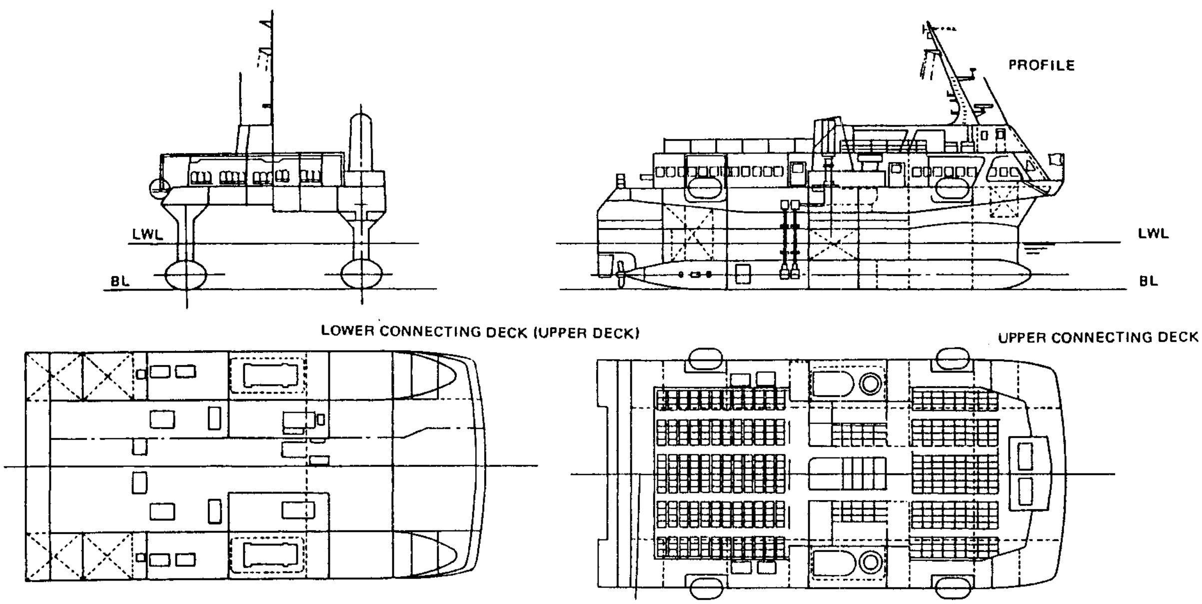


Fig. 3 General Arrangement of SEAGULL

Full-scale trials including a comparative sea trial with conventional monohulls were conducted to investigate powering, seakeeping, maneuvering and fin control response from October 1979 to April 1980.

Extensive seakeeping tests with the SEAGULL were carried out near a operational route in order to confirm the SSC's seakeeping characteristics including fin control effect and deck impact. During these test periods, waves of 2.6 meter significant height were measured by a wave-rider buoy and also a wave height of about 3 meters in significant value was visually observed in another test.

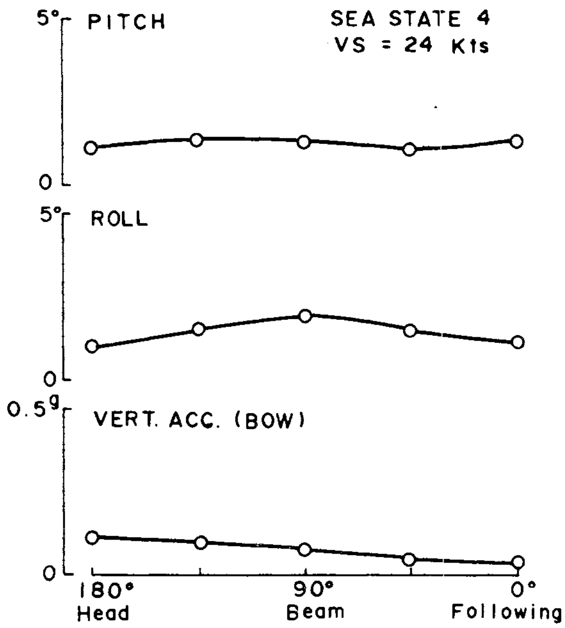


Fig. 4 Pitch, Roll Motions and Vertical Accelerations for SEAGULL

Fig 4 shows the significant pitch and roll motions and vertical accelerations in Sea State 4 with a 2.4 meter significant wave height at ship's speed of 24 knots. The fins were automatically controlled during these tests. As can be seen in this figure, less than 0.1 G vertical acceleration and less than 1.5 degree pitch and roll motions were measured for all headings. This indicates the SSC's excellent ride quality since the comfort of passengers on board is strongly affected by the magnitude of vertical acceleration and motions. In fact, the acceptable level of vertical acceleraiton for passengers' comfort is considered to be less than about 0.2 G.

In April 1980, side-by-side running tests with four different monohulls were carried out in wave conditions of Sea State 3 to 4 in order to directly compare the seakeeping performance of the SSC with these monohulls. Ship's motions were observed and recorded both on board and from a helicopter. Especially, pitch, roll motions and vertical acceleration at the bow were measured at a ship's speed of 24 knots both on the SEAGULL and one of the high speed monohull vessels with a length of 35 meters.

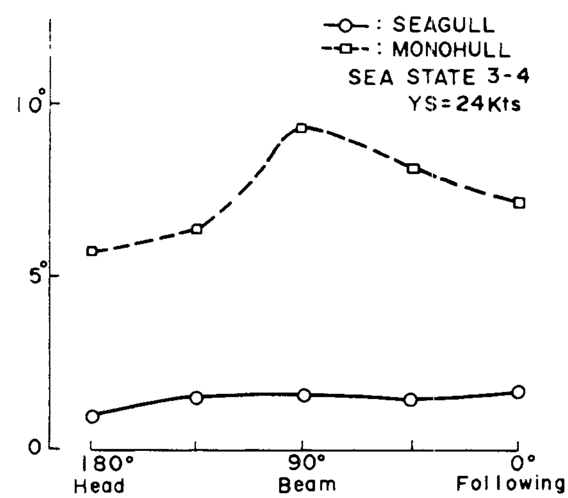


Fig. 5 Comparison of Roll Motion SEAGULL and Monohull

During the tests on all headings the SEAGULL experienced about 1/4 to 1/6 the roll angles and about 1/3 to 1/7 the vertical accelerations at the bow compared with the monohull as can be seen in Figs. 5 and 6. Possible degradation of the mission effectiveness caused by sea sickness of crew members and measurement staff were also experienced on board the high speed monohull, while no one felt motion sickness on the SEAGULL.

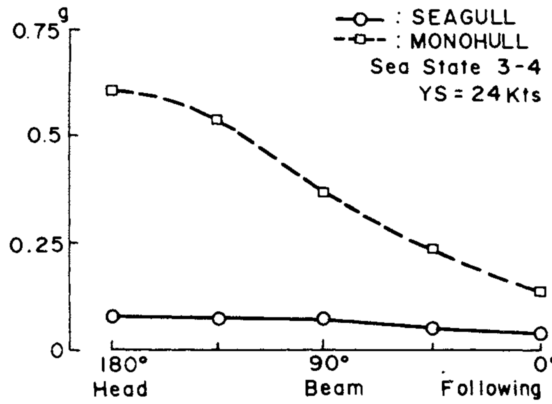


Fig. 6 Comparison of Vertical Acceleration at the Bow between SEAGULL and Monohull Ship

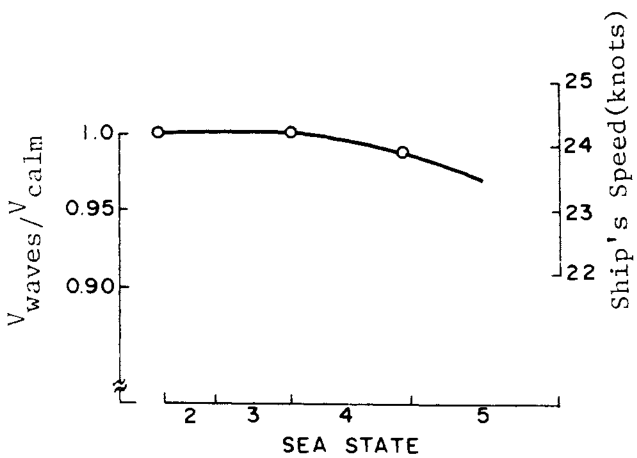


Fig. 7 Speed Loss in Waves for SEAGULL

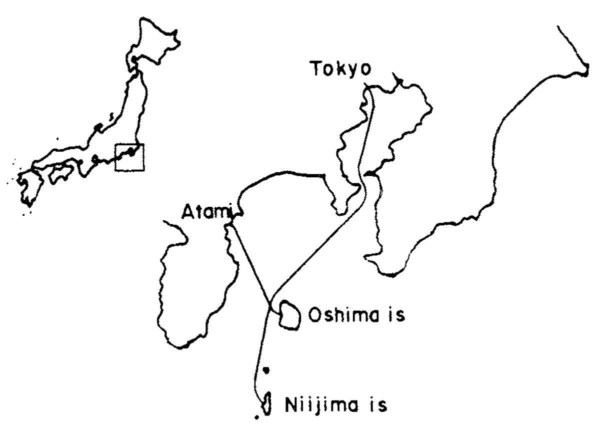


Fig. 8 Operational routes of SEAGULL

Another advantage of the SSC is sustainability of the speed in waves. Fig. 7 shows measured speed loss at service power in various Sea State for the SEAGULL. As a result, the speed loss of the SEAGULL was less than 2 percent even in Sea State 4.

These sea trial results proved that the SSC can maintain a service speed with good seakeeping quality and passenger comfort even in rough sea conditions.

Service Experiences

The SEAGULL was put into commerical operation on the route between Tokyo and the remote islands of Oshima and Niijima, as shown in Fig. 8, in July 1981. Except for summer season, July and August, she has been running twice daily round trips between Atami and Oshima island.

Passenger comfort in the SEAGULL has been optimal because of relatively minor motion and acceleration as proved during full-scale seakeeping tests.

The seasickness ratios among SEAGULL's passengers were less than 0.2 percent from August 1981 to February 1982 and 0.6 percent in 1982 according to the record by the operator. Women, children and aged, who are liable to get seasickness easily, particularly enjoy this mode of sea travel. The children are also fascinated by the novelty. The SSC has changed the image of high speed passenger boats.

The accumulated operating distance was more than 90,000 n.m. from July 1981 to December 1983. The main engines were driven more than 7,400 hours as of February 1984. The Z-drive system with dual vertical shafts which was newly developed by Mitsui proved its high reliability as well as high transmission efficiency.

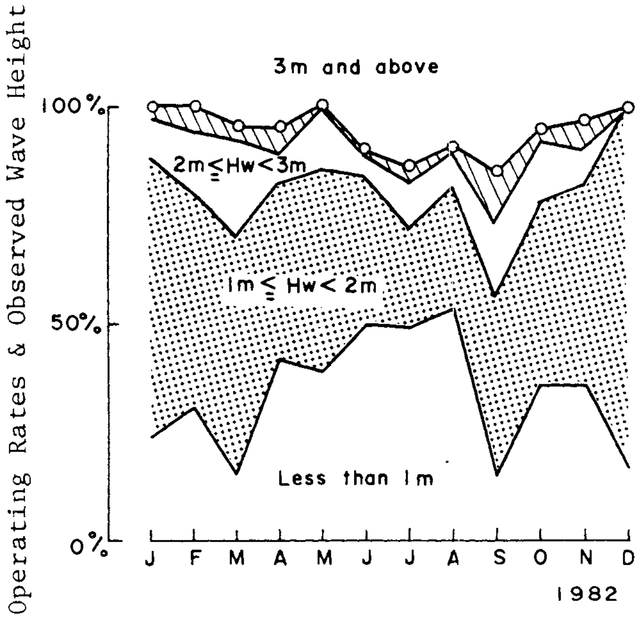


Fig. 9 Operating rates and observed waves heights during operation

Regarding the operating rate the actual service operated runs was 94 percent of the total scheduled runs in 1982. This operating rate is considered to be quite high because we should take into account the facts that some runs were cancelled due to vulnerable port facilities on Oshima island facing the open sea, and due to the operator's in-house rule by which the ship is not operated in case of more than 3.5 meter waves will be prospected before leaving the mainland port. Therefore the operating rates in the summer season or the typhoon season were obliged to be decreased. Fig. 9 shows the distribution of the operating rates and the visual wave heights during operation in 1982. (4)

The figure indicates the operators of the SEAGULL maintained their regular survices in high waves of more than 3 meters in significant value except for some extremely bad conditions caused by a typhoon. The operator was concerned about severe wave impact on the underside of the upper structure; however, no excessive wave impact nor damage were reported.

The SEAGULL has enjoyed a good reputation for ride comfort and this fact resulted in higher seat occupation ratios than those of conventional monohull ships.

4. HYDROGRAPHIC SURVEY VESSEL SSC KOTOZAKI

The 250 G/T hydrographic survey vessel KOTOZAKI of SSC type was designed and built by Mitsui as the general arrangement is shown in Fig. 10, and delivered to the Fourth District Port Construction Bureau, Ministry of Transport in March 1981. Now this vessel is being utilized for bottom and water sampling work as well as for meteorological and oceanographical observations in the Inland Sea of Japan.

The main particulars of KOTOZAKI are shown in Table 2.

Table 2 Main Particulars of KOTOZAKI

Length, overall	27.0 m
Length b.p.	25.0 m
Breadth, mld	12.5 m
Depth, mld	4.6 m
Design draft, mld	3.2 m
Complement	20 persons
Main engine	1,900 PS x 2
Speed at M.C.O.	20.5 Knots

As a hydrographic survey vessel, KOTOZAKI provides a stable platform from which data can be taken as well as a deck area sufficient to set equipment and conduct various work effectively, laboratory facilities suitable for scientific researches, and comfortable living space for the crew and research personnel.

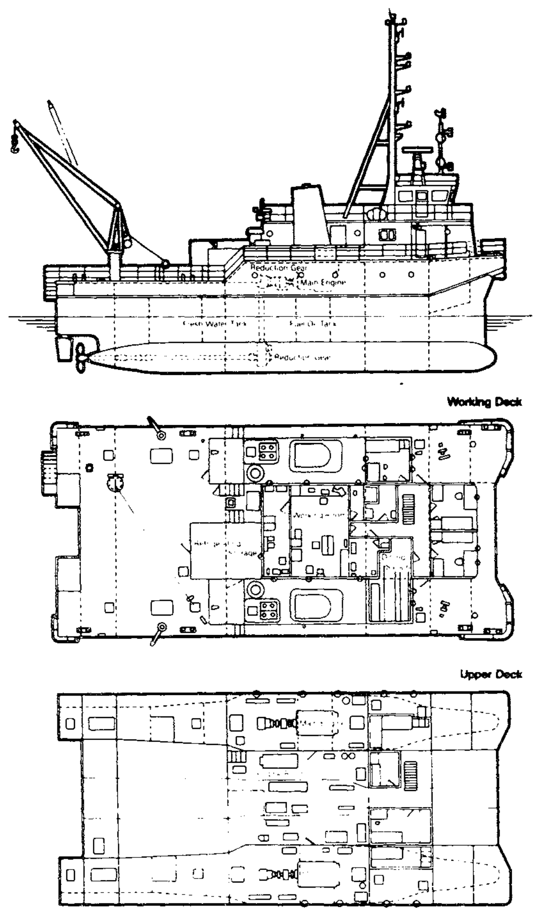


Fig. 10 General arrangement of KOTOZAKI

In order to confirm the superiority of motion performance of the SSC type as compared with the monohull and the conventional catamaran with 250 G/T, motion amplitude of heaving, pitching and rolling were investigated. Fig. 11 shows an exmpale of the comparison of motions at zero speed. Motions presented in this figure are predicted by theoretical calculation with experimental corrections of viscous damping for regular seas in which the ratio of wave length to wave height is 20. (5) Heaving and pitching amplitudes of the SSC shown in this figure are sufficiently small within the wave height of 2 meters. Even in the waves of 2 meter height, the motion amplitudes of the SSC are about one fifth of those of the monohull and the catamaran.

Considering the mission of this SSC, the deck level was designed to be relatively low for easy access to the water.

As the hull construction, a hybrid structure, which is composed of the main hull made of high tensile steel and the deck parts of anti-corrosive aluminum alloy, was chosen to allow a reasonable design with respect to speed performance, maintenance and cost. Aluminum-clad steel was used for connecting these different materials at the top of the struts.

Two high speed diesel engines each supply 1900 PS were located on the port and starboard sides of the deck. The simplified vertical bevel gear system was also adopted for power transmission from the engine to the propeller. Controllable pitch propellers were chosen for smooth operation at a wide range of speed from zero to 20 knots.

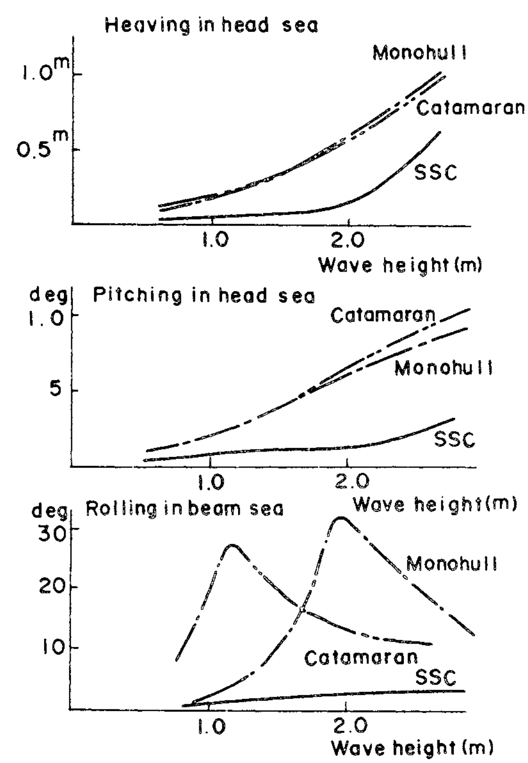


Fig. 11 Motion characteristics at rest

Table 3 Natural Period of Motions

	SSC	Monohull	Catamaran
Heave (sec)	5.0	3.4	3.5
Pitch (sec)	9.9	4.3	4.5
Roll (sec)	15.0	5.9	4.8

The rolling motion of the SSC in beam seas is also very small. While, in cases of the monohull and the conventional catamaran, very large rolling motion occurs in the waves of abt. 1 and 2 meter height respectively due to synchronized motion response to the wave caused by their shorter natural period of rolling, as indicated in Table 3.

Motion characteristics of each vessel in high speed operation are quite similar to those at rest. The motion of the SSC in this condition is much less than other types of vessel. The operator of the KOTOZAKI has reported that she is successfully working at sea as an advanced hydrographic survey vessel, ensuring high performance beyond the limitations of conventional ships. It is worth noting here that the captain said the tasks in rough seas, which they couldn't do with conventinal ships, could be achieved with this SSC-type survey vessel.

5. 2800 G/T SSC TYPE SUPPORT SHIP

Having little natural resources on land, it is an urgent task for Japan to search for mineral deposits in continental shelves, secure energy and biological marine resources as well as to utilize ocean space. Under these circumstances a high-performance specialized vessel was urgently needed to support large-scale underwater experiments in the sea and on seabeds.

Therefore, JAMSTEC decided to construct a support vessel equipped with a submersible decompression chamber (SDC) and a deck decompression chamber (DDC). She would help to establish new diving techniques and obtain highly precise experimental results in various research and developmental projects as well as oceanographic surveys.

After an extensive study of the basic features of the vessel, the SSC hull form was selected because of its excellent stability at sea and spacious work deck with a center well which provides easy and safe handling of the SDC during hoisting and lowering from and to the water. (6) Fig. 12 shows the comparison of the SSC's rolling motion with a conventional monohull. (7)

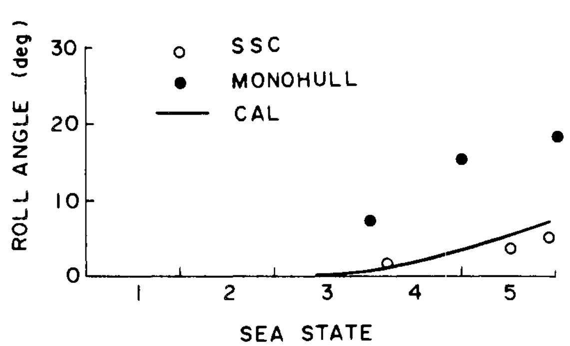


Fig. 12 Experimental Results of Significant Roll Response in Irregular Beam Waves (7)

Table 4 Main Particulars of SSC type Support Ship

Length b.p.	53.0 m
Breadth, max.	28.0 m
Depth	10.6 m
Draft, max.	6.3 m
Gross tonnage	2,800 tons
Main propulsive motors	
Rated output ..	860 KW x 4 sets
Normal ouput ...	760 KW x 4 sets
Speed	abt. 12 knots

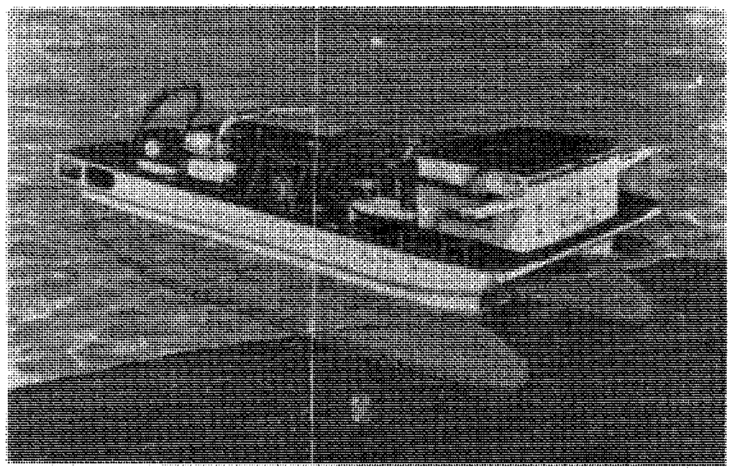


Fig. 13 Artists impression of the SSC support ship

Construction work for this SSC was started in 1983 at Mitsui and the SSC will be completed in May 1985. The main particulars and artist's impression of this SSC are shown in Table 4 and Fig. 13 respectively.

The construction and operational experiences with this large SSC as well as experience with the first Japanese-designed & built Dynamic Positioning System (DPS) will be very valuable for future designs of various ships of this type in the field of ocean development.

6. SSC PLEASURE BOAT

The experiences gained from the MARINE ACE and the succeeding SSCs indicated the possibility and utility of a small SSC in the field of marine recreation for its inherent stability and safety as well as ample deck space.

In order to confirm total performance and special problems on such a small boat design, several small SSC boats were built and tested by Mitsui. The most recent one with length of 5 meters was completed in 1982 under the sponsorship of the Japan Marine Machinery Development Association (JAMDA).

Table 5 Main Particulars of 5 meter SSC Leisure Boat

Length overall	4.97 m
Breadth, max.	2.60 m
Depth	1.54 m
Draft, full	abt. 0.83 m
Engine, Gasoline outboard engine	25 PS x 2 sets
Complement	8 persons
Speed, at 70 percent load draft	abt. 17.5 knots

The main particulars of this prototype SSC leisure boat are shown in Table 5.

This small SSC is equipped with a pair of movable forward fins whose angle can be adjusted to change the ship's trim adequately under various load conditions on deck. Main portions of the hull are made of fiber-reinforced plastic (FRP) from the maintenance point of view.

In recent years, demands for marine recreation has become versatile and some of boators strongly hope seasickness free boats. Seasickness doesn't make boating a pleasure but a nightmare.

The SSC's advantageous features, i.e., smaller motions and accelerations in waves, greater deck space, less speed loss in waves, less shock in waves as well as easier maneuvering by defferential thrust of each propellers can realize a small-sized stable luxurious cruiser as shown in Fig. 14. This cruiser, called SSC SEA SALON, accommodates, for example, one big salon (15 feet long, 18 feet wide and 6 feet 8 inches high), one owner's room, two guest rooms, one head and shower and aft open deck. The main particulars of SEA SALON are shown in Table 6.

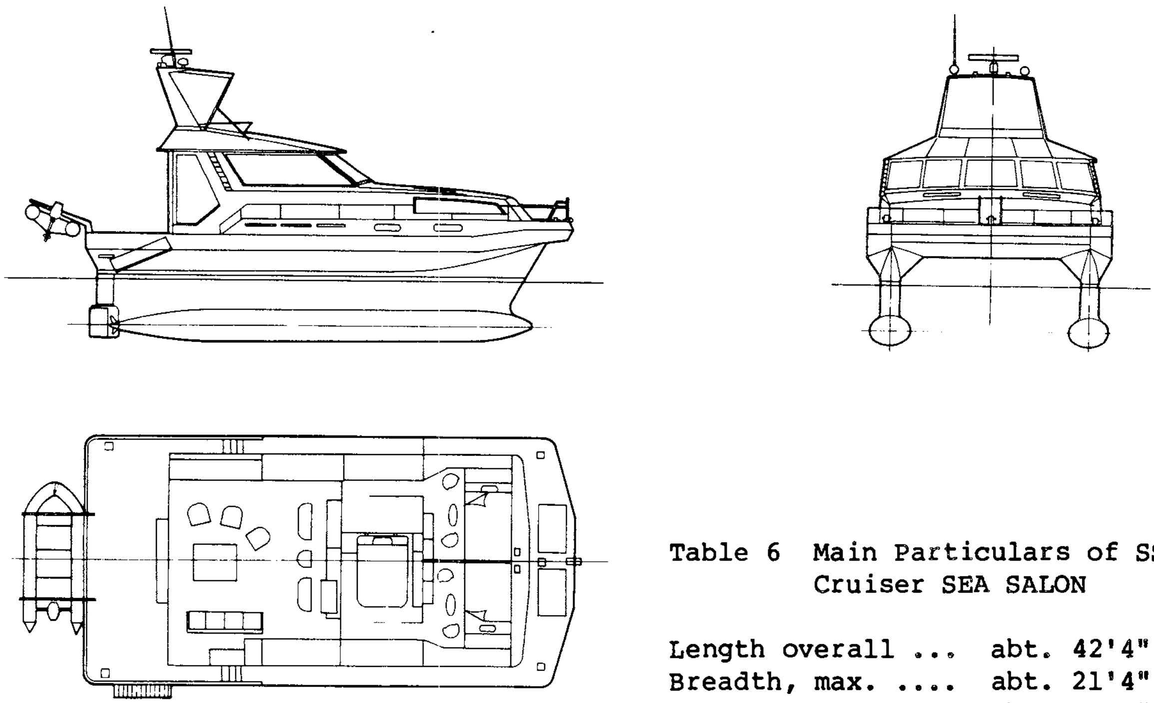


Fig. 14 General Arrangement of 12 meter SSC Type Cruiser SEA SALON

Table 6 Main Particulars of SSC Cruiser SEA SALON

Length overall ...	abt. 42'4" (12.90 m)
Breadth, max.	abt. 21'4" (6.50)
Draft, full	abt. 5'5" (1.65 m)
Hull materials	FRP
Main Engines ...	Diesel 200 PS X 2 sets
Speed, cruising	abt. 16 KTS

7. CONCLUDING REMARKS

The unique superior features of the SSC in variety of performance, such as excellent seaworthiness, maintaining speed in rough seas, have been proved by full scale trials. And combined with its spacious deck, the concept of SSC has been confirmed by Mitsui's design studies to realize high performance vessels beyond the limitations of the conventional monohull in various fields of application.

Development of the SSC has continued for more than 10 years. Three different types of the SSC, i.e., MARINE ACE, SEAGULL, and KOTOZAKI were built by Mitsui and a larger SSC support ship of 2800 G/T will be delivered in 1985. Experiences of design and construction of the SSC have been accumulated, and all of these have contributed to establish the basic technology of the SSC.

In addition, some small prototypes and experimental craft were built in order to expand the applicable area of the SSC to the field of marine recreation.

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TODAY'S CATAMARAN TECHNOLOGY: LIFELINE TO THE ISLAND NATIONS

Rudy Choy
Aikane Catamaran Cruises
Honolulu, Hawaii, U.S.A.

Abstract

The historic development of the catamaran in the Pacific Islands will be reviewed and current capabilities and uses examined. The application of today's technology in vessel construction and sailing equipment to bring the catamaran into the 20th Century as the commercial lifeline for the Pacific Island nations will also be discussed.

BULK TERMINALS FOR UNDERDEVELOPED AREAS

Ray W. Jenkins
Mining Consultant
Kailua, Hawaii, U.S.A.

Most Pacific Rim bulk ocean traffic is between natural deep draft harbors which have been improved. Most of the remaining unimproved potential harbor sites will require prohibitively high cost construction for the conventional berths and breakwaters. To meet this problem, especially where major natural resource developments require the economic service of very large bulk carriers, offshore terminals have been constructed. Their use has proven to be highly satisfactory and more of them are being constructed to service bulk carriers up to 275,000 DWT.

This paper examines the possibility of using this economic method of port construction for the requirements of the underdeveloped countries. The applications considered are for vessels with loaded drafts of eight to twelve meters. Both receiving and loading ports will be considered. The materials to be handled would be coal, fertilizer and other bulk industrial minerals products. Port traffic would be in the order of one million tonnes per year.

Suitable sites would be those with the following characteristics. Meteorological conditions would permit operation throughout the year. The distance from shore to the terminal site would not be excessive from an economic standpoint. The direction of swells would permit a vessel to approach the mooring dolphins without ship assist. Sea states of four or less would prevail for 85% of the time at the terminal. Studies have shown that the maximum wave condition for dry bulk unloading is 1.6m and loading is 2.1m Self-unloading vessels are less sensitive to wave height. At sea state four, the pitch amplitude increases the terminal draft requirements by 125%.

Offshore terminals are oriented into the swells and connected to the shore by several hundred meters of trestle. The trestle is wide enough to accommodate a conveyor structure and one-way vehicular traffic. Pipe lines and cables are also carried as required. The trestle terminates at a small deck structure sized to carry the equipment required for single-point loading or unloading.

The deck structure would incorporate soft but robust fendering against which the vessel may operate in a "breasted-on" condition most of the working time. The mooring dolphins would be so arranged that under some conditions the vessel can float free in a breasted-off condition while being worked. In both loading and unloading, the vessel is warped along the deck as the hatches are unloaded or loaded.

Semi-offshore terminals are possible where suitable channel depths are within a few tens of meters of the shore. The deck structure and mooring arrangements would be modified to accommodate the less severe conditions. In both cases it is assumed that the minimum of dredging would be required to clear the channel to working depth.

A modification of the semi-offshore facility which would require minimal marine structures is obtained where a channel suitable for a self-unloading lies close inshore. In this type of operation the vessel is warped to and fro along the shore while its discharge boom casts a stockpile onshore.

The equipment options depend on whether the facility is operated as a receiving or a loading port. It is possible that with some ingenuity and the use of a reversible trestle conveyor the facility could be arranged for both receiving, loading, or transshipment. For unloading, the terminal deck would be equipped with a whirley crane or a level luffing kangaroo crane. The crane would load from a single hatch into the fixed conveyor hopper. These machines are popular and flexible but have a limited unloading rate of an average of 300 tonnes per hour from a maximum vessel size of 30,000 to 40,000 DWT. These machines can be equipped with a hook, grapple or a magnet. They can also be arranged to discharge into a barge alongside assuming that mooring structures are provided.

The hopper can also be loaded with ships gear if desired. Where a self-unloading vessel is available the boom can discharge directly into the hopper. Where there is a limited distance between the channel and the shore, the cranes can be mounted on a barge with or without a fixed hopper. If distance permits the crane can discharge directly on shore.

Loading from a shore stockpile would be by fixed feeders fed by mobile loaders. The feeder would discharge on the trestle conveyor to the platform hopper. There a feeder would discharge onto a boom conveyor whose spout would discharge into the vessel's hatch. The vessel would be warped to move the hatches under the conveyor. The conveyor would be extensible or be equipped with a hinged terminal section to clear the vessel when required. The conveyor would be enclosed on the trestle and the boom section would be suitably covered against dusting.

Onshore stockpiles can be constructed and recovered using the variety of contractors portable conveyors. Mobile loaders with portable feeders can be used for moving and recovering the stockpiles. Suitable belt cleaning equipment should be supplied where multiple products are handled.

The facilities described in this paper will provide the benefits of lower cost ocean transport to underdeveloped countries for importing fuel and supplies and possible exploitation of minerals.

FAST DEPLOYED OFF-LOAD SYSTEM

Harold Chalmers
Naval Ocean Systems Center
Kailua, Hawaii, U.S.A.

Lawrence Benen
Naval Sea Systems Command
Department of the Navy
Washington, D.C., U.S.A.

This paper proposes the development of a recoverable fast deployed offload system utilizing equipment and systems previously developed by or in support of the Offshore Petroleum Industry. It recommends the modification of a large jack-up drilling rig to support a combination of pedestal and gantry type container cranes as indicated by Figure 1 to provide a variable depth, docklike offload facility for containerships. It will augment our auxiliary crane ships to provide an improved sea state offload capability for amphibious force operations in exposed open roadstead and other austere port environments as depicted by Figure 2, where a system using two jack-ups is shown.

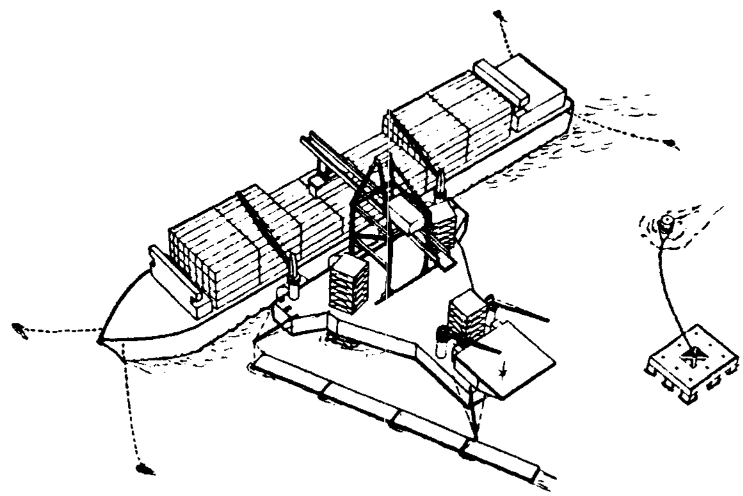
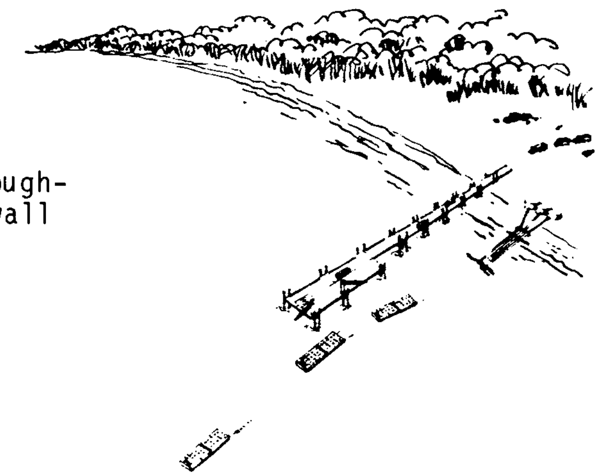


Figure 1.

The rigid, docklike jack-up will eliminate the swell driven heave and load pendulation and also the load induced heeling motions which complicate and limit safe cargo handling operations between ships and lighters using floating crane platforms. Crane operators cannot integrate and safely contend with these compound multiple platform motions above a relatively low range of sea state and motion conditions, especially when they themselves are tied to and move with one of the relatively long period motions, i.e., when they have and are fixed with a variable moving reference. Motion compensation systems have been under development for some time now that attempt to mitigate the problem by the judicious use of both power and control systems; however, no reliable system exists to date that provides the response and control needed for an adequate range of load and motion conditions.

The jack-up will passively eliminate these load pendulation, heave and heeling motions leaving the crane operator to contend with the much simpler, external, alongside ship or lighter motions. Familiarity with the crane control responses will allow the operator to better anticipate and gauge his control actions to pick and land the load at the appropriate moment. It will also allow him to better judge when conditions have reached the limits of crane response and safe cargo handling operations. The helo deck will allow helo transfer of high priority items during those periods when lighter operations cannot continue. The jack-up structure could also provide support for additional ancillary systems and facilities that benefit from a steady platform, a controlled environment or a ready supply of raw water, i.e. a hospital, clean rooms, repair facilities, reverse osmosis fresh water units, petroleum storage and pumping, etc. Finally, if and when conditions allow, the jack-up could be quickly moved to a more protected harbor or port area where mooring loads would be lower and its portainer type container crane would allow a much higher throughput and offload rate using a pier or quay wall bridging ramp system.



Holding a large containership safely alongside the jack-up in the wind, swell and current conditions anticipated for the exposed operational areas of interest will limit the operational envelope for cargo transfer to the capabilities of the containership mooring system. Although the jack-ups being considered are hurricane capable platforms, the leg systems, stout as they are, cannot withstand the unrestrained side loading that an alongside 50,000 ton ship could deliver. Accordingly, the installation of a rapidly deployable system of 150K to 200K lb moorings to safely hold the ship 15 to 20 feet off the jack-up as shown in Figure 3 is a critical requirement of the system. This should provide a reasonably balanced system vis a vis the anticipated envelope of motion conditions under which we anticipate the cranes should safely operate to provide an approximate sea state 4 operational system. Two line handling craft and two nominal 2000 hp offshore tug and anchor handling boats would be required to set the moors and assist the containerships in coming alongside and to later slip the moorings.

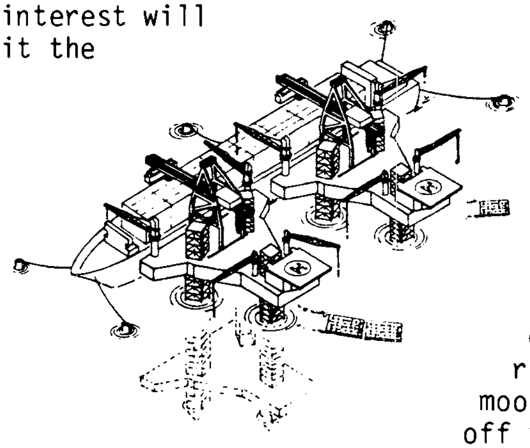


Figure 2.

The jack-up, along with the support craft and the rapidly deployable embedment and/or barge type gravity anchor moorings, the latter shown on Figure 1, would be delivered at relatively high speed (15 to 20 knots) by a large semi-submersible ship to the port, bay or open roadstead of interest. Offload and set-up time for the jack-up and mooring system would take from 24 to 48 hours depending on conditions at the offload and set-up sites and the distance separating them. Both can be accomplished in up to five foot sea and swell and two knot current conditions with set-up in a

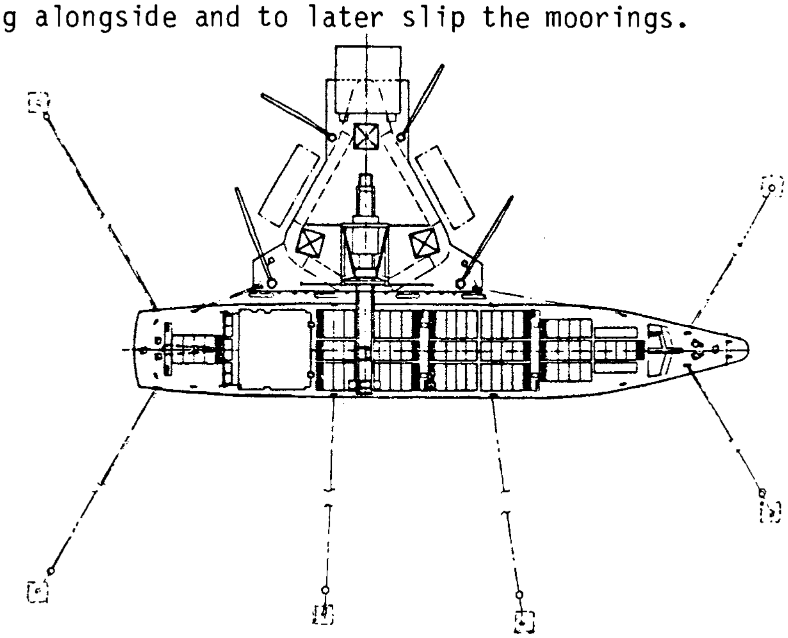


Figure 3.

range of water depths of 40 to 150 feet and virtually any bottom conditions. The semi-submersible ship would require from 65 to 80 feet of water for loading and unloading depending on the ship's size, hull depth and other load factors. Protected waters are needed for the loadouts due to the critical positioning requirements of the load.

These ships, in use for about five years now, routinely deliver power plants, paper plants, jack-ups and even very large semi-submersible drilling rigs. Built new from the keel up or by conversion of large tankers, they range in capacity from 15k to about 44k DW tons. Figure 4 shows the major steps required for a tanker conversion which we recommend for this system for cost reasons. The conversion design must insure that the hull shortening and reduced section parallel mid-body provide the deadweight capacity and clear deck length needed, sufficient freeboard, adequate deck and longitudinal hull girder strengths, reasonable loading drafts, and sufficient stability over the range of loading anticipated, especially for the critical flooding down and lift out phases when the main deck is just awash. The design should include a ballast control and computerized hull girder loading and stability system with automatic liquid ballast and draft sensing to provide continuous hull girder loading and stability readouts during the critical loading and unloading phases of an operation. Following a delivery, the ship could be used as a forward area drydock facility providing that a system of keel and bottom blocks has been included along with supporting shop and portable crane facilities in the design. As with the loadouts, protected and sufficiently deep waters would be required for this use.

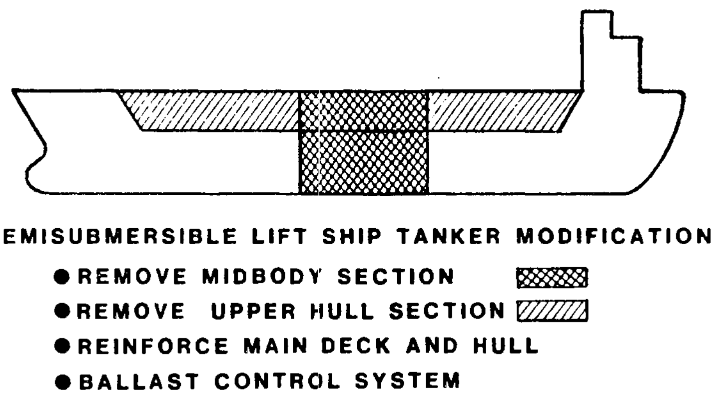


Figure 4.

A feasibility study for this system is currently being conducted for the Naval Sea Systems Command. Preliminary results indicate that it would result in a relatively low risk development with excellent potential for signifigant improvements in the Navy's forward area container discharge capabilities.

The general concept of the jack-up could also prove useful in the commercial arena especially in the Pacific and Indian Ocean basins to provide a temporary or instant port facility to allow development of limited mineral deposits, seasonal agricultural or forest products, fisheries, etc., where long land transport, sea distances, or permanent port development costs have inhibited development and/or where some degree of mobility is required to develop the asset.

MRM-7: MARINE EDUCATION

EDUCATIONAL RESOURCES AND NEEDS FOR MARINE TECHNOLOGY DEVELOPMENT IN THE PACIFIC OCEAN REGION

Dale E. Ingmanson
Natural Science Department
San Diego State University
San Diego, California, U.S.A.

Why is marine technology development so important for the region? First, most of the countries and territories are undergoing substantial population growth. At the same time, the cultures are shifting from traditional subsistence life styles to semi-urban life styles. This is resulting in large scale unemployment and low productivity. Second, most countries are burdened with extraordinary balance of payments deficits. They are not able to produce enough for world markets to offset the demands for imported goods and energy needs. Third, there is a need for environmental cooperation with respect to ocean pollution monitoring, ocean research and the identification of marine resources. One can argue that marine technology development is the key factor that could lead to the resolution of these needs.

In recent years, a number of studies and reports have advocated programs of research, education and innovation as keys to increased productivity and economic development. The same studies and reports agree that the importance of research, education and innovation transcends disciplines and national boundaries. The statement applies, therefore to marine technology and to the nations of the Pacific Ocean region.

The needs for marine technology development in the Pacific Ocean region are complicated by many factors. First, marine technology is a broad field as exemplified by the fifteen sessions of this conference ranging from remote sensing to fisheries. Second, the distances between countries and between the resource and the location of use are very great. Third, the languages and cultures of the region are diverse, making communication and cooperation difficult. Fourth, there is a great range in level of economic development between the countries of the region. Fifth, the pending UN Law of the Sea will affect vast areas of the region.

Abundant high quality institutions of higher education offering degrees in oceanography or marine technology are available in the region (Table 1) especially in the USA and Japan. Access, costs, language, and distances are factors which limit availability.

Unfortunately, educational resources for precollege students are limited throughout the Pacific region. Consequently, there is a basic need for quality teachers, books and equipment and facilities. Clearly, these needs cannot be met independent of basic economic growth and development.

What could be done to foster basic economic growth and development through marine technology? First, a system of exchange between universities and developing nations can occur. The university would provide scholarships for students from the nation, and the nation would provide research opportunities for the university faculty and graduate students. Second, an international marine advisory program similar to the Sea Grant model should be established to foster rapid application of information. This could be financed by a special tax on private sector users such as oil comparies, tuna canneries, etc. Third, three leading universities such as the University of California, University of Hawaii, and the University of Hokkaido should develop a coordinated interdisciplinary Pacific Ocean region study center. This could be initiated through Sea Grant, USAID and/or the UN University. Fourth, a commonwealth governing system should be pursued linking the smaller developing nations for marine technology development in order to pool resources and avoid competition. This system and the advisory program could be administered by an international university consortium (Joint Oceanographic Institutions for Pacific Ocean Development, JOIPOD). JOIPOD could also be expanded to include representations from the private sector.

Table 1 Universities Offering Degrees in Oceanography or Marine Technology in the No. Pacific Ocean Region

CANADA
- University of British Columbia

HONG KONG
- Hong Kong Polytechnic

JAPAN
- Kyoto University
- Hokkaido University
- Nagoya University
- Kobe University

MEXICO
- Universidad Nacional de Mexico
- Universidad Autonoma de Baja California

PHILIPPINES
- St. Louis University

REPUBLIC OF CHINA
- Taiwan National University
- Tamkang University

USA
- Alaska
  - University of Alaska
- California*
  - Scripps Institution of Oceanography, UC-San Diego
  - UC-Berkeley
  - University of Southern California
  - Humboldt State University
  - Naval Post-graduate School, Monterey
- Hawaii
  - University of Hawaii
- Oregon
  - Oregon State University
- Washington
  - University of Washington

*For a detailed list of programs in California see:
Anderson, Kelly. Directory of Academic Marine Programs in California Higher Education. California Sea Grant College Program, Institute of Marine Resources, La Jolla, CA 92093.

DESIGN CRITERIA FOR TECHNOLOGY UNITS IN A SECONDARY MARINE SCIENCE PROGRAM

E. Barbara Klemm
Curriculum Research and Development Group
College of Education
University of Hawaii at Manoa
Honolulu, Hawaii, U.S.A.

Recently, concern has been expressed in the United States over the need for upgrading and expanding science and technology education. In September 1983, the National Science Board called for efforts at finding effective means for including technology education in the secondary school science curriculum. Specifically cited is the need for research on curricular approaches which address both the relationships between science and technology, and the effects of science and technology upon society.

In response to this call, this paper describes the experience over the past decade of the Curriculum Research and Development Group (CRDG) at the College of Education, University of Hawaii, in developing instructional materials which integrate technology into secondary science curricula. More specifically, this paper reflects on CRDG's experiences in developing instructional materials in marine technology as the third of three themes integrated into the Highschool Marine Science Studies (HMSS) Program.

HMSS is a one-year general science program set in a marine context for heterogeneously grouped students in grades nine through twelve. The first two HMSS themes are "The Living Ocean," which includes biological and ecological investigations of oceanic phenomena, and "The Fluid Earth," which includes physical, chemical, and geological investigations. Topics on marine transportation, aquaculture, and coastal engineering are in the HMSS "Technology" theme.

In the process of designing the HMSS marine technology materials, several criteria emerged which have served as guidelines in selecting and organizing content (i.e., what should be taught), and in shaping the nature of student activities (i.e., how it should be taught). These design criteria are suggested as model guidelines to be tested in future development of other curricular units which integrate technology as a component of a secondary science program. The criteria are that developed activities will reflect the following:

1. that technological concepts are inseparable from their natural content in the sciences. This criterion implies that technology topics should be selected to reinforce concepts and skills from the science disciplines as well as to develop understanding of technological concepts and skills. Technology components should teach not only the practical and applied but also the theoretical. Through their experiences with integrated technological studies, students gain insight into the application of theory in practical situations. In the HMSS program, for example, students learn that understanding of buoyancy and density allows them to specify ship capacity and control hull stability.

2. that student understanding of technological as well as scientific concepts begins with personal, concrete experience. Technology

components of the science curriculum should begin with student manipulation of tangible phenomena. Out of manipulative experience, ideas may be abstracted or generalized to global understandings. For example, before investigating ship hull design, HMSS students first determine through laboratory investigations that objects made of materials like concrete and steel can float. Additional research is warranted to determine what types and how many precursor manipulative experiences children need in order to be able to grasp more abstract notions. In the past girls lacked many of the opportunities provided for boys in "tinkering" or building and repairing things. We find today that an increasing number of boys are also lacking such experiences because in today's urbanized and computerized world there are fewer simple devices in the environment to manipulate. How many students today can take a digital watch apart and learn how it operates?

3. that student activities in the technology components of the science curriculum should encourage a variety of modes of thought and expression, including verbal, mathematical, visual-symbolic, and psychomotor (tactile). There are two reasons for this criterion. First, because in practice, technological problem solving today typically requires teamwork involving all of these. Second, because in a typical classroom setting students differ widely in their individual abilities and in the ways they learn. Therefore, by selecting and developing student activities which are as authentic as possible to real technological situations, we provide opportunities not only for the student to discover and use their own unique talents, but also opportunities for them to discover how diverse talents are used in a teamwork approach to solving technological problems. In the HMSS program, for example, students work together in teams to design a ship, draft its blueprints, plan and carry out construction of a scaled model, performance test the model, and explain the processes involved.

4. that technology components will provide examples of present problem solutions while encouraging creative new solutions. Two notions are implied here. First, by assuring some historical treatment of technological ideas, students gain perspective on how a technology evolved in response to changing situations or demands. Second, by engaging students in explorations of present and future needs, students are encouraged to use their own creativity and to take an active role in finding and testing alternatives. In the HMSS program, activities are designed so that students learn some of the history of shipbuilding as they investigate the size of ships and compare the evolving scale of ship-building technology over time. HMSS students are then challenged to project their own ideas on the future of ocean transportation. Another aspect of creativity is that HMSS students are also encouraged to be resourceful in using readily available materials to transform their ideas into working models.

5. that technological components take into consideration the socioeconomic, legal, ethical, and aesthetic factors which bear upon the use and preservation of the oceans. Technical studies should be related to real-world complexity rather than studied as isolated bits and pieces. Using this criterion helps direct selection of topics and activities which have broad relevance. For example, in explaining why transportation, a topic often presented in elementary school, is included in the HMSS program, HMSS developers point to the importance of modern shipping to support the complexity of today's economics.

GRADUATE PROGRAMS IN AIR-OCEAN SCIENCES AT THE NAVAL POSTGRADUATE SCHOOL

Christopher N.K. Mooers
Department of Oceanography
Naval Postgraduate School
Monterey, California, U.S.A.

The Naval Postgraduate School (NPS) is celebrating its 75th anniversary. It has been located in Monterey for over three decades. It has grown and altered its scope over the years. Today, NPS is strictly involved in graduate education for U.S. uniformed services and federal civilians, plus allied military officers and defense ministry civilians. There are eleven academic departments and approximately thirty curricula. Several areas of physical science, engineering, and mathematical science are covered, as well as political and administrative science. Some of the curricula are in traditional disciplines; some are interdisciplinary and operational in orientation. All have been focused to have relevance to defense operations and systems. However, training is not conducted; rather, graduate education is offered which provides the intellectual basis for defense applications.

As defense technologies and priorities change, so do the curricula. Each curriculum is sponsored by a flag officer responsible for managing a set of afloat and ashore billets requiring graduate education, and for managing the community of personnel qualified for those billets. Biennially, the curriculum sponsor reviews the curricula for which he is cognizant. For this purpose, he surveys the afloat and ashore establishments to update the set of educational skills with which the graduates should be equipped. The faculty responds to the revised set of educational skill requirements with proposed alterations in existing curricula, and with new curricula.

The vast majority of the students are enrolled in Masters programs; a few are enrolled in doctoral programs. A typical M.S. program requires two years plus some preparatory work. A thesis is required in almost all curricula. Instruction is in progress four quarters per year. The current enrollment is nearly 1600 and growing; approximately 60% of the students are U.S. naval officers, approximately 20% are allied military officers or defense ministry civilians, and approximately 20% are from other U.S. uniformed services or are federal civilians. Students matriculate and graduate each quarter in many curricula, including the Air-Ocean Sciences Curricula.

The Air-Ocean Sciences Curricula date from over thirty years ago. Initially, Meteorology was offered, but soon Oceanography was added. Nearly a decade ago, Hydrographic Science (MC&G) was added. There are approximately 1500 alumni from these programs. Beginning in 1976, the curricula for U.S. naval officers began to be focused in meteorology plus physical oceanography. More recently, the U.S. Navy restricted line officers have had MC&G courses added to the Air-Ocean Sciences Curriculum per se, and the U.S. Navy unrestricted line officers have had operations research courses added to the

Air-Ocean Sciences (Operational Oceanography) Curriculum. These two curricula lead to the M.S. in Meteorology and Oceanography. Today, the Meteorology Curriculum primarily serves U.S. Air Force officers; the Oceanography Curriculum primarily serves allied naval officers and federal civilians; and the Hydrographic Sciences Curriculum primarily serves NOAA Corps officers, allied naval officers, and federal civilians. These three curricula lead to the M.S. in Meteorology, in Oceanography, and Hydrographic Sciences, respectively.

The Oceanography Curriculum is basically a physical oceanography program, with substantial amounts of underwater acoustics and meteorolgy, as desired. It is the most flexible curriculum of the five and can be tailored to meet individual student needs and interests. It has a Ph.D. as well as a M.S. program, as does the Meteorology Curriculum.

The emphasis of all the curricula is geophysical prediction, which requires a solid basis in applied mathematics and statistics, geophysical fluid dynamics, numerical methods, modern computing, and geophysical observations. The co-location of the Fleet Numerical Oceanography Center (FNOC) and the Naval Environmental Prediction Facility (NEPRF) with NPS greatly fosters the emphasis on prediction. To facilitate experience with geophysical observations, NPS operates a research vessel (the R/V ACANIA), sponsored by the Oceanographer of the Navy. There is also a rapidly growing emphasis on satellite remote sensing of the ocean, atmosphere, and geoid. The thesis research program is a very important element in the educational program: it allows the student to integrate his/her academic and professional knowledge, and to apply it to problems of scientific and operational interest.

The Oceanography and Meteorology Departments provide most of the academic support to the Air-Ocean Sciences Curricula, as well as some support to several other curricula. Each of these departments has about ten regular faculty members plus a similar number of adjunct research faculty and visiting scientists. There is a also a substantial number of technical staff personnel to assist in instructional and research tasks. Overall, the research programs of the two departments are strong and growing, which serves to enhance the academic program. Special expertise exists in nearshore processes, mesoscale ocean prediction, upper ocean observations and modeling, ocean turbulence, ocean optics, ocean acoustics, satellite ocean remote sensing, Arctic oceanography, and shallow water oceanography.

Finally, the faculty and curricula are serving to develop some of the requisite human resources needed for the era of real-time, operational and applied oceanography ahead.

EDUCATION IN SMALL-SCALE AQUACULTURE

Lorraine Madsen Buckley
Windward Community College
Kaneohe, Hawaii, U.S.A.

ABSTRACT. Windward Community College on Oahu, Hawaii, provides educational opportunities in aquaculture through an undergraduate course entitled AQUA 106: Small-Scale Aquaculture and through the Hawaiian Backyard Aquaculture Program. The Small-Scale Aquaculture course emphasizes the design of aquaculture systems incorporating subsistence, recreational, self-improvement, social, and commercial aspects. Each student plans a system, selects appropriate organisms, develops husbandry and management schedules, and analyzes the economic feasibility of the system. The course objectives also include field trips to local aquaculture operations and "hands-on" experience gained from weekly skill development sessions at the aquaculture facilities of the college. Students of the Hawaiian Backyard Aquaculture Program, funded by the University of Hawaii Sea Grant Program and the Aquaculture Development Program (Department of Land and Natural Resources), conduct research projects on selected topics in "backyard aquaculture" as partial fulfillment of certificate requirements for the Marine Option Program. Both the course and the academic program utilize experiential learning which has proven to be an invaluable pedagogical method in that students develop specific skills, display an increased rate of learning, develop a better data base for career decisions, and improve their self-reliance and self-confidence.

Small-scale aquaculture can be a rewarding endeavor for the individual who understands the principles of aquatic biology and who has experience with essential aquaculture technology. To enhance the success of the beginning lay-aquaculturist, Windward Community College in Kaneohe, Hawaii provides education in backyard and small-scale aquaculture through a course entitled Small-Scale Aquaculture (AQUA 106) and through student research projects in the Hawaiian Backyard Aquaculture Program (HBAP)[1/]. "Hands-on" experience as well as more traditional pedagogical techniques are utilized in both aspects of the curriculum.

Educational goals in AQUA 106 stipulate that the student should acquire an understanding of biological and ecological theories necessary to practice small-scale aquaculture, the ability to plan, design and develop a small-scale aquaculture system, and a proficiency in small-scale aquaculture techniques and procedures. Lectures, audiovisual media, textbooks (Bardach, et al., 1972; Boyd, 1979; Bryant, 1980; and Chakroff, 1976), and supplemental reading assignments supply the necessary background for learning basic biological principles and aquaculture concepts. Field trips and guest speakers broaden the scope of the course by introducing the student to larger scale commercial operations in order to enhance technology transfer to small-scale systems. The course emphasizes that all levels of aquaculture require careful planning for success.

1/Hunt (1982) defines backyard aquaculture as aquaculture systems designed for non-commercial purposes on house lots or other small backyard land areas typically found in Hawaii, e.g. 500 to 1400 m^2. Small-scale aquaculture may encompass backyard systems as well as small commercial ventures.

During the semester, each student designs an aquaculture system using a systematic approach in which all aspects required in the operation are thoroughly investigated. Assignment topics form a planning framework and include (1) a description of objectives and assessment of expertise, (2) research of the site characteristics for the aquaculture system, (3) an assessment and selection of aquaculture species, (4) an appropriate design and construction plan for the system, (5) the development of a husbandry and management plan and schedule, and (6) an economic analysis of the system.

The first step in starting a successful small-scale aquaculture system is to determine objectives and assess expertise necessary to accomplish the chosen objectives. The majority of students in the course have described their objectives as subsistence or recreational although some have identified interests in aquaculture research as well as large scale commercial ventures. The students' objectives will influence the emphasis of their study. For example, if the objective is to practice subsistence aquaculture, management becomes more crucial than if aquaculture is practiced simply as a hobby; the quantity of the crop obviously becomes more important than its size and appearance. Emphasis on quanitity rather than "supermarket" quality of the crop is especially advisable in light of preliminary results described by Hunt (1982) which indicate that small-scale aquaculture crops tend to grow somewhat slower and are smaller in size than those raised in larger commercial operations. After completion of this section the student has developed more realistic expectations of a small-scale aquaculture venture.

A thorough investigation of the site characteristics for the system is the next assignment. The "legalities" of aquaculture, i.e., the required regulations, permits, and approvals are determined first. Students are referred to a thorough treatment of this subject by Hunt and Pang (1982). There is a tendency among lay-aquaculturists to ignore these legalities, but they are nevertheless an important part of aquaculture systems and must be considered. Other site characteristics such as water source, topography and soil characteristics which are unique to each situation will limit the scale and type of system which can be realistically supported.

Once the physical parameters of the system have been determined, species assessment and selection worksheets are prepared with specific comparisons of critical characteristics and tolerance ranges. At lease five species are initially screened by the students but these may all be discarded if they are not compatible with the previously determined objectives or site characteristics! In general, species lower on the food chain, especially herbivores, those that utilize "waste" materials, and those that are usable in polyculture are preferable (McLarney and Todd, 1977). Students are referred to the publication "Aquaculture Development for Hawaii: Assessments and Recommendations" (Aquaculture Planning Program, State of Hawaii, 1978) and to literature in the extensive college collection for appropriate species descriptions and selection criteria for their specific location.

The design and construction plan for the aquaculture system is based on the information gathered to this point and may incorporate applications of appropriate technologies in mechanization, electronics, recycling, and alternate energy sources. Students are encouraged to start with a system which requires low capital cost and is of modular design as suggested by McLarney and Todd (1977). In addition, plans which utilize backyard gardens by integrating agricultural porducts and wastes as feeds and pond residues as garden fertilizers are encouraged (McLarney and Todd, 1977).

After the design is drawn to scale and described in detail, operations and maintenance schedules are proposed and the economic prospects are studied by analyzing the system as if it were a commercial operation. Determination of costs and returns for an aquaculture operation introduces accounting principles and develops consumer awareness.

The last few weeks of lecture sessions are devoted to presentations of each system design followed by discussions of potential problems and solutions for the system. These group discussions heighten student interaction, promote student inquiry, and aid the internalization of aquaculture concepts.

Weekly skill development sessions at the Hawaii Backyard Aquaculture Program facilities[2/] allow students in AQUA 106 to practice activities encountered in subsistence-level aquaculture and to observe various system designs at work. Students stock, cull and harvest crops as well as build, repair and maintain the pond system. They learn techniques in data recording, feed calculations, growth measurements, water quality sampling, animal husbandry, and, of course, how to cook their crops! Although mistakes are common as students first attempt activities such as handling and cleaning fish, by the end of the semester, student harvests run smoothly and efficiently.

Students with special interests may further their aquaculture education by selecting a Marine Option Program (MOP)[3/] skill project in the Hawaiian Backyard Aquaculture Program (HBAP)[4/]. Each HBAP student writes a proposal in which literature is reviewed, hypotheses are developed, experiments are designed, data is collected and analyzed, and a scientific report is written. As part of the proposal, a budget and timetable are required.

[2/] HBAP facilities, which are also utilized by the small-scale aquaculture course, consist of nine above-ground vinyl-lined ponds (12 ft. in diameter x 3 ft. deep), ten earthen ponds (13 ft. x 13 ft. x 3 ft.), one butyl rubber-lined nursery pond (15 ft. x 20 ft. x 3 ft. deep), and one growout pond (30 ft. x 50 ft. x 3 ft. deep). Each pond has an air and water supply and a drain. All ponds were designed and built by students (Hunt, 1983).

[3/] The Marine Option Program (MOP) jointly sponsored by the University of Hawaii and the Sea Grant College Program, is an undergraduate certificate-granting program which requires nine to fifteen credit hours of coursework in aquatic or marine science and a skill project designed by the student to gain experience in the techniques and methods of a selected marine-related topic such as aquaculture.

[4/] The Hawaiian Backyard Aquaculture Program (HBAP) is one type of project which will fulfill the skill requirement for the MOP certificate. Partial funding for HBAP has been provided to Windward Community College by two state agencies, the Aquaculture Development Program of the Department of Land and Natural Resources and the Ocean Resource Office of the Department of Planning and Economic Development, and the University of Hawaii Sea Grant College Program. Since September 1980, students enrolled in the Hawaiian Backyard Aquaculture Program have been researching, developing, and testing materials, methods, and appropriate technology usable in backyarad aquaculture situations uniquely Hawaiian. To date, students have conducted research on the regulations and permits required for backyard aquaculture; construction and cost of backyard ponds; species assessment and selection; diseases and parasites; and pond management. Their results will be published in a comprehensive guide (Hunt, 1983).

An exemplary HBAP project was the study of growth rates in three pond environments. Catfish (Ictalurus punctatus) and prawns (Macrobrachium rosenbergii) were cultured in various combinations of free-flowing, aerated, and stagnant ponds. Other "HBAPers" are researching the feasibility of growing prawns (M. rosenbergii), catfish (I. punctatus), tilapia (Sarotherodon sp.), grass carp (Ctenopharyngodon idellus) and other locally caught fish capable of adaptation to freshwater such as mullet (Mugil sp.) and aholehole (Kuhlia sp.), in various monoculture and polyculture systems.

Student research projects such as these provide opportunity for students to experience diverse aspects of aquaculture as well as to practice techniques of time management, technical writing, data analysis and rigorous thinking. Additionally, students may learn about grant proposals, budgetary considerations, and publication level writing. These investigations also have a highly practical side for the lay-aquaculturist; they reveal how to maintain high yields at low cost.

Besides previously described research which measures growth in ponds with varying water flow and aeration, students are testing other methods of decreasing cost of electricity, water and feed. Recent HBAP proposals include a study of low cost or backyard feeds. Results discussed by Hunt (1983) indicate that small-scale aquaculture efforts can be successful and that the crops are not only competitive with supermarket prices but fun to raise. For example, pan-sized tilapia and catfish have been raised at the HBAP facility for $.50 to $1.50 per pound and $1.50 to $3.00 per pound, respectively, and submarket-sized prawns for $1.50 to $3.50 per pound. These costs depend upon the type and design of the backyard system, operational costs (feed, water, and electricity), and management procedures (Hunt, 1983).

There is, however, clearly much more to small-scale aquaculture education than demonstrating possibilities in reduction of food costs. Both the course and the Hawaiian Backyard Aquaculture Program utilize contemporary methodology such as experiential learning which has proven to be an invaluable instructional strategy (Johnson, et al, 1979). "Hands-on" experience enhances the student's attention span, rate of learning, and perfection of techniques in aquaculture. Daily operational problems and mishaps provide opportunity for individuals to improve their aptitude in problem-solving through innovation and trial and error. After participation in the small-scale aquaculture course or the Hawaiian Backyard Aquaculture Program, students display improved self-confidence and self-reliance and they have developed a broader data base for career decisions. These individuals are more productive members of society due to their expanded vocational potential, consumer awareness, and skills in interpersonal relationships.

Humanistic education or a curriculum that develops the "whole person," such as aquaculture education at Windward Community College, is highly desirable and is receiving renewed attention in the literature (Saylor, et al, 1981). Experiential learning caters to students unable to learn from traditional lecture/reading instructional modes. Some students' display improved academic performance as they discover relevance in previously neglected classroom subjects such as mathematics and english. Experiential learning may be another potential solution to American educational inadequacies and preferable to extended instructional hours or expanded homework assignments.

At the same time aquaculture students are completing their curriculum and learning a survival skill, they are also working to improve the livelihood of the people of Hawaii. They are bridging the communication gap between university-level research and development, which has been directed toward large-scle commercial operations, and the needs of the small-scale aquaculturists of Hawaii. Many students share their experiences with friends and neighbors. In fact, backyard and small-scale aquaculture is much like backyard gardening, with backyard aquaculturists meeting to exchange fish (instead of vegetables), ideas, and techniques, resulting in a camaraderie that is lacking in many urban areas (Hunt, 1983).

Commercial aquaculture development is enhanced by aquaculture education in less obvious ways. Students who have completed the small-scale aquaculture course and/or a project in the Hawaiian Backyard Aquaculture Program are well-qualified as aquaculture technicians. Thus, the quality of entry-level applicants in aquaculture is improved. In addition, the reservoir of potential aquaculture investors is enlarged by increasing the average citizen's awareness of the growing industry.

In summary, small-scale aquaculture education at Windward Community College benefits the community and the aquaculture industry in Hawaii and develops the intellectual, productive, social, and personal dimensions of the student.

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POSTGRADUATE EDUCATION - A CRITICAL ELEMENT

C. B. Ihli, Jr.
Air-Ocean Sciences Programs
Naval Postgraduate School
Monterey, California, U.S.A.

ABSTRACT

The United States Navy recognizes the critical importance of postgraduate education in meeting its mission requirements in Mapping, Charting and Geodesy (MC&G) both today and in the 21st century. Keeping pace with rapidly advancing technologies will continue to be a major challenge. One approach in meeting this important challenge is being addressed through the Hydrographic Sciences Curriculum at the Naval Postgraduate School (NPS). The objective of this curriculum is to provide students with a sound understanding of oceanography and hydrography. As a sub-discipline of MC&G, Hydrography is the science of the measurement, description and charting of the sea floor with special reference to navigation and marine operations. This paper will review the Hydrographic Sciences Curriculum in detail.

OBJECTIVE & DESCRIPTION

The objective of the Hydrographic Sciences Curriculum is to provide students with a sound understanding of oceanography and hydrography. This interdisciplinary program integrates the scientific principles of oceanography with the practical engineering procedures of hydrography. Students achieve the technical expertise to provide and utilize hydrographic data in support of all aspects of hydrographic operations.

This education enhances performance in duties associated with operational billets, technical management assignments and policy making positions. Students will develop sound graduate level technical ability based on general engineering and scientific principles, develop analytical ability for practical problem solving, broaden their capacity for original thought and acquire diverse professional knowledge. These qualities will assist in supporting productive achievement throughout their career. Detailed program objectives are included in Appendix 1.

The program consists of preparatory subjects, basic courses in numerical and statistical analysis, a dynamics sequence and a core of MC&G subjects. The curriculum recognizes the importance of precise positioning systems, error budget analysis, accuracy requirements, data collection methods and data reduction techniques as applied to the planning, conduct and evaluation of hydrographic, magnetic and gravity surveys. Graduates will be prepared to make optimum use of the ocean environment in the course of their duties and to conduct and evaluate research in oceanography and hydrography, both basic and applied.

Classroom instruction is supplemented by laboratory exercises both ashore and afloat. The Research Vessel ACANIA, sponsored by the Oceanographer of the Navy, is available for class laboratory experience as well as for individual research efforts. Guest lectures, seminars and field trips serve to round out the curriculum. Each student is required to complete a thesis. In so doing, he is introduced to research methods and develops his technical writing skills, while at the same time completing a project of several quarters duration that requires planning, initiative and originality. The student often solves a problem of scientific interest and practical value to his sponsoring agency.

The degree Master of Science in Hydrographic Sciences is granted upon successful completion of the program. Matriculation may occur any quarter of the year with preferred entry in the fall. A typical program consists of seven to eight quarters. However, highly qualified students may have this period shortened by validation of courses previously taken, transfer of credits and by completing, prior to enrollment, courses offered by the NPS Office of Continuing Education. A detailed course listing is included in Appendix 2.

QUALIFICATIONS FOR ADMISSIONS

A baccalaureate degree with above average grades in mathematics and physical sciences is required. Differential and integral calculus, one year of college physics and one year of college chemistry are required.

The program is open to officers of the National Oceanic and Atmospheric Administration (NOAA), Coast Guard, Corp of Engineers, civilian employees of the U. S. federal government, and allied officers. Foreign civilians may participate provided they are Ministry of Defense (MOD) employees of eligible Foreign Military Sales (FMS) countries and/or those countries participating in International Military Education and Training Programs. Applications should be addressed to the U. S. Military Assistance Advisory Group (MAAG) located in the applicant's country. In the absence of a MAAG office in a country, application may be made through the U. S. Naval Attache, the Department of State or the Agency for International Development (AID) of the sponsoring country.

FIG/IHO Certification of the Program for Category A Hydrographic Surveyor

The FIG/IHO International Advisory Board on Standards of Competence for Hydrographic Surveyors has advised that the Hydrographic Sciences Curriculum will be reviewed during session of the board in Brest, France during May 1984.

APPENDIX 1

PROGRAM OBJECTIVES
HYDROGRAPHIC SCIENCES CURRICULUM

The Hydrographic Sciences Curriculum requires officer-scientists to obtain a thorough functional knowledge, at the graduate level, of the principles of Mapping, Charting, and Geodesy (MC&G). Certain aspects of Physical Oceanography, Meteorology and Computer Science must also be mastered to support managerial decisions in MC&G activities. Graduates must be able to apply these principles to:

1. Manage technical Mapping, Charting, and Geodesy programs. Requirements include:

a. Application of hydrographic, photogrammetric, and geodetic principles to data acquisition and processing methods.

b. Knowledge of how these data are incorporated in MC&G products and how they are utilized by the Navy and civilian users.

c. Evaluation of positioning data accuracy (both short and long range electronic navigation systems as well as satellite navigation) for hydrographic surveying.

d. Knowledge of the determination of the precise time.

e. Evaluation of vertical data accuracy including soundings, tides, and ties to datum.

f. Evaluation of error budgets and their contribution to the overall accuracy of MC&G products.

2. Manage MC&G data management systems. Requirements include:

a. Preparation of MC&G products from hydrographic, photogrammetric, geodetic, and oceanographic data.

b. Evaluation of data products and data dissemination methods.

3. Manage R&D programs involving:

a. New equipment and methods for acquiring position, depth, and topographic information.

b. New computer techniques and hardware to acquire, process, and portray MC&G data more rapidly and accurately.

c. Development of new data products.

Requirements include communication with:

a. Various MC&G agencies.

b. Research scientists and engineers.

c. Systems developers.

4. Perform liaison with NAVOCEANO, DMAHTC, NOAA, NASA, USGS, IHB, and other national and international agencies. Requirements include:

a. Provision for efficient exhange of data.

b. Evaluation of data acquisition instrumentation and other systems of common interest.

c. Planning sensor, computational, and communication facilities for data acquisition, analysis and dissemination.

d. Planning of data collection.

5. To support the above functional skills, the general educational requirements include:

a. Analytical methods for solving ordinary and partial differential equations.

b. Statistical methods for analyzing data.

c. Ocean dynamics including theory, gravity waves, nearshore and shallow water oceanography.

d. Acoustical, optical, and electromagnetic propagation physics.

e. Data acquisition, processing, analysis, and interpretation methods for hydrography, geodesy, and photogrammetry.

f. Marine geophysics, physical oceanography, meteorology, cartography, photogrammetry/satellite remote sensing, and electronic navigation systems.

g. Computer utilization for data analysis and production of MC&G products.

h. Conduct of research and reporting of its results.

i. Law of the sea.

NOTE: The functional skills described in paragraphs 1 through 4, above, describe the major functions by officers/scientists in the MC&G community. They are not all acquired as part of the graduate educational process. For one reason, it is not practical to do so in the time available. For another, many skills are more appropriately acquired elsewhere. Further, the required skills are forever developing. Finally, not all members of the MC&G community will need all skills equally. However, the theoretical basis and some of the connections to applications are developed in the graduate education program. On-the-job training and continuing education will complete the process.

APPENDIX 2

#441 - HYDROGRAPHIC SCIENCES

QTR						CLASS-LAB
1	MA 2121 DIFFERENTIAL EQUATIONS (4-0) 1,2,3,4 B	MA 2047 LINEAR ALGEBRA & VECTOR ANALYSIS (4-0) 1,2,3,4 B	OC 3230 OCEANIC THERMO-DYNAMICS (3-1) 1,2,3,4 B	CS 2810/11 INTRO. TO COMP. SCI./FORTRAN LAB (5-0) 1,2,3,4 B		16-1 (16.5)
2	MA 3132 PARTIAL DIFF. EQUATIONS (4-0) 1,2,3,4 B	MR 2220 MARINE METEOROLOGY (4-1) 2 B	OC 3130 MECHANICS OF FLUIDS (3-2) 2 D	GH 3901 MAPPING, CHARTING & GEODESY (4-2) 2,4 MCG		15-5 (17.5)
3	OC 3120 BIOGEOCHEMICAL PROC. IN THE OCEAN (4-3) 3 O	MR/OC 3140 PROB. & STATS. FOR AIR-OCEAN SCIENCES (3-2) 1,3 B	OC 4213 NEARSHORE & WAVE PROCESSES (3-1) 3 D	GH 3902 HYDROGRAPHIC & GEODETIC SURVEYING (4-2) 1,3 MCG		14-8 (18.0)
4	CS 3010 COMP. DEVICES & SYSTEMS (4-0) 1,2,3,4 B	OC 3260 SOUND IN THE OCEAN (3-0) 4 P	GH 3903 ELECTRONIC SURVEYING & NAVIGATION (4-0) 4 MCG	GH 3906 HYDRO. SURVEY PLANNING (1-3) 4 MCG	GH 4908 PHOTOGRAMMETRY & REMOTE SENSING (3-2) 4 MCG	15-5 (17.5)
5	GH 3910 HYDROGRAPHIC SURVEY FIELD EXPERIENCE (2-9) 1 MCG	GH 3911 GEODETIC SURVEY FIELD EXPERIENCE (1-5) 1 MCG	GH 4906 GEOMETRIC AND ASTRONOMIC GEODESY (4-0) 1 MCG			7-14 (14.0)
6	OC 0810 THESIS RESEARCH 1,2,3,4	OC 3325 MARINE GEOPHYSICS (3-0) 2 MCG	GH 3912 ADVANCED HYDROGRAPHY (3-1) 2 MCG	TRACK OPTION (4-0 EST.)		10-1 (10.5) EST.
7	OC 0810 THESIS RESEARCH 1,2,3,4	OC 4212 TIDES (4-0) 3 D	GH 4907 GRAVIMETRIC & SATELLITE GEODESY (4-0) 3 MCG	TRACK OPTION (4-0 EST.)		12-0 (12.0) EST.
8	OC 0810/0999 THESIS RESEARCH & PRESENTATION 1,2,3,4	NS 3962 OCEAN, MARITIME & TORT LAW (4-0) 4 O	TRACK OPTION (4-0 EST.)	TRACK OPTION (4-0 EST.)		12-0 (12.0) EST.

(NUMBERS) QTRS OFFERED	CODE LTR

COURSE GROUPS

B - BASIC/PREREQUISITE MCG - MAPPING, CHARTING & GEODESY

D - DYNAMICS P - PHYSICAL O - OTHER

APPENDIX 2

HYDROGRAPHIC SCIENCES

BASIC/PREREQUISITE

MA 2047 Linear Algebra and Vector Analysis (4-0)
MA 2121 Differential Equations (4-0)
MA 3132 Partial Differential Equations and Integral Transforms (4-0)
CS 2810/11 Introduction to Computer Science/FORTRAN Programming Laboratory (5-0)
OC 3230 Oceanic Thermodynamics (3-1)
MR/OC 3140 Probability and Statistics for Air-Ocean Sciences (3-2)
MR 2220 Marine Meteorology/Laboratory (4-1)
CS 3010 Computing Devices and Systems (4-0)

DYNAMICS

OC 3130 Mechanics of Fluids (3-2)
OC 4212 Tides (4-0)
OC 4213 Nearshore and Wave Processes (3-1)

PHYSICAL

OC 3260 Sound in the Ocean (3-0)

HYDROGRAPHIC SCIENCES

OC 3325 Marine Geophysics (3-0)
GH 3901 Mapping, Charting and Geodesy (4-2)
GH 3902 Hydrographic and Geodetic Survey (4-2)
GH 3903 Electronic Surveying and Navigation (4-0)
GH 3910 Hydrographic Survey Field Experience (2-9)
GH 3911 Geodetic Survey Field Experience (1-5)
GH 3906 Hydrographic Survey Planning (1-3)
GH 3912 Advanced Hydrography (3-1)
GH 4906 Geometric and Astronomic Geodesy (4-0)
GH 4907 Gravimetric and Satellite Geodesy (4-0)
GH 4908 Photogrammetry and Remote Sensing (3-2)

OTHER REQUIRED COURSES AND RESEARCH/SEMINARS

OC 3120 Biogeochemical Processes in the Ocean (4-3)
NS 3962 Ocean, Maritime and Tort Law (4-0)
MR/OC 0110/0111/0112 Application Seminars (1-0) - no academic credit
MR/OC 0810/0999 Thesis Research (0-0)/Seminar (2-0)

HYDROGRAPHIC SCIENCES TRACK OPTIONS

MANAGEMENT OPTION

MN 2106 Organizational Systems I (4-0)
MN 3105 Organizational Systems II (4-0)
MN 3301 Introduction to Systems Acquisition and Project Management (4-0)
MN 3371 Contracts Management and Administration (4-0)
MN 3124 Analysis of Bureaucracy (4-0)

ACOUSTICS OPTION

MR/OC 3150 Analysis of Air-Ocean Time Series (3-2)
PH 2151 Mechanics I - Particle Mechanics (4-1)
PH 3451 Fundamental Acoustics (4-1)
PH 3452 Underwater Acoustics (4-2)
PH 4454 Transducer Theory and Design (3-2)

ELECTROMAGNETIC PROPAGATION OPTION

MR/OC 3150	Analysis of Air-Ocean Time Series (3-2)
PH 4953	Propagation Phenomena in Geophysical Environment (4-0)
PH 3360	Electromagnetic Wave Propagation (4-1)
MR 4416	Atmospheric Processes in Electromagnetic and Optical Propagation (4-0)
EE 2621	Introduction to Fields and Waves (4-0)
EE 2622	Electromagnetic Engineering (3-1)
EE 3600	Electromagnetic Radiation, Scattering and Propagation (3-2)

OPERATIONS ANALYSIS OPTION

MR/OC 3150	Analysis of Air-Ocean Time Series (3-2)
OA 3101	Probability (4-1)
OA 3102	Probability and Statistics (4-1)
OA 3301	Stochastic Models I (4-0)
OS 4301	Stochastic Models II (3-2)

PHYSICAL OCEANOGRAPHY OPTION

MR/OC 3150	Analysis of Air-Ocean Time Series (3-2)
OC 3240	Ocean Circulation Analysis (4-2)
MR/OC 3321	Air-Ocean Fluid Dynamics (4-0)
OC 4220	Shallow Water Oceanography (3-2)
OC 3610	Wave and Surf Forecasting (2-2)
MR/OC 3522	Remote Sensing of the Atmosphere and Ocean (4-2)

METEOROLOGY OPTION

MR/OC 3150	Analysis of Air-Ocean Time Series (3-2)
MR 3222	Meteorological Analysis/Laboratory (4-3)
MR/OC 3321	Air-Ocean Fluid Dynamics (4-0)
MR 3420	Atmospheric Thermodynamics (3-1)
MR 4322	Dynamic Meteorology (4-0)

COMPUTER SCIENCE OPTION

MA 3232	Numerical Analysis (3-2)
CS 2812	Programming Laboratory - FORTRAN and COBOL (2-0)
CS 3020	Software Design (3-2)
CS 3030	Operating Systems Structures (4-0)
CS 3111	Fundamental Concepts of Programming Languages (4-0)
CS 4320	Data Base System Design (4-0)

INFORMATION SYSTEMS OPTION

MA 3232	Numerical Analysis (3-2)
MN 2155	Accounting for Management (4-0)
NM 3105	Organizational Systems II (4-0)
IS 3170	Economic Evaluation of Information Systems I (4-0)
IS 4185	Computer-based Management Information Systems (4-0)

(xx-xx) - (Class-Laboratory) Hours

TECHNOLOGY & EDUCATION: PREPARING STUDENTS FOR THE REAL WORLD

Jim Shon
Curriculum Research and Development Group
College of Education
University of Hawaii at Manoa
Honolulu, Hawaii, U.S.A.

I. The world is challenged by issues which are not easily confined to a single nation, or to a single academic discipline. This is true of energy, human rights, arms control, pollution, the law of the sea, communications, world hunger, and economic development, to name a few. Unfortunately, most secondary schools have constructed their curricula as if most of the world can be understood in terms of a particular nation's history, or a particular discipline's perspective.

The study of technology is useful not only because it is an interesting and informative study itself, but also because it is a vehicle for injecting both international and multidisciplinary elements into the core curriculum. At the Curriculum Research and Development Group, we are developing materials on Bays and Harbors and Ocean Fishing which contain a strong element of technology. Technology forces students to deal with the world as it is, clusters of concerns and areas of knowledge, not discrete school subjects.

II. The study of technology, especially marine technology, is by its nature multidisciplinary. If we want to understand Ocean Thermal Energy Conversion (OTEC) for example, we may well find ourselves involved in some aspects of physics, chemistry, biology, oceanography, the location and behavior of marine life, the construction of underwater cables, the economics of energy production and consumption, the comparative impacts of other energy production systems, the measurement of pollution, social trade-offs, the education of skilled professionals, cultural attitudes towards exclusive use of ocean space, natural resource management, enforcement problems, bureaucracy, and politics. OTEC, in other words, cannot be categorized in one of the various conventional disciplines. The only subject matter which occasionally does attempt a multidisciplinary approach is social studies, in that it attempts to take a comprehensive look at the human experience. Of course teachers of social studies are not qualified to teach all school subjects, but they are qualified to assist students in understanding the social applications and implications of those disciplines in the real world. Indeed, social studies is the only arena where it is possible to take this comprehensive approach. It is for this reason that The Ocean Project's Ocean Fishing in the Pacific course has focused on social studies as the target "discipline" for our efforts.

III. The history and status of technological development is international. We cannot examine human creativity, technological innovations, or their impacts without a journey from continent to continent, from civilization to civilization, from culture to culture. We will find ourselves learning of Egyptian irrigation, Chinese canals, Polynesian sailing canoes, Korean movable type, Dutch windmills, Italian telescopes, American clipper ships, British steam engines, German missiles, Soviet sputniks, Japanese mariculture, and multinational seabed miners. It is the nature of technological change in general, and marine technology in particular, to be international in its sources and impacts. The personalities are European, African, Asian, Pacific and American. The dynamics are part of global systems of economics, law, politics, religion, and life styles which express themselves in hundreds of different tongues. From the circumnavigation of the globe by Magellan to the orbiting of the earth by Skylab, technology cannot be examined without an eye to the atlas, and an appreciation of the interdependencies we all share.

IV. Our schools often do not provide an adequate diet of either multidisciplinary studies or international affairs. Like universities, secondary schools and teachers are divided by the conventional disciplines. In Hawaii, it is theoretically possible for students not to be exposed to an international perspective beyond the ninth grade. This is because in the last two years of high school social studies shifts into a primarily elective mode. Among the electives are American Problems, Economics, Anthropology, Sociology, Geography, International Affairs, Ethnic Studies, European Studies, Consumer Education, Marine Studies, Environmental Studies, and many more. To be sure, many of these may contain international and multidisciplinary approaches, depending on the teachers and the materials. However, NONE of these are required. We cannot count on every student receiving geography, for example, or marine studies, or European history. Because of this, if we want to improve the chances of students receiving a broader, more real world perspective, we need to find ways to offer attractive alternative components for this varied list of elective courses. Here is where technology can play a role. Nearly every social study subject could include some aspect of technology. If skillfully crafted, supplemental materials which deal with technology could be an important vehicle for ensuring a better education.

V. The Ocean Project is an international effort by educators in Hawaii, Canada, Alaska, Oregon, the State of Washington, Japan, Australia, New Zealand, Kosrae, and others to develop curriculum relating to the ocean and the Pacific. Two projects are now well on the way to completion: a Bays and Harbors course for 6th graders; and an Ocean Fishing course for senior high students. In both, marine technology is a vital component.

While technology is not the primary focus of the materials, it is an essential and useful element in each of the four units on Ocean Fishing. Unit I, for example, attempts to look at fish systems, and technology is examined for its impact on the survival of Pacific fisheries, especially tuna. The cost and importance of technology in the economic development of a fishing industry is examined in Unit II, Fish as a Resource. Unit III deals with conflicts over fishing, and we include the role of technological disparity in ocean resource conflicts. Finally, Unit IV looks at the importance of technology in the management of fishery resources. Technology emerges as an important factor in determining what and how much can be harvested, what kinds of fishing industries can be developed, what can be monitored, and what can be controlled. To deal with the technology of fishing means we must deal with culture, economic systems, political systems, ethics, and natural resources management.

There is reason for optimism in the growing use of technology in the classroom. Education is increasingly forced to confront the impacts of technology, such as the negative effects of TV on students, and the promise of computer education. It is possible we will find a growing sensitivity and receptivity towards the inclusion of all kinds of studies of technology, and especially marine technology.

Marine technology stands out because the history of societies and the sea has been particularly dependent on the history of technology and the sea. Indeed, it could be argued that the best way to study the impacts of technology is to study marine technology.

CURRICULUM MODELS FOR TECHNOLOGY EDUCATION

Francis M. Pottenger
Curriculum Research and Development Group
College of Education
University of Hawaii at Manoa
Honolulu, Hawaii, U.S.A.

Though normally resistant to change there are moments in American education when bold, new ideas can emerge and redirect the programs of its schools. One of those moments seems to be now. After nearly fifteen years of aimless reaction against the academic programs of the fifties and sixties, educational commentators are calling for a return to a strong academic program. High on their list of priorities is an increase in the amount of time that students spend studying science and technology.

Though the guidelines for science have been generally spelled out there exists little more than vague rhetoric concerning what content should constitute the technology program of the school. It is the position of this paper that the moment has arrived for support of the development of a new technology curriculum with a major marine emphasis, that America's school curriculum has been woefully lacking in content reflecting our dependence on the sea, that unless the next generation gains a better understanding of our ocean dependence there is danger that a landlocked mentality will abandon our marine interests to others. The question then is how should marine technology be presented in the school program. Four models are suggested here each reflecting particular views of technology as it might appear in the subject matter now taught in schools.

Science Model. One way of viewing technology is to present it as the application of scientific principles. Because there are marine technologies that are rooted in each of the major areas of science, biology, geology, chemistry, and physics, this structure is relatively easy to build. To gain a sense of the special problems of a technology adapted to the marine environment the science model is best used in support of a marine science program.

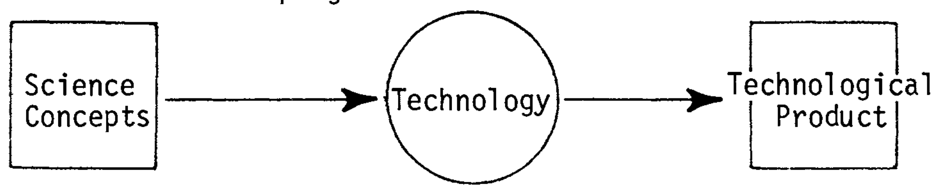
Vocational Training Model. In coastal states there often are programs that are designed to give students an experience in the work world of ocean technology. Such programs have proved to be valuable to the few who will work the docks and take on the traditional chores of tending vessels. The limited nature of such programs prevent them from reaching the vast majority of students who will be tomorrow's voters.

Humanities Model. This is potentially a rich entry point into the curriculum. It allows studies of contrasting views of the world of technology as seen through the lens of society and society as seen through the lens of technology. Studying philosophical values and aesthetic perceptions appearing in literature, drama, graphic arts, etc. could provide a most provocative and sympathetic view of marine technology.

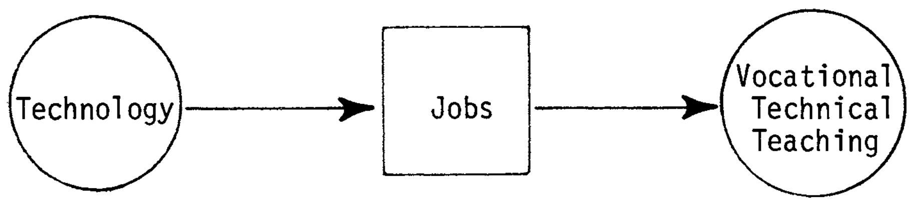
Social Studies Model. Social studies in the schools has taken on the task of incorporating a pot pourri of disciplinary studies including: history, law, economics, government, sociology, and psychology. Because of the mix of factors bearing upon the success of any technological enterprise, social studies lends itself in a very special way to the telling of the technology story.

Though the engineer and the production managers weigh heavily in determining if a product, a technique, or a service is feasible it is in the jungle of permits, finance, current events, law, and advertisement that technological decisions are made. To have an even modest sense of the nature of modern technology the student must gain an awareness of these ever deepening complexities.

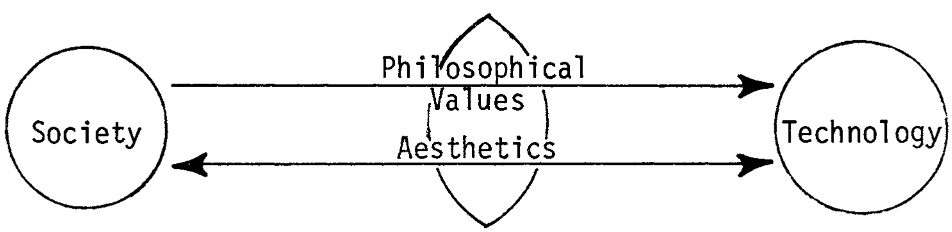
As can be seen the message that will be gotten by students will be mainly determined by the subject areas into which the new technology programs make an entry. Technology is viewed by most school people as a child of the sciences and by default it will probably continue to be dominated by science texts. If, however, there is a broader message that students should hear then it will take action by strong advocates to insure that technology is more comprehensively presented in the schools' program.



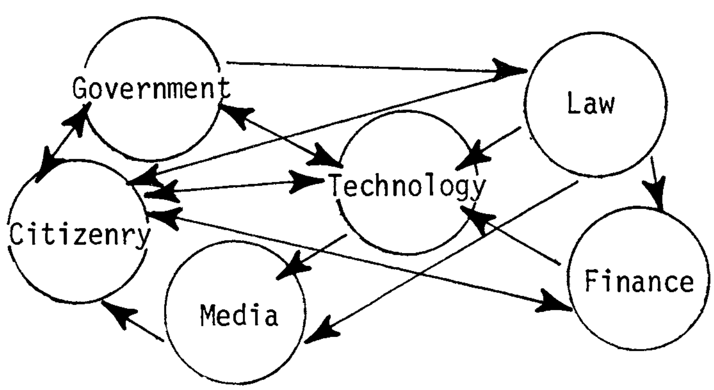
Science Model



Vocational Technical Model



Humanities Model



Social Studies Model

MRM-8: MARINE PROJECT FINANCING

A FINANCING OPTION FOR OTEC PLANTS

E. J. Francis
Ocean Energy Programs
The Johns Hopkins University Applied Physics Laboratory
Laurel, Maryland, U.S.A.

During 1983 A Financing Option document was prepared in the form of a proposed project financing package for discussion with seven industrial and seven financial corporations. The document was prepared by the Argent Group Ltd., a financial services company specializing in tax-oriented project and lease financing. Cost and design information was provided by the Applied Physics Laboratory (APL). Two financing approaches were developed: a sponsor company project financing and a financial lease. Two OTEC "baseline" engineering designs were used to establish cost and operating parameters: an OTEC vessel designed to generate electric power and cable it to a utility substation onshore, and a "cruising" OTEC plantship that would produce methanol on-board through a process of water electrolysis and coal gasification. The first design was for delivery of 51.4 megawatts average power ashore and used data based on a two volume report by APL published in June 1980. The second design used basic OTEC plant data from the June 1980 report and methanol plant data from 1983 work by Brown & Root, Rockwell International, Ebasco Services and APL. Total construction and deployment costs for the two OTEC vessels were $404.0 and $417.4 million, including detailed design costs, contingency and profit, as spent in the projected construction years 1984-1986.

The paper will discuss the results of the work, discussions with industry officials, the commercial viability today of OTEC construction and needed additional information for OTEC future decisions. Neither the discussions with key industry officials nor the proposed financing plan itself were designed to result in the actual financing of any particular project at this point. Had this been the case, certain key issues would necessarily have been resolved first.

The industry consensus was that OTEC projects, based on input assumptions used in the underlying computer financial model, provide an attractive financial return in today's U. S. market, but that additional work is needed to clarify the availability of the operating credit support (a take-and-pay contract). Also reported will be the perceived risks and risk reduction opportunities available for the OTEC projects and other conclusions reached as a result of the OTEC financing work. All of the assessments are based upon the structure of the financing used and the costs and other inputs selected by APL. These inputs were generally deemed appropriate by the industry officials who commented in detail.

The final element of the paper will include a discussion of the sensitivity analysis done by the author on OTEC projects for various sites. The effect on the net present value of the cash flow stream will be shown when major input assumptions are varied.

FINANCING OCEAN VENTURES

Myron H. Nordquist
Herrrick and Smith
Washington, D.C.
U.S.A.

Commercial Lending Institutions

Commercial lenders have been a major source of credit for the fishing industry. Most banks willing to finance vessels offer loans through either their installment loan or commercial loan departments. Borrowers can expect a seven to ten year repayment period for new vessel loans and a five to seven year repayment period for loans on used boats. Banks will require full insurance coverage for the appraised value of the boat and protection and indemnity coverage for other contingencies.

Farm Credit Service

The Farm Credit Service makes loans for commercial fishing and related purposes, including shoreside facilities and fishermen's homes. Aquatic loans are available to commercial fishermen who are owner/operators of commercial fishing businesses. Fishermen can borrow directly for current operating expenses or capital expenses like vessels, engines or gear. Most operating loans mature in a year, while loans for capital expenses like fishing vessels can be scheduled over a maximum of a 15 year repayment period. Repayment periods will vary depending on the vessel's age and useful life. Repayment schedules on Farm Credit Aquatic Loans are flexible enough to allow for seasonal income fluctuations commonly found in the fishing industry.

National Marine Fisheries Service Programs

Capital Construction Fund

Substantial tax savings may be realized through use of the Capital Construction Fund when purchasing a new vessel or reconstructing a used one. The Capital Construction Fund is a special investment program that enables owners of commercial fishing and charter boats to use tax-deferred income for the purchase of a new vessel or to reconstruct one presently owned.

Two sections of the 1976 Tax Reform Act provide even larger tax savings than were previously allowed when utilizing a Capital Construction Fund agreement. First, the Tax Reform Act of 1976 allows the investment credit to be applied toward fifty percent of withdrawals from the Capital Construction Fund's capital gain and ordinary income accounts. This allows increased tax savings when accumulating capital for a qualifying fishing vessel under a Capital Construction Fund agreement. Second, the Tax Reform Act of 1976 lessens the eligibility limit for a vessel owner to qualify for a Captial Construction Fund from five to two net tons.

Fishing Obligation Guarantee Program

The Fishing Obligation Guarantee Program can be used for financing construction of new vessels, reconstruction of existing vessels, or for certain on shore fishing facilities. Under this program, the National Marine Fisheries Service will typically guarantee a loan from a commercial bank for 70-75% of the cost of constructing the new vessel, or reconstructing a used one. The repayment period will vary for each loan according to the borrower's ability to repay and the vessel's useful economic life. Vessels must be documented and of five net tons or more to qualify for the guarantee program.

The Fishing Obligation Guarantee program can be used to obtain financing for onshore fisheries facilities like processing equipment, holding facilities and other shoreside facilities directly related to commercial fishing operations.

Small Business Administration

The Small Business Administration (SBA) operates a direct loan program which is dependent upon federal funding, a SBA loan guarantee program, and a disaster loan program for economic injury and physical damage cases, which may prove useful for financing ocean ventures. The SBA loan programs have generally gone toward financing onshore fisheries-related facilities like packing and processing plants rather than construction of new fishing boats. However, SBA has provided some direct loans for small new and used fishing boats and loan guarantees for used fishing boats.

Farmers Home Administration

The Farmers Home Administration program offers financial assistance in rural areas through its Business and Industry Loan Program. This program guarantees 90% of a loan starting at $500,000 or more. Interest charged is calculated at the prime interest rate plus two percent. Business and Industry Loan Program Guarantees have been used to obtain financing for shoreside fishing facilities and may be use for fishing vessels and onboard processing equipment.

Economic Recovery Tax Act of 1981

The Economic Recovery Tax Act of 1981 promises significant improvement in the depreciation tax shelter for an ocean mining program with a corresponding increase in internal rate of return. More direct tax "breaks" (higher investment credits and tax forgiveness) would also enhance this return. Increased awareness of potential strategic metal shortages could stimulate this type of indirect government support. Provision of construction and operating differential subsidies as provided by the 1936 Merchant Marine Act (as amended) would provide direct support with resulting improvement of returns.

International Joint Ventures

Until recently most foreign fisheries investments took the form of licensing arrangements, the establishment of subsidiaries, and the creation of contractual agreements between national and foreign fishing enterprises involving the transfer of fish products and related services in return for other services, products, or money. With the development of extended jurisdictions and economic zones has come an expansion of international joint ventures.

An international joint venture often begins with a feasibility study, during which a foreign firm undertakes an analysis of opportunities, costs, benefits, returns, and rates of return for a given industry sector. Once a partner has been chosen the two (or more) parties must negotiate a basic understanding, including discussions of financing, responsibilities, and profit distribution.

Once the preliminary negotiations have been completed, the parties will execute a written contract. The contract should include the procedure for conflict resolution or withdrawal of a party from the venture, as well as the form of the capital to be contributed, the proportion of voting rights as shareholders, the ratio of debt to equity to be maintained, the terms upon which one party will extend credit or loans to the other, and an opportunity cost to be used in evaluating further investments.

In July of 1976, the U.S.-U.S.S.R. Marine Resources Company was incorporated in Washington State. The capital stock is held equally (50% each) by Bellingham Cold Storage and Sovrybflot, the Soviet international fishing investment arm of the Fisheries Ministry. Plans for the venture include (1) hiring U.S. fishermen to catch hake and pollock for delivery at sea to Soviet floating factoryships; (2) Soviet processing for the venture on the factoryships; (3) transfer of the product to (a) Mexico for export back into the U.S., (b) to Japan for sale in the Far East, or (c) to the U.S.S.R. for domestic consumption or export to Europe; (4) opening U.S. ports for Soviet purchase of supplies; and (5) stationing of a Sovrybflot representative in Bellingham and an American representative in Nakhodka.

While the international joint venture can be viewed as a bulwark against foreign dominance and as a stimulus for rapid development and increased industry integration, damage may be done to existing domestic competitors. However, the threat of protection by the host country may be sufficient to encourage the foreign investor to act in the best interests of growth.

Overseas Private Investment Corporation ("OPIC")

The Overseas Private Investment Corporation (OPIC) offers four types of financial assistance to U.S. companies to support economic development objectives in developing countries. They are (1) direct loans, (2) loan guarantees, (3) funding of feasibility studies, and (4) direct grants.

Before committing to any type of assistance, OPIC reviews the track record of the U.S. company and the nature of foreign participation. Although the financial structure may vary with the nature of the project, OPIC prefers projects with no less than a ratio of 60% debt to 40% equity.

Export-Import Bank ("Eximbank")

Eximbank provides direct loans to foreign buyers to facilitate purchases of major capital equipment (requiring repayment terms over 5 years) from U.S. sources. Commercial banks usually provide any remaining financing. Eximbank may guarantee some or all of these commercial bank loans. Loans from the Private Export Funding Corporation ("PEFCO", which is owned by U.S. commercial banks and exporters) will be guaranteed by Eximbank. Although loans are extended to foreign purchasers, the funds are paid directly to the U.S. exporters. The "loan" actually takes the form of a line of credit to the overseas buyer.

The Eximbank will provide credit for up to 65% of the export value of the U.S. purchases. The foreign buyer must provide at least 15% of the export value of the U.S. purchases in cash. The buyer/borrower must arrange for the balance of the financing. Interest rates on Eximbank loans are fixed at 10% (poor countries), 11.35% (intermediate countries), or 12.4% (rich countries). There is a one-time credit application fee of 2% of the loan value and an annual commitment fee of 1/2% per year on the undisbursed amount of the loan. Repayment of principal and interest is scheduled in equal semiannual installments, usually beginning 6 months from the date of delivery of the product or the completion of the project. Eximbank usually requires a repayment guarantee from a financial institution in the buyer's country.

Eximbank will guarantee repayment of medium-term (181 days to 5 years) export credits extended by U.S. banks to foreign buyers. A fee of 1/2% is charged on the outstanding balance of a guaranteed loan and a guarantee fee of 1/8% is charged on the undisbursed amount of the loan.

OPTIONAL STRATEGY FOR FINANCING A 40 MWe OTEC POWER PLANT

Emilio C. Paoloni
Ocean Thermal Corporation
New York, New York, U.S.A.

ABSTRACT

Ocean Thermal Corporation (OTC), a wholly owned subsidiary of BASIX Corporation, finds itself on the verge of launching a lucrative enterprise: the selling of electricity which has been generated by a process called ocean thermal energy conversion (OTEC). Ocean Thermal Corporation will present its preliminary Financial Plan describing the optional strategies under consideration for financing the capital cost of such an OTEC power plant.

After two years of effort, OTC will soon complete the preliminary design of a 40 MW(e) electrical power plant to be built in Hawaii. The design team assembled by Ocean Thermal Corporation consists of TRW, as the systems integrator, Burns & Roe, Dillingham Corporation, R.J. Brown & Associates, the Hawaiian Electric Company and several other firms. What makes this facility unique is that it will be the world's first commercial size power plant generating electricity by converting the thermal energy stored in the surface waters of the ocean, first, into mechanical motion and, then, into electrical energy. Enough electricity will be produced to serve forty to sixty thousand households.

The Financial Plan utilizes a realistic computerized financial model of an OTEC facility operating at the specified site and employing OTC's design. This approach seeks to determine the financing structure which maximizes the economic viability of the OTEC enterprise and meets the requirements of various classes of investors in order to attract private capital.

OTC integrated the requirements of potential investors using the financial model developed in this study. As a result of this iterative interaction between potential investors and OTC, several attractive economic scenarios were formulated involving different capitalization structures. Based on these scenarios, potential investors and OTC agreed in principle to actively pursue joint participation in financing and owning the OTEC plant at Kahe Point. As a result of all these discussions, OTC has developed five alternatives for the private-source financing of the Kahe Point Project.

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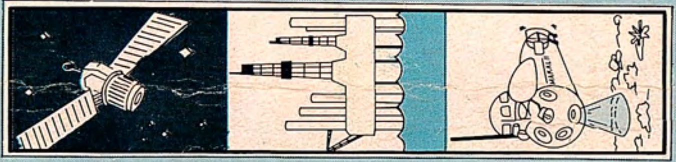

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