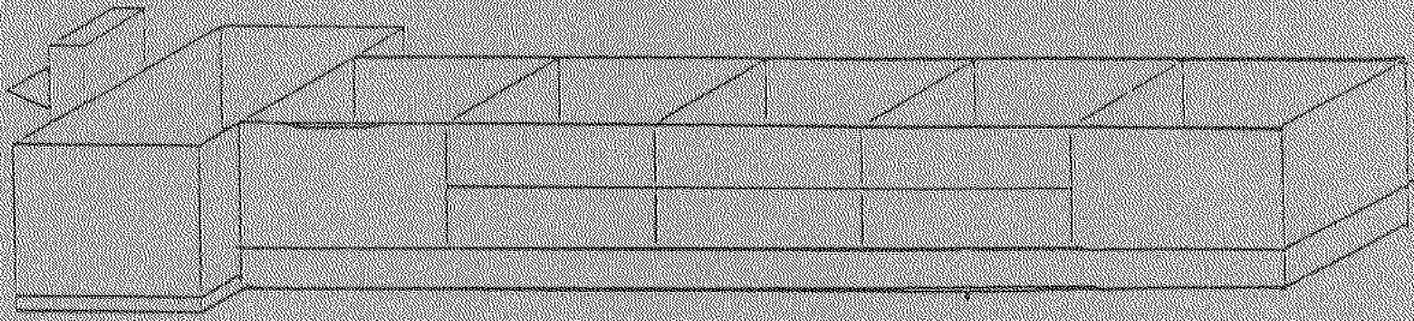
THE DESIGN AND CONSTRUCTION OF A PISTON-TYPE WAVE GENERATOR AND WAVE TANK



A Report For:
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ABSTRACT

A wave tank is very useful for modeling situations in which the forces and reactions of periodic progressive waves are needed to make sound engineering decisions. The size of the tank is not critical,yet should be sufficient enough such that capillary waves are not significant and do not effect the generated waves. Length and energy dissipation are important in the sense that the successive waves are absorbed and do not reflect back into the test section nor create a standing wave in the tank.

The piston type wave generator has proved satisfactory for the generation of transitional and shallow water waves and is used in this case. Measurements for the monitoring of these waves should be readily and easily accessible for such factors as wave height, and wave speed. Other facilities should allow for the measurement of factors critical to the experiment being performed such as wave forces on an object.

ACKNOWLEDGEMENTS

The members of this project wish to extend thier deepest thanks to Bob Doucette and Bob Blake for all the effort they put into this project to make it a success. Further thanks go to Greg Charello and Maura Foster for their assistance and aid. Special thanks are extended to the advisors, Professor Ken Baldwin and Professor Tom Ballestero, Professor David Gress, Professor Charles Goodspeed and Professor Jean Benoit , who all gave excellent technical assistance, and guidance.

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1. INTRODUCTION

Wave Tanks are used for the hydrodynamic modeling of real life sea situations and are therefore very helpful in predicting the performance of structures and the behavior of the ocean bottom due to wave motion. This gruop has taken the task of designing and constructing a wave tank to be jointly used by the engineering departments at UNH for undergraduate labratories, and by the Ocean Engineering program. This project was co-supported by the Ocean Projects Course and Master of Science in Ocean Engineering Program at UNH.

The tank as an overall entity , had several design constraints on it from the system point of view. It had to be ruggedly constructed to take the loads of the water and waves. It also had to be very rigid, especially the walls, so that there is no flexure which could result in transverse waves of unkown properties. The tank had to provide a means to absorb waves that were created by the wave generator generator.

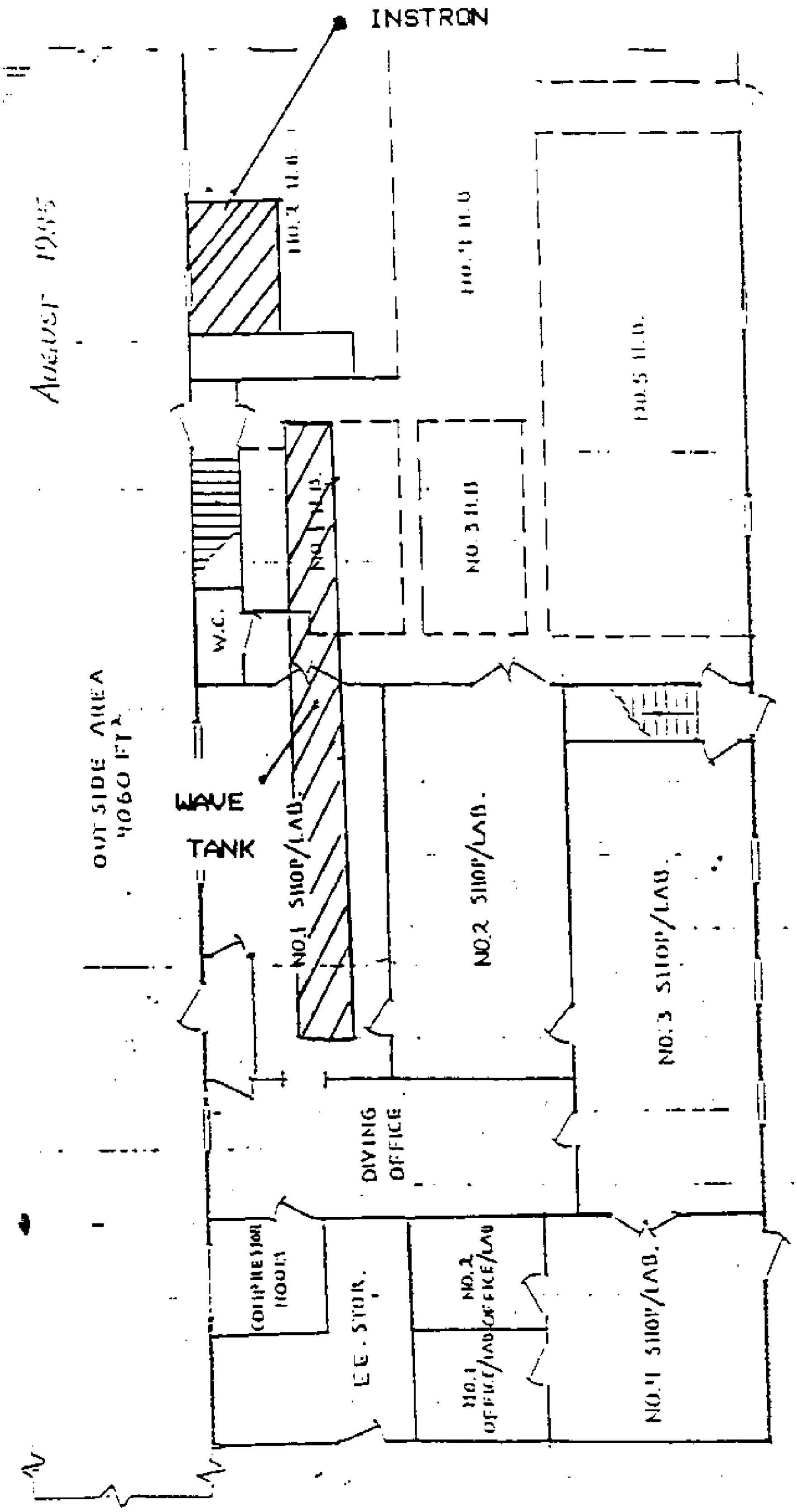
Additional constraints placed on the design were external to the tank but influenced the design. First the tank was to be built in the UNH Marine Program building and placed on the first floor. Since the tank also had to comply with fire safety codes, it severly limited the available room , thus limiting the overall length and width.

The next major restriction was that the tank had to be modular so it could be disassembled and moved to the new engineering building upon it's completion. This constraint remved the possibility of making a permanent foundation.

Final constraints were those imposed by economy . Existing glass panels from the old wave tank, which were already framed in aluminum,were utilized. The Instron cylic loading machine was used as a hydraulic source for the wave generator. These also made some major restrictions on size of the within the building (figure 1.1).

The design was broken into two major categories, the wave generator, and the tank and accompaning sub-structure. Each of these was again broken into subsequent parts and compared for overall compatability to reach a finalized, stable and executable project.

Background for wave tanks in general seemed to vary as much as the sources. The general feeling seem to be to build to appropritate constraints and calibrate the tank after completion. After visiting the M.I.T. Parsons Lab, wave tank and tow tank facilities, the general concensus was to use this approach and thus the following design resulted.



MARINE PROGRAM BUILDING - FIRST FLOOR

FIGURE 1.1

2. WAVE GENERATION

LINEAR WAVE THEORY AND BACKGROUND

To satisfactorily hydrodynamically model waves, it is imparative to understand basic linear wave theory and the assumptions utilized in it's developement . The characteristic dimensions of a typical wave appear in figure 2.1 . Through the use of linear wave theory, which assumes ideal fluid properties of non-viscous,negligible surface tension and incompressibility, the dispersion relationship is derived (Dean and Dalrymple,1984) as a function of certain wave parameters. This relationship is as follows:

$$C^2 = L^2/T^2 = g/k \tanh kh \qquad \text{where } k = (2\pi\ L)$$
$$L = (gT^2/2\pi) \tanh (2\pi h/L)$$

this in turn can be expressed a

$$L = Lo \tanh (kh) \qquad \text{where } Lo = gT^2/2\pi$$
$$C = Co \tanh (kh) \qquad \text{where } Co = Lo/T$$

Within these equations are hyperbolic functions which have asymptotic values which allow waves to be placed into three regimes based on relative water depth, shallow , transitional ,and deep water waves. From this the dispersion relationship can also be developed for these regimes(Dean 1984).

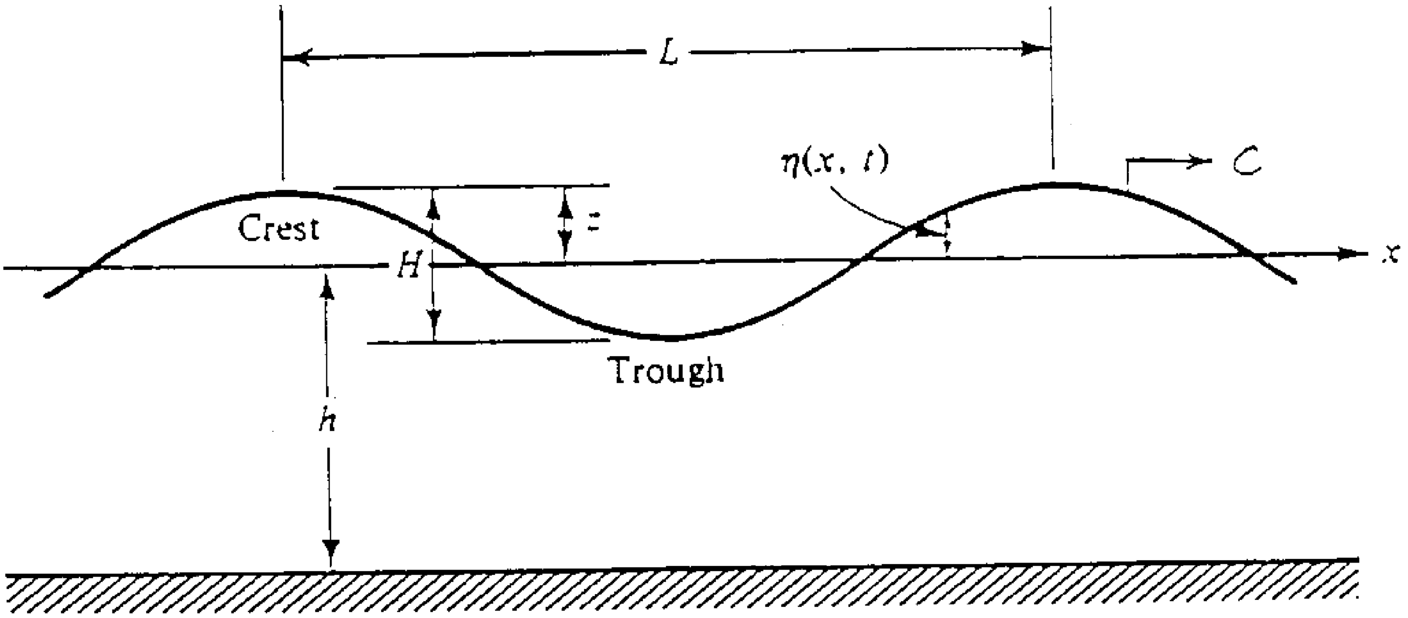


FIGURE 2.1 Wave characteristics.

H WAVE HEIGHT

L WAVE LENGTH

T WAVE PERIOD

h WATER DEPTH

SOURCE : DEAN AND DALRYMPLE, 1984

SHALLOW WATER $kh < .1\pi$

$C = \sqrt{gh}$ $L = T^{2}gh$

DEEP WATER $kh > 1.0\pi$

$C = Co$ $L = Lo$

The general dispersion relation holds for the transitional region between these two extremes. From this it can be seen that shallow water waves are a function of water depth and interact with the bottom,while deep water waves are unaffected by depth.

WAVE MODELING

The hydrodynamic modeling to be done in the wave tank would consist mainly of near shore structures, or sediment transport type experiments. Therefore it was decided that waves of transitional to shallow water characteristics would best suit the purpose since these waves interact with the bottom. Thus a wave generator was needed to meet this criteria.

Wave generators that are popular among many existing tanks,such as those at Parsons Lab at the Massachusetts Institute of Technology, fall into two basic categories: piston type and flap type. There are also several unique types but information on these are limited.

The flap type wave generator consists of a flat plate which is verticle in the water column and hinged where it is attached to the bottom . The top is pushed back and forth to "flap" and create the wave. The displacement of the paddle varies with depth and is zero at the very bottom ,therefore the waves created do not interact with the bottom and are of deep water characteristics (figure 2.2).

The piston type wave generator is also a flat plate which is vertical in the water column. It is supported on a rail system to move linearly forward and back such that the plate always remains perpendicular to the still water surface and has the same linear displacement at all depths including the bottom(figure 2.2). Because it moves linearly all the way to the bottom it causes waves that interact with the bottom and is therefore ideal for creating transition and shallow water waves making it the choice for this tank.

WAVE MAKER THEORY

It is generally accepted that in generating waves with a piston type wave maker that the volume of water displaced by the piston is equal to the volume of water in the wave crest and there exists a relatioship between piston stroke S and wave height H (Dean and Dalrymple,1985) The relationship is as follows:

$$H/S = 2(\cosh 2kh-1)/\sin(2kh) + 2kh$$

Again with asymptotic values for the hyperbolic functions the equation becomes;

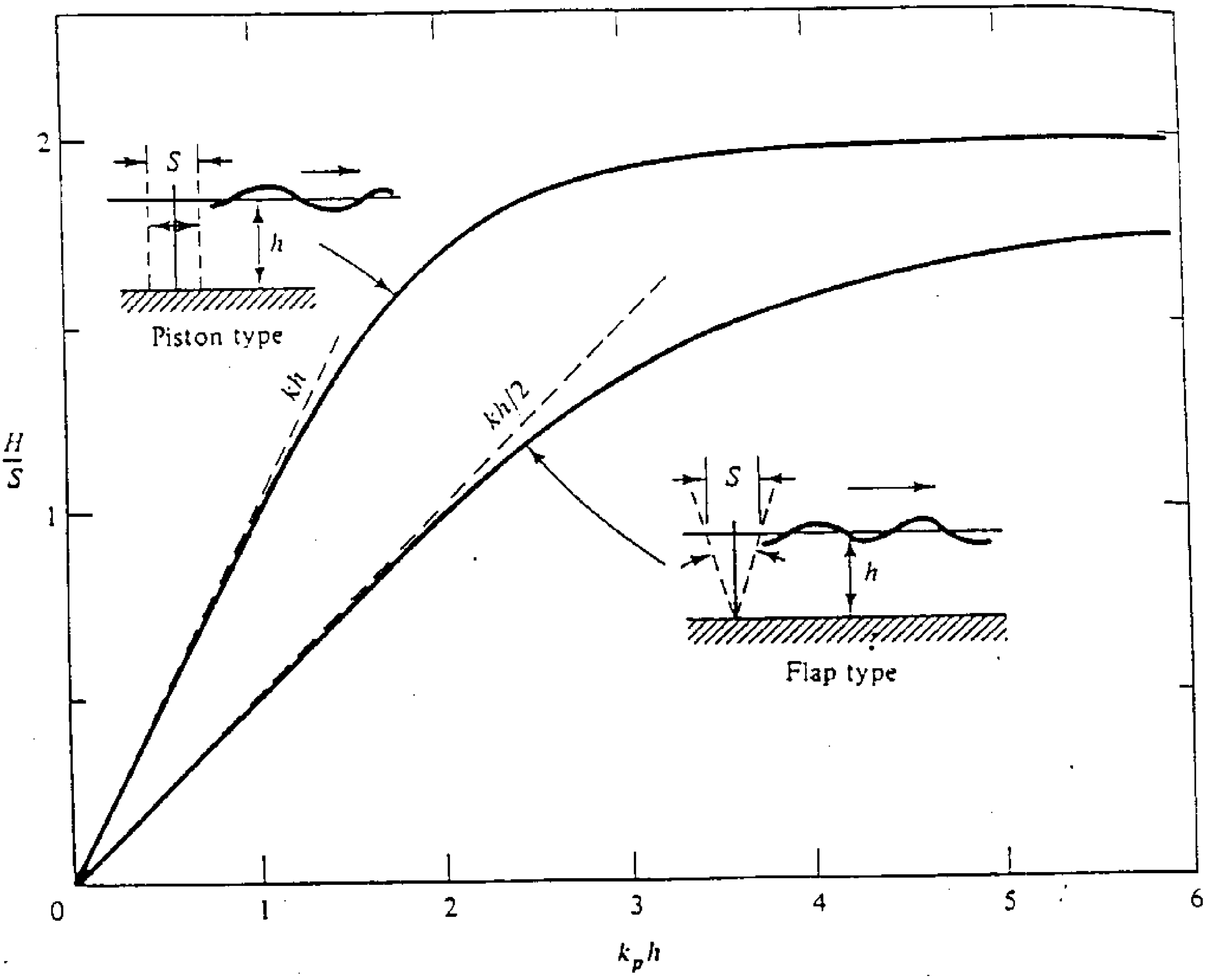


FIGURE 2.2 WAVE GENERATORS AND CHARACTERISTIC CURVES

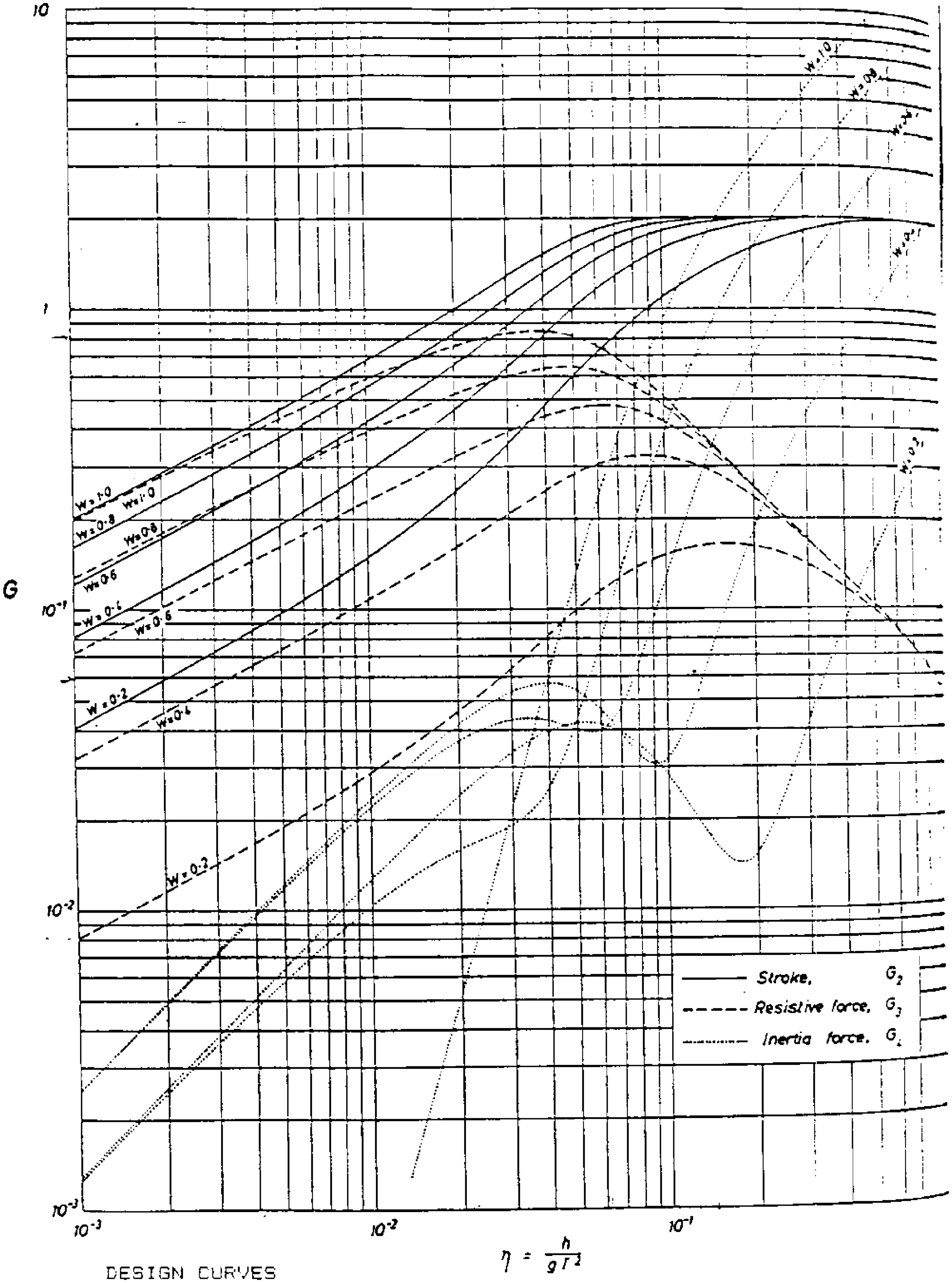
SOURCE : DEAN AND DALRYMPLE 1984

$H/S = kh$ for shallow water waves (figure 2.2).

This again is for the piston type wave generator and is different for the flap type.

DESIGN ANALYSIS

Design of the piston type wave maker was based on the on the forces on the face of the plate to generate the shallow water waves desired. These forces were determined with the aid of a set of design curves that were developed by Gilbert ,Thompson ,and Brewer,(1971) . These curves are plotted on a set of axis which give relationships between various wave parameters as defined previously by the dispersion equation (figure 2.3). Combining these parameters with the wave maker theory allows for the determination of the worst case wave and the resultant forces on the wave generator under such situations. The worst case conditions for this tank were determined to be a water depth of thirty six inches and a wave period equal to two seconds. From these and the dimensionless parameters defined in the article, two forces can be predicted to be summed for the total force. The two components are the resistive force which is in phase with the velocity of the piston ,and an inertial force which is in phase with the acceleration of the piston. With an adequate factor of safety the total worse case force was determined to be six hundred and

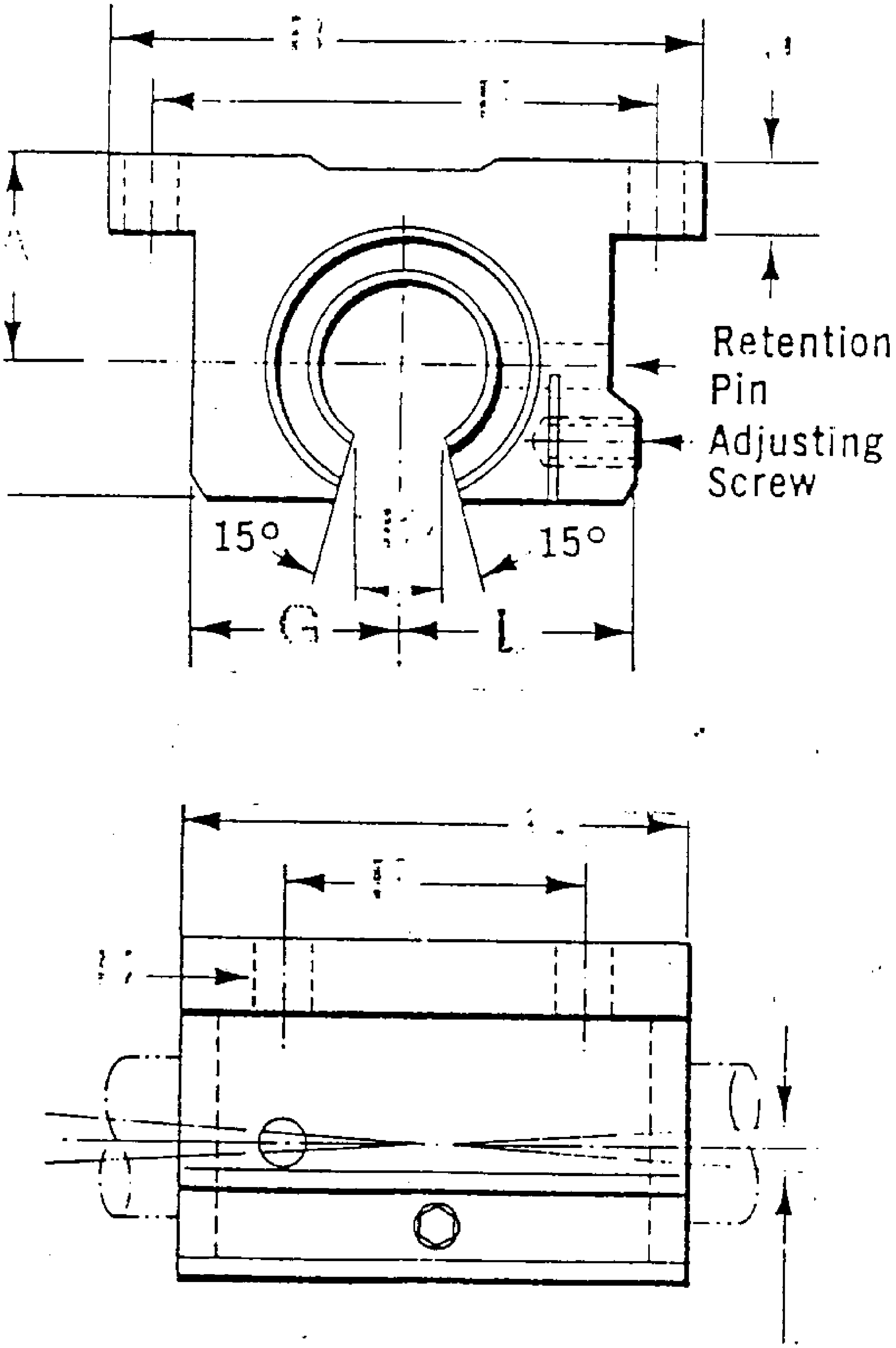


DESIGN CURVES

Piston and wedge regular wave generators. FIGURE 2.3 SOURCE : JOURNAL OF HYDRAULIC RESEARCH VOL 9 1971 thirtytwo pounds.

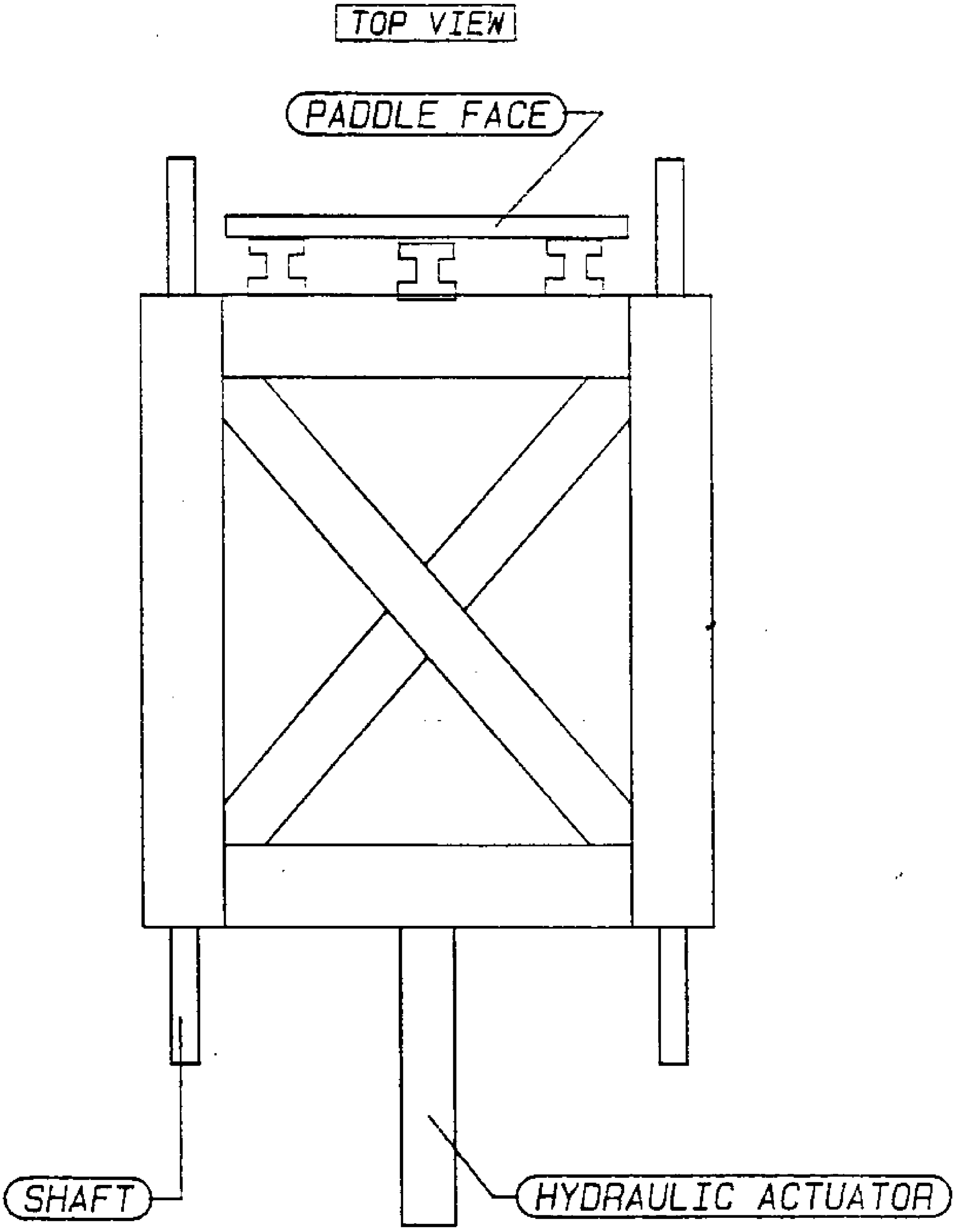
With the criteria established thus far, the final design was chosen. The M.I.T.wave tank influenced the method chosen for obtaining the linear motion of the piston. The hardware for this function consists of linear ball bushings, supporting a piston carriage riding on case hardened steel shafts(figure 2.4). The carriage itself is made out of 6061 aluminum I -beams and channels, which are welded into a truss type frame which supports the piston's flat plate face of 3/8" aluminum (figure 2.5). The truss design was incorporated to provide a rigid non-flexing frame. Besides meeting the strength criteria the piston must remain a flat plane to guarantee that the generated wave propagates axially down the length of the tank without having any transverse velocity components. Thus the carriage was actually stronger than it had to be to provide extra rigidity . Another factor that led to the size of the truss members was the availability of materials. Some of the materials were obtained from donations while the rest was bought as scrap to save money. Some members were more than adequate yet were less expensive in the end. The back of the face is also strengthened by aluminum I-beams, three running vertically and two running horizontally (figure 2.6).

The linear ball bushings that the carriage moves on are 1 1/2" I.D. Thompson Super Bushings which are self aligning in all directions. These slide on Thompson case hardened shaft rails which are four feet long. The rail in turn are mounted to steel Ibeams which support the whole

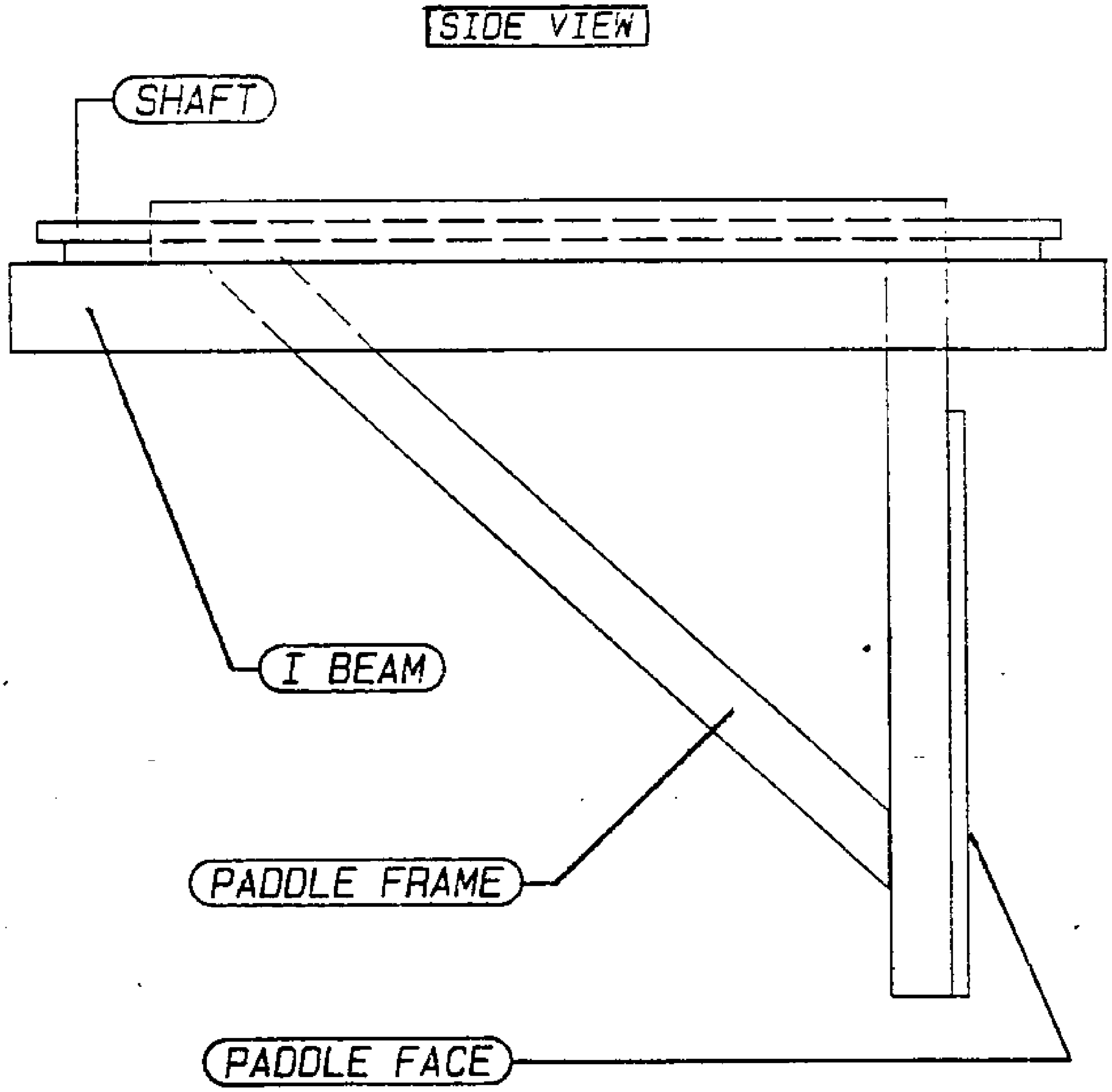


Self-aligning in All Directions

FIGURE 2.4 SOURCE : THOMSON BEARINGS 198



WAVE GENERATOR
FIGURE 2.5



WAVE GENERATOR

FIGURE 2.6

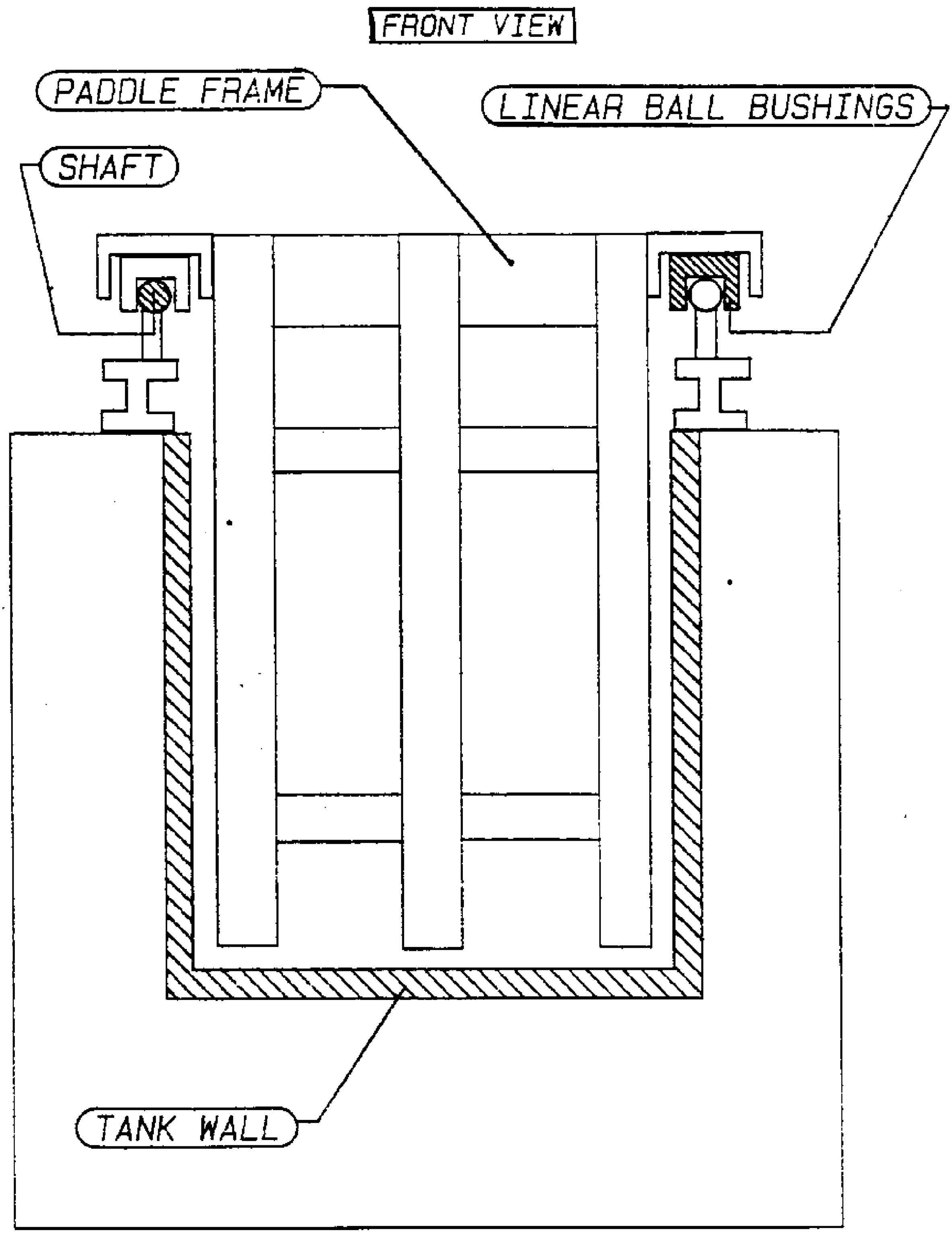
mechanism well above the water level (figure 2.7).

WAVE GENERATION ELECTRONICS AND CONTROLS

There are many ways to drive a wave generator. The first attempts were to use a variable speed motor which drove a cam. The cam had a follower attached to the piston . The problem with this system is that it can only produce one kind of wave, which was a function of the cam shape. The cam has to be changed in order to vary wave characteristics.

A more common and refined way to drive the generator is with the use of a hydraulic actuator . The fluid flowing into the actuator is again controlled by a hydaulic valve. The full system is then driven with the aid of a computer. This hydraulic system is much more flexible and versitile system with a smoother response than a straight mechanical system.

The hydraulic system used for this wave tank and piston type generator was obtained through donations and therefore made the selection more than easy. The actuaor and accompaning hydraulics as well as the electronic controls were provided by the UNH Civil Engineering Department. An Instron Testing machine was already located in the Marine Program Building near the tank site as was an unused five thousand pound ,force actuator mounted in a reaction frame (figure 2.8). Permission was obtained to use the actuator and frame in the actual tank construction, and to tap into the Instron pumps and electronics.

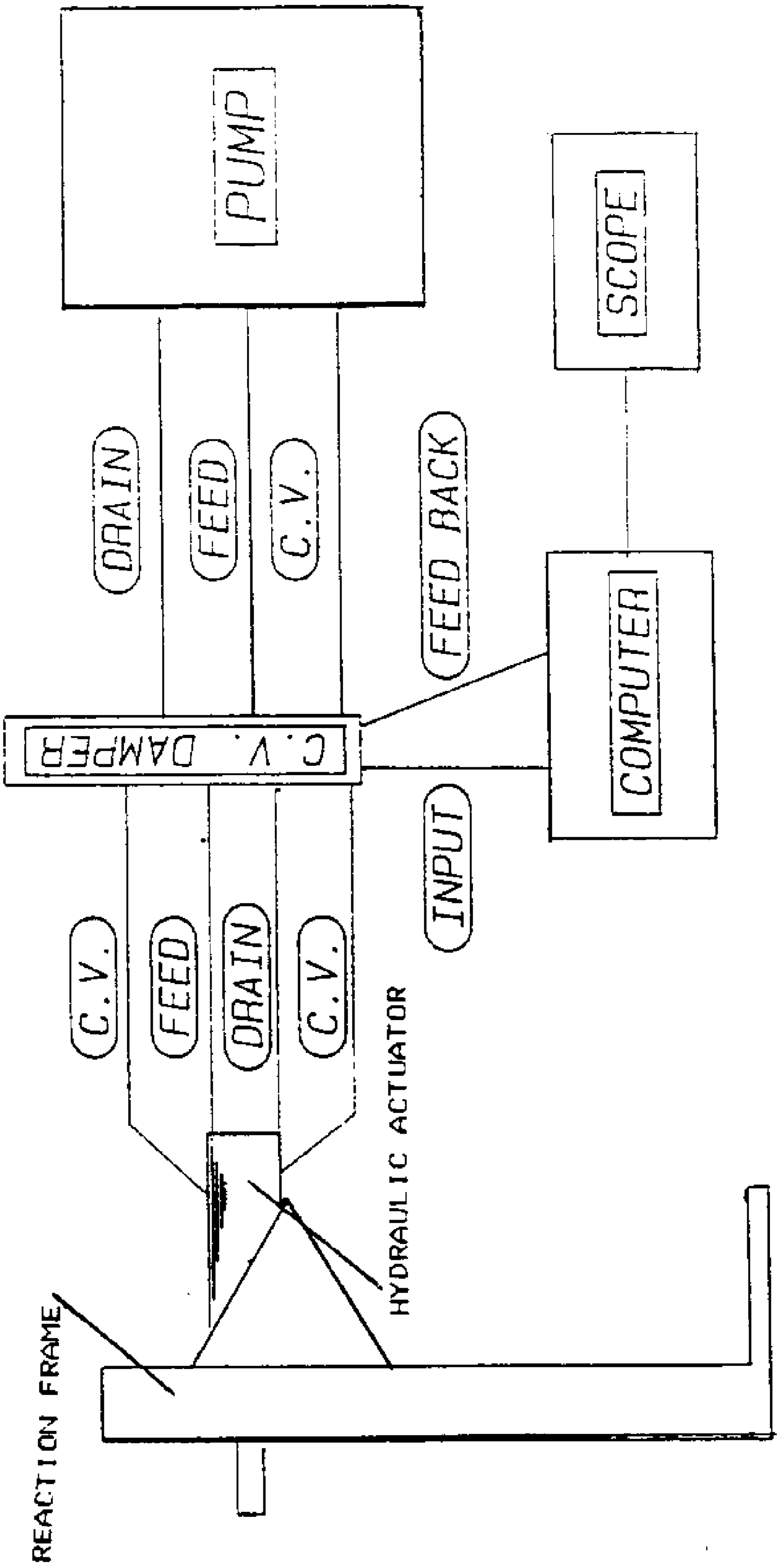


WAVE GENERATOR

FIGURE 2.7

The Inston machine uses a computer to control the movement of the actator which has a six inch stroke and a 2 1/2" shaft (figure). This is done with a program which has a wide range of capabilities, making it more than adequate for any type of wave generation (figure 2.9). The general program allows the actuator ram to move in two modes,position and load. When the program is loaded into the computer, the user is allowed to enter different data into the program to obtain the output of the ram at the proper response the correct waveform in the test section of the tank.This data entry is in the Control Predata section of the program. In this section the user can determine whether to control the ram by load or position. The next choice is the waveform of the actual ram output , which will result in the desired wave field in the tank.The three basic waveform available are sinusoidal,square, and triangular. Next ,if position control is desired is the input for the Mean Level of the input wave, the mean position of the actuator shaft. Following this is a prompt for the amplitude of the input wave,the actual amplitude of the ram's movement. The next value to be entered is frequency at which the ram will pulse. All of the above information is the data that makes up a single "block" in the execuitable portion of the general program.

This general program has the capability of handling five of the "blocks" mentioned above. Each block can be totally diferent with variations in any of the parameters. The user is then allowed to link the blocks



NOTE: C.V. = CONTROL VALVE

FIGURE 2.8

```
                              Block Progrmming Set Up

LD=      0.0001        KIPST1=    0.012 %            ST3=
PN=      1.4563         in ST2=                      ST4=
                  CYCLES .....                BLOCKS .....                 LOOPS .....
ERROR                STATUS                   LIMITS
                                 CONTROL PREDATA

BLOCK-1                          * POSITION          CONTROL
WAVEFORM                           SINE
MEAN LEVEL                         ...............   IN
AMPLITUDE                          ...............   IN
FREQUENCY                          ...............   HZ
NEXT BLOCK                         NEXT
TRIGGER                            CYCLES
CYCLES                             ...............



F1= PRINT            F2=          F3=           F4= TRIGGER

---  -----------------------------------------------------------------------------

A. SELECT DESIRED CONTROL MODE, USING THE SCRATCH PAD.
B. SELECT A CONTROLLING WAVEFORM FROM CHOICES IN THE SCRATH PAD.
C. ENTER A MEAN LEVEL/RAMP START USING THE KEYPAD.
D. ENTER AN AMPLITUDE/RAMP END VALUE USING THE KEYPAD.
E. ENTER A FREQUENCY/RAMP RATE USING THE KEYPAD.
F. SELECT AN ACTION FOR NEXT BLOCK USING THE SCRATCH PAD.
G. SELECT A BLOCK TRANSFER TRIGGER ACTION.
```

REF FIGURE 3-14 CONTROL PRE-DATA PAGE INSTRON MANUAL

These steps should be followed when entering data into the instron computer.(Note the operator should be checked out on the system before use.) For added blocks of data, step (F) in the outline should be changed from the default of (END) to one of the other options available in the scratch pad.

SOURCE: INSTRON INSTRUCTION MANUAL   SERIES 1330

FIGURE 2.9

together in some sort of series and to recycle throughthem continuously until terminated. Each block can be terminated in several different ways. For the purpose of wave generation the terminating factor will either be the number of cycles or a period of time. This is determined by choosing either a cycles or time anser to the "type of trigger" prompt. Following the termination of the block the program can be told to continue, end, or loop back to any of the previous blocks.

The Instron system of block programming is good for the present purpose because by properly inputting into each of the blocks and looping these blocks correctly, the operator can provide a very wide range of wavefields. If a random sea state is desired , five different blocks can be used to superimpose the effects and differences. For a breaking wave the blocks might be set up such that each successive block has an increasing amplitude and frequency. The wave field can be either deep or shallow water waves. When operated in the shallow water range, the tank can be used to study sediment transport.

The Instron allows the maximization of the wave tank by enabling the reproduction of virtually any natural sea surface form. This will allow for accurate information to be gathered on any hydrodynamic system modeled in the tank.

3. TANK AND STRUCTURE

MAIN TANK

The tank itself is considered to be the part of the structure in front of the paddle. It is 40 ft long, 4ft high, and has an inner width (paddle width) of 28 inches. The primary materials used were steel and marine plywood purchased new, and most of the old UNH wave tank which was built of aluminum and glass. In designing this wave tank leakage, performance, wall deflections, and most importantly, the structural soundness of the tank and its potential hazard to human life were considered. The ease of assembly and disassembly was also an important consideration because disassembly in the future may be neccesary if the tank is indeed moved to the new UNH engineering building.

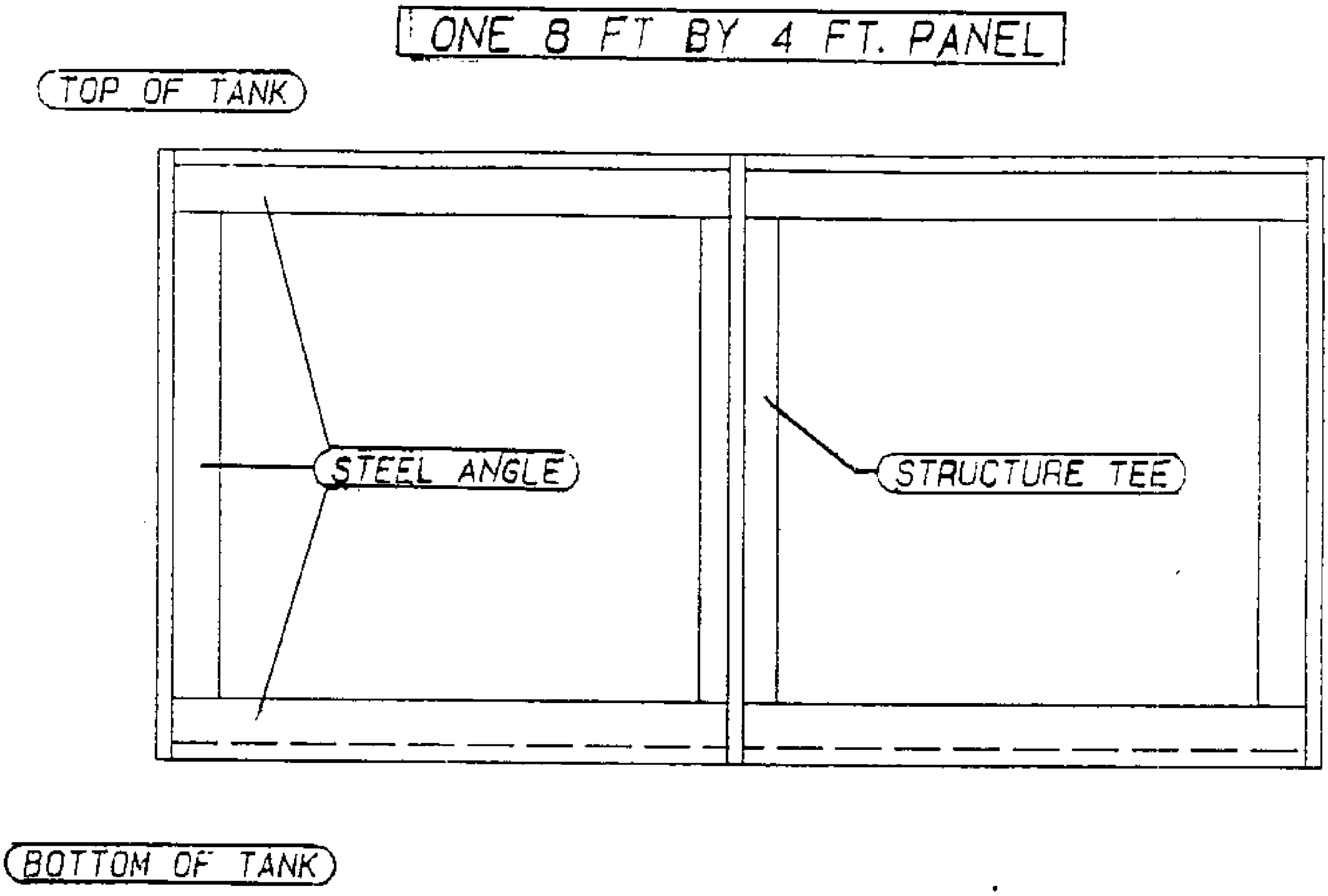
From the constraints in section one, the final dimensions and location of the wave tank were determined to be 47 feet overall length by 32 inches wide with an overall height of 65 inches. The Tank is located on the first floor of the UNH Marine Program Building partially in a fifteen foot by thirty foot room and extending approximately eighteen feet into the highbay area where the Instron testing equipment, used to power the generator is located (figure 1.1)

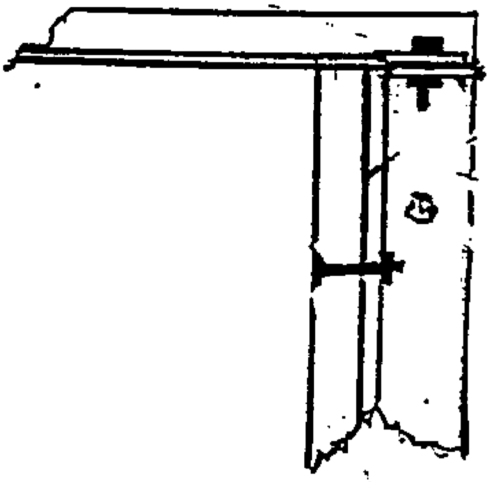
The tank is made up of 10 panels, each 8ft long and 4ft high. Seven of the panels are plywood with external steel frames and the other three are glass with external aluminum frames. Five of these panels comprise each side, connected on top and bottom with steel angles and flat stock to form the 3 dimensional tank with an inner width of 28 inches. The five back wall panels are marine plywood, while the front side has one panel of marine plywood in the wave generation section, three panels of glass for a viewing area, and one panel of plywood at the far end in the wave energy dissapation section. The bottom of the tank is marine plywood which is connected to the bottom angle of the side panels and the steel flatstock(figure 3.1)

The glass sections were obtained from the old wave tank. Permission was granted to use any or all of the old tank in the new design at no cost. Due to the budget and the high cost of glass, it was decided to to use all six of the 1/2" thick, 2ft. high, 8ft. long panels from the old tank for a 24ft. long,four ft. high viewing section in the new tank. Fortunately, the size of the glass panels made it simple to connect together one on top of the other to form a 4ft. high, 8ft. long panel which conveniently matched the 4. x 8ft. sheets of plywood. The one disadvantage to using these glass panels is two angles run horizontally through the viewing area. However, this minor inconvenience in wave observation couldn't justify altering the size and design of the tank in order to purchase new glass.

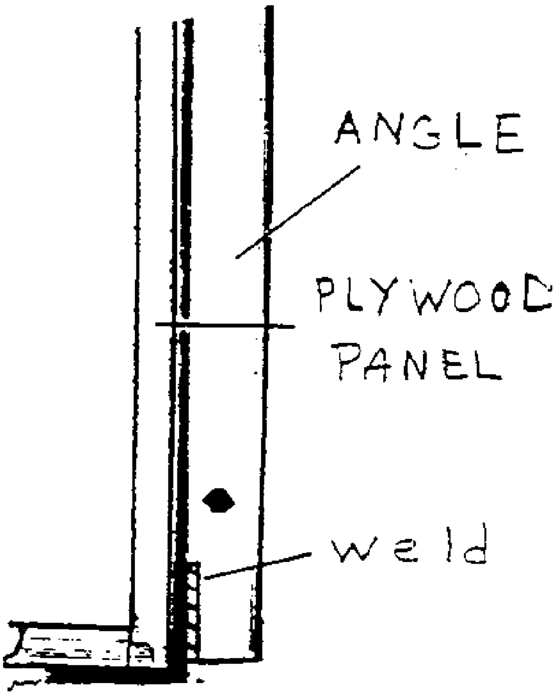
The steel frames and unsupported sections of marine plywood were analyzed by estimating stresses developed during normal operation and comparing them to accepted yield stresses for the particular materals (see appendix). Maximum loading conditions were taken to be 3 1/2ft. of hydrostatic pressure with an adequate factor of safety applied to account for the dynamic loading of the wave movement. 2" x 2 "x 1/2" angles were chosen to construct an 8 x 4ft. panel with a 4ft.section of 4"x2"x1/2" structural tee beam connected vertically in the middle of the panel. The relatively small tee beam was not available, so the steel company agreed to split a 4"x4"x1/2" H beam in half . The glass panels were built by securing one of the 2 x 8ft. panels from the old wave tank to another. The panels left a 4 x 4ft. section of plywood and 2 x 8ft. section of glass which were safely able to support maximum load with tolerable deflections. The 4 x 8ft. panels are connected to one another on bottom with 1/4 x 2 inch flatstock and on top with 2" x 2" x 1/4" steel angle. Loads in these members were taken to be purely axial and the limiting factor turned out to be the size and number of bolts connecting them to the side panels.

The construction of the tank began by prefabricating the seven steel frames for the wood panels. Each frame was constructed by welding two 8ft. long and 4ft. long angles and one 4ft. long tee together (see fig 3.1). These frames were than bolted to one another or to a glass panel section with three pieces of flatstock running across the bottom, and three pieces of the same angle running across the top. The bottom piece of marine plywood was then bolted in with 1/4 - 20 flathead screws to the flat stock and sealed with





UPPER JOINT



BOTTOM JOINT

FIGURE 3.1

silicon caulking. Each of these 5 sections was set and aligned on the foundation at which time the side pieces of plywood was bolted to the side panels and the tank sections were bolted together. This part of the tank was then secured to the rear section under the wave generator, providing one continous structure.

The completed tank had one problem which needed to be corrected. When shaken from the top, the midsection of the tank would sway from side to side about 2 inches. The problem was solved by wedging and angle against the bottom of a wall in the vacant room and bolting it into the back side of the tank;providing the extra bracing that added rigidity to the midsection of the tank, which corrected the sidesway problem.

PISTON ENERGY DISSIPATION

The rear section of the tank located behind the piston-type wave generator and in front of the reaction frame (figure 3.2) was designed to dissipate the wave energy created behind the piston during the generation of waves on both the forward and return stroke. This section also provides the main support for the generator rail's and the weight of the generator itself. This being the lowest section of the tank ,it will also have the drain port in it.

In order to dissipate the wave energy during generation this section of the tank had to have a greater volume than that displaced by the piston ,thus a greater

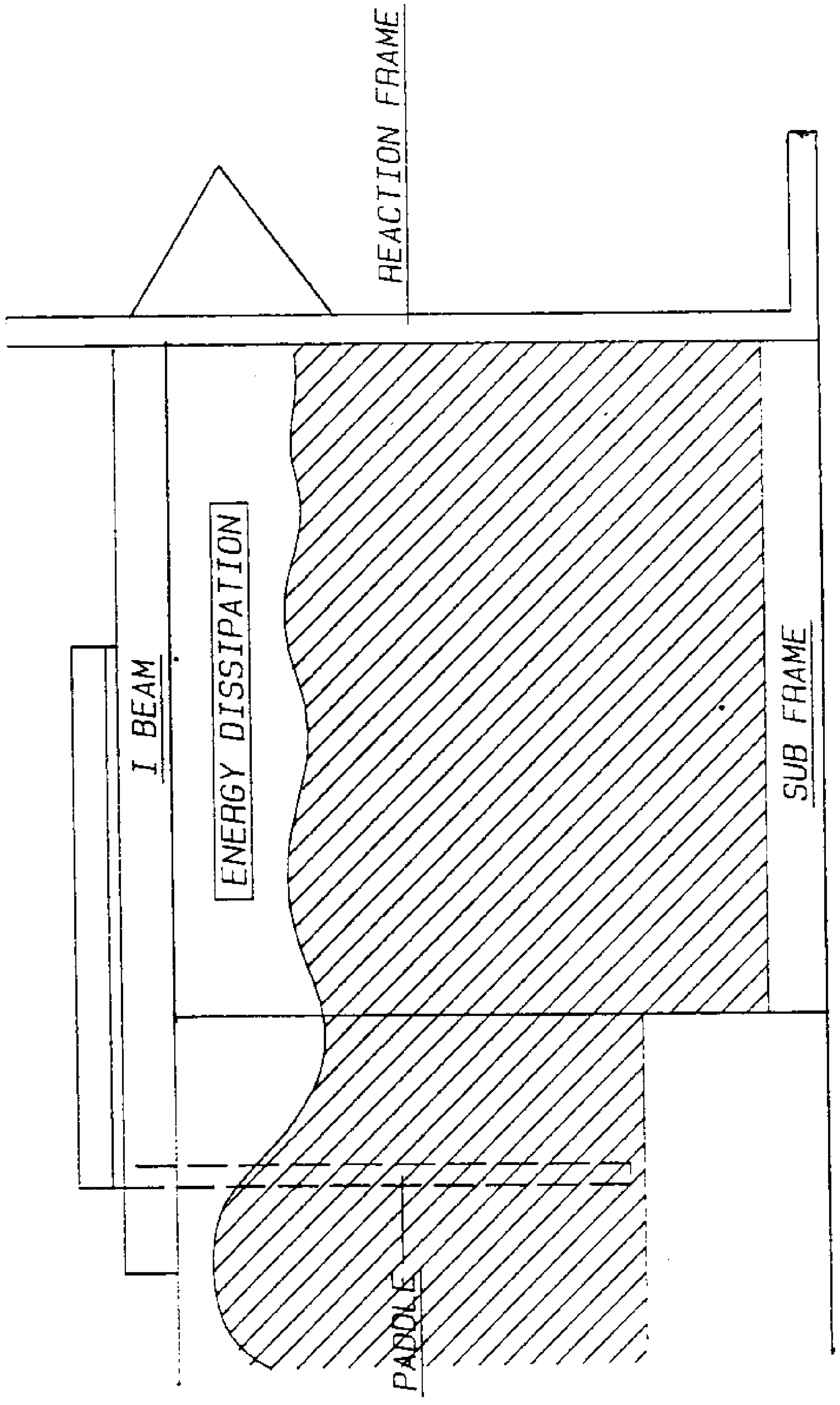


FIGURE 3.2

cross-section than that of the normal tank. The actual dimensions were dependent on size limitations of the location and the materials available. Additional energy dissipation will be provided by horse hair type large particle filter to prevent any wave reflections from the rear and side walls.

This increase in the volume allows the waves to spread perpendicularly to the direction of propagation. Since the wave generator is designed to create shallow water waves, the increase in water depth caused by the drop off of the bottom of the tank entering the rear section allows the wave to enter the rear with less bottom interaction and reflection.The end result is a decrease in wave energy per unit volume.

DESIGN CONSTRAINTS

HEIGHT: limited to allow clearence of the hydraulic actuator

LENGTH: limited to mcomply with the overall length restrictions

WIDTH: limited to the size of materials available for construction

After examining the overall tank length constraint it was apparent that the maximum length allowable for this section was four feet and that this would be more than adequate for the job. With this length the tank could still be accessed from all sides and was in the fire safty codes for the building.

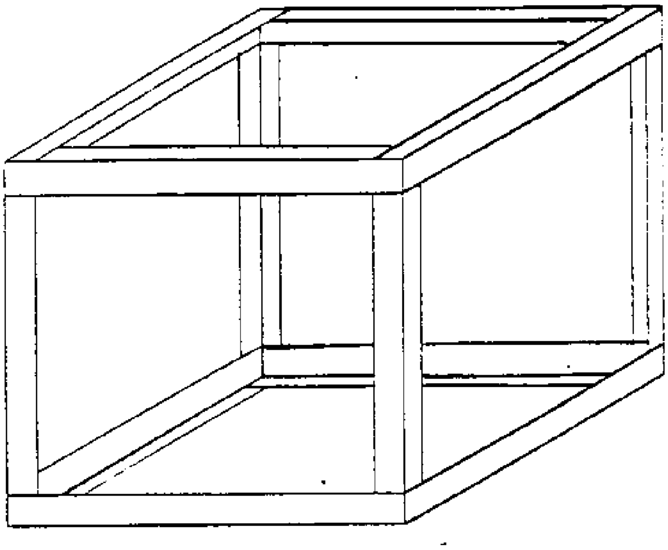
The height of the back section was limited to the height of the hydraulic actuator already mounted in the reaction frame, while also being no lower than the height of the rest of the tank. Thus the finalheight of five and one fourth feet was arrived at.

The width of this section was based on size of the material used for the tank construction . The marine plywood was in four feet by eight foot sheets. The tank height was already greater than four feet therefore the maximun width would be four feet to allow one piece sides to aid in ease of construction and sealing.

Finally ,this sectioon was supported on a sub-structure of inter-locked two -by-sixes forming a four foot by four foot grid ,six inches high. The wall sections were attached to a external cage of two inch by two inch angle iron welded at all corners (figure 3.3)

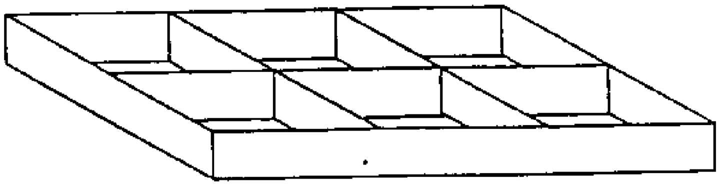
SUBSTRUCTURE

The main objective in the design of a wave tank substructure are safety and minimized deflection of the tank bottom. An adequate factor of safety is imperative due to the close proximity of students and faculty while testing is taking place. Minimizing the defections of the wave tank floor is the greater problem than the factor of safety due



STEEL ANGLE FRAME

SUB-FRAME



MADE FROM 2"BY 6"

FIGURE 3.3

to the Ocean Projects limited budget.

During October 1985, members of the wave tank project visited the Parsons Lab at M.I.T. to observe the two wave tanks there. The first tank was a ship towing tank that is cast in concrete. The second smaller tank ,which has a similar cross section to those of the tank being built by this group,was supported on tapered steel legs. The legs were connected to the concrete floor by moment resisting guassett plates. The bottom of this tank was supported by steel channel running lengthwise, and I-beams running across these. Rigidity of this tank was unquestionable, yet there were two factors that made a similar design prohibative.

The first restriction was the required mobility of the wave tank from the Marine Program Building to the new UNH Earth, Wind, and Fire building.The second factor to consider was the high cost of such a large quantity of steel required for such a design.

The idea of a concrete substructure was also impractical due to it's permenence. Thus a different method of support was needed. The idea of building concrete forms and filling them with compacted sand instead of concrete was devised as a feasible solution to the problems and the adequacy of it's supprting properties are outlined in the appendix.

By performing stress analysis methodology employed in earthen retaining wall design, structural components of the substructure were properly sized. The form is a plywood box forty feet long,thirty inches wide and sisteen inches deep. It is framed with two" by four" framing lumber "whalers",and tied across the width, top and bottom,every two feet with 3/16" diameter stainless steel wire rope (figure 3.4). The spacing of the tie wires was determined with the aid of a naval manual (NAVFAC DM-26) ,which considers sand under vertical loading to be portrayed as having 100% translation of vertical to horizontal stresses as opposed to 33 % translation under static loading. In addition the Navy Manual required a factor of safety o 1.7. By placing the tie wires at two foot intervals a factor of safety of 2 was obtained for worst possible loading condition.

Economically this was the most attractive design, an also provided an easily managed medium for the construction and the subsequent levling and grading. The substructure is also easily disassembled for moving,though moving the sand will be an inconvient ,but managable task.

WAVE ENERGY DISIPATION

The final goal of this wave tank is to propagate a clean wave that will be usefull for hydrodynamically modeling. The wave must remain the same throughout the test section and then dissipate so to not reflect off of the back wall and set up secondary waves in the test section that will effect experimentation . Another need for adequate wave energy dissipation is the possibility of setting up a

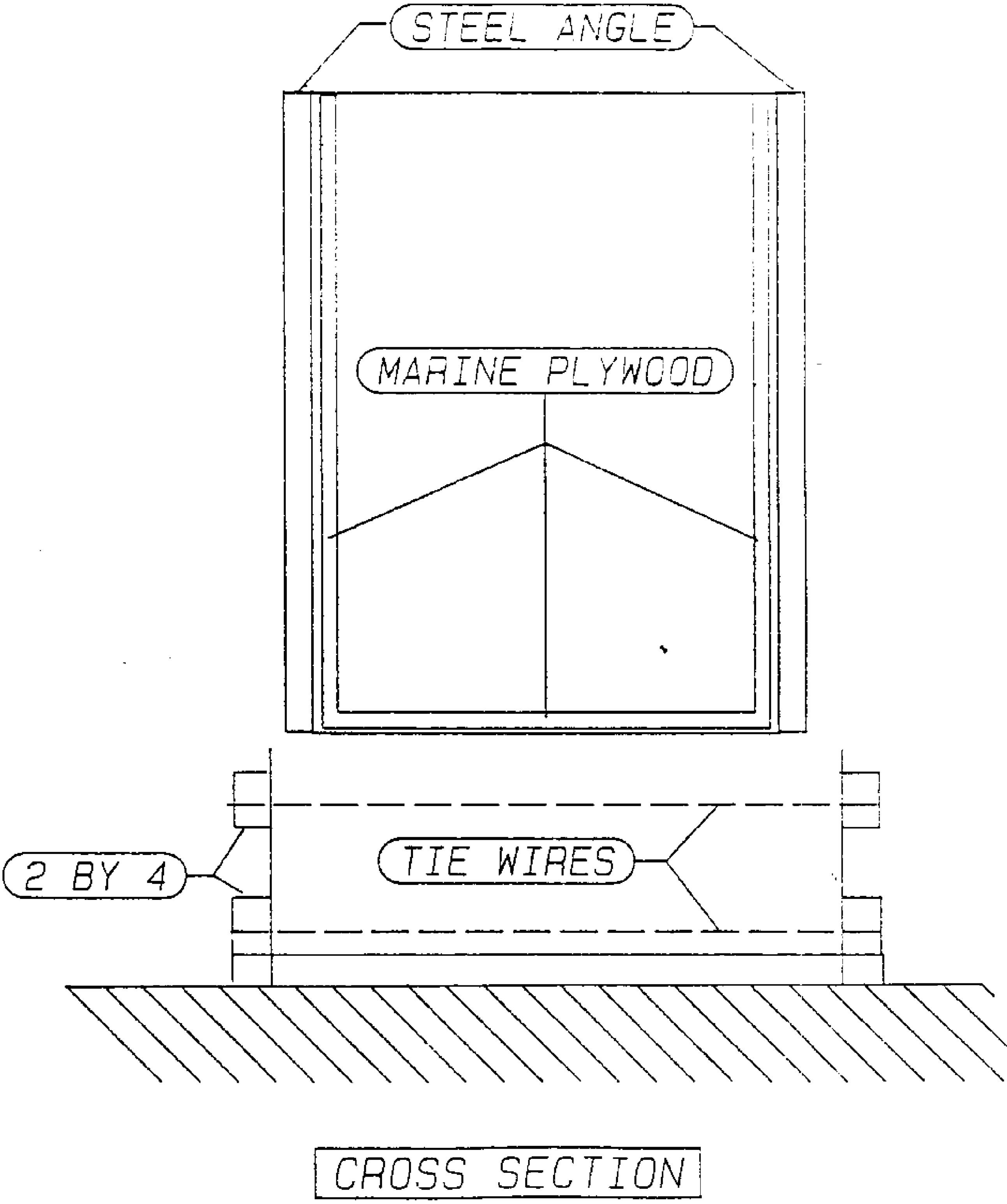
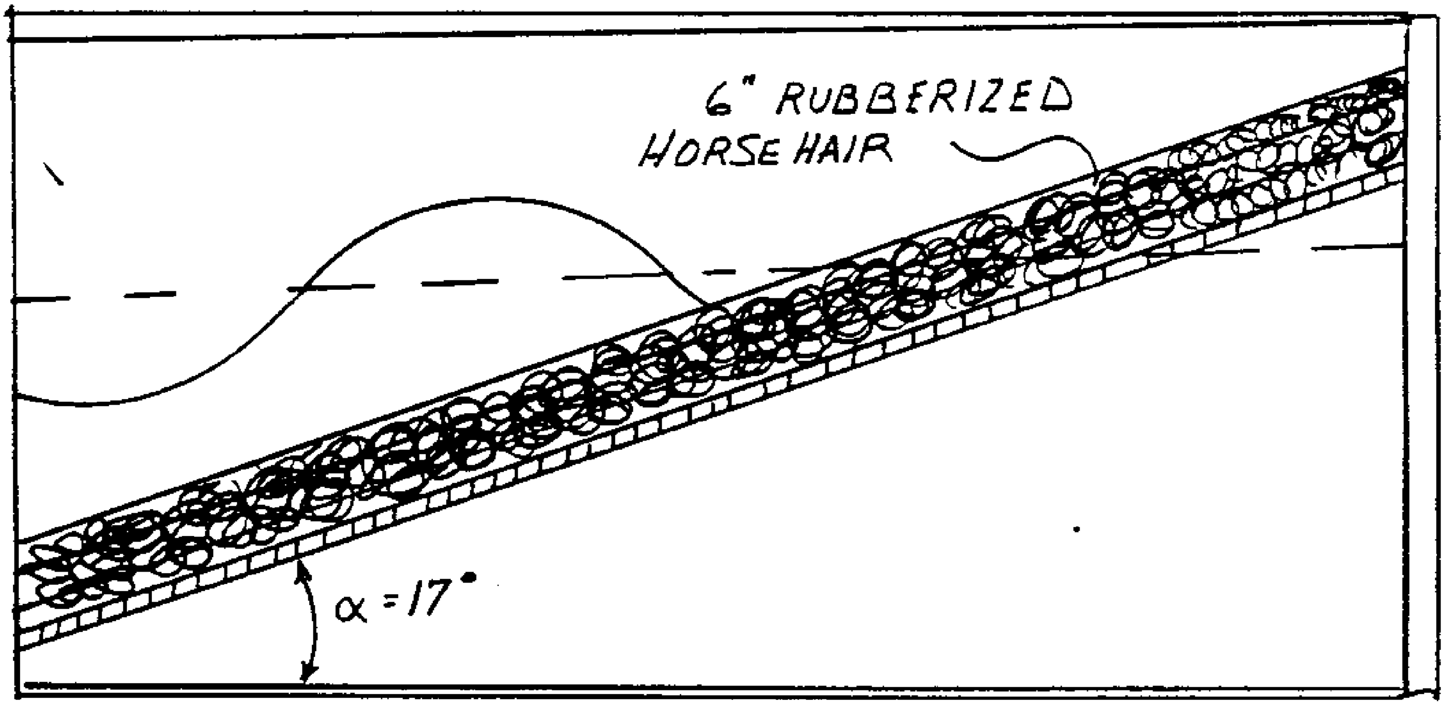


FIGURE 3.4

standing wave within the basin like tank.

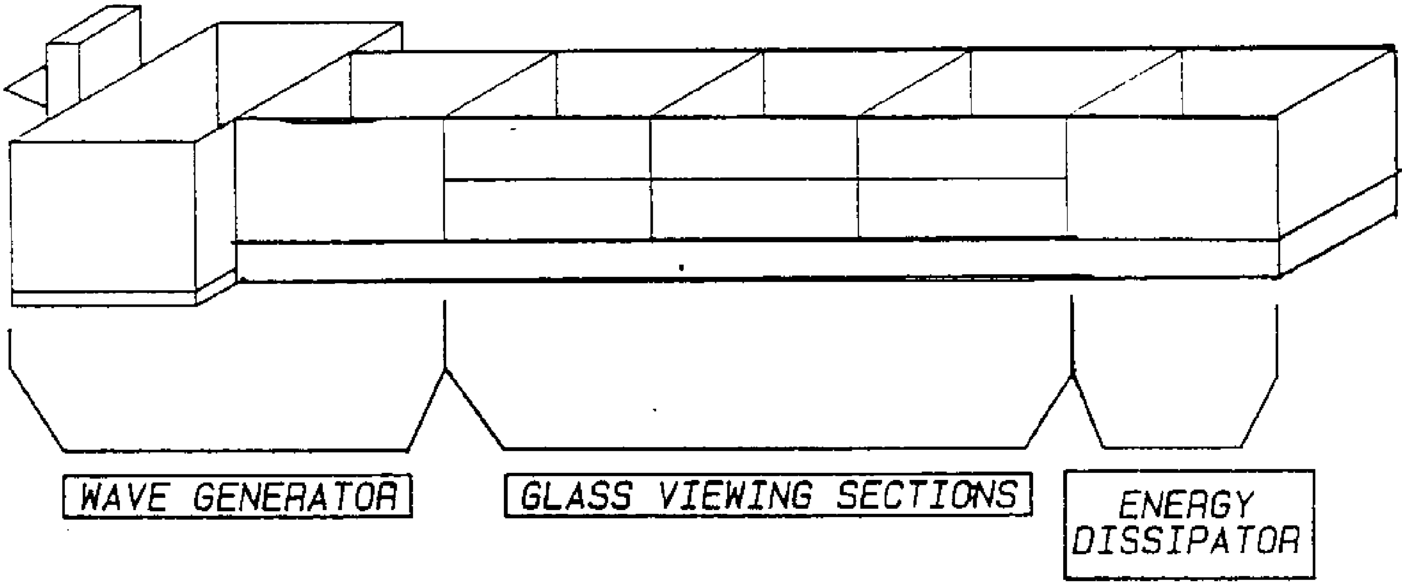
There are two types of water wave energy dissipation that were considered in the design stages of the wave tank. The first was active wave absorbers.The basic idea behind active absorbers is to greet the wave with the same type of paddle that it was generated with moving at the waves current velocity.This type of dissipation has been proven effective (Milgram) and at the same time proven costly.

The second type of wave energy absorber/dissipator looked at was the passive system. This system, composed of a beach and an absorbing mediun was shown to be very effective at both wave tanks at M.I.T. and the cost of the materials was very minimal compared to the active system. Thus the passive system was chosen. The beach for this tank was made from a sheet of marine plywood sloped up from the end of the test section to the end of the tank to give the maximum amount of dissipation available from the size constraints of the tank. The plywood was then drilled with regular pattern of 1 1/2" holes to allow water to pass through. Layered on top of this plywood ramp are six inches thick of rubberized "horse-hair" type large particle filter material. This material absorbs the shock of the incoming wave and transmitts it into the many random fibers of the material to effectively absorb the incoming wave energy. The slope of the beach formed an angle of 17 degrees and had the effect of taking away a small portion of the waves energy, starting from the bottom and increasing as the wave progresses up the beach (figure 3.5).



TANKEND WAVE ENERGY DISIPATION

FIGURE 3.5



COMPLETED WAVE TANK

FIGURE 3.6

4. TESTING AND DATA ACQUISITION

To assure that the wave tank has useful and meaningful functions it must first be calibrated. Ideally the tank will follow the equation of the piston type wave maker described in section 2. In other words , it is necessary to plot the curve in figure 2.2 for this particular tank and compare it to the theoretical one . To do this testing must be done that records the wave height as a function of the piston stroke. For this sort of test a data acquisition system is required.

Another critical factor that must be tested is the tanks ability to absorb any wave energy and not reflect it in to the test zone . Test of this sort will be done by analogue means and will be visual.

DATA ACQUISITION

Initially a fully computerized data aquisition system was planned for the wave tank and research was performed in that direction. However due to time and monetary constraints a system was never acquired. The following will be an outline of the direction such a system was taking and could used for reference in the future.

The data acquisition system for the wave tank must be capable of measuring both tank and wave parameters , as well as being able to to monitor any experiments that are being carried out in the tank. The parameters that should be constantly monitored in the tank during all experiments are the instantaneous wave heght of the inputed wave and the wave period. Both of these could be easily measured with a bottom mounted pressure transducer. Such a transducer measures water depth as a function of the hydrostatic,and dynamic pressures of the water above it (Dean and Dalrymple,1984). By recording the instantaneous wave height, a real time record of the sea state can be created. An adequate transducer for this case should be able to detect surface elevation changes of one to two millimeters. This corresponds to a sensor with a pressure rang of 0 to 2.5psi.with a .01% accuraccy full scale.

In all actuality ,a pressure transducer could make all the necessary measurements to know what type of wave field makes it to the test area .Yet another type of sensor that would do pretty much the same thing is a capacitance type wave gage. This gage is composed of two rigid wires which extend into the water from above the surface. As the water level increases ,the frequency output of the gage changes in a linear fashion thereby allowing the wave height to be calculated as a function of frequency. This method is less expensive than a pressure sensor but is more cumbersome because it interferes with the surface.

Data acquisition from the sensor involves some sort of analog to digital conversion to get the data from the out put into a data logging computer for analysis. Such an A/D converter should be large enough to handle an adequate number of sensors for any practical test that could be performed. A good size for the wave tank would be 16 single ended inputs. Also to be considered is the sampling rate which should be about 10,000-20,000 samples per sec for good resolution and perhaps a sample and hold feature. Yet signal conditioning is also very important and must be adequate to bring the transducer output up to the board input level.

Of course these components must be compatible with the computer chosen. The IBM PC,XT,AT and the clones of these are very good for the job since a wide variety data acquisition systems are available for these. Along this line ,the software must also be considered. Much of the software comes with easy to use menus and extensive graphics capability that analyze data and plot it out with professional results.

Several systems were investigated for this need and were based around the IBM or clone. Though costly such a system would provide a fast accurate way to run the wave tank as efficiently as possible.

5. CONCLUSION

The design and construction of this wave generator and tank went smoothly with few minor complications. The result was a very rigid tank that with initial testing showed no appreciable flexure and caused no transverse waves. The wave generator worked well, riding smoothly on the linear bearings though a provision should be added in the linkage between the actuator and the piston carriage to allow for any missalignment to be accounted for.The electronics and the Instron preform well in this situation , but when shut off at the end of a cycle create a large banging noise in the hydraulics. This should be corrected.

Upon filling the tank the first time a severe leak was started through the crack in one of the glass panels and thus the tank had to be drained before any further testing could take place. The tank is under current repair and should be completed soon so that the final stages of testing can proceed.

Other recommendations that wold improve the tank shoul be considered before it is moved to the new building. First the tank should be oriented so that the operator of the Instron can see the wave field that is being ceated so that it may be corrected . Also it would be advised to create a more permanent foundation once the tank is in its final resting place. Finally as mentioned before , a complete data acquisition system should be obtained for the tank.

The completed tank should be very useful to the acedemic community. The waves that it ceates easily viewed in the more than adequate test section.
This should enable a wide variety of experimentation in the field of hydrodynamic modeling.

REFERENCES

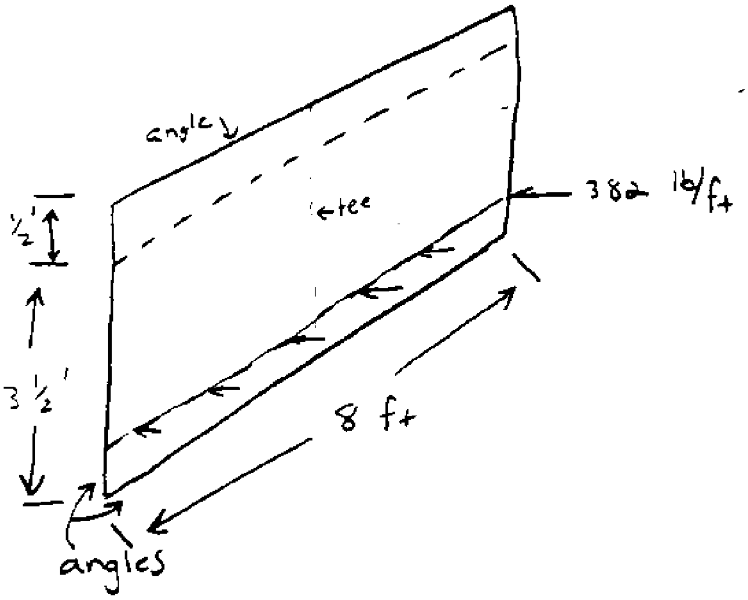
Dean,R.G. and R.A. Dalrymple, Water Wave Mechanics For Engineer And Scientists, Prentice Hall, Englewood Cliffs, N.J.,1984

Design Manual- Harbor and Coastal Facilities, NAVFAC DM-26,July 1986

Instron Instruction Manual No. 11-7-2(A),Series 1330 Dynamic Test System,Instron Corp. Canton, Mass.

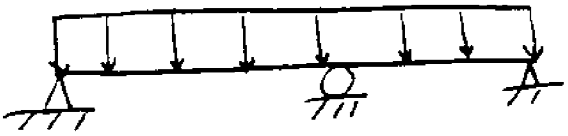
"The Wavemaker at M.I.T. Ship Model Towing Tank",Dept. of Ocean Engineering, M.I.T.

Design Load = 3 ½' water



Design bottom angle

assume $\frac{2}{3}$(382 lb/ft) = 255 lb/ft



maximum moment = $.1\,w\,l^2$

= .408 kip-ft

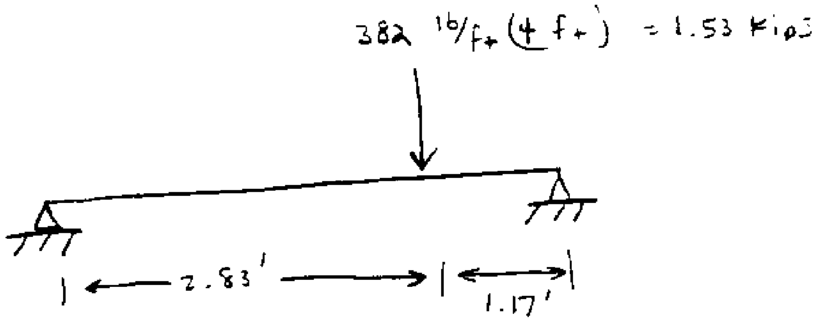
S_x for 2×2×4 = .247 in^3

$$F = \frac{.408(12)}{.247} = 19.8 \text{ ksi} \quad \underline{\underline{ok}}\ ✓$$

$F_{all} = .66\,F_y = 23.7$ ksi

top angle has less load than bottom $\underline{\underline{ok}}$

Design Tee



Max $M = 1.28$ kip-ft

$S_x = 1.5 \text{ in}^3$

$F = \dfrac{1.28(12)}{1.5} = 10.2$ ksi $\underline{\underline{\text{ok}}}$ ✓

check bolts on bottom for flat stock connector

2 bolts @ $\frac{1}{4}$" diameter

$A = .1 \text{ in}^2$

$P = 255(4) = 1.0$ kips

$F = \dfrac{1.0}{.1} = 10$ ksi $\underline{\underline{\text{ok}}}$ ✓

Worst Dynamic Conditions

3.5 ft of water @ 62.4 $\#/ft^3$

= 218.0 $\#/ft^2$

allow 20 $\#/ft^2$ for material weights

∴ total surcharge on substructure

$\cong$ 240 $\#/ft^2$

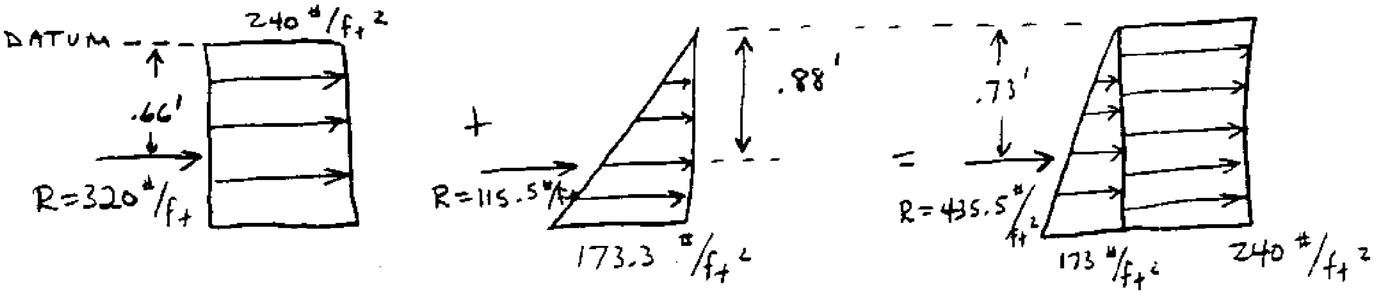
let soil density = 130 $\#/ft^3$

@ $1.\overline{3}$ ft depth = $173.\overline{3}$ $\#/ft^2$ max

allowing for total translation of vertical to horizontal stresses

Stress Diagram :

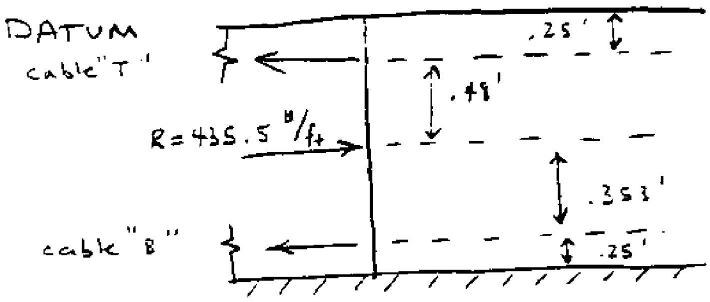
Water + Tank + Soil = total



$$\Sigma M_{DATUM} = 320(.\overline{66}) + 115.5(.\overline{88}) - 435.5\,\bar{y} = 0$$

$$\therefore \bar{y} = .73'$$

load distribution/ft



$$\Sigma M_{\text{cable "T"}} = 0 = 435.5\,(.48) - \text{cable "B"}\,(.83)$$

$$\therefore \text{cable "B"} = 251\ \#/\text{ft}$$

each cable supports 2' length of tank

$\therefore$ tension in lower cables $\cong$ 502#

<u>according to Navy Design Manual</u>:

For Dynamic loading there is a possibility of total translation of vertical to horizontal stresses,

Utilization of 1.7 factor of safety provides sufficient conditions.

$\therefore$ 1.7 (502#) = 853# < 1250# cable test ✓ OK

<u>2 x 4 Analysis</u>

yeild moment = 6250 in-lb = 521 ft-lbs

$$\frac{wl^2}{8} = \frac{1.7\,(251\ \#/\text{ft})\,2^2}{8} = 214\ \text{ft-lbs}$$ ✓ OK