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Quarterly Report

Ocean Waste Disposal and Good Water Quality Can Be Compatible

Boston Herald Traveler, November 1971—"High Priority for Harbor Cleanup"; Boston Globe, December 1979—"Time for Action on Boston Harbor Pollution"; Boston Globe, July 1985—"New Sewage Plant Still Years Away."

Fourteen years passed between the first and the last of these headlines. During that time earnest people in earnest arguments have been unable to come to a common plan to manage Boston's wastes and clean up the harbor. Communities have accused and sued each other about the effect of existing outfalls and the location of new treatment plants. The municipal agency in charge, the state legislature, the governor's office, the federal government, citizen committees, and finally the courts have wrangled with each other over how best to act. Sewage disposal is not a tidy problem, nor are there any neat solutions. However, according to one group of twenty-four scientists, engineers and social scientists, who undertook to review the issues attending ocean waste disposal, there *are* ways for municipalities to use coastal waters and keep them fit for fishing, swimming and boating. There is a wealth of scientific and engineering knowledge that makes oceans not only possible but preferable, in some instances, to land and atmospheric disposal of wastewater and sludge. E.P. Myers, a NOAA physical scientist, led the effort that has resulted in an 1100 page, 2-volume overview, "Ocean Disposal of Municipal Wastewater: Impacts on the Coastal Environment."

Myers and his group sought to shed some light on the problems faced by coastal cities large and small. They have taken the life history of contaminants from source and treatment plant through the physical dilution, transport and chemical conversion, analyzed the effects on marine life and water quality and then examined existing technologies and economic and institutional issues.

James Krier, Professor of Law at the University of Michigan, who prepared the

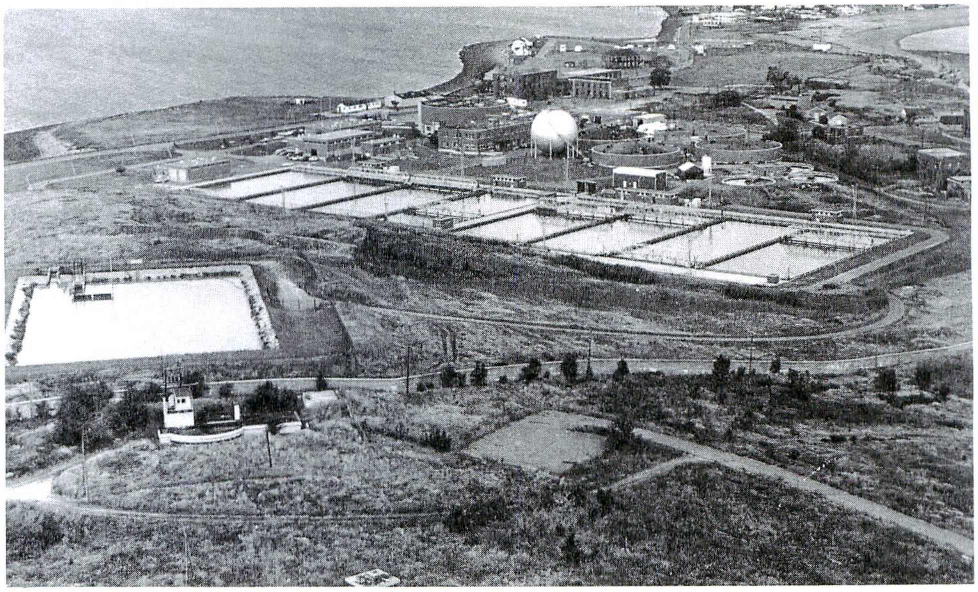

Figure 1. Boston, like many other coastal cities, has been growing, but is still dependent on an outdated sewerage and treatment system that does not meet current EPA waste disposal standards.

chapter on the institutional aspects of waste disposal, maintains that when Congress passed the Ocean Disposal Act and EPA implemented it, they made a presumption that disposal of digested sludge in the ocean is unacceptable, regardless of how or where it is done and that other methods of disposal must, in each case, be preferable. According to Krier this policy does not have an adequate scientific basis, nor does it consider the impacts and costs of other alternatives for disposal, which may produce additional air or land pollution. He is also critical of the Clean Water Act of 1972 which mandated secondary treatment of effluent, but did not consider that the greatly increased volumes of sludge (resulting from the higher degree of treatment) would be problematic. According to Krier, the Act set the same high minimum treatment standards for all discharges large and small regardless of where and how the effluent was discharged. This has resulted in "unnecessary uniformity nationally" which has been "costly and inefficient." Krier and other authors applaud the objectives of Section 301 (h) of the 1977 revision of the Clean Water Act as a step in easing the rigidity of that approach and suggest continued research is needed to assure that important effects are not overlooked.

California is used as an example of an area that adopted comprehensive requirements for ocean discharge which are well conceived and implemented. In addition to routine monitoring by various agencies, there is also a long-range research program for the Southern California Bight conducted by the Southern California Coastal Water Research Project (SCCWRP). SCCWRP is organizationally separate from the regional sewerage agencies and operates under an independent board. They conduct ongoing and long-term studies, with special care taken to look at *new* problems. In most places monitoring well-known pollutants is employed principally to gauge compliance with existing regulations rather than to measure newly

In this issue

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recognized trace contaminants and to look for previously undetected effects.

Coastal cities all over the world discharge sewage effluents with varying results on water quality. Whether the receiving water is polluted or protected depends on what is in the raw sewage (level of toxicity), the degree of treatment (primary and secondary), the appropriateness and design of the disposal system (outfall or barge), and the characteristics of the waters into which the wastes are fed (biological, chemical and hydrodynamic).

In assessing how to design the most efficient and effective waste disposal systems it is essential to analyze the kinds of pollutants in the sewage. There are four classes to be considered: 1. those materials which are natural to the ecosystem; 2. disease-causing pathogens, bacteria and viruses; 3. trace metals, such as cadmium and lead, which are concentrated more heavily in wastes than in the natural environment; and 4. radioactive materials and manufactured organic chemicals, such as PCBs which are highly toxic.

According to E.P. Myers, the greatest concern in the long-term health of coastal ecosystems is related to the last group of pollutants, particularly the organic chemicals. These are being synthesized at "an alarming rate," and it is known that their effects can last for decades and beyond. Norman Brooks, Professor of Environmental and Civil Engineering at the California Institute of Technology, wrote in the final chapter of the study "the experience record is short, but it is absolutely essential that adequate source control be made a reality in the next decade. There simply are no technically feasible alternatives." This could be done by—reducing or eliminating the use of a chemical; recovering waste products from industrial wastewaters and reusing them; treating them chemically to reduce toxicity; or removal by burning or discharging into the atmosphere.

Brooks concludes that government agencies have the information and technological resources to plan and regulate a well designed program of disposal of municipal wastewater and sludge to the ocean. To do so it is necessary to include a mixture of source control, sewage treatment, sludge processing, appropriate outfalls or barging operations, and monitoring and research efforts commensurate with the scale of discharge and the risks. He recommends a program of geographically varying management standards, i.e. requirements for waste management which are set on a regional or case-by-case basis in sensible time steps, with the flexibility to adjust each control program in response to the ocean observations of a particular discharge.

See the abstract insert in this issue of the Quarterly Report for information on how to order this study. □

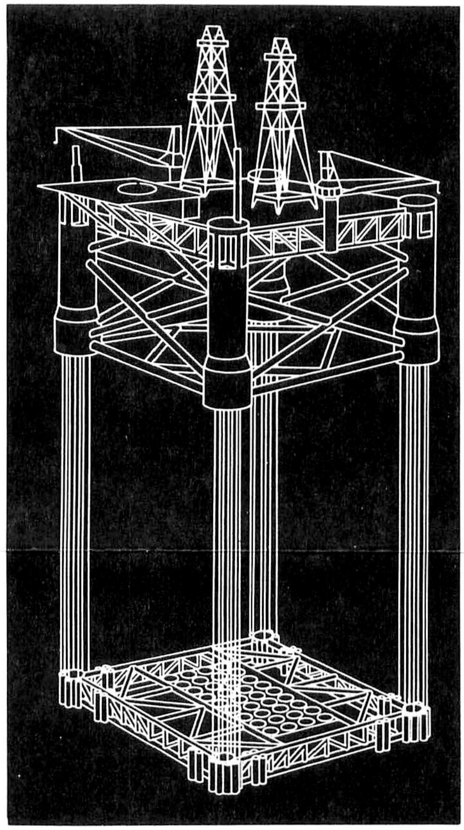

Figure 2. Second-order wave forces will be an important design consideration for new deep-water, compliant structures such as this Tension Leg Platform.

New Structures Demand Consideration of Second-order Wave Forces

"O, God, let the world be linear and Gaussian."

—student prayer

Unfortunately, often it's neither. Nevertheless, engineers designing offshore structures have ignored the world's nonlinearity for years and gotten away with it. They have designed structures to withstand the beating of ocean waves as if the load on the structures corresponded linearly to the waves beating on them. Despite the fact that the force/wave relationship is not in fact linear—that is, nonlinear forces also exist—structures are not collapsing. However, says Professor Dick Yue in MIT's Department of Ocean Engineering, with proposed new designs for deeper water, engineers will have to contend with a nonlinear world.

Engineers have reasoned that a platform is like a swing. The swing sways from peak to peak in a certain period defined by the length of the rope and gravity. If someone wanted to increase the swinging motion, they would push at a critical point in the swing's momentum. Pushing at a wrong time would only interrupt the momentum and do little to increase the amplitude.

Similarly offshore structures sway within a certain time period, or frequency. If they are engineered with a frequency outside that of the ocean's waves, the waves, like pushing the swing at the wrong time, can do little to affect the platform's motion.

That straightforward theory has successfully governed the design of fixed offshore platforms. Rigid structures are designed to vibrate at frequencies far above the frequency of wave energy, which has a period of around 10-20 seconds. Ignored is the fact that together waves create second-order forces at frequencies which may fall within a structure's natural period.

"What is devastating is that the second-order forces are not at the same frequency as the first-order forces," says Professor Yue. Two or more waves can act together at either the difference or sum of the component wave frequencies, and in an irregular sea such combinations often fall within the natural frequency of the platform, Yue adds.

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The MIT Sea Grant Quarterly Report reviews the Program's marine-related research, education, and advisory service activities at the Massachusetts Institute of Technology. Funding is provided by the National Oceanic and Atmospheric Administration through the Office of Sea Grant. Free subscriptions of the Quarterly Report are available on request from the MIT Sea Grant College Program, Building E38-302, Cambridge, MA 02139. Telephone (617)253-3461.

Against fixed structures composed of relatively small members up to several feet in diameter such wave forces are insignificant. However, Yue thinks that with the migration to deeper water and the introduction of compliant structures featuring legs up to diameters of 50 feet or more, nonlinear wave forces can no longer be overlooked. Yue's Sea Grant research is aimed at predicting nonlinear, second-order forces on vessels and structures.

Compliant structures such as the Tension Leg Platform (TLP), like a long, slow pendulum, sway at very low natural frequencies below those of wave energy, having natural periods up to or longer than one minute. On the other hand, anchored by taut cables the platforms bob vertically at high frequencies with periods of only several seconds. Second-order wave forces at the sum frequencies of component waves can resonate the vertical motion of TLP's, while wave forces at the difference frequencies affect the horizontal motion. Aside from possible damage, excessive horizontal drifting can impair or halt operations onboard. More importantly, vertical motion creates fatigue in the TLP legs, which must be accounted for in TLP designs.

Steady drifting caused by a single regular wave can be calculated using linear theory. But the motion caused by the sum and difference frequencies of several waves is more difficult to determine. Previous studies have concluded that slowly varying drift can be deduced approximately from the known steady drift forces of the component waves. This, however, applies only to low frequencies, and does not allow for prediction of moderate to high frequency second-order forces. Yue thinks second-order forces are important enough to require systematic calculations, not approximations, which will apply to all frequencies.

Yue's research on the simultaneous excitation of waves of different frequencies is part of a larger objective to develop a complete theory for second-order wave forces on structures and vessels. Such a theory must include another important effect, hydrodynamic interaction.

Many large offshore platforms such as the TLP have a composite configuration of many legs. Each leg diffracts waves towards the other legs which diffract waves themselves. Such interactions complicate the prediction of wave forces on a multi-leg platform. In principle, interactions between platform legs would be studied by performing numerical computations for the total structure. These analyses, however, are expensive and become prohibitive as the size of the structure and the number of legs increase. Consequently the results are commonly not available to the structural designer in the early design phase, when the designer needs them most.

An alternative is to calculate the forces on one leg and then account for the hydrodynamic interactions among individual members through an interaction theory. In fact, Yue has developed such a theory, solving the total interaction problem through a system of algebraic equations. Instead of treating the platform as a single body, the wavefield around each leg is expressed as a sum of waves with unknown amplitudes. By relating these wavefields to each other and to the diffraction characteristics of the individual legs, Yue can obtain simultaneously the first-order and second-order forces on each leg as well as on the total platform.

Using his theoretical results, Yue will devise a numerical method engineers can use to calculate second-order forces. A database of computed wave force results will be produced for a class of benchmark structural geometries over a range of wave and motion parameters. Yue will also develop statistics on second-order forces in an irregular sea, such as the probable extreme loads and motions during a given time period. His studies will bring the overall knowledge and understanding of second-order wave effects to a level where they can be incorporated into routine engineering design. □

Deterioration of Synthetic Fiber Rope During Marine Usage

Today's ships no longer have webs of manila hemp ropes to raise and lower sails, stabilize the masts and serve as ladders for sailors to scramble around the rigging. However, ropes continue to be vital for anchoring boats and mooring lines, moving objects around a ship, making slings to handle cargo, and towing everything from sailboats in trouble to disabled tankers.

Modern marine ropes are made of synthetic fibers such as polyester, nylon, polyproplene, and in special cases aramid (Kevlar). Compared to natural fibers, the synthetics are stronger, more durable and more resistant to sunlight and biological degradation. However, they are not impervious to damage. Professor Stanley Backer in the MIT Department of Mechanical Engineering has been involved in a long-term project on how and why ropes deteriorate. The eventual goal is to predict when seemingly stout ropes are no longer safe for their intended purpose.

Part of Professor Backer's project involves dissecting ropes and examining them under a scanning electron microscope to check how they have deteriorated over years of use. That painstaking task requires dissecting the

Figure 3. Professor Stanley Backer and Collegium Manager Norman Doelling examine rope that failed under the stress of Hurricane Gloria, which battered the New England coast in September.

rope to separate out the fibers and measure their mechanical and chemical properties. The researchers study any loss in strength or changes in chemical structure or properties within various parts of the rope, and see how the fibers break. In some cases they can measure the molecular weight, which is related to changes within the fiber caused by photochemical degradation.

As expected, the outside surfaces of well-used ropes show photochemical degradation as well as abrasions from being dragged over rough surfaces and wound around winches. Sunlight affects the fibers only on the surface, and cannot penetrate more than one or two yarns deep. Even though the inside fiber may be identical to the outside fiber, it is protected and receives entirely different kinds of forces and photochemical exposure.

Since Backer had expected to find very little deterioration in the protected inside fibers, he was surprised to uncover a considerable amount of damage. When he started to construct models, he realized that the damage was caused by high pressure and lateral motion, and the resulting friction. This type of internal friction can lead to abrasions, which can eventually degrade a rope that displays no outward signs of weakness.

Damage to ropes usually accumulates over many years. Some accelerated tests are being done in the laboratory to subject the rope to cyclic loading, but Backer notes, "The results of the accelerated tests are different from the results from the long-term experiments." In the tensile cycling machine the residual amount of stretch diminishes as the machine pulls a rope fiber toward its breaking limit. Fibers from ropes showing abrasions after having been in the ocean for eight years also have less residual stretch. But the fibers in the old ropes that aren't abraded have a greater residual stretch than new fibers. In a laboratory test the fiber slowly stretches out, reaches its ultimate elongation, then breaks. In practice, the fiber is loaded cyclically while being in water, and depending on the load applied it may shrink and get shorter. Such a shrunken fiber then displays greater residual elongation.

"Ropes have single fibers twisted into yarns, then twisted into rope yarns, which are twisted into plied yarns. The plied yarns are twisted into strands, which are twisted into ropes. The geometry of all those helixes around helixes is very complicated," says Backer. He is building the geometry of the rope into a mathematical model to predict how the rope will resist stretching.

Backer thinks the mathematical model should be useful in predicting trends, such as what would happen if larger fibers or yarns are used or if the twist is increased. It might tell how much untwisting will take place with a three-stranded rope or how much twisting torque will develop when the rope is pulled. One great disadvantage of the three-stranded rope is that it tends to untwist when a weight is hung on it. After the weight is released, such as when an anchor hits bottom and the rope goes momentarily slack, the rope snarls up on itself. This process changes the rope geometry and builds in stresses which could subsequently lead to a rupture of the rope.

With the model Backer and colleagues can determine the lateral compression within different parts of the rope and can calculate the relative movement between different strands in the rope. In laboratory tests fibers are rubbed against each other with different pressures to see how much they abrade. "If we could calculate the pressures and the relative motion within a rope, and if we know from laboratory tests how fast the fiber wears out under those conditions, we should be able to predict how fast the rope will wear out. We should be able to predict how changes of design will affect the internal abrasion resistance," says Backer. "At the present time we cannot really test that internal abrasion characteristic very easily."

"Our prime objective is to find out why rope deteriorates, then to model the rope so we know what factors dominate its properties. Eventually we will combine the deterioration information and the mechanical structures information based on the models to predict what a worn rope will do. If we can predict how it will behave or how long before it wears out, then presumably the Navy or a maritime organization could judge how long to use it in a particular application before entering the danger zone," says Backer. □

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Abstracts

☐ **Wave and Ice Impact Loading and Response of Ocean Structures: Opportunity Brief #39**

Marine Industry Collegium
MITSG 85-20   21pp $3.50

The report summarizes several MIT research projects on environmental damage to ships and offshore structures, including: deepwater wavebreaking forces on ocean structures; local response of marine structures to hydrodynamic impact loads; slow drift motion of ocean structures; and selection of strengthening criteria for navigation in ice.

☐ **MIT Underwater Technology Research: Telemanipulator Developments: Opportunity Brief #40**

Marine Industry Collegium
MITSG 85-27   17pp $3.50

Several laboratories at MIT are conducting research on the use of manipulator systems for undersea and outer space environments, as well as for factory automation. Projects in the Space Systems Laboratory, Man-Machine Systems Laboratory, and Artificial Intelligence Laboratory, as well as the Deep Submergence Laboratory at the Woods Hole Oceanographic Institution, are summarized in this report. The projects described include the following: touch sensing; parallel link manipulator; impedance control of manipulators; underwater teleoperators for space simulation; and development of a supervisory controlled telemanipulator for the ARGO/JASON vehicle system.

☐ **Remote Sensing and Oceanographic Equipment Technology: Some Present Systems and Future Needs: Opportunity Brief #41**

Marine Industry Collegium
MITSG 85-21   21pp $3.50

This report describes projects presented at an MIT Sea Grant workshop focused on the interdependence of satellite measurements, in situ measurements, and modeling for understanding the dynamics of the ocean. Projects presented include remote sensing of large-scale ocean processes; the value of in situ measurements for modeling the dynamics of warm core rings; and the scientific program of the world ocean circulation experiment (WOCE). A description of a new moored current and density profiler is also given.

☐ **Marine Related Research at MIT 1985-1986**

Compiled by Susan D. Stolz
MITSG 85-31   101pp   No charge

This directory provides an overview of ocean and coastal research from all departments at MIT. Short descriptions of research in progress pinpoint major objectives and list the names and departments of principal investigators. The directory is organized by subject areas, including: fisheries and food and drugs from the sea; marine biology; marine mineral resources; alternative energy sources; pollution, including coastal zone management, water quality, oil spills and waste disposal; oceanography, including chemistry, geology and physical oceanography; ocean engineering, including acoustics, instrumentation, underwater vehicles and robotics, materials and offshore structures; ship design and operation; shipping and transportation systems; and marine education. Indexes by subject area and principal investigator help make this directory easy to use.

☐ **Ocean Disposal of Municipal Wastewater: Impacts on the Coastal Environment**

Edward P. Myers, ed.
MITSG 83-33   2 vols.   1115pp $25.00

This two-volume, multi-author publication is a thorough discussion of the problem of ocean disposal of municipal wastewater. The organization of chapters essentially follows the life history of a contaminant in coastal waters from its source through physical dilution and transport and chemical conversion, to effects on marine and human life. The final chapters address some socioeconomic, legal/institutional, and management considerations.

☐ Human Interactive Simulation and Display of an Underwater Remotely Operated Vehicle

Thierry Royer
MITSG 85-29TN 92pp $5.00

As the fleet of unmanned submersibles grows in the next several years, so will the demand for trained human operators who can supervise underwater vehicles using analog controls, computers, and video. This report offers a framework for developing training procedures for the operators through simulation. The simulator, implemented on a PDP 11/34, is made up of four modules which work in parallel: a dynamic model of the vehicle, a static model for the shape and tension of the tether, a graphics display, and a simulator of the environment. The modular concept makes it easy to change or adapt individual elements, and simulation costs can be cut by using a multi-microcomputer system. The report was written as a thesis in the MIT Department of Ocean Engineering.

☐ A New Generation of Underwater Unmanned Tethered Vehicles Carrying Heavy Equipment at Large Depths

M.S. Triantafyllou
A.M. Amzallag
MITSG 85-30TN 243pp $14.00

The offshore industry and deep ocean mining companies operating in deep water will require unmanned vehicles which can perform heavy duty tasks. This report describes in detail a rational process for designing an appropriate tethered submersible for those conditions. Simulations of the submersibles are presented to evaluate performance and power requirements, with and without payload. These are then repeated with a control methodology which uses LQG/LTR.

☐ Tow Tank Results of Bulbous Bow Retrofits on New England Trawler Hulls

Angelos D. Heliotis
Clifford A. Goudey
MITSG 85-7 40pp No charge

This report describes the research conducted at MIT on bulbous bow retrofits applied to two New England type trawler hulls of 76 and 119 foot overall length. A 4.5′ model of each hull was constructed and a series of twelve cylindrical-type bulbous bow retrofits were prepared for each. Calm water model resistance tests were conducted on the bare hull and then with each retrofitted bulb. The bare and bulbous models were then tested in regular waves over a range of wave lengths at both steaming and trawling speeds. Pitch, heave, bow accelerations, and resistance were measured.

Editor's Note:

With this issue of the Quarterly Report, we are introducing a new category of publications—MIT Sea Grant Technical Notes. These are being added to our report series which currently encompasses directories, advisory service opportunity briefs, journal reprints and research reports. The purpose: to help us to disseminate a wider range of information related to Sea Grant research interests, including theses, results of small, short-term projects and relevant non-Sea Grant funded projects. Each Technical Note will be given an MIT Sea Grant report number with the suffix "TN" (MITSG-85-32TN). Because they are being reproduced in small quantities, Technical Notes will cost slightly more than our regular research reports.

You may order one copy of any of these reports, except for Technical Notes, free of charge.

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