# Chapter 44

## ON THE DESIGN OF SMALL CRAFT HARBORS

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### INTRODUCTION

There is little useable, up-to-date written data on the design of small craft harbors. That which has been written does not in general fit the needs of today's crowded marinas. Therefore, we are pioneering a new phase of coastal engineering, one that needs the cooperation of both scientist and engineers, of private practice, university and government. To develop these needs, we must have specialization, as today's research, development, and design is too complex for any one individual to be expert in all. In larger organizations, such as government, three specializations must be developed. It is necessary that all of us in coastal engineering realize and admit this. Therefore, in this introduction the delineation of the responsibilities of these specialties are discussed.

The designer must go to the shore, evaluate the needs of the area, conceive the works that will accomplish the needs, relate to the researcher where his lack of understanding lies and therefore the areas where research is needed. The researcher must then go to the laboratory and to the basic mathematical relationships and establish the relationship of one factor to another. The designer must then take these relationships to the drawing board and devise the structures to furnish a useable harbor. The relationship between the designer and the researcher must be initimate with each having full confidence in the other. Each of these takes long experience, training, and direction of thought that is peculiar to his calling. However, most frequently one in his specific knowledge feels that he can better do the job of the other. Here is often perpetrated a mistake that is severely injurous to the general public. A designer cannot be developed by reading literature, doing laboratory experiments, and discussing design with field personnel, even with frequent visits to the sites. A designer is developed by consultation with the scientist, or researcher, living with the on-site problems, and bearing full responsibility for the designs he devises by living with his projects. A scientist or a research engineer is developed by love of delving into the unknown, logically relating one factor of truth to another, starting with idealized conditions completely unrelated to actual conditions, then developing coefficients to compensate for the irregularities of nature until a procedure is developed that the designer, with his long experience with actual conditions, can utilize in the development of a project. Rarely is both specialties inherent in one man. Therefore, grave errors are made by giving principal research responsibilities to a designer or principal design responsibilities to a researcher.

In a large organization, such as the Corps of Engineers, there must be, in between these two, another type of specialist who must be trained and experienced in both research and design, but basically be a designer. He must be technically aware and appreciative of the skills, problems, and needs of the researcher and provide the direction of the research. He must also be aware of the problems and skills of the designer and provide the guidance in techniques for him. He must remain intimate with the work of the researcher and designer and, with their advice and cooperation, assure that all facets are investigated fully and, based on his design knowledge, give proper weight and impetus to each factor. He must take sole responsibility that findings are ready for application and that they apply to the specific requirements of the project site. Recognizing the limits of the research and the many other variables in nature, he must assure that the findings are used in proper perspective in the design. Success in research and in design is dependent on development of these three types of personnel. Each is a full time venture and delegation of the responsibility of one to the other can only result in chaos.

## PROBLEMS

In the United States earlier small craft harbors were constructed to provide for swing-line mooring rather than the more convenient marina type construction. With this type of mooring, the boats could swing and face the on-coming waves directly and could withstand greater wave heights without damage. As small boating increased, space became too small for the number of boats, and it became necessary to use marinas to obtain a greater population density of boats. The type of person interested in boating also changed. With these changes, came the need for greater convenience of access. In addition to that, there also became a greater number of boaters who were unskilled in the handling of their crafts. All this combined, required a smaller wave height, smaller currents, and the elimination of surge in recreational craft harbors.

To fulfill the need of the greater number of crafts, larger harbors were designed. With the larger harbors came greater problems. These larger harbors also required the greatest utilization of area to economically justify their cost. This required increased use of vertical wall wave protection, which reflects rather than absorbs the energy which enters the harbor. Naturally with larger areas of reflective surface, there is a greater capability for the development of resonance. The combination of these reflected waves may reach heights several times that of the impinging wave. This is one cause of great problems in mooring and in the stability of the mooring facilities. Short period waves have little effect on the deeper draft ships, but by slapping against the bottoms of the shallow draft boats and the floating mooring facilities causes racking by quickly lifting them and allowing them to fall.

Studies have been undertaken under Corps of Engineers contract by the California Institute of Technology to determine the effect of various wave characteristics on small boats of various dimensions. This study will also investigate the effect of basin shape on the response to waves of various characteristics. These studies have not been completed, therefore, present criteria for maximum allowable wave height is based generally on the knowledge of small boat operators and the opinions of those closely connected with small craft harbors. It is generally considered that wave heights in recreational craft harbors should be reduced to one foot or less. This is often very difficult when it is considered that wave energy varies as the wave height squared.

When there is a large variation in the direction of the approach of the waves, it may be very difficult or impossible to provide a suitable width of entrance to the harbor and to reduce the wave heights to less than one foot. In this connection, methods must be employed to reduce the wave height after it enters the harbor but before it endangers the craft within the harbor. One method of accomplishing this is by the utilization of wave absorbers. Although there are several such structures in operation, there has been no distinct design criteria developed.

Upon the development of the larger small craft harbors, many unanticipated problems arose. It is considered that these problems can best be discussed by specific examples. The harbors to be discussed are at Marina del Rey, Redondo Beach, and Half Moon Bay, California, and were concerned with short period waves.

## MARINA DEL REY

One of the most complex problems experienced to date is that of Marina del Rey, a small craft harbor located in Santa Monica Bay, about 15 miles west of Los Angeles, California. This harbor is exposed to wind waves, both sea and swell, generated from all deep water directions between west-northwest and south-southwest. The limiting directions are determined by Point Conception and Point Dume to the west-northwest, and Santa Catalina Island and Point Vicente to the south-southwest. The harbor was designed in 1954-55 and was one of the first attempts to establish a large marina for the protection of small craft, with an entrance exposed to a severe wave climate. Plate 1 shows the layout of the harbor.

At the time of design of this harbor, our knowledge of oceanographic phenomena was not sufficiently advanced to forecast the conditions which resulted. Upon the opening of the harbor, it was found that resonance occurred in the basins and that the height of the waves entering through the entrance channel were more than doubled in various basins. Reduction of the width of the 1000-foot wide entrance channel to reduce the energy input was not desirable because of the great number of craft, over 8,000, to be based in the harbor. Basin B was the most critical area of resonance with basins A and H following closely. It was unfortunate that the first development was undertaken in Basin B, and that it was severely damaged during the first storm after construction. It was necessary to transfer boats and remove floats until temporary protective works were undertaken.

The unforeseen wave heights and surge caused severe damage to both craft moored in the basins and to the mooring facilities themselves. It was clear that improved conditions must be provided for suitable functioning

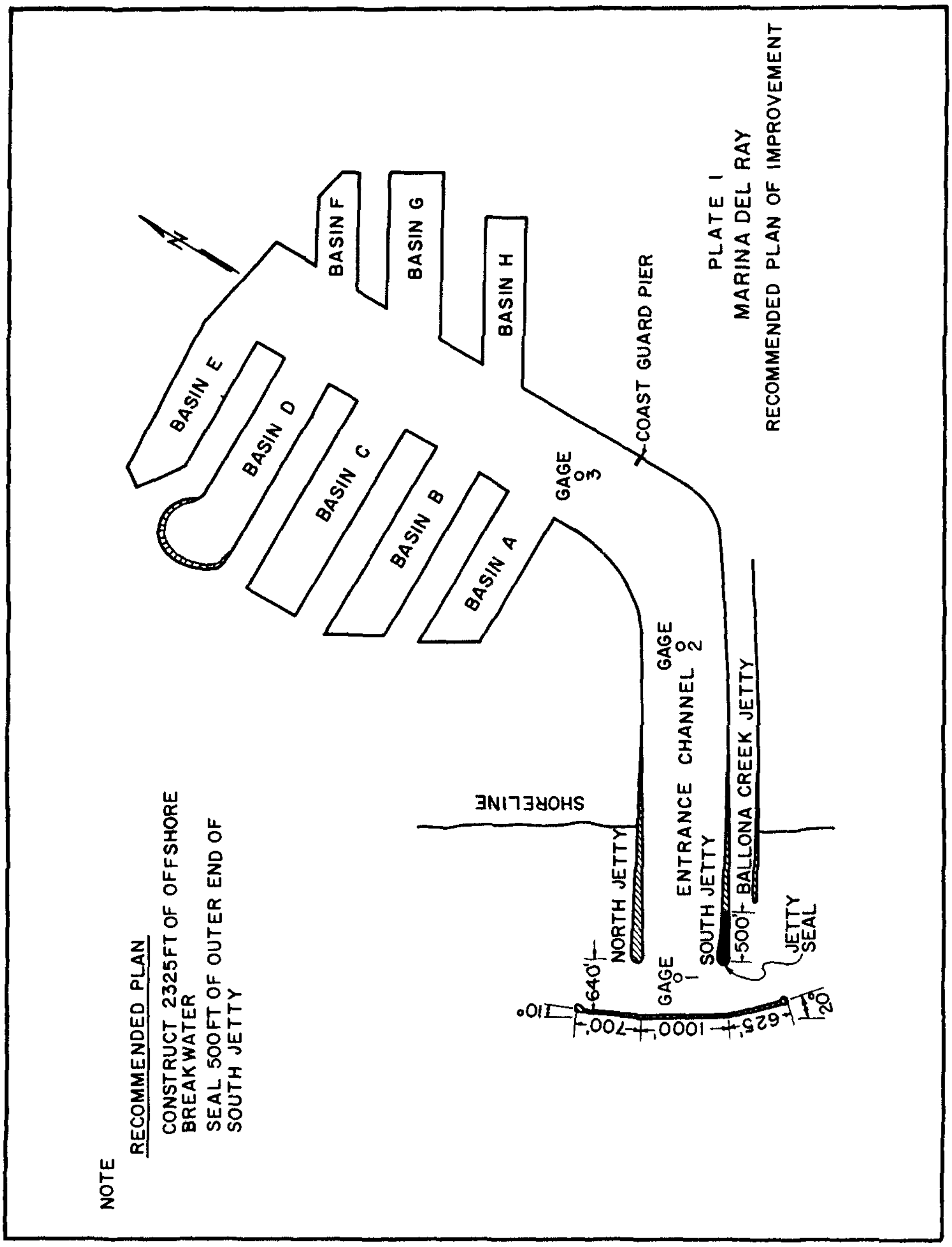


PLATE I
MARINA DEL RAY
RECOMMENDED PLAN OF IMPROVEMENT

of the harbor. One of the principal factors requiring consideration in the design of such an improvement is the determination of the height, period, and direction of travel of the design wave. Since actual wave observations were not available for this purpose, statistical hindcast studies were used to predict the characteristics of the waves that would attack the proposed breakwater. From the statistical study, considering the effects of shoaling and refraction, a design wave 16 feet in height, with a 13-second period approaching from a deep water azimuth of $260^{o}$, was selected.

To determine the most efficient plan of improvement, a hydraulic model study was undertaken at the U. S. Army Engineer Waterways Experiment Station at Vicksburg, Mississippi. The selection of a geometrically undistorted model to a linear scale of 1:75 was based on model bottom friction effects, the absolute size of waves to be produced, available shelter area, characteristics of the apparatus, and cost. The model was constructed of concrete and reproduced to scale the existing prototype harbor and the contours of Santa Monica Bay adjacent to the harbor. Sufficient area of Santa Monica Bay was included to permit generation of waves and wave front patterns from the different directions selected for testing. The model waves were generated by a 40-foot long plunger-type wave-machine mounted on casters to permit flexibility in direction for generation. Wave heights were measured by wave rods and were recorded on chart paper of a six-channel electrically operated oscillograph.

Model tests were conducted of a rubble-mound wave absorber installed along the east side of the main channel, of a wave refraction plan, several different offshore breakwater arrangements, and 38 different combinations of these components. The model study determined that a breakwater 2,325 feet long, as shown on Plate 1, or a combination of absorber in the main channel together with constriction of the entrances to the various basins, would reduce wave action in the marina to a satisfactory level. After considering all factors, such as loss in revenue and lease adjustment, it was concluded that the breakwater plan was the most desirable improvement. The construction of the recommended breakwater should prevent approximately 95 percent of the wave energy from entering the harbor.

Elements of the selected plan consists of an offshore breakwater, totaling 2,330 feet in length, located 640 feet seaward of the ends of the existing jetties, and made up in three sections, a center section 1,000 feet long with a top elevation at +22 feet, MLLW; a northerly section 700 feet long to elevation +22 feet; and a southerly section, 630 feet long to elevation +17 feet. To prevent excessive transmission of energy through the existing southerly jetty, it will also be sealed for distance of about 1,000 feet from its outer end. This sealing will make it impervious to about elevation +8 feet, MLLW.

It is planned to accomplish the sealing as at Mission Bay, California. This was accomplished through two-inch diameter intrusion holes drilled 12 feet apart on center to a depth of 14 feet below the top of the existing jetty, which is the top of the existing core. As the drill used for this purpose has to drop through voids and encounter wiggling and sloping surfaces, a percussion drill was specified in lieu of a rotary drill. Grout containing a mixture of sand, cement, clay, calcium chloride and water was introduced to the voids through a pipe under gravity flow. The pipe was withdrawn at such a rate as to build grout cones. The spacing of the grout entry holes are of such a distance as to produce intersections of the grout cones thus formed to a height 8 feet above the top of the core.

The breakwater is under construction at the present time. It is of layered construction with a core of graded stone ranging in size from 20 pounds to 1 ton. It is considered that the core will form a dense, compact, impervious mound with a top elevation ranging from 7 to 12 feet above MLLW, depending on requirements. The armor stone will be select quarrystone with a specific gravity of at least 2.56. The minimum size and gradation varies but in general no armor stone will weigh less than 10 tons and the 50 percent size will not be less than 13 to 16 tons. Size requirement to withstand the wave force was calculated by the Hudson equation and is substantiated by successful structures in the area.

To temporarily alleviate the condition, until the permanent breakwater construction could be accomplished, Los Angeles County Division of Small Craft Harbors constructed constricting works in the entrance channel just seaward of the bend. This consisted of two steel sheet pile walls, with batters, which overlapped a 300 foot wide entrance. The constriction reduced the wave energy reaching the basins to tolerable proportions and allowed sufficient entrance width for the small amount of development. However, as previously mentioned, removal of the temporary works is necessary before complete development of the harbor is realized. The temporary works will be removed in increments, after completion of the breakwater, and the effect of the removal of each increment observed before removal of the next.

## REDONDO BEACH-KING HARBOR

Redondo Beach-King Harbor is located about 6½ miles south of Marina del Rey and, therefore, is subject to very similar wave climate. The harbor was protected by two rubble-mound breakwaters, approximately 4,985 feet in total length with the crest elevation of 14' above MLLW. The inner harbor consists of three boat basins inclosed by moles with revetted slopes. The basins are dredged to depths ranging from 8-12 feet below MLLW. The harbor is designed to provide berthing for approximately 1,350 small craft and for land storage facilities for about 150 boats. See Plate 2.

The breakwater was constructed with an impervious core up to elevation -10 feet. Above the core, armor stones weighing about 13 tons were placed to a crest elevation of +14 feet. As the structure above elevation -10 was constructed entirely of the large armor stones, excessive wave energy permeated through the interstices of the structure. During intense storms overtopping occurred. The combination of the overtopping and energy transmission through the structure caused severe damage to boats and their facilities during the winter of 1962-63. It is considered that during the time of design, the knowledge of wave phenomena was not advanced and that inadequate

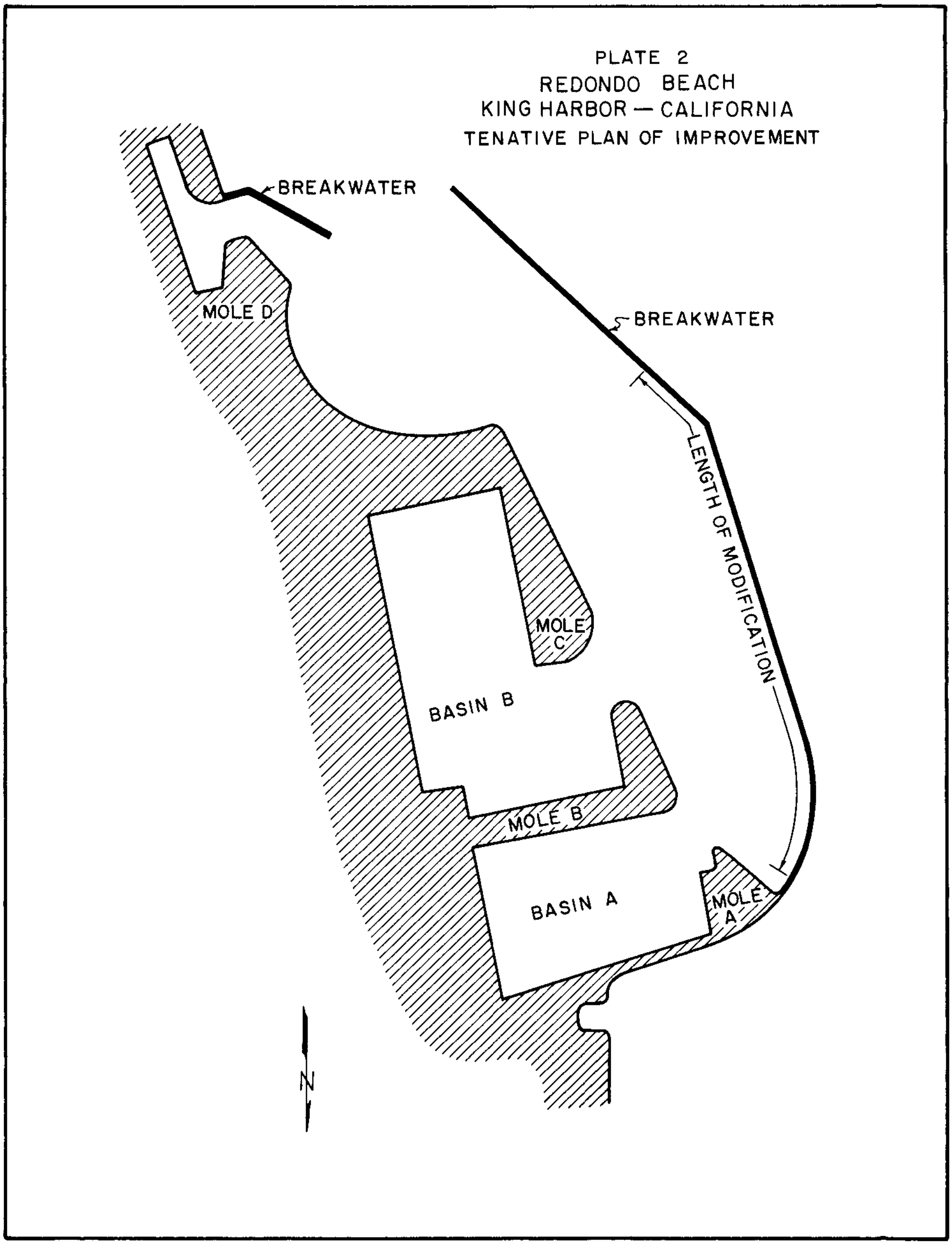
PLATE 2
REDONDO BEACH
KING HARBOR — CALIFORNIA
TENATIVE PLAN OF IMPROVEMENT
BREAKWATER
BREAKWATER
MOLE D
LENGTH OF MODIFICATION
MOLE C
BASIN B
MOLE B
BASIN A
MOLE A
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knowledge of the actual characteristics of the waves impinging on the harbor, the degree of energy transferred through the voids, and the degree of wave reformation resulting from overtopping were not fully considered. Design of a modification included hydraulic model study, which was accomplished during the fall of 1963.

The model tests were made at the Coastal Engineering Research Center in two phases. Initially tests were made at a 1 to 50 scale in a small wave flume, 96 feet long, 1.5 feet wide, 2 feet deep. In this tank, a wide variation of plans were investigated and the less effective eliminated. Favorable appearing plans were further tested at a scale of 1 to 5 in the large wave tank, which is 635 feet long, 15 feet wide, and 20 feet deep. The investigation program consisted of stability, overtopping, and wave reformation tests using various wave periods. Wave heights of 10 and 17 feet at the structure and tide elevations of 5.5 feet (MHHW) and +7 feet (MHHW plus storm setup). The model tests indicated that: (1) a seaward slope of 1 on 2 is stable, (2) a harborside slope of 1-1/4 on 1, or steeper, is not stable, (3) placing a layer of core material to elevation +9 on the harborside and covering it with B stone and cover stone provides a stable slope, (4) placing the core too high does not allow sufficient porosity and weight to hold the sections. When the core is too high, the upper portion of the new layer collapses en masse as a slide, and (5) with a slope of 1 on 2 with a top elevation of +22, the overtopping was decreased to the degree that the height of the regenerated waves were within a tolerable range.

The plan of improvement devised consisted of impervious layer placed on the harborside of the structure to an elevation of 9 feet above MLLW, as shown on Plate 3. This was covered by armor stone to prevent damage during severe storms. The model indicated that with the initial structure approximately 1.5 to 3 percent of the incident wave energy passed through and over the breakwater at a tide of 0 feet MLLW, and approximately 16 to 21 percent of the incident wave energy passed through and over the breakwater at a tide of +7 feet. It is estimated that the modified plan will reduce the wave energy passing through the breakwater to about one percent at mean higher high tide, with a 17 foot incident wave. The resulting reformed wave would be about 1.7 feet high.

The purpose of the proposed breakwater improvement is to reduce the height of waves entering Basins 1 and 2 to 2 feet or less. This is no greater than the height local winds can generate in the harbor entrance channels. Although it is not part of its purpose, the improvement also reduces the wave energy arriving at the faces of Moles B and C. A detailed analysis of the wave heights arriving at the basins and moles show that waves of this height result with a storm of design magnitude occurring at mean higher high tide. This would have an approximate frequency of occurrence of 5 years. The heights are summarized as follows:

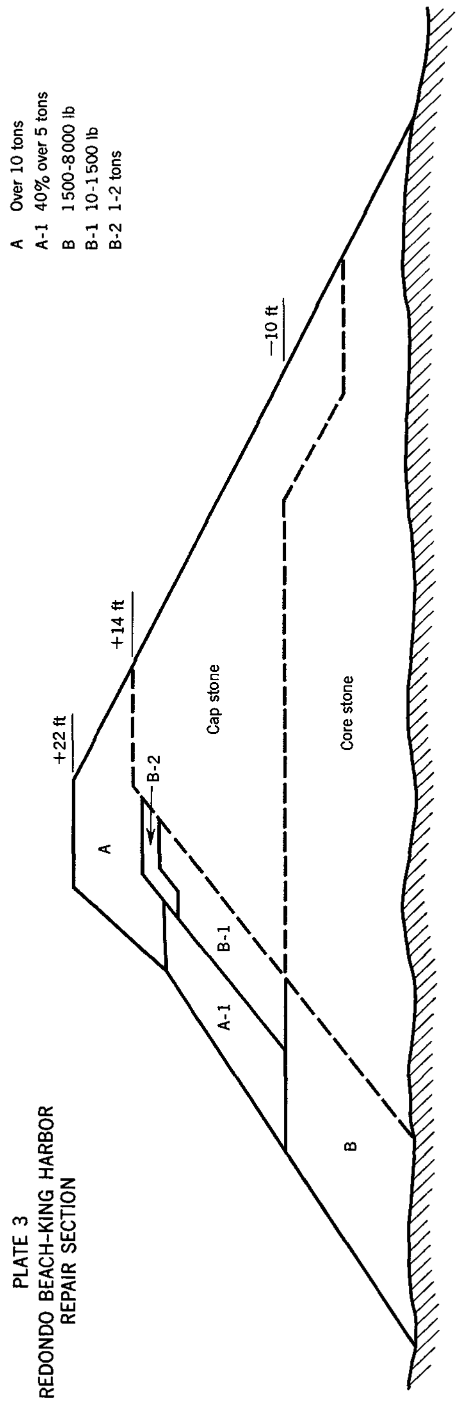


PLATE 3
REDONDO BEACH-KING HARBOR
REPAIR SECTION

Wave height at mouth of Basins 1 and 2.....2 feet or less
Wave height at mouth of Basin 3...........about 3½ feet
Wave height along Mole B..................2 feet
Wave height along Mole C..................2 to 6 feet
Wave height along Mole D..................about 10 feet
Wave height between Mole C and D...........about 7 to 10 feet

The wave heights given for Basins 1 and 2 and Moles B and C are considered to be reliable estimates of the worst wave conditions which are likely to occur. Those heights given for Basin 3, Mole D, and the reach between Moles C and D are somewhat questionable because of the simplifying assumptions and approximations which are necessary to facilitate analysis.

## HALF MOON BAY

The case of Half Moon Bay Harbor is presented to describe a different type of problem. At Half Moon Bay, the energy was entering through the entrance, and was not properly attenuated for small boat harbor requirements. This project is located about 20 miles south of the entrance to San Francisco Bay, California. The harbor is protected by two rubble-mound breakwaters, the westerly one being about 2620 feet long, and the companion easterly breakwater about 4420 feet long. The navigation entrance is 600 feet wide. Half Moon Bay is exposed to waves approaching from directions between west and south-southeast. Deep water waves from the west and west-southwest are of greater magnitude as they range to a maximum of about 21 feet. Analysis of the wave data showed that significant waves, ranging from 9 to 12 feet in height, occur in the navigation entrance for more than 100 hours each year. Model tests data indicate that waves greater than two feet occur along the bulkhead line of the inner harbor from five to twenty percent of the time.

The waves travel through the entrance and, according to their direction of approach, severely effect different sections of the harbor. The principa public piers are located directly opposite the opening, and severe agitation occurs there under most directions of severe wave approach. Due to the natur of the problem, it was determined that a hydraulic model study would be required to devise a suitable plan of protection. An undistorted linear scale of 1 to 100 was selected, after consideration of such factors as: (a) the required depth of water in the model to prevent appreciable frictional resistance and surface tension effects, (b) absolute size of model waves, (c) available shelter space, (d) available wave generating and measuring apparatus, (e) cost of construction, and (f) model operation convenience. The model was constructed of concrete and the breakwaters were constructed of graded stone to simulate different degrees of porosity and wave absorbing characteristics of the rubble-mound breakwaters. The model covered an area of about 13,000 square feet approximating 4.7 square miles in the prototype. The model waves were generated by a vertical bulkhead type wave machine, which was 60 feet long and mounted on casters so it could be positioned for any required direction of wave approach. Analyses of the model data indicated that an angular extension to the west breakwater provided the best overall protection. The extension 1050 feet long would reduce the average wave heights along the inner bulkhead line to about 1.5 feet during the design storm.

The model data has now been presented to the design engineers, who will review the efficiency of each plan tested, and make the final selection of the project modification that will best suit the requirements of this specific harbor.

## RESEARCH

There is a need for much research in the area of small craft harbor design. The Corps of Engineers has initiated several research programs to help devise suitable design criteria. However, research is time consuming; and there will probably be many mistakes made in the future before the design criteria is developed to the stage that we can confidently anticipate all problems. As mentioned previously, one of the research programs that is vital to small boat harbor design is the study of the design of wave absorbers and their effect on wave action in harbors. The initial phase of this study will be (1) Conducting critical review and preparing a summary of the theoretical and experimental aspect of: (a) natural sand beaches, (b) wave traps and resonators, and (c) rubble-mound absorbers in the form of a simple mound backed by an impervious vertical wall. The transmission of waves through rubble-mound breakwater type of absorber will also be investigated. (2) Showing by specific examples how the findings from the literature review can be adapted to actual situations. (3) Making a special theoretical investigation on the feasibility of using rubble-mound or other pervious construction for the absorbing of wave energy entering the harbors. (4) Preparing a review of scale-effects related to wave absorbers for both long and short period waves and proposing a solution or outline of an experimental investigation to evaluate or correct the scale effect. The initial study will be followed by an analytical and model study to determine actual design criteria for various combinations of wave characteristics and water levels and to fill the gaps in existing data. The Corps of Engineers is planning to use wave absorbers in connection with breakwater protection in at least three small boat harbors which are now being considered by Congress for authorization. It is felt that much additional information will be available in a short period of time on this subject. One rubble-mound wave absorber that appears successful in protection of a small craft harbor is that at Oceanside, California. The small craft basin and the absorber are shown on Plate 4. The absorber is of saw-tooth design with varying slopes on the teeth.

The second contract aimed specifically at the solution of small craft harbor problems is underway at the California Institute of Technology at Pasadena, California, entitled "Wave Induced Oscillations of Small Moored Vessels". Serious ship and dock damage can be caused by wave induced oscillations of moored vessels. The ship and its mooring system constitute a mechanical system capable of response characteristics analagous to a simple spring-mass combination, so that the ship can experience resonant oscillations significantly amplifying the motions and restraining forces.

The specific aim of the research is to investigate theoretically and experimentally the response of prismatic bodies moored to floating platforms under the action of standing and progressive waves. Later phases of the

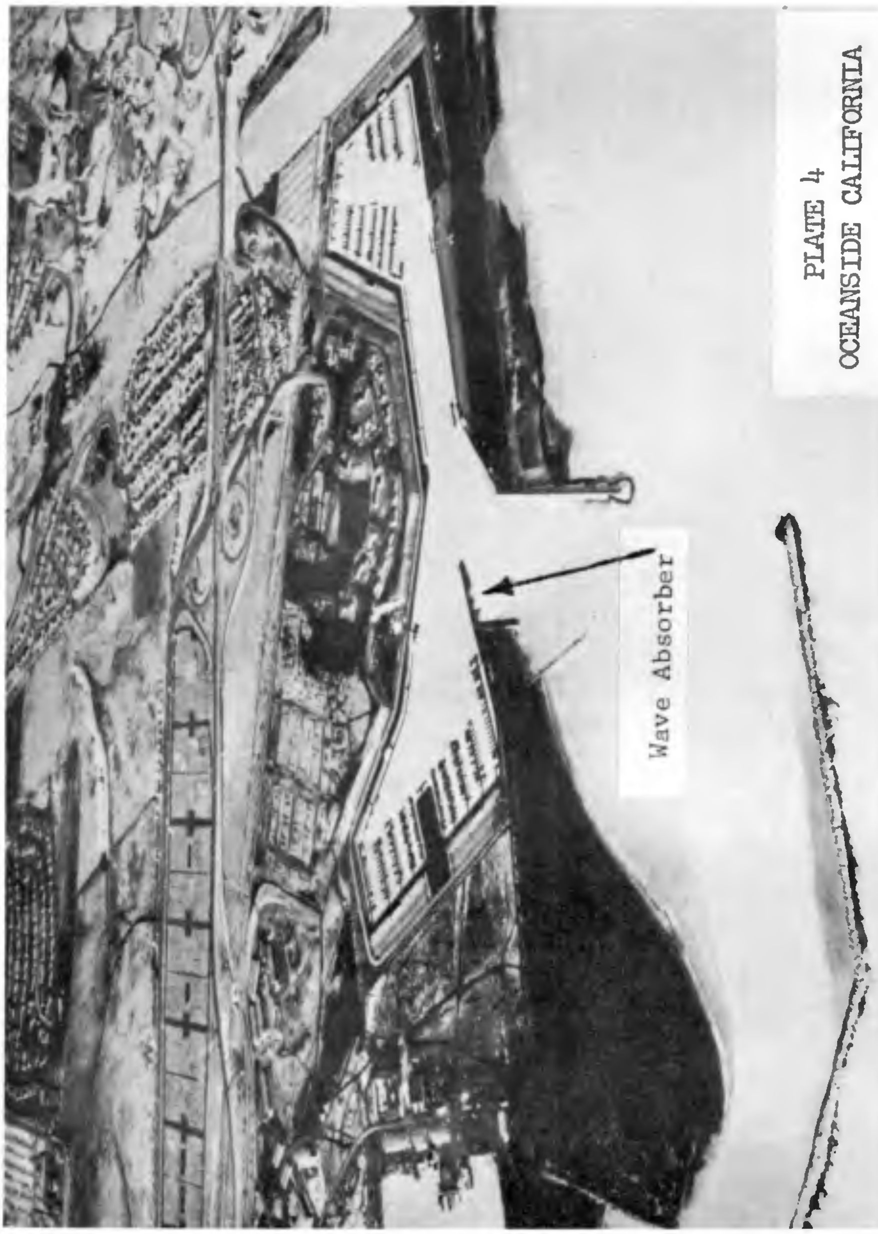


PLATE 4
OCEANSIDE CALIFORNIA

study would be concerned with the harbor oscillations which create this problem; the major attention being devoted to the response characteristics of complex harbor shapes to wave induced surging.

The Corps of Engineers is involved in many types of research effecting small boat harbor design. It is planned to increase the scope and accelerate the completion of these studies.

## MODEL STUDIES

Our present knowledge of the phenomena that occurs when a wave enters a small craft harbor makes it necessary that most of our small boat harbor designs be supplemented by a hydraulic model study. At the present time, it appears necessary to simulate the actual conditions of the site in order to fully anticipate wave travel, attenuation and reflection within the confines of the harbor. It is hoped that research programs will soon yield sufficient general design criteria that some model tests may be eliminated. However, it is assumed that for the more complex problems, specific project model studies will be required for some time in the future.

## CONCLUSIONS

More research and study is necessary before effective small craft harbor design criteria is developed. Some of this research is underway, but much additional must be planned and initiated in the near future. Specific harbor cases, such as the three discussed herein, give some data on which to proceed. Case histories should be given detailed analysis for proper guidance of future research programs.