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Engineering and Ecological Evaluation of Artificial-Island Design, Rincon Island, Punta Gorda, California

by

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(Biota Appendix by William L. Brisby)
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by wave attack; that subsidence ranging from about 3 inches to 1.5 feet has occurred, mainly due to the deterioration of some inferior material in the revetment; that littoral transport has been almost unaffected; that adjacent bottom topography shows minor changes; and that a large, thriving community of marine organisms has developed in the environment created by the island. The report includes recommendations for instrumentation to provide measurement of waves and nearby bottom sedimentation.

PREFACE

This report prepared under Contract No. DACW72-73-C-0004, describes design and construction procedures used in the construction of Rincon Island, and includes a current evaluation of those procedures. The island and causeway were designed by John A. Blume & Associates, Engineers, for the Richfield Oil Corporation (now incorporated in the Atlantic Richfield Company). The island was constructed by the Guy F. Atkinson Company with field engineering services provided by John A. Blume & Associates. The causeway was constructed by the Healy Tibbetts Company. This report was prepared by James M. Keith and Roger E. Skjei, Vice Presidents of John A. Blume & Associates. The authors gratefully acknowledge the consultation provided by John A. Blume and Joseph P. Nicoletti. Appreciation is also due Professor William L. Brisby of Moorpark College, California, who furnished the Appendix.

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NOTE: Comments on this publication are invited.

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JAMES L. TRAYERS
Colonel, Corps of Engineers
Commander and Director

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Aerial Oblique View of Rincon Island

ENGINEERING AND ECOLOGICAL EVALUATION OF ARTIFICIAL-ISLAND DESIGN, RINCON ISLAND, PUNTA GORDA, CALIFORNIA

by

James M. Keith and Roger E. Skjei

I. INTRODUCTION

1. Objective of the Study

The basic objective of this study was to improve design capabilities for construction of fill-type islands in exposed offshore locations, and to document environmental changes related to one such island. Rincon Island (Blume and Keith, 1959), is a unique example of this type of island, and a detailed comparison of its behavior with the assumptions made in its design will provide a sounder basis for the design of similar structures in the future.

The design of Rincon Island required extrapolation of much available data, and the adaptation of many design procedures to conditions differing by various degrees from conditions for which the design procedures were originally developed. The degree of conservatism has been evaluated to determine if any design parameters were unconservative and could pose a future threat to the stability of the island, or if, on the other hand, the design was overly conservative and not as economical as it could have been. As of the date of this study (1973), Rincon Island has been completed for approximately 14 years.

Adequate data are not and were not expected to be available to fully evaluate all phases of the island's design and subsequent behavior. Gaps in available data have been evaluated, and appropriate recommendations for future programs to supply data for an improved evaluation of critical design parameters have been made.

2. Design and Construction History

a. Background - In 1954, the State of California Lands Commission called for competitive bids for the exploration, development, and production of oil and gas from a 1,175-acre offshore area called the Rincon Lease. This submarine land lies offshore from existing production wells on piers constructed many years ago. Proposed offshore facilities had to be designed to accord with 1954 requirements and court rulings, which specified "solid manmade islands of natural materials".

Richfield Oil Corporation was awarded the lease. The engineering firm, John A. Blume & Associates, had already performed preliminary offshore studies as consultants to Richfield, and was told to proceed with all engineering phases of the project except those pertaining to oil exploration and production, which were done by Richfield.

Richfield's offshore lease stipulated that the area be drilled from shore, from existing offshore structures, or from a solid island of natural materials. A comparison of the costs of slant drilling from shore with rough estimates of island costs indicated that an offshore island of natural materials would be more economical. Geological criteria dictated the general island location; the basic problem thus became the design of an economical, permanent island of natural materials suitable as a base for oil well drilling and production. Moreover, the installation was not to detract from the natural appearance of the coastal area.

The size of the island was determined by operational area requirements plus allowances for armor layer thickness and necessary side slopes. These factors in turn were functions of the optimum number of oil wells on the island, production functions to be done on the island versus those done onshore, ocean wave heights and periods, and many other considerations.

b. Project Location and General Description - Rincon Island is located offshore between Santa Barbara and Ventura as shown in Figures 1 and 2. The location within the lease area was chosen by Richfield to provide maximum production from the greatest area at the least total cost of installation, drilling, and operation.

The water depth from the shallowest to the deepest toe of the island ranges from 41 to 48 feet referred to MLLW as datum. Tidal ranges for this area are shown in the following table:

Table 1. Tidal Ranges at Punta Gorda

ESL* Data for 1963-1966	
Extreme High	7.50
MHHW	5.40
MSL	2.58
MLLW	0.00
Extreme Low	-2.5

* Earth Science Laboratories, National Oceanic and Atmospheric Administration.

Although Rincon Island is in the Santa Barbara Channel between the mainland and the natural offshore Channel Islands, it is actually in the Pacific Ocean. The Channel Islands provide some protection to the channel and reduce the energy of many ocean storm waves before they reach shallow water, but this protection is by no means complete, nor is it very significant for a fixed structure. Many ocean storm waves entering the channel proceed easterly with little loss of energy, and their energy can then be further increased by local winds, and by shoaling and refraction.

The unusual plan-shape of the island, shown in Figure 3, was developed to obtain optimum wave protection. The area of the island on the ocean floor is about 6.3 acres; at MLLW the area is 3.2 acres; gross area at elevation +16 feet is 2.1 acres. Net usable flat area at +16 feet,

Figure 1. Location Map, Rincon Island

Figure 2. Location Plot, Rincon Island

excluding the wharf, is 1.1 acres, although additional usable space is obtained by the effective use of vertical wall surfaces inside the rock armor.

Rincon Island was constructed of rock revetments containing sand fill. It was constructed in stages and contains many types and gradations of rock. The most exposed, western face is protected with 1,130 concrete tetrapods, each weighing 31 tons. (Covered by U.S. Patent No. 2,766,592 issued 16 October 1956 to Etablissements Neyrpic which has given Sotramer (Societe d'Exploitation de Brevets pour Travaux a la Mer) an exclusive license to promote and exploit the use of tetrapods throughout the United States. The U.S. patent and the agreement expired 16 October 1973.) The top elevation of the seaward breakwater wall is at +41 feet, the sides at +24 feet, and the wharf and working area at +16 feet. Including the 35,000 tons of tetrapods, there are approximately 618,000 tons of material in the island. The exterior sides of rock rubble slope at 1.5 on 1 except on the east wings which are at 1.25 on 1. The tetrapod armor slopes at 1.5 on 1. Figure 4 shows vertical sections through the island. Locations for these sections appear in Figure 3.

A small wharf of prestressed concrete piles, concrete cap, and timber deck was constructed on the lee side of the island within a semiprotected harbor created by two "wings", or rock breakwater stubs. A single-lane causeway, of steel pipe piles and timber decking on steel stringers, extends from this wharf to the abutment on shore some 2,730 feet away. Most bents are at 40-foot centers, and are of alternating single-pile and double-battered-pile construction. The deck level climbs sharply from +16 feet at the island and is level for most of its course at 35 feet above MLLW.

c. Site Investigation - Bottom contours from National Ocean Survey (formerly U.S. Coast and Geodetic Survey) charts were supplemented by lead-line soundings and fathometer runs from one of Richfield's exploratory drilling ships, the *La Ciencia*. By several methods, soil borings of the ocean bottom were made from the *La Ciencia* with two primary purposes. The first was to examine the suitability of the ocean floor as a foundation for the island; the second was to see if a satisfactory source of dredge-fill material for the island core was available within economical pumping distance. The simplest sampling device for obtaining samples of the surface material on the ocean floor is a *snapper*, or small spring-loaded clamshell. The *dart* sampler is a heavily weighted stabbing device which, when dropped to the ocean floor, recovers a cylindrical sample up to 3 feet long. A jet-churn rig was used to recover cylindrical samples from various depths by jet-churning to the desired depth and then stabbing samples from the bottom of the hole. This last rig was later replaced by a rotary rig which could also obtain cylindrical samples by the same method. The first two methods of sampling were used in the search for dredge-fill material, and the latter two for obtaining deeper information near the island site.

Bottom conditions vary uniformly throughout the lease area. Overburden material on the ocean floor is a silty sand ranging into sandy silt,

Figure 4. Rincon Island Sections

increasing in thickness as water depth increases. At the island site it ranges from 14 to 25 feet in thickness. Shoreward from the lease area the sand content increases, but the overburden thickness decreases. The average bottom slope at the island site is 3 percent.

Table 2 indicates some of the materials encountered in the subsurface investigation. Underlying the overburden is a geologically recent shale or siltstone formation. Consolidation estimates indicated a probable settlement of less than 6 inches at the ocean floor from the weight of a solid island, and most settlement was expected to occur during construction. Bottom material shoreward of the island was not coarse enough to be desirable for dredge fill, but studies indicated that proper control of the discharge location could use ocean currents to separate and winnow out the fine fractions, leaving a satisfactory granular core of dredged material.

d. Rock Sources - The operating quarry most convenient to marine loading facilities was on Catalina Island. Because using this quarry would have required a barge haul of about 90 miles to the island site, a significant effort was devoted to locating alternate rock sources. Laboratory tests of samples taken from near Prisoner's Harbor on Santa Cruz Island, only 27 miles from the island site, indicated that this rock was suitable for the island revetments, but it was estimated that few units weighing more than 15 tons could be obtained. The igneous rock from Prisoner's Harbor appeared similar to other Santa Cruz Island rock used in the construction about 30 years previously of the Santa Barbara breakwater, which has shown excellent weathering characteristics. Richfield arrived at an agreement with the owner of this part of Santa Cruz Island whereby the new quarry site was offered to all bidders as a royalty-free source of rock and gravel. Exploratory blasting was financed by Richfield and witnessed by all interested bidders. Other quarries on the mainland involved either long hauls with transfer to barges or produced materials considered unsuitable for seawater and wave exposure.

Bidding documents were prepared to allow any source of rock on a specification basis of quality, density, size, and gradation. Alternate sizes of armor rock units were specified depending upon the specific gravity of the rock.

e. Precast Concrete Armor - Studies of precast concrete armor units revealed several factors which made it desirable to allow for their use as an alternative to the rocks of the largest (Class A) category. Research (U.S. Army, Corps of Engineers, Waterways Experiment Station, 1955) shows that, for a given weight and specific gravity, tetrapods are more stable against wave action than quarried rocks. Practically, this meant that lighter weight armor could be used; hence a smaller crane could place the armor on the seaward face of the island. Equally important was the elimination of the necessity for quarrying and transporting heavy rocks. It is usually difficult to predict the maximum rock size a quarry will economically produce until actual operations are underway. In addition to tetrapods, the design included tetrahedrons as optional precast concrete armor.

Table 2. Typical Overburden Materials at Island Site

	Surface	5	12	18	24
	(feet)				
Sample Depth Below Bottom (feet)					
Dry Wt., lbs/ft ³	80.0	98.0	99.0	97.0	94.0
Wet Wt., lbs/ft ³	101.0	123.0	123.0	119.0	117.0
Percent Moisture	27.0	26.0	25.0	23.0	25.0
U.S. Standard Sieves Percent Passing (number)					
30	99.7	100.0	100.0	99.8	99.8
50	99.5	-----	99.8	-----	-----
80	99.2	99.8	99.6	99.7	99.5
100	98.9	99.6	99.3	99.5	99.1
140	96.8	98.8	97.6	98.0	95.1
200	59.6	76.6	81.2	80.6	61.3
270	30.9	37.1	56.4	52.9	37.9
Hydrometer Test Effective Particle Size (mm) (percent smaller)					
0.050			46.0		
0.037			32.5		
0.024			23.0		
0.017			19.1		
0.010			15.9		
0.0072			12.7		
0.0050			11.1		
0.0035			9.5		
0.0027			6.3		

The precast concrete armor alternate also made it practical for a contractor to build the island from an onshore quarry since the next largest rock size required, the B grade, could be hauled over public roads with normal equipment. Required sizes of Class A tetrapods and other armor rock classifications varied with specific gravity and are shown in Table 3. All armor was randomly placed in two layers.

f. Filter and Core Material - To avoid loss of core material through the rock layers from "pumping" caused by wave action, an effective filter is essential. The island's filters could not conform with the generally accepted filter gradings recommended by Terzaghi and modified by the U.S. Army, Corps of Engineers, Waterways Experiment Station at Vicksburg (Posey, 1957). Because it was considered impractical to place the relatively thin blankets assumed by the usual filter gradings in an exposed ocean location, the size spread in each material was made considerably greater than recommended. It was anticipated that there would be minor losses in the filters, especially of the Class G material; however, as the fines were lost from the outer layers it was expected that a stable grading would be achieved. Most of this readjustment is believed to have occurred during construction as the Class G material was normally the first material placed in each lift.

The Class F material served a dual function: as the lightest class of armor in the lower layers, and as the outer layer of filter elsewhere. Class F material was a quarry-run material with an open gradation ranging from 4 tons down to a minimum of 15 percent less than 5 pounds. Class G material was an optional quarry-run gravel material with a dense gradation ranging down to not less than 25 percent passing the No. 20 sieve. The core was sand because it was less costly than even quarry waste. Bidders were allowed to choose between placing the core by dredge from underwater borrow areas or importing from shore borrow areas.

g. Construction History - Sealed bids, on a unit price basis using the engineer's quantity estimates for total cost comparison, were obtained from selected contractors. The contract was awarded in August 1956 to the low bidder, who elected to open his own onshore quarry about 6 miles from his loading-out site, and to use precast concrete tetrapods for the Class A armor. At the loading-out site, 4.5 miles upcoast from the island site, the contractor built a temporary loading structure in about 22 feet of water. It consisted of an L-shaped pier of eight 40-foot-diameter steel caissons filled with rock and sand and connected to shore by a trestle. The pier was sized to provide moderate protection for one flat barge. A 50-ton stiff-leg derrick was mounted on the pier to handle materials.

Tetrapods were cast in a construction yard onshore near the loading-out pier. Because locally available sand and aggregates are mildly reactive, the cost of obtaining nonreactive sand was investigated. Also, type II low-alkali cement had been specified, and recent production from the selected cement mill had been averaging approximately 0.3 percent alkali calculated as equivalent sodium oxide. It was decided to use locally available sand and aggregates, but to maintain a close check on the free alkali content of the cement. The job average was 0.29 percent,

Table 3. Armor Weight Requirements for Various Specific Gravities

Class	Specific Gravity	Solid Weight per ft ³ (lbs)	Minimum Weight per Unit (tons)	Thickness of Two Layers (ft)	Minimum Average Weight per Unit (tons)
Tetrapods					
A	2.3	143.5	38.0	18.3	—
A	2.4	149.8	31.0	16.9	—
A	2.5	156.0	26.5	15.0	—
A	2.6	162.2	22.5	14.7	—
A	2.7	168.5	19.5	13.9	—
Armor Rock					
B	2.25	140.4	29.0	15.4	32.0
C			12.0	11.5	13.0
D			6.0	9.1	6.5
B	2.35	146.6	23.0	14.2	26.0
C			10.0	10.6	11.0
D			5.0	8.4	5.5
B	2.45	152.9	20.0	13.2	22.0
C			8.25	9.9	9.25
D			4.25	7.3	4.5
B	2.55	159.1	17.0	12.4	19.0
C			7.0	9.2	7.75
D			3.5	7.3	4.0
B	2.65	165.4	14.0	11.6	16.0
C			6.0	8.7	6.75
D			3.0	6.8	3.5
B	2.75	171.6	13.0	10.9	14.0
C			5.25	8.2	5.75
D			2.75	6.4	3.0
B	2.85	177.8	11.0	10.3	12.0
C			4.5	7.7	5.0
D			2.25	6.1	2.5
B	2.95	184.1	10.0	9.8	11.0
C			4.0	7.3	4.5
D			2.0	5.8	2.25
B	3.05	190.3	8.5	9.2	9.25
C			3.5	6.9	4.0
D			1.75	5.5	2.0

with a range from 0.20 to 0.48 percent. The concrete mix used five sacks of cement per cubic yard, and 3-inch maximum size of aggregate. Calcium lignin sulphonate water-reducing additive was used at the contractor's option. A dual drum paving mixer operated on a bulkhead ramp adjacent to the casting pit so that its bucket could discharge directly into the tetrapod forms.

The forms were of two-piece steel construction: the bottom section formed the bottom half of the three lower legs, and the top section formed the top half of the lower legs and the upstanding leg. End gates for the bottom legs were hinged to the top section. The contractor used 36 bottom sections and 12 top sections, which allowed pouring 12 tetrapods per day. The top forms were stripped after 20 hours, and the tetrapods removed from the bottom forms after 3 days. For this first lift, a special compression sling developed by the contractor gripped the tetrapod by pressing a bearing plate against the flat end of each bottom leg, thus allowing the tetrapod to be handled while the concrete was still green without damage or over-stressing. A large crawler crane lifted the tetrapods from the casting pit and placed them in an adjacent storage yard for the 28-day curing period.

The first material for the island was placed in February 1957, after several months of quarry development and the construction of temporary facilities. Most of the marine work was done on a two-shift, 6-day work week since marine equipment charges represented a sizable proportion of the contractor's costs. The general procedure was to build the exterior rings of each lift out of Class G and F material, then place the armor rock and the core material. Class G, F, and core materials below elevation -15 feet were placed by bulldozing the material over the sides of carefully located barges. Except for the top lifts of tetrapods and armor rock, which were placed by a crawler crane from the island, all armor materials were placed by barge-mounted cranes.

The contractor placed wood-pile dolphins on the north and east sides of the island work area, and used targets strung between the dolphins to provide position lines for placing materials below water. The island first broke water in October 1957. The seaward face was constructed first, to elevation +17 feet, to provide some protection from the approaching winter weather. Before complete closure of the island above water, sufficient core material was placed on the south side to allow the barge-mounted crawler crane to be unloaded. This was accomplished by beaching the barge against the core and walking the crane off on a temporary ramp of core fill. The final closure of the north face was made in January 1958.

Core fill for the island was a medium to fine sand obtained from the cliff behind Punta Gorda about 1,320 yards from the island site. It was first hauled by truck to the contractor's loading-out pier, then by barge to the island site. It was not surprising that the contractor elected not to dredge the core fill, since the final design required a relatively small amount of sand for an economical dredging operation. The lift-type construction required core sand to be placed on an intermittent schedule, and the open sea is an insecure place to operate a dredge even on larger projects.

Two moderately severe storms occurred during January 1958. Although the island was in an incomplected and vulnerable state, it received light damage. The contractor's loading-out pier was damaged in the second of these storms and required a month for repairs.

The 68 steel conductor pipes were driven when the core elevation was at about +11 feet. These pipes, the initial casing for future oil wells to be drilled through the island by the owner, were driven 15 feet into the original ocean floor. Work on the concrete walls on the surface of the island was started after all the conductor pipes were driven. For this work a small concrete batch plant was placed on the island. Work was substantially completed in August 1958.

h. Field Engineering - One basic problem for the engineer providing supervision and inspection throughout the construction was to ensure that the filter zones of the revetment construction were adequately placed and that no openings in this essential element of the island's defense were left for the relentless attack of the seas. Another responsibility was to see that the various rock layers were placed within acceptable location tolerances. The fact that two-thirds of the island's cost was for materials placed below water points up the difficulty of these problems. Survey and layout work was basically a contractor responsibility, and a high percentage of his marine work was directly or indirectly concerned with performing this task. A lead line was almost constantly in use during all underwater material placement operations.

The magnitude of the survey work made it impractical for the engineer's staff to check all survey operations. Field inspectors observed and spot-checked the contractor's marine survey operations, but considerable reliance was placed on independent surveys by a modern ultrasonic depth recorder of the underwater mounds placed in the early stages. An essential feature of this instrument was the narrow (approximately 6°) cone of response, which allowed adequate delineation of the sharp breaks in grade typical of the island form. As anticipated, vertical accuracy of the instrument when properly calibrated by a steel plate suspended by a survey tape was not a significant problem.

The echo sounder is a portable instrument, so the transducer was mounted outboard toward the stern. A preferred method of position control was by taking simultaneous sextant angles on three targets from the boat. To help reduce plotting errors, a platform was rigged to overhang the transducer, so that both sextants could be located over the transducer when taking position shots. To help obtain conveniently large horizontal chart scale, a special high-speed chart drive motor was installed in the echo sounder. In addition, "spoiler plates" were lowered into the water directly behind each of the twin propellers. The spoiler plates effectively reduced boat speed while maintaining good rudder control. The slow boat speed was desirable for close spacing of position shots and to aid in maintaining a large horizontal scale on the echo sounder charts. These techniques enabled a small field staff to take accurate and continuous three-dimensional sweeps of underwater construction when required.

Adequate control of rock quality proved a difficult assignment. Constant effort by both the contractor's quarry force and the engineer's field staff was required in order to ensure a supply of rock of adequate quality. Rock specifications required two quality tests -- the Los Angeles rattler test, and the sodium sulfate soundness test. The soundness test was considered especially important because of the marine exposure. Rock quality varied widely throughout the quarry site. Much of the rock, of the Cold Water Sandstone Formation, Eocene Age, was of excellent quality, but some deposits were poor and weakly cemented. There were also many intermediate grades. The quarry site, however, contained a vast amount of good material of a type which could be quarried in very large unit sizes.

During the initial quarry development the contractor drove many small tunnels or *coyote holes* into the canyon sides searching for the best quality rock. The coyote holes in sound rock were later used for primary blasting. An extensive field testing program was carried out by the engineer on samples taken from these coyote holes, and a search was made for any quickly identifiable characteristics which would correlate with soundness. Acid reaction, specific gravity, Schmidt-hammer reading, color, density, grain size, and microscopic examination were all tried, but found unreliable. The final solution was to test each separately identifiable rock type found in the quarry and to classify each according to its actual soundness test results. Over 100 samples were required for adequate coverage. To speed testing, the engineer's field office was equipped to perform soundness tests on a continuous basis. Untested portions of each sample were retained and small chips from these were carried in a compartmented box as an aid in quick field identification of the rocks. This method proved effective in most of the cases, but a few types of rock, which straddled the acceptance line, remained difficult to classify throughout the job.

Rock quantities were measured for payment by barge displacement. Occasional checks of barge-gaging accuracy were made by weighing all loads on truck scales and agreements were normally within 1 percent. Individual weights of armor stone were normally judged by eye. In doubtful cases, weight was checked by truck scales or by measuring the volume of the rock.

Voids in the rock materials, as placed, varied from 40 percent for armor rock which was nearly of uniform size to 30 percent for Class G material of reasonably dense gradation. If losses of core fill material are ignored, the tonnage placed would indicate about 20 percent voids in the core, most of which was placed under water. A more reasonable assumption of 35 percent voids in place indicates that about 23 percent of the core material was lost due to ocean currents and wave action.

A model of the island was built by the engineer's field staff at a scale of 1:120,000. Progress on the model matched construction progress, so that the model served as an easily understood progress report. While the island construction was still below water, the model was especially useful for visualizing the status of the work; and all persons connected

with construction of the island watched their efforts reflected in the model with gratifying interest.

Scuba diving gear, also used by the engineer's field staff for inspecting the underwater port of the work, proved useful. Although there are drawbacks to the use of scuba gear, its outstanding advantage is that it allows the engineer to see the object in question. Additional advantages of scuba inspection are summarized as follows:

- (1) Equipment is relatively inexpensive.
- (2) For a diver with limited training and experience, scuba is safer than conventional diving gear, although basic training is still essential.
- (3) Equipment is easily portable, so that elaborate preparations for a dive are not necessary.
- (4) The diver has greater mobility and flexibility of operation.

Against these advantages the following disadvantages must be balanced:

- (1) There is no underwater communication system equal to a helmet diver's phone system. Some of the other drawbacks mentioned are a direct result of this deficiency.
- (2) Unless the water is clear, orientation is more difficult to maintain than when using conventional deep-sea gear. A compass is often very helpful, but is useless if ferrous metal is in the vicinity.
- (3) Scuba divers should work in pairs for safety.

II. EVALUATION OF DESIGN CHARACTERISTICS

1. Wave Exposure

a. Predicted Wave Exposure - Wave forecasts for the island site were prepared in great detail, and covered estimated heights, periods, direction, and frequency of occurrence. Basic data for wave forecasts were compiled from available wave measurements by wave recorders and trained observers, hindcasting from synoptic weather maps, and past records of severe storms. Refraction studies were then used to adjust this information to the specific location of the island. The Channel Islands and the generally east-west trend of the coastline west to Point Conception serve to protect the island site from many, but by no means all, of the Pacific's winter storm waves. That this partial protection confines the approach of large waves to a narrow sector of almost unlimited fetch to the west had considerable influence in determining the odd configuration of the island, as well as its orientation.

Wave studies also included an examination of lower wave heights from all directions, which, though less damaging, still had an influence on the

island's design. The frequency of occurrence of these lower waves is especially important in planning and scheduling marine operations in exposed locations. Figure 5 is a plot of predicted wave height, direction, and frequency of occurrence for the Rincon Island site; Figure 6 presents a wave height occurrence frequency chart.

b. **Actual Wave Exposure** - Unfortunately, no direct quantitative data are available to determine the actual exposure for the 14 years since construction. The Corps of Engineers had a surface staff gage mounted on a platform pile at a Philips Petroleum Company installation near Point Conception from 1965 to 1967, but its operation was not satisfactory and the location is too far from Rincon Island to provide relevant data.

An array of five pressure gages was installed near Point Mugu, in 26 to 28 feet of water. Data were transmitted by phone to CERC in Washington, D.C. However, these gages are too far from Rincon Island to provide relevant data.

Efforts to obtain wave data from other private installations in the vicinity, or to determine if such data exist, have been fruitless, and it has been necessary to rely on indirect data for an evaluation of the actual wave exposure.

One source of indirect wave data is related to the actual performance of the armor units. The armor is designed to be stable enough to require no maintenance as long as maximum wave heights are less than about 27 feet. If it is assumed that armor unit design calculations are valid, it can also be assumed that wave heights have not exceeded 27 feet, since no wave damage to armor units has been noted to date. Another source of indirect wave data comes from wave runup considerations. It was calculated that a 34-foot wave would have a runup causing a 3-foot overtopping and observable flooding of the west face. Since such flooding has not occurred, wave heights can be assumed to have been less than 34 feet.

Wave heights can also be calculated from synoptic meteorological data. Design wave heights were calculated from such data and from wave recorders at Pacific coast locations. However, the use of such data, assuming no unusually severe wave occurrence in the interim, should result in repeating the design wave calculations and predictions. Since no such unusual wave attack has been experienced to modify the original calculations, it is assumed that no additional information on actual exposure can be deduced from synoptic meteorology.

This lack of actual wave data introduces uncertainty into evaluating design parameters related to wave attack. Ideally the island should be instrumented with wave recorders as discussed below. At present, it seems reasonable to assume that actual wave heights have not exceeded 27 feet. Eyewitness evidence indicates that actual wave heights may not have exceeded 20 feet.

Figure 6. Estimated Wave Height Frequency at Island Site by Months

2. Plan Shape

The plan shape, shown in Figure 3, evolved from five basic inter-related considerations: island area and shape, revetments, filter and core, general scheme of construction, and, of course, cost. Area requirements were established by Richfield to provide space for oil drilling and production facilities consistent with the anticipated drilling and production program. The final shape was developed from oceanographic, model, design, and economic studies. The west, or seaward, face is designed to withstand heavy seas from winter storms and to protect the rest of the island. The north and south faces, or sides, are designed to be stable against 12-foot waves, since maximum wave height from these directions is limited by the fetch inside the Santa Barbara Channel. The east face, or shore side of the island, is provided with a small wharf protected from ocean waves by the northeast and southeast stub breakwaters, or "wings", as they came to be called. To reduce the cost, the original design did not include a causeway; it was intended that the island would be served by the wharf only.

The revetment for the west face includes a cellular wall structure adjacent to the double line of conductor pipes that serves as a support platform for the drill rig which straddles the drill cellar. The rig can be skidded in a north-south direction to center over any desired well. The cellular wall structure also serves as a backstop or secondary line of defense for the west face revetment, which is designed to withstand 27-foot waves without damage, but which can sustain significant damage before the wells are exposed to direct wave attack.

Behavior of the prototype has been as expected, in that the broader west face creates a wave shadow zone providing shelter from westerly waves for the north and south faces. The wings further shelter the east face. No damage to armor rock has occurred on the north, south, and east faces. Assuming that maximum wave heights have been near 27 feet, the high range estimate derived from indirect data, then it appears that the shape is providing the desired attenuation of waves approaching from the west.

3. Use of Model Tests in Design

As is typical of many hydraulic design problems, several elements of the design could best be checked by laboratory model tests, which were conducted in two series. The first was a three-dimensional model test to check the configuration of the island and the second involved two-dimensional models in a wave channel. Both models were constructed at a linear scale of 1:70,000. To keep costs low and still obtain a maximum amount of information, movies were made of most tests and time-consuming measurements of runup patterns were kept to a minimum.

At one stage of the design, Richfield wanted a small concrete slip, about 40 by 150 feet, on the leeward side to be used as a small boat harbor for servicing the island. One purpose of the three-dimensional model tests was to determine if a permeable or partial gate would maintain

quiet water in the slip during stormy weather. Although some resonance of the slip was expected, the model showed the slip was highly resonant to wave periods typical of Pacific storms, and only a watertight door (or lock gate) would provide quiet water in the slip. An alternate solution of providing short stub breakwaters at each of the eastern corners of the island was so effective in maintaining quiet water during most wave conditions that the slip was replaced by a small wharf. In general, the other features of the island plan were found to be satisfactory, as was the concept of a high seaward face sheltering the lower-elevation island work area.

Using the same three-dimensional model, the feasibility of using two concrete ship hulls as a separate, submerged breakwater seaward of the island was investigated. By considering wave runup on the island's sides, the effectiveness of different locations and spacing for the hulls was studied. Although cost studies indicated possible savings in construction cost, Richfield elected not to use the hulls because of the less attractive appearance and possible adverse public reaction.

The second series of laboratory tests involved two-dimensional wave channel tests to evaluate the proposed seaward face revetment section. The first test runs, with a wave height slightly below the design wave height of 27 feet, verified stability for the design wave. Following these initial tests, wave heights were increased by steps to a maximum prototype height of 34 feet.

As anticipated, the section showed damage under attack of waves larger than the design wave. A gratifying feature, however, was that the section showed no tendency towards catastrophic failure due to any single wave, but only gradually increasing damage. This was consistent with the basic design objective of an economical section which might sustain damage, but which would not endanger the whole island when subjected to rare large waves.

The model tests were useful in developing the final shape of the island and in verifying the west face revetment design and attenuation of westerly waves. Prototype performance to date has been as predicted by the tests.

Testing was conducted in February 1956 to meet a 16 March 1956, deadline for incorporation in the design, which went to bid shortly thereafter for a subsequent 25 May 1956, contract date. An optimum schedule would provide for three-dimensional model testing at three stages of design progress. Design concepts should first be tested with a small-scale model (about 1:150,000) allowing many tests at a reasonably low cost per test. The objective would be to investigate many design concepts in a qualitative manner. Next, as a given design is being developed, a major test program should be conducted, using a large-scale model (1:70,000 or larger) for definitive and quantitative input to the design development. As the design stage nears completion some additional testing should be done to verify the expected performance of the near-final design. The second and final stage

will probably require fewer tests than the first conceptual investigation, but with a larger scale and more detailed model the cost per test will be higher.

4. Armor Stability

a. Economic Considerations - Preliminary studies of the history of conventional breakwaters along the Pacific coast made it clear that it was not economically feasible to design the seaward revetment to be completely stable against all possible storms. All breakwaters in deep water with a severe exposure are expected to and generally have suffered occasional damage. The extreme consequences of complete failure of the island's revetments made this problem much more critical than for breakwater design. A rational approach was therefore developed which consisted of six steps: (1) prediction of the frequency of occurrence of large storm waves at the site; (2) correlation of predicted storms with laboratory tests of revetment sections; (3) estimates of cost and damage for various trial designs; (4) evaluation of damage to the various designs; (5) economic analyses of various designs; and (6) selection of final revetment sections.

Table 4 summarizes the calculations for estimating average annual repair cost for a trial design of the island's seaward face revetment. Columns 1 and 2 were developed by oceanographic study of the island site. For column 3, the maximum wave of a storm was assumed to be 1.9 times the significant wave of the storm. Column 4 correlates the storm waves with laboratory waves.

Based on observations of the model tests, it was assumed that the maximum wave of a wave train best describes the destructive ability of the wave train. The maximum wave of the laboratory wave tests was about 1.16 times the laboratory designated wave height for the test, a figure derived from a study of a typical wave record of the wave channel tests. Based on these assumptions a wave height = $1.9/1.16 = 1.64$ times the significant wave of a predicted storm was used in the modified Iribarren formula to determine the armor for a no-damage design. Columns 5 and 6 are based on damage estimates obtained in the laboratory wave tests. Considerable refinement of such damage estimates was later published. (Hudson, 1959.) The estimated repair cost in column 7 is based on a unit price for armor materials replaced or recovered, and a lump sum cost for mobilization and demobilization. Column 8 is column 7 divided by column 2 and gives the incremental part of the average annual repair cost contributed by each class of storms.

Figure 7 is a plot illustrating the economic analysis of several trial designs. Curve *a* is the average annual repair cost for various designs computed as illustrated in Table 3, and curve *b* is the present worth of the average annual repair cost for a 25-year period at an interest rate of 6 percent. Curve *c* is the estimated construction cost of each of the various trial designs. The capitalized cost, curve *d*, is the sum of curves *b* and *c* and its low point represents the most economical design.

Table 4. Estimated Annual Repair Cost for 27-Foot-Maximum Wave Design

1	2	3	4	5	6	7	8
Significant Wave Height in Storm (ft)	Frequency Storm Recurs Once in Years Shown (yrs)	Maximum Wave Height in Storm (ft)	Equivalent Wave Height for Use with Armor Formula (ft)	Ratio Maximum Wave Height to Maximum No-Damage Wave (:)	Estimated Damage to Armor per Storm (%)	Estimated Repair Cost per Storm (\\$)	Incremental Average Annual Repair Cost per Storm (\\$)
14	14.4	26.6	23.0	0.96	none	-----	-----
15	23.8	28.5	24.3	1.01	2	81,500	3,420
16	43.5	30.4	26.2	1.09	7	130,000	3,000
17	74.0	32.3	27.9	1.16	13	208,000	2,810
18	141.0	34.2	29.5	1.23	23	286,000	2,030
19+	107.0	36.1+	31.2	1.30	35	400,000	3,740
Average Annual Repair Cost = \$15,000

Figure 7. Economic Evaluation for Various Design Wave Heights

Figure 8 presents another method of analyzing the same information. Starting with a trial design which is definitely less stable than the most economic, curve *a* represents the additional investment required for various more stable designs and curve *c* is the corresponding average annual repair cost. Curve *b* is the incremental reduction in average annual repair cost. Curve *e* is curve *d* divided by curve *b* and represents the effective return on each incremental investment. The economical design is selected as the one beyond which an additional increment of investment fails to offer an attractive return.

It is realized, of course, that such procedures involve low, if not negative safety factors under extremely adverse conditions. Although this is a logical philosophy for severe but infrequent conditions like destructive earthquakes, bomb blast, or severe storm waves, catastrophic failures must be considered and avoided in such calculated-risk designs.

b. Armor Design - The required tetrapod weight was determined by extrapolation of U.S. Army, Corps of Engineers, Waterways Experiment Station (1955), tests conducted for the Crescent City breakwater design. Using the modified Iribarren formula,

$$W = \frac{K' w S_f S_r \mu^4 H^3}{(\mu \cos a - \sin a)^3} (S_r - S_f)^3$$

where

- W = required weight of individual units of armor material in pounds
- K¹ = dimensionless coefficient,
- w = unit weight of fresh water,
- S_r = specific gravity of armor material,
- S_f = specific gravity of fluid,
- H = wave height for no damage,
- μ = coefficient of friction of armor material,
- x = angle, measured from horizontal of breakwater slope,

values of K¹ = .0223 and μ = 1.10 were used. A principal reason for the laboratory wave tests of the west face revetment was to verify these values, which were confirmed.

Figure 8. Alternate Incremental Investment Analysis

Using the current formula from U.S. Army, Corps of Engineers, Coastal Engineering Research Center, TR-4 (1966),

$$W = \frac{w_r H^3}{K_D (S_r - 1)^3 \cos \alpha}$$

where

W = weight of armor unit in primary cover layer (lbs),

w_r = unit weight (saturated surface dry) of armor unit (lbs/ft³),

H = design wave height at the structure,

S_r = specific gravity of armor unit, relative to the water in which structure is situated

$$\left(S_r = \frac{w_r}{w_w} \right),$$

w_w = unit weight of water (lbs/ft³),

α = angle of breakwater slope, measured from horizontal, in degrees,

K_D = coefficient that varies primarily with the shape of the armor units, roughness of the surface, sharpness of edges, and degree of interlocking,

a value of $K_D = 8.2$ for no damage on a 1.5 on 1 slope gives required unit weights close to those used for the island design. CERC TR-4 (1966) recommendations for two layers of tetrapods are $K_D = 8.5$ for nonbreaking waves on a structure trunk, and $K_D = 6.5$ on a structure head.

The seaward face height of +41 feet above MLLW was selected to limit overtopping from a 34-foot wave to an approximate height of 3 feet. As shown in Figure 4, five classes of armor are used in the west face revetment. The heaviest is Class A for which the contractor selected the option of using 31-ton precast concrete tetrapods with a specific gravity of 2.40. Precast concrete tetrahedrons were also optional in place of rock for Class A armor. The bid documents actually offered numerous options for each of the five classes of revetment armor since no single developed source of rock material was definitely better than others. The individual minimum weight requirements for Class A, B, C, and D rock were allowed to vary with the specific gravity of the rock. Because weight variations also

changed the armor layer thickness, the quantities of all revetment and core materials varied with the different options. In all, 59 optional quantity tabulations were included in the bid documents, allowing bidders to evaluate the advantages of using high specific gravity rock and the consequent considerable reductions in weight of the armor units.

When all factors except specific gravity are constant, the required weight of individual armor units, W, reduces to:

$$W = \frac{C S_r}{(S_r - 1)^3}$$

where

C = a constant.

c. Stability Evaluations - Surface examinations of the condition of the armor rock have been made regularly. Underwater inspections have been made less frequently. On one underwater inspection, conducted on January 28 and 3 February 1970, following a period of heavy seas from late December 1969 to early January 1970, no evidence of movement of bottom silt and marine growth was seen, and no rock displacement was observed.

Table 4 shows that the recurrence frequency for the 26.6-foot storm wave is 14.4 years. Since the island was completed in August 1958 the 14.4-year recurrence interval would have lasted until early 1973, if a uniform probability model is assumed. The probability of recording a 26.6-foot maximum wave in a 14.4-year period is about 64.5 percent, (i.e., there was roughly a two-thirds chance for a 27-foot storm wave to occur once during the 14.4-year period.) It follows that the lack of wave damage by this date is merely a mild indication that either the wave forecast or the armor design is more conservative than assumed.

5. Settlement

a. Sources of Settlement - Several possible sources of settlement were identified during the design and construction of Rincon Island:

(1) Area subsidence from oil production, similar to subsidence at the Terminal Island area of Long Beach. However, a repressurization program has been maintained by Richfield, which would eliminate this.

(2) Local subsidence of original bottom materials due to the superimposed load of the island itself.

(3) Subsidence of the revetments by consolidation, loss of armor materials due to wave action, erosion, or decomposition from weathering or seawater exposure.

(4) Subsidence of the filter materials by loss of fines while developing a filter or by decomposition from seawater exposure and currents created by wave action.

(5) Subsidence of the island core due to additional consolidation of the core from its own load and from superimposed loads.

(6) Subsidence of the island core due to loss of material through the revetments by wave pumping action.

(7) Subsidence of the island due to consolidation from earthquake shocks.

(8) Subsidence in the vicinity of pipeway risers due to consolidation of the core above elevation -20 feet, caused by material lost from this zone when a sheet-pile cofferdam was used to excavate down to the pipe-way flanges to extend the pipeway risers to the working elevation.

(9) Subsidence in the vicinity of the conductor pipes due to consolidation of the bottom material near the conductor pipe bottoms, caused by material lost from this zone during construction. This loss occurred when the interiors of the conductor pipes were excavated and pumped dry to allow survey of their alignment.

Of these sources, it was anticipated that only the subsidence of revetments due to wave action or erosion, or a nearby major earthquake would produce any significant settlement after construction.

b. Level Check Surveys - A program of releveing has been conducted to monitor elevations at selected points on the island. The surveys of these points have all been referred to a bench mark on the pile-supported wharf structure at the east end of the island. Because the piles supporting the wharf penetrated to the siltstone formation, the wharf structure was expected to show no subsidence unless area subsidence occurred.

At less frequent intervals than for the intrainland checks, surveys have been made to relate the wharf structure to the onshore level net maintained by the Earth Sciences Laboratories of the National Oceanic and Atmospheric Administration (ESL). These level surveys to the onshore ESL net and releveing of the ESL net have shown no significant elevation changes for the island bench mark or the ESL net in the vicinity of the island.

Figure 9 shows the location of the island level check points; Figure 10 shows settlements measured during the latter part of the construction, from April to mid-August 1958. During this period, settlements ranged up to 0.4 feet and generally conformed to construction activities. Most of the settlement can be attributed to elastic compression of the core, revetments, and foundation materials as additional weight was added to the island.

Figure 9. Level Check Point Locations

Figure 10. Construction Period Settlements

As shown in Figure 11, postconstruction settlements have been much slower than settlements during construction. The west revetment has settled about 1.5 feet, the south wall about 0.5 feet, and the north wall about 0.3 feet. The sumps have settled 0.2 to 0.3 feet, the cellular wall up to 0.5 feet, and the east wings about 0.4 to 0.5 feet. No check points on the interior of the island could be retained, and the pile-supported wharf has shown little settlement.

c. Evaluation of Settlement - Settlement of parts of the island relative to the island bench mark is primarily attributed to deterioration of the Class F and G quarry-run material. This conclusion is deduced from the following:

(1) Magnitude of settlement tends to conform to the degree of wave exposure, but armor materials show no relative displacement typical of wave damage.

(2) Weathering loss observed on exposed rock indicates that a significant deterioration of the Class F and G material is occurring. The average quality of the smaller quarry-run F and G material was known to be poorer and thus probably more subject to deterioration.

(3) The east face, which shows little or no settlement, contains a Ventura River gravel Class G material, chosen so that piles could be driven through it. This gravel is of sounder quality and is less erodible than the quarry-run Class G material used elsewhere.

(4) The settlement rate has not changed radically since construction. This tends to eliminate development by wave action of a graded filter in the Class F and G materials as a source of settlement since a decreasing rate of settlement is characteristic of that mechanism.

(5) Loss of core material by wave action would produce a similar result, (i.e., larger settlement where wave action was strongest) but such settlement would be more irregularly developed. The uniformity of settlement in any particular area therefore suggests that loss of core material is not occurring. Also, there has been no noticeable discoloration of adjacent water during periods of severe wave attack, as would be expected with loss of core material. The island's filter zones were designed to preclude such loss of core material, and observation of effects elsewhere in this area suggests that they are effective.

6. Littoral Transport

Rincon Island is situated in a coastal region which is characterized by substantial littoral transport with a pronounced longshore movement of sand. The prevailing direction of the longshore transport is downcoast toward Ventura.

Studies of longshore transport at Santa Barbara Harbor, as summarized by Wiegel (1964), provide a better than average estimate of average annual

Figure 11. Settlements to 1970

longshore transport in the vicinity of Rincon Island. When the Santa Barbara Harbor breakwater created a barrier to downcoast longshore transport a serious accretion problem occurred on the upcoast side of the harbor and an equally serious beach erosion problem developed downcoast. It has been necessary to restore the longshore transport at Santa Barbara by sand bypassing - dredging on the upcoast side and depositing the dredged sand on the downcoast side. There are no significant gains or losses of littoral material between Santa Barbara and the Ventura River, and throughout this region the prevailing waves are westerly. The estimated average annual accretion of sand at Santa Barbara (280,000 cubic yards) is therefore a fair estimate of the average annual net longshore transport in the vicinity of Rincon Island.

The downcoast, or southeast, direction of this movement is also well delineated by the shorelines adjacent to Punta Gorda. Immediately upcoast of Punta Gorda the shoreline is a dynamically stable beach oriented along an azimuth of 148° . This stable shoreline orientation is such that the downcoast longshore transport capacity must match the average supply of littoral material. Immediately downcoast the shoreline has an azimuth of about 82° , and the downcoast longshore transport capacity exceeds the supply until the shoreline orientation again approaches an azimuth of 150° , slightly over a mile downcoast from Punta Gorda. The excess longshore transport capacity zone is characterized by a rocky shoreline undergoing erosion and with no sandy beaches.

The potential problem of the island's interference with littoral transport processes was considered during its design. An offshore structure's interference with longshore transport arises from a reduced longshore transport capacity caused by wave attenuation in the shadow of the island. The affected area becomes an accretion zone, and where attenuation is great, the beach will build out to the structure. Considering the island's distance offshore in the direction of its shadow, ($\pm 7,000$ feet), and its maximum width of about 500 feet, it was concluded that little interference with longshore transport would result.

The coastal region from Rincon Point to Pitas Point, the next point below Punta Gorda, has not generated sufficient complaints of beach erosion in the past to cause the Corps of Engineers nor any other agency to conduct organized beach erosion studies or measurement programs. However, aerial photos taken in 1947, 1959, and 1967 provide a means of examining the shoreline configuration in the vicinity of the island. Such examinations permit a qualitative evaluation and comparison of accretion and erosion processes over the timespans between these flights. Changes in coastal processes would be reflected by changes in the width of upcoast and downcoast beaches.

The photographic coverage available for the 1947, 1959, and 1967 photography is small scale, ranging from about 1:22,000 to 1:34,000. However, even at these scales, significant differences in shoreline configuration are readily detectable.

A visual comparison of the aerial photos revealed no detectable change in the shoreline configuration adjacent to the shadow of Rincon Island between 1947 and 1967. Small differences between the 1947 and the 1959 shorelines and between the 1959 and the 1967 shorelines can be seen, but these appear to be caused by transient seasonal effects or those attributable to shoreline freeway construction. Figure 12 shows 1947 and 1967 aerial vertical views of this region.

7. Bottom Sediments

a. Contour Data - The potential effect of the island's construction on nearby bottom sediments was considered during its design. Such effects could occur if currents, eddies, and wave-induced turbulence in the water near the bottom were substantially altered by the island. Except for a shallow surface layer of loose material, the bottom materials appeared dense, and were considered stable against reported steady currents in the area (less than 1 knot). Because water depths near the island range roughly from 40 to 50 feet, near-bottom, wave-induced turbulence can only arise from long-period waves. Severe storm conditions are relatively infrequent, and it was concluded that little change in the bottom sediments would be caused by the island's construction. To evaluate this conclusion, comparisons have been made between preconstruction and postconstruction bottom contours adjacent to the island.

National Ocean Survey (formerly USC&GS) hydrographic charts of the area provided initial data on water depths. Data from these charts, supplemented by lead-line and fathometer soundings from surface craft, will be termed the 1956 soundings. Fathometer surveys by the field engineering staff will be termed the 1957 soundings. The most recent survey was conducted in March 1973 with a fathometer and a subbottom sounder. Scuba surveys show a deposit of mussel shells at the base of the west face and smaller deposits at the base of the north and south faces. Such deposits could compensate for bottom scour in these locations. Shallow-drive samples at various distances from the north and south faces showed no consistent differences.

Figure 13 shows results of the several surveys. Contours of the 1956 soundings show a gentle, regular bottom slope, deepening gradually to the southwest. The 40-foot-depth contour lies just northeast of the island, the 45-foot contour bisects the island location, and the 50-foot contour lies just southwest of the island. As a compromise of the various sources, these are represented as straight and evenly spaced. The 1957 soundings, shown plotted in 1-foot-depth increments, generally have the same orientation as the 1956 contours, and depths generally agree within 1 or 2 feet.

Causeway pile driving records provided additional detail on depths in the immediate vicinity of the causeway. They showed some variation from the 1957 fathometer survey, and specifically disclosed the presence of a slight rise in the bottom at about midlength of the causeway, which closely agrees with the 1973 soundings. Nearer the island, a slight depression was revealed by the pile driving records, but was not picked

20 August 1947

13 August 1967

Figure 12. Aerial Vertical Views of Rincon Island Area

Figure 13. Bottom Contours

up on the fathometer surveys. In general, the 1957 soundings and the pile driving data agree within 1 or 2 feet, but at the two slight irregularities described the difference is closer to 3 and 4 feet. It should be noted that the causeway area of the 1957 soundings was uncertain at that time. The 1973 fathometer survey is judged more reliable than the 1957 soundings because the tidal correction data are more reliable. On both the 1957 and 1973 soundings, position control was poorest along the causeway. Also, the 1957 soundings were primarily restricted to the actual island site. The same slight rise at about midlength of the causeway that was observed from the pile driving records is shown in the 1973 survey. A trough projects northeastward from the island, approximately on the causeway line. A ridge parallels the trough to the east. Other slight irregularities occur near the island itself.

The 1973 fathometer soundings also provided data from which subbottom contours, presumably of the top of the siltstone underlying the bottom sediments, were drawn. As noted in Figure 14, the overburden depths are based on the arbitrary assumption that sound velocity in the overburden is the same as sound velocity in the seawater.

b. Evaluation - Some mismatch between the various hydrographic surveys is to be expected considering the impossibility of maintaining a continuous reference elevation in a surface craft with both wind waves and tidal variations occurring during the surveys. The small scale of the original hydrographic charts and the general smoothing of depth data from these and other earlier surveys tends to mask irregularities of the type disclosed by the pile driving records. Although all differences between the various soundings could be explained as random errors to be expected with the technique used, certain features discussed below are consistent and appear reliable.

The area west of the island shows erosion of 1 or 2 feet. Considering the mussel shell deposits of up to 2.5 feet thickness at the toe of the west face, an estimated maximum erosion of about 3 feet appears reasonable, probably as a result of wave-induced turbulence on the weather side of the island.

The lee side of the island shows a long tail of deposition 1 to 2 feet thick. Such a deposition is consistent with the reduced wave action on the lee side. Observation of the construction during the early winter period of 1957-1958 strongly suggests that a part of this deposit occurred during construction when the core fill had only partial protection. An estimated 23 percent of the core fill was lost during construction.

A smaller eroded area seems to exist along the south side of the island, tapering to about no change at the east end. Such behavior is consistent with the westerly and easterly areas.

On the north side, some deposition is indicated. This could also be a construction-period change, since most barges were unloaded by crane in this area and a thin blanket of rock protection was placed over the end of the pipeway here.

Figure 14. Subbottom Contours

To summarize, there have been detectable changes in the bottom sediments adjacent to the island. Although larger than anticipated during the design process, the changes are not a significant threat to the island at this time. A gravel blanket over the eroded areas adjacent to the island would probably reduce further erosion to a negligible rate.

8. Causeway Versus Wharf

a. Design Criteria - Because of the lack of a suitable commercial harbor close to the island, the savings in running production and utility lines ashore along a causeway rather than on the ocean floor, the convenient access of truck-mounted oil field equipment, and numerous other reasons, Richfield constructed an open causeway to the island instead of using marine transportation. Because traffic density requirements were light, the design aim was for maximum economy.

Most causeway piles are subjected to breaking waves. A probability study of storm damage resulted in the selection of a 25-foot-high, 12-second-period wave as maximum for design. Each bent was checked for wave forces at high and low tides, since either could control the design, depending on the vertical distribution of the load.

Span lengths of 40 feet with alternate single- and double-pile bents were selected from economic studies. The deck elevation of 35 feet above MLLW was judged adequate to keep the deck structure well above crests of the design waves. While 25 feet is not the highest possible wave at the site, its selection represents a calculated risk based on providing an economic life for the structure.

At the same time borings were made for the site investigation of the island, several additional borings were made from the *La Ciencia* along the probable alignment for a causeway. These borings indicated little overburden above the shale formation from about the 25-foot depth into shore. Subsequent fathometer runs over most of the proposed alignment established the bottom profile and revealed occasional rock outcrops out to a depth of 30 feet. Scuba inspection of some of these outcrops indicated they were similar to the onshore rock outcrops at Punta Gorda. Although a solid-fill causeway was considered for the shore section, an open causeway all the way to shore was selected instead so that there would be no effect on the normal littoral transport in this area.

The design vehicle load, which represented Richfield's forecast of the heaviest conventional oil field equipment they would require in their operations, was a tractor-trailer of about 34 tons gross. If heavier loads were required, they could be handled by barge shipment to the island wharf. Wave forces created the greatest lateral loads, but seismic forces based on 0.08g and wind loads of 30 pounds per square foot were also investigated in combination with other loads.

All piles were assumed to be fixed below the ocean bottom. The point of assumed fixity varied from 5 to 10 feet, depending upon the type of

material at the bottom and the amount of moment induced at the lower end of the pile by horizontal loads. The top supports of the single-pile bents were treated as elastic supports with their top reactions taken by the adjacent bents through the superstructure. For expansion, the cause-way was divided into three longitudinal sections. Battered-pile frames, set longitudinally, provide necessary support in the longitudinal direction.

Many sources were investigated for applicable drag coefficients. What appears to be a logical approach to the problem of waves breaking on piles with relatively small $\frac{D}{H}$ ratios was given by Reid and Bretschneider (1953).

Using the Berkeley-Monterey field data, which consisted of measurements of moments on piles subjected to breaking or near-breaking waves, the drag coefficient was obtained from the relation,

$$C_D = \frac{M}{\frac{W}{2g} D H^2 K_{Dm} S_{D/d} d} ,$$

where

C_D = drag coefficient,

M = measured moment at ocean bottom on cantilever pile,

w = unit weight of water,

D = diameter of pile,

H = wave height,

K_{Dm} = maximum value of wave force factor for drag effect of pile applicable to nearly breaking waves,

S_D = vertical position of action of total drag force on pile above ocean bottom,

d = stillwater depth

Total forces and their centers of gravity were computed. The forces were ten distributed along the pile. Instead of using a smooth curve for this dynamic force distribution, the loading was simplified to an equivalent straight line distribution which gave the same or slightly higher results.

The basic uncertainty in the correct value of the drag coefficient and the fact that pile-frame analysis using the more refined smooth curves for

dynamic force distribution is cumbersome were deciding factors in selecting the simplified loading diagrams.

b. Causeway Construction Procedures - The bid documents provided for five optional combinations of steel pipe or prestressed concrete piles with steel or concrete caps, steel stringers and timber deck, or 40-foot prestressed concrete slabs. Pile emplacement alternates were driving, driving and jetting, or drilling and grouting in the shale rock. It was presumed that driving might be practical for the steel pipe pile alternate, but that drilling and grouting would be required for concrete piles near shore.

The low bid submitted was for steel piles, steel caps and stringers, and timber deck. Before final award of the contract, two test piles were driven into rock on shore to determine whether or not it would be necessary to drill and grout the steel pipe piles. The 16-inch-diameter test piles with 0.5-inch-thick walls were successfully driven with a heavy drop hammer. As a result of these tests, the option of driving the steel piles was selected; a lump sum contract was awarded on that basis.

The contractor's construction plan was to build a temporary work trestle of his own design from which the piles for the causeway were driven by a heavy drop hammer handled by a small crawler crane. Stringer assemblies were shop-fabricated and placed by a truck crane operating on the work trestle. The cap connection to the piles consists of a stiffened connection plate welded to the bottom flange of the cap, which fits into vertical transverse slots in the piles as shown in Figure 15. The work trestle afforded ready access for aligning the piles and cutting the slots, and thus made the erection work a simple operation. Construction of the work trestle paced the causeway erection work.

Specified pile penetration for the typical single-pile and double-pile, transverse-battered bents was 8 feet into the shale formation or a minimum penetration of 20 feet into other materials and a driving resistance giving not less than 45-ton safe load by use of the Engineering News Record (ENR) pile driving formula. Required penetration for the four longitudinally-battered bents was 50 percent greater. Pile dimensions ranged from 16-inch diameter, 0.375-inch wall at the shore end to 24-inch diameter, 0.563-inch wall for the deepwater longitudinally-battered bents. All piling was sandblasted and coated with coal tar enamel. The expansion joints are semi-insulated for a cathodic protection system. Concrete pipe sleeves were installed at the bottom line on the first nine nearshore bents as a precaution against sand abrasion.

Work on the causeway started in November 1957; the first vehicles crossed in July 1958. The 26 January 1958 storm caused about 1 month's delay by knocking over about 750 feet of the contractor's temporary work trestle. Only the onshore abutment of the causeway had been completed at this time.

Figure 15. Causeway Pile Cap Details

The great convenience of access and supply provided by the causeway has resulted in very little use of the wharf. A minor exception is that following the 1968 Santa Barbara oil spill, the wharf was used by small boats engaged in clean-up operations. This alternative to supplying clean-up boats at Santa Barbara or Ventura resulted in a considerable savings in time during these operations.

9. Ecological Effects

a. Study Procedure - Although Rincon Island was constructed for other purposes, it was anticipated that the construction of armor revetments on the island faces would furnish desirable habitats for marine organisms, and thereby favorably alter the environment for marine biota in the area. A study of this topic conducted by William L. Brisby, Professor of Marine Biology at Moorpark College, Moorpark, California, was undertaken for this report. Professor Brisby is particularly qualified for this study because of his personal knowledge of the marine environment prior to the island's construction, and because he has been conducting detailed field studies of the same environment during the postconstruction period, using the island as a field station.

Brisby's study consisted of observing and identifying marine organisms on and near the island. The observation program was adjusted to accommodate two major problems. The solution to the first of these, the obvious difficulty posed by observation of an underwater environment, was the use of scuba gear. Brisby estimates that 85 to 90 percent of all observations were made using scuba. Most observations were conducted using the island as a base. When it was not feasible to proceed with the scuba technique, surface craft and mechanical collecting gear were used, including Peterson grabs (a small clamshell), dredges, trawls, fishing gear, and traps.

The second major impediment to the observation program was the frequent underwater turbidity caused when fine-grained bottom sediments were stirred by waves or currents. Visibility is severely restricted under these conditions. Underwater lighting was tried, but was of little or no help. The solution was to schedule observations for those times when the area had been sufficiently calm long enough to allow most of the fine materials to settle out. Brisby notes that turbulence tends to keep some of this material in suspension, limiting average visibility to 1 to 2 feet at the bottom and to about 8 feet at the surface.

In addition to visual observation and identification, Brisby used underwater color photography. The camera used was a Nikonos 2 with Ektachrome film and flash lighting.

b. Preconstruction Conditions - Brisby notes that prior to the island's construction, the area supported only a sparse population of marine organisms. This is generally attributable to the presence of a soft, fine-grained bottom which to a large extent excluded reef-dwelling organisms and also provided no means of attachment for sessile or base-attached organisms. No organized study of the biological population of the area was

made before the island's construction, but Brisby estimates from personal observations and from discussions with others that the population was restricted to: coelenterates (i.e., the radially symmetrical invertebrate animals such as corals, sea anemones, jellyfish, and hydroids); crustaceans, primarily crabs; and echinoderms, such as starfish. Occasional growths of giant kelp were also seen in the area. The fish population included migratory sport fish, silversides, and turbot. California gray whales, sea lions, and harbor seals passed through the area, and there was also a substantial transient movement of birds characteristic of the coastal environment.

c. Postconstruction Biota - Brisby's assessment of the greatly-increased present biological population of the island area is set forth in detail in his report, attached as an Appendix. It is summarized here.

Brisby has identified 27 species of algae including all three major types (red, brown, and green). These are primarily restricted to the region above the 30-foot depth, and the greatest variety is found in the upper 10 feet. The larger stands of algae are destroyed by winter storms but a rapid regrowth occurs in late spring and summer. The algae provide both a food supply and a habitat for many of the marine organisms. Brisby lists 10 major Phyla of fauna:

1. Porifera. Over 24 species of sponges have been observed, of which 14 have been identified.

2. Coelenterates. These form one of the most diverse groups of organisms on the island. At least 19 species have been identified, and possibly others might be found in the deeper recesses of the armor rock surface.

3. Platyhelminthes. The flatworms are present in large numbers. Brisby has tentatively identified four species.

4. Nemertea. Several ribbon worms have been observed, but none has yet been identified as to species.

5. Annelida. These worms are common, generally large, and therefore comparatively easy to classify. There are probably many more species present than the 10 which have been identified.

6. Arthropoda. Arthropods, the invertebrate animals with articulate body and limbs (crabs, barnacles, lobsters, and shrimp) are present in abundance and diversity. Brisby lists 21 species that have been identified. He also notes that their presence in such numbers indicates that oil spills and contamination are not occurring at the island, since these animals are particularly sensitive to hydrocarbons.

7. Mollusks. Brisby notes that of the fauna, the mollusks have experienced probably the greatest increase in numbers. He identifies 61 species, representing four classes of mollusks, with gastropods and

bivalves being most numerous. The California Department of Fish and Game planted some abalone, but all other groups of animals have been introduced through natural means.

8. Bryozoa. Of these marine invertebrates, which characteristically form branched or mossy colonies, eight species have been identified. They occur as encrusting forms with delicate structures, growing on hard surfaces such as rocks or shells.

9. Echinodermata. Brisby notes that the echinoderms are one of the most noticeable forms of life generally found in the intertidal zone. Of the five major classes, four are represented at Rincon Island, and of these, 15 species have been identified.

10. Chordata. These include the numerous kinds of fishes, birds, and marine animals. Brisby lists five classes of chordates: the tunicates or sea squirts; the chondrichthyes which include sharks and rays; the osteichthyes, including the many kinds of fish; the aves or birds; and the mammals. A total of 118 species of chordata have been identified.

c. Biological Impact - In his assessment of the biological impact of the island, Brisby notes that with its construction a new environment was established with a great number of hard surfaces for the attachment of various organisms. The placement of the large slabs of quarry rock and tetrapods added positive components to the environment by providing crevices and caves into which various animals could retreat for protection from both currents and predators. The sand-silt bottom has an effect upon the island, however, as turbid currents continually carry the benthic sediments up onto the rock revetments to a height of about 6 to 10 feet.

The position of the island, one-half-mile offshore, also allows a varied environment in respect to exposure to the open ocean waves and currents. This in turn provides for an environment which exposed zonation, protected zonation, and intermediate stages, making possible a greater diversity of life than is usually found in an area of this size. Nearly all forms of life found on the offshore Channel Islands now exist on and around Rincon Island. Of great importance in maintaining this diversity is the fact that the island is closed to the general public and the various organisms are given an opportunity to grow and develop undisturbed.

The seaward side of the island is particularly rich in life. A rather extensive kelp bed has developed, and the more than 1,000 tetrapods have provided an optimum environment for the reproduction and rearing of numerous organisms, especially many pelagic forms. The kelp bed on this part of the island becomes quite luxuriant in the summer. Mussel beds, several feet thick, have developed on the tetrapods with the myriad population of organisms associated with these beds. The primary fish forms resident in this section are the perches and blennies. This is also a primary roosting ground for marine birds, with temporary populations of several hundred brown pelicans, cormorants, and gulls observed regularly.

The landward side of the island, on the other hand, which is not as open to ocean waves and currents as it is to be "backwash" or eddies that come around the island, has a larger amount of life than might be expected in an area with somewhat excessive water turbidity. Small kelp beds develop here in the summer months, and the presence of great numbers of small fish testifies to the value of an area protected from the assaults of the open ocean.

The other two sides provide an intermediate environment and each, because of the difference in exposure to the prevailing currents and waves, has a somewhat different ecology. The north side has a great variety of marine algae near the surface and contains the largest gorgonian coral formations around the island, one of which is over 50 feet long and 20 feet wide. The side of the island with the more southerly exposure has the least amount of algae growth, but the large population of sea urchins here may be contributing factor to this lack of foliate algae. Gastropods are the predominant form of invertebrate life on this side, with a fairly well-developed and varied bivalve population also present.

The three seaward sides of the island have a "talus slope" of mussel and bivalve shells detached by wave action which in some areas extends 15 feet above the toe of the rock slope. This formation is important in helping to keep down sediments and in providing small shelter areas for nudibranchs, gobies, and various marine worms. While the landward side has a small footing of this type, it is probably not so prominent because of the lack of large mussel beds and the destruction and dispersing of the mussel beds by wave action on the other three sides.

In summarizing the impact of the island, Brisby states that the construction of Rincon Island has encouraged the development of a mature and balanced reef out of an area which might well have been previously considered a biological desert. The total number of species present before construction probably numbered no more than 25 to 30 (by count only 14 species were observed), and now, after construction has been completed and sufficient time has elapsed for a climax community to be established, 298 species have been recorded, representing all of the major marine phyla, and there probably are more present.

Two major advantages have made possible this climax marine community: (1) the establishment of a substrate conducive to the attachment of various marine forms, and (2) the island's position one-half mile off the coast, which has allowed the relatively undisturbed growth of marine organisms. Brisby notes that Rincon Island has demonstrated the potential that an offshore structure can have in establishing biological communities with diverse and sometimes rare forms of life. Such a structure can be used to study various marine forms and to provide seeding ground for the distribution of these forms to adjacent areas.

10. Aesthetic Effects

Richfield has incurred high costs in establishing palm trees and shrubbery on the island. All topsoil for the trees and shrubbery was

imported and is contained in concrete planting boxes built on top of the rock revetment.

Normally the island is closed to the public and access is only granted to authorized visitors. In 1971, however, an open house was observed, and visitors were allowed access to it, having to walk the 2,700-foot causeway to and from the island. Nevertheless, about 1,500 people were interested enough to make the walk. The visiting group was of course biased, in that they had enough initial interest to make the visit, and their reaction to the island was reported as being universally favorable.

The effectiveness of the owner's efforts to provide an aesthetically pleasing appearance was not determined in a rigorous manner, and so this discussion of the subject is somewhat general in nature. The neighborhood response to the island's presence is judged to be satisfactory. Two distinct neighborhoods are considered: Santa Barbara and Ventura.

In the Santa Barbara area, response to the island can be considered favorable only in a negative way. That is, it has not noticeably contributed to the prevailing general opinion that all offshore developments in the Santa Barbara Channel are bad. To a large extent this may be because the island is in Ventura County rather than Santa Barbara County. The Ventura area was an oil-producing area long before the island was built, and general public opposition to offshore oil developments has not developed here as it has in Santa Barbara.

11. Precast Armor Versus Quarry Rock

Relative economy is always dependent on a specific site and an available construction plant. For Rincon Island, two factors prevailed and made precast armor units more economical:

(1) The quarry site required a haul over public roads, and the Class A quarry rock would have greatly exceeded legal highway loads. Although such loads can be hauled over public roads, haul costs are much greater than for legal loads.

(2) The contractor had available a construction plant which could handle and place the Class A precast armor, but would have had to rent or acquire heavier equipment to handle the heavier Class A quarry rock.

12. Construction Methods

The contractor's construction methods were basically sound, and the following discussion is in no sense an attempt to question the wisdom of his choices.

An initial choice of construction technique, especially because an onshore quarry was used, was whether to use a floating construction plant, or whether to build with shore-based equipment from a work trestle. The owner's initial decision not to include a permanent causeway was

undoubtedly a strong factor in the contractor's decision to use a floating plant. If the causeway had been included in the original bid package the work trestle approach would have been a more attractive alternate. Such a method greatly reduces both investment and operating costs of the required construction plant, and greatly reduces rehandling of materials. Such savings, of course, are balanced to some degree by the expense of building the required temporary trestles.

The construction methods used for the island would in general be equally appropriate today, with the minor exception of survey control methods. Laser beams for position lines and an electronic positioning system for spot location would probably be used in place of the wood dolphins and survey tower.

As mentioned in the discussion of seismic considerations, compaction of the submerged core fill would probably be an additional contract requirement. Submerged vibratory equipment of some type would be the most economical method of fulfilling such a requirement.

13. Island and Causeway Maintenance

Maintenance requirements for the basic island structure have been nominal to date. Assuming that the wave predictions were accurate and the revetment design exact, some wave damage to the west face armor rock should have occurred. However, the lack of damage to the west face armor to date is insufficient proof that the wave predictions or design are overly conservative.

The east wings were not designed to be stable against waves much higher than 12 feet. No direct measurement of the degree of wave attenuation was made, but design assumptions based on qualitative data from the model studies indicated damage could be expected from westerly waves about 20 feet high, which would be somewhat attenuated before they reached the east wings. Again, the lack of wave damage to armor rock on the easterly wings is not an adequate criterion for establishing maximum wave heights at the island to date, since the individual weights of armor rock actually placed were considerably higher than the specified minimum weights used for the design.

Based on discussions with operating personnel, it is believed that maximum wave heights to date are about 20 feet. Topsoil in some of the concrete planter boxes on top of the east wing has been lost, and one of these boxes has a 0.5-inch crack, indicating some minor shifting of cap rock on the southeast wing.

Causeway maintenance has been slight. The most troublesome item has been painting of the steel on the abutment span. The causeway profile was designed to keep the deck structure clear of wave crests, but keeping the shore end high enough to also avoid most of the spray from the abutment fill would have been desirable.

The untreated timber decking shows considerable deterioration, and a deck timber replacement program is currently in progress.

The cathodic protection system installed by Richfield is working well, and the steel piles are in good condition, even though marine life has stripped some of the coal tar enamel at the bottom line.

The concrete abutment cap, the only concrete in the causeway contract, has become an example of the need for good concrete specifications and their rigid enforcement in a marine environment. Concrete specifications for the island contract and the causeway contract were similar. Concrete testing for the causeway was infrequent, since so little work was involved; the island concrete was carefully controlled. The cause way abutment concrete now shows considerable crazing typical of alkali-aggregate reactivity; all concrete placed on the island is in excellent condition.

14. Seismic Evaluation

Earthquake safety was a critical consideration during the design. It was recognized that damage to the island from seismic events could result from four causes: slope failure of the revetments, liquefaction of the sand core, flooding of the island from earthquake-generated tsunamis, or area subsidence due to tectonic fault movement.

The slope stability of the island revetments required for resistance to wave action was judged adequate against slope failure from earthquakes.

Liquefaction of the sand core was difficult to evaluate because liquefaction risk and phenomena were not then so well recognized as today. Although compaction of the sand would have essentially eliminated the risk of liquefaction, the cost of compacting the underwater part of the core fill would have added about 10 percent to the estimated island cost, so the final design called for high compaction of only the part of the core above water.

The possibilities of tsunamis and area subsidence from earthquakes are related -- both phenomena are usually generated by vertical block movements during fault-associated earthquakes. The Santa Barbara Channel area has not shown the susceptibility to damage from distant tsunamis that a few critical areas show, so the prime concern was for locally generated tsunamis. Recent San Andreas and most California fault movements have been primarily horizontal rather than vertical and the probability of a large locally generated tsunami appears very low. Placing the island work level about 10 feet above the mean higher high water level was primarily based on wave action requirements, but this was also considered reasonable protection against tsunamis or sudden area subsidence from earthquakes.

As part of a current seismic evaluation of the island, the seismicity of the area was studied. Figure 16 shows all earthquake epicenters within 100 miles of the island above magnitude 4.5 that occurred in the 42 years from 1930 to 1972. Also noted are the most recent earthquake felt at the

island, which occurred on 21 February 1973, had a magnitude of 5.7, and was located near Oxnard about 31 miles from the island, and the closest earthquake to the island since its construction, which occurred on 14 July 1958, had a magnitude of 4.7, and was 2.8 miles west. Because both these events were felt at the island, they were of special interest. Careful examination of the island immediately after each quake revealed no detectable damage. Each examination also included a recheck of the level check points on the island.

A current estimate of the island's threshold of damage from liquefaction of the core is that damage would occur from a magnitude 6.5 earthquake within 10 miles of the island, a magnitude 7.0 earthquake within 20 miles of the island, or a magnitude 8.0 earthquake within 80 miles of the island. Figure 16 shows the three fault systems of primary concern to the island. Because of the correlation between California earthquakes and the length of the associated fault system, earthquakes on the Santa Inez or Malibu faults would not exceed a magnitude of 7.0 to 7.5, and the nearest earthquakes of greater magnitude will not occur closer than the longer San Andreas fault, about 45 miles away from the island. Using the same data plotted in Figure 16, it is estimated that there is a 3 percent probability in a 50-year period that an earthquake within 10 miles of the island will have a magnitude of 6.5, a 5 percent probability in a 50-year period that an earthquake within 20 to 30 miles of the island will have a magnitude of 7.0 to 7.5, and a 3 percent probability in a 50-year period that an earthquake within 45 to 80 miles of the island will have a magnitude greater than 8.0. Combining these probabilities indicates an 11 percent chance of an earthquake causing some liquefaction of the island's core within a 50-year period.

The island's construction of rock rings containing a sand core makes a prediction of the damage resulting from liquefaction of the core a difficult problem. Uneven settlements of the island work surface are the most likely result of core liquefaction, but a maximum possible earthquake on the San Andreas fault at its closest location to the island could cause more serious damage by inducing partial collapse of the upper part of the revetment.

Earthquake engineering is a rapidly improving technology. Design of a similar island today would include a more refined analysis of the core liquefaction problem, and would probably specify either vibratory compaction of the underwater position of the core fill or a single height ring of rock which would remain stable irrespective of core liquefaction, thus ensuring reduced damage should this occur.

III. RECOMMENDED ADDITIONAL DATA COLLECTION

1. Wave Gages

The design of Rincon Island was influenced both by considerations of the probable effect of the environment on the island and the probable impact of the island on the environment. One major environmental influence was

Figure 16. Rincon Island Seismic Evaluation. Earthquake epicenter map of southern California

that of wave exposure, which strongly affected the design of the island revetment and causeway, and the plan shape of the island. The tetrapods and armor rock were such significant contributors to the total cost that wave exposure became a predominant design factor, justifying a detailed evaluation of the economies of various possible design wave heights.

A comparison of design assumptions to actual performance should be based on wave exposure data. Because direct measurements of such data are available, the evaluation has been made on indirect evidence, qualitative in nature, and consequently unsatisfactory for a rigorous evaluation.

Wave gages are needed to obtain the necessary quantitative information on actual wave exposure. Three basic gage types are presently available: the surface-mounted staff gage, the pressure-sensitive gage which is mounted on the bottom, and wave-rider buoys with telemetry systems. Examples of the first two types are described by Williams (1969). If the pressure-sensitive bottom gage can be used in water depths of about 45 feet, then a desirable installation would consist of a set of three such gages mounted in a triangular configuration at a depth of about 45 feet southeast of the island, but far enough from it to eliminate any significant reflection or refraction influences. This installation would monitor the principal sector of wave exposure: from the southeast to the west.

If bottom-mounted pressure gages cannot be used in more than 30 feet of water, as Williams advises, then the installation should be moved to a location due north of the island. At this location the principal exposure of maximum wave attack from the west would still be monitored. Waves from the south would be influenced by refraction and diffraction on reaching this location, and would therefore not be characteristic of the unaffected exposure of the island to the south.

In addition to either of these monitoring systems, it would be desirable to mount a recording staff gage on a causeway pile at about midlength along the causeway. From this location the westerly wave exposure could be adequately monitored, and the data used both to substantiate that from the bottom gages and to provide information on the smaller, sharper waves which are attenuated by pressure gages.

2. Sediment Gages

One major consideration of the impact of the island on its environment is the effect on littoral transport. The influence of the island on waves and currents might have had serious consequences with respect to sedimentation or erosion in the coastal vicinity. However, it was generally concluded that any such effects would not be serious, and the comparison of aerial photos and sounding surveys substantiate that conclusion. However, sufficiently accurate quantitative data are not available to determine the precise effect of the island on these processes. The island's effect on nearby bottom sediments appears to warrant further study. A suggested technique would be to install a network of thin calibrated reference rods in the ocean floor adjacent to the island where the

comparison of the sounding surveys indicated erosion or accretion. Installation by scuba divers would include a reference mark or measurement to record the bottom elevations at each reference mark. Subsequent checks would give a relatively precise measurement of elevation changes, thereby providing reliable data concerning the pattern and rates of erosion and accretion of bottom sediments in the vicinity of the island.

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APPENDIX

THE BIOTA OF RINCON ISLAND

by

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I. PRECONSTRUCTION BIOTA

Rincon Island was constructed on a sand-silt substrate with relatively little biota present. These soft sediments eliminated, to a large extent, those organisms which are commonly found in reef areas and, except for a few exposed rocks, provided no basis for attachment of sessile organisms.

The in- and epi-fauna consisted primarily of coelenterates such as *Stylatula elongata*, *Ceriantheopsis* sp., and *Pachycerianthus* sp., crustaceans of the genus *Cancer*, and echinoderms, primarily *Astropecten armatus*, *Patiria miniata*, and *Parastichopus* sp. Occasional growths of *Macrocystis* sp. came to the surface from the few rock outcroppings on the bottom.

The pelagic organisms were mostly transients, with the exception of silversides and turbot which might be considered resident forms. Transient vertebrates included many of the migratory sportfish and the three major mammals, *Zalophus californianus*, *Phoca vitulina*, and *Eschrichtius glaucus*.

The information on the biota of the area before construction is not complete as no organized study of this parameter was undertaken. The information in this report is from personal observation and from discussions with sportsmen and the California Department of Fish and Game. Undoubtedly there were other forms of life present that are not listed here, but the area can be called a "biological desert" and the listing here simply is to indicate this sparsity of life.

II. POSTCONSTRUCTION BIOTA

With the construction of Rincon Island a new environment was established with a great number of hard surfaces for the attachment of various organisms. The placement of the large slabs of quarry rock and tetrapods provided additional positive components to the environment by providing crevices and caves into which various animals could retreat for protection from both current and enemies. The sand-silt bottom still has an effect upon the island, however, as the turbidity currents continually carry the benthic sediments up onto the base structure to a height of approximately

6 to 10 feet. This silting prevents attachment of many organisms on the footing and also causes turbidity in the water which limits visibility to an average of approximately 8 feet at the surface and 1 to 2 feet at the bottom.

The position of the island one-half mile off the coast also allows a varied environment in respect to exposure to the open ocean waves and currents. This in turn provides for an environment which has exposed zonation, protected zonation, and stages in between, making possible a greater diversity of life than is usually found in an area of this size. Nearly all of the forms of life found on the offshore Channel Islands now exist on and around Rincon Island. Of great importance in maintaining this diversity of life is that the island is closed to the general public and thus gives the various organisms an opportunity to grow and develop undisturbed.

The seaward side of the island is particularly rich in life. A rather extensive kelp bed has developed and the more than 1000 tetrapods have provided an optimum environment for the reproduction and rearing of numerous organisms, especially many pelagic forms. The kelp bed on this part of the island becomes quite luxuriant in the summers with both *Egregia* sp. and *Macrocystis* sp. predominating. Mussel beds several feet thick have developed on the tetrapods with the myriad populations of organisms which are associated with these beds. The primary fish forms that are resident in this section are the perches and blennies. This is also the primary roosting ground for the marine birds where temporary populations of several hundred brown pelicans, cormorants, and gulls are regularly observed.

The landward side of the island, while not as open to the general ocean waves and currents but rather in the "backwash" or eddies that come around the island, has a larger amount of life than might be expected in an area with high water turbidity. Small kelp beds develop here in the summer months and the great number of small fish found here testify to the value of an area protected from the assaults of the open ocean on these small developing forms.

The other two sides provide an intermediate environment and each, because of the difference in exposure to the prevailing currents and waves, has a somewhat different ecology. The north side of the island has a great variety of marine algae near the surface and contains the largest gorgonian coral formations around the island. One of these, primarily composed of *Muricea* sp., is over 50 feet long by 20 feet wide. The side of the island with the more southerly exposure has the least amount of algal growth, but the large population of sea urchins may be a contributing factor to this lack of foliate algae. Gastropods are the predominant form of invertebrate life on this side. A fairly well-developed and varied bivalve population is also present.

The three seaward sides of the island have a "talus slope" of mussel and bivalve shells which in some areas extends 15 feet above the toe of the rock slope. This formation is important in helping to keep down the sediments and in providing small shelter areas for nudibranchs, gobies,

and various marine worms. While the landward side has a small footing of this type, it is probably not so prominent because of the lack of large mussel beds and also the lack of general storm action which may be in a large way responsible for the destruction and dispersing of the mussel beds on the other three sides.

III. THE FLORA

While all three types (red, brown and green) of algae are found around the island, they are primarily restricted to the top few feet. Practically no algae exist below 30 feet except toward the end of the summer, probably due primarily to the silting and turbidity at greater depths. In the winter the local storms destroy most of the larger stands of algae but in late spring and summer there is a tremendous growth taking place, with measurements of as much as 1 foot being recorded in a 24-hour period.

The greatest variety of algae occurs in the top 10 feet. Much of the algae in this region of the water column shows the effect of being grazed upon by a wide variety of organisms. This variety of plant life also provides an excellent habitat for many of the smaller invertebrates and is thus an indication of a balanced reef community.

Table 1. Algae Observed at Rincon Island

Division	Scientific Name
Chlorophyta	<i>Bryopsis corticulans</i> Setchell
	<i>Chaetomorpha aerea</i> Kützting
	<i>Cladophora trichotoma</i> Kützting
	<i>Codium fragile</i> (Suringar)
	<i>Enteromorpha intestinalis</i> (Linnaeus)
	<i>Ulva angusta</i> Setchell and Gardner
	<i>Ulva californica</i> Dawson
Rhodophyta	<i>Bossiella</i> sp.
	<i>Callithamnion</i> sp.
	<i>Corallina</i> sp.
	<i>Gigartina canaliculata</i> Harvey
	<i>Gigartina spinosa</i> (Kützting)
	<i>Hildenbrandia prototypus</i> Nardo
	<i>Lithothrix aspergillum</i> Gray
	<i>Polysiphonia paniculata</i> Dawson
	<i>Porphyra perforata</i> Agardh
	<i>Prionitis lanceolata</i> Harvey
	<i>Rhodymenia pacifica</i> Kylin

Table 1. Algae Observed at Rincon Island-Continued

Division	Scientific Name
Phaeophyta	<i>Cystoseira osmundacea</i> (Menzies)
	<i>Desmarestia herbaceae</i> Lamouroux
	<i>Ectocarpus</i> sp.
	<i>Egregia laevigata</i> Setchell
	<i>Halidrys dioica</i> Gardner
	<i>Macrocystis pyrifera</i> (Linnaeus)
	<i>Pterospongia rugosum</i> Dawson
	<i>Pterygophora californica</i> Ruprecht
	<i>Ralfsia</i> sp.

IV. THE FAUNA

The number and kinds of animals found on and around Rincon Island is as varied and numerous per given area as can be found in any of the more distant offshore Channel Islands. The following discussion is not meant to be conclusive, but simply to list the major species of animals seen at the island in the 16 years since construction was initiated.

Porifera: Over 24 species of sponges have been observed on the island, but only 14 have been identified. Sponges range from the tiny and simple ascon type to the large and quite complicated leuconoid type. Many of the sponges form thin colorful splashes on the rocks while others get to be quite large and easily recognized. These animals provide food, shelter, and camouflage for many other larger animals.

The following sponges have been identified at Rincon Island:

Table 2. Sponges at Rincon Island

Common Name	Scientific Name
Geode sponge	<i>Geodia mesotriaenia</i> Lendenfeld
Lavender sponge	<i>Halichoclona gellindra</i> de Laubenfels
Lavender-blue encrusting sponge	<i>Haliclona ecbasis</i> de Laubenfels
Leaf sponge	<i>Hymeniacidon sinapium</i> de Laubenfels
Little Leaf sponge	<i>Hymeniacidon ungodon</i> de Laubenfels
White sponge	<i>Leucetta losangelensis</i> (de Laubenfels)
Cream sponge	<i>Leucetta</i> sp.
Thistle sponge	<i>Leuconia heathi</i> (Urban)
Finger sponge	<i>Leucosolenia</i> sp.
Noxious sponge	<i>Lissodendoryx noxiosa</i> de Laubenfels
Urn sponge	<i>Rhabdodermella nuttingi</i> Urban
Liver sponge	<i>Spheciospongia confederata</i> de Laubenfels
Orange puff-ball sponge	<i>Tethya aurantia</i> (Pallas)
Sulfur sponge	<i>Verongia thiona</i> de Laubenfels

Coelenterata and Ctenophora: One of the most diverse groups of organisms on the island are the coelenterates. Before the island was constructed there were only two species resident, with one or two jellyfish being transient. Now there are at least 19 species and possibly more that are hidden in some of the clefts and caves formed by the quarried rock. All three classes of coelenterates are represented with the anthozoa being the predominant form.

While the turbidity of the water has a rather definite effect upon most of the organisms found around the island, it seems to have a minimum effect upon some of the coelenterates. The burrowing anemones, such as *Ceriantheopsis* sp. and *Pachycerianthus* sp. were established long before the island was constructed, as well as the sea pen *Stylatula* sp. These animals are still abundant around the island and have now been joined on small rock outcroppings by the various kinds of Gorgonian coral. Turbidity appears to have some effect, as the greatest number of both species and individuals is found in the top 20 feet of the island reef.

The following is a listing of the coelenterates and ctenophores observed at the island:

Table 3. Coelenterates and Ctenophores at Rincon Island

Common Name	Scientific Name
<u>Coelenterata:</u>	
Ostrich plumed hydroid	<i>Aglaophenia</i> sp.
Elegant anemone	<i>Anthopleura elegantissima</i> (Brandt)
Green anemone	<i>Anthopleura xanthogrammica</i> (Brandt)
Campanulate hydrozoan	<i>Campanularia</i> sp.
Burrowing anemone	<i>Cerianthiopsis</i> sp.
Pink colonial anemone	<i>Corynactis californica</i> Carlgren
Prolific anemone	<i>Epiactis prolifera</i> Verrill
Purple sea fan	<i>Eugorgia rubens</i> Verrill
Pink gorgonian	<i>Lophogorgia chilensis</i> Verrill
Solitary anemone	<i>Metridium</i> sp.
California gorgonian	<i>Muricea californica</i> Auriveillius
Rust gorgonia	<i>Muricea fruticosa</i> Verrill
	<i>Obelia</i> sp.
Tube anemone	<i>Pachycerianthus</i> sp.
Stony coral	<i>Paracyathus</i> sp.
Purple striped jellyfish	<i>Pelagia panopyra</i> (Peron and Lesueur)
Sea pansy	<i>Renilla kyllikeri</i> Pfeffer
Elongate sea pen	<i>Stylatula elongata</i> (Gabb)
Purple sailor	<i>Velella lata</i> Chamisso and Eysenhardt
<u>Ctenophora:</u>	
Comb jellies	<i>Pleurobrachia bachei</i> Agassiz

Platyhelminthes: While flatworms are present, probably in large numbers, their identification is difficult. The author has observed at least three species in working with the *Mytilus* communities. If proper identification could have been made, possibly two specimens might have been representative of different species, making four species present.

Nemertea: Several ribbon worms have been observed around the island, but none have been identified.

Annelida: Annelid worms are probably the most common type of worm found in the ocean and this is also true at Rincon. Most of the annelids are larger and more easily classified, which explains the numbers that have been identified for this study. As in the case of the worms listed above, there are probably many more species present, but collecting and classifying them is not easily done. The following is a list of the annelids that have been cataloged:

Table 4. Annelids at Rincon Island

Common Name	Scientific Name
Parchment tube worm	<i>Chaetopterus variopedatus</i> (Renier)
Feather-duster worm	<i>Eudistylia polymorpha</i> (Johnson)
Nereid worm	<i>Eunereis longipes</i> Hartman
Scale worm	<i>Halosydna brevisetosa</i> Kinberg
Nereid worm	<i>Nereis eakini</i> Hartman
Nereid worm	<i>Nereis mediator</i> Chamberlin
Chrysopetalid worm	<i>Paleonotus bellis</i> (Johnson)
Colonial tube worm	<i>Salmacina tribranchiata</i> (Moore)
Serpulid worm	<i>Serpula vermicularis</i> Linnaeus
Serpulid worm	<i>Spirorbis</i> sp.

Arthropoda: Many arthropods are important to skin and scuba divers as game and to the fishery industry for commercial use. This is also true of the area around Rincon Island since the construction of the island has provided the necessary shelter and breeding area for the larger crustaceans. During the commercial season licensed fishermen place a large number of lobster pots around the island and take an average of 10 lobsters per day along with a number of cancer crabs.

Arthropods in general and crustaceans in particular are very sensitive to hydrocarbons. This sensitivity is important at Rincon Island as it provides a natural indicator for any type of oil seepage. The abundance and diversity of crustaceans would seem to indicate the success of the safeguards employed to eliminate spills and contamination on and around the island.

The following crustaceans have been collected at the island:

Table 5. Arthropods at Rincon Island

Common Name	Scientific Name
Acorn barnacle	<i>Balanus cariosus</i> (Pallas)
Acorn barnacle	<i>Balanus orenatus</i> Bruguière
Acorn barnacle	<i>Balanus glandula</i> Darwin
Acorn barnacle	<i>Balanus tintinnabulum</i> (Linnaeus)
Rock crab	<i>Cancer antennarius</i> Stimpson
Yellow crab	<i>Cancer anthonyi</i> Rathbun
Red crab	<i>Cancer productus</i> Randall
Pistol shrimp	<i>Crangon dentipes</i> (Guérin)
Red rock shrimp	<i>Hippolytina californica</i> Stimpson
Moss-covered crab	<i>Loxorhynchus crispatus</i> Stimpson
Sheep crab	<i>Loxorhynchus grandis</i> Stimpson
Spider crab	<i>Loxorhynchus</i> sp.
Goose barnacle	<i>Mitella polymerus</i> (Sowerby)
Striped shore crab	<i>Pachygrapsus crassipes</i> Randall
Hermit crab	<i>Paguristes turgidus</i> (Stimpson)
Shrimp	<i>Pandalus gurneyi</i> Stimpson
Spiny lobster	<i>Panulirus interruptus</i> (Randall)
Porcelain crab	<i>Petrolisthes cinctipes</i> Randall
Kelp crab	<i>Pugettia producta</i> (Randall)
Masking crab	<i>Seyra acutifrons</i> Dana
Bent-back shrimp	<i>Spirontocaris brevirostris</i> (Dana)

Mollusca: Possibly the greatest increase of numbers in any one phylum since the construction of the island is in the mollusks. The greatest biomass consists of the mussel beds in the upper littoral zone. Studies of samples taken from this area indicate that a cluster 10 inches in diameter contains an average of 2,600 individuals with 11 phyla represented. This indicates the fundamental part the mollusks play in the establishment of a mature, well-balanced reef community.

The 61 species present represent four classes of mollusks with the gastropods and bivalves being the most numerous forms. Many of these animals are sought by divers. The California Department of Fish and Game planted some of the more sought-after species of abalone, but within a year most of these had been collected by sport divers. This is the only group of animals to be artificially introduced to the island; all others have been introduced through larval forms being brought in by the normal ocean currents.

Table 6. Mollusks at Rincon Island

Common Name	Scientific Name
Spotted thorn drupe	<i>Acanthina spirata</i> (Blainville)
Rough limpet	<i>Acmaea scabra</i> (Gould)
Fingered limpet	<i>Acmaea digitalis</i> Eschscholtz
Shield limpet	<i>Acmaea pelta</i> Eschscholtz
Mask limpet	<i>Acmaea persona</i> Eschscholtz
Amphissa	<i>Amphissa</i> sp.
Sea hare	<i>Aplysia californica</i> Cooper
Sea hare	<i>Aplysia vaccaria</i> Wood
Light yellow sea slug	<i>Archidoris montereyensis</i> (Cooper)
Pansy sea slug	<i>Armina californica</i> (Cooper)
Wavy turban snail	<i>Astraea undosa</i> Wood
Red turban snail	<i>Astraea gibberosa</i> (Dillwyn)
Ship worm	<i>Bankia setacea</i> (Tryon)
Channeled top-shell	<i>Callistoma doliarium</i> Holten
Granulose top-shell	<i>Callistoma supragranosum</i> Carpenter
Wart-necked piddock	<i>Chaeca ovoidea</i> (Gould)
Agate chama	<i>Chama pellucida</i> Sowerby
Kelp scallop	<i>Chlamys latiaurata</i> (Conrad)
California cone	<i>Conus californicus</i> Hinds
Slipper limpet	<i>Crepidula</i> sp.
Chestnut cowry	<i>Cypraea spadicea</i> Gray
Yellow sea slug	<i>Dendrodoris fulva</i> (MacFarland)
Circle-spotted sea slug	<i>Diaulula sandiegensis</i> (Cooper)
Rough keyhole limpet	<i>Diodora aspera</i> (Eschscholtz)
Volcano limpet	<i>Fissurella volcano</i> (Reeve)
Purple sea slug	<i>Flabellina iodinea</i> (Cooper)
Sunset clam	<i>Gari californica</i> (Conrad)
Pink abalone	<i>Haliotis corrugata</i> Wood
Black abalone	<i>Haliotis cracherodii</i> Leach
Green abalone	<i>Haliotis fulgens</i> Philippi
Red abalone	<i>Haliotis rufescens</i> Swainson
Yellow-green sea slug	<i>Hermisenda crassicornis</i> (Eschscholtz)

Table 6. Mollusks at Rincon Island-Continued

Common Name	Scientific Name
Rough nestling clam	<i>Hiatella arctica</i> (Linnaeus)
Purple-hinged rock scallop	<i>Hinnites multirugosus</i> (Gale)
Blue-orange sea slug	<i>Hypselodoris californiensis</i> (Bergh)
Festive murex	<i>Jaton festivus</i> Hinds
Kellett's whelk	<i>Kelletia kelleti</i> Forbes
Nestling clam	<i>Kellia laperousii</i> (Deshayes)
Orange-white sea slug	<i>Laila cockerelli</i> MacFarland
File shell	<i>Lima hemphilli</i> Hertlein and Strong
Date mussel	<i>Lithophaga</i> sp.
Eroded periwinkle	<i>Littorina planaxis</i> Philippi
Checked periwinkle	<i>Littorina scutulata</i> Gould
Ida's miter	<i>Mitra idae</i> Melville
Keeled dove snail	<i>Mitrella carinata</i> (Hinds)
Mossy chiton	<i>Mopalia muscosa</i> (Gould)
California mussel	<i>Mytilus californianus</i> Conrad
Bay mussel	<i>Mytilus edulis</i> Linnaeus
Pink louse shell	<i>Neosimnia</i> sp.
Beaked piddock	<i>Nettastomella rostrata</i> Valenciennes
Smooth turban	<i>Norrisia norrisii</i> Sowerby
Poulson's dwarf triton	<i>Ocenebra poulsoni</i> Carpenter
Two-spot octopus	<i>Octopus bimaculatus</i> Verrill
Flap-tipped piddock	<i>Penitella penita</i> (Conrad)
Abalone jingle	<i>Pododesmus cepio</i> Gray
Reversed chama	<i>Pseudochama exogyra</i> (Gray)
Three-winged murex	<i>Pterynotus trialatus</i> Sowerby
Rock dwelling semele	<i>Semele rupicola</i> Dall
Scaled worm-snail	<i>Serpulorbis squamigerus</i> (Carpenter)
Gilded tegula	<i>Tegula aureotincta</i> Forbes
Brown tegula	<i>Tegula brunnea</i> (Phillipi)
Black turban snail	<i>Tegula funebris</i> (Adams)
Ship worm	<i>Teredo diegensis</i> Bartsch
Yellow-brown sea slug	<i>Triopha maculata</i> MacFarland

Bryozoa: While not a dominant form or even a readily observed form of life, the bryozoa are another type of indicator organism. These are usually encrusting forms with rather delicate structures found growing on rocky substrate, shells of organisms, and other hard surfaces.

Table 7. Bryozoans at Rincon Island

Common Name	Scientific Name
Moss animal	<i>Bugula</i> sp.
Moss animal	<i>Diaperoecia californica</i> (d'Orbigny)
Moss animal	<i>Membranipora membranacea</i> (Linnaeus)
Moss animal	<i>Membranipora savarti</i> (Audouin)
Moss animal	<i>Membranipora tuberculata</i> (Bose)
Lace moss animal	<i>Phidolopora pacifica</i> (Robertson)
Moss animal	<i>Smittina</i> sp.
Moss animal	<i>Thalamoporella californica</i> (Levinson)

Echinodermata: The echinoderms are one of the most noticeable forms of life on the island and a good cross-section of this phylum is now to be found in the intertidal zone. Four of the five major classes are represented. The class Asteroidea is more widely represented than any other, with seven species present. The following echinoderms have been collected at Rincon Island:

Table 8. Echinoderms at Rincon Island

Common Name	Scientific Name
Sand starfish	<i>Astropecten armatus</i> Gray
Sea cucumber	<i>Cucumaria</i> sp.
Leather star	<i>Dermasterias imbricata</i> (Grube)
Yellow sea cucumber	<i>Eupentacta quinquesemita</i> (Selenka)
Brittle star	<i>Ophiothrix spiculata</i> LeConte
Brittle star	<i>Ophiopteris papillosa</i> (Lyman)
Red-brown sea cucumber	<i>Parastichopus californicus</i> (Stimpson)
Sea cucumber	<i>Parastichopus parvimensis</i> (Clark)
Bat star	<i>Patiria miniata</i> (Brandt)
Short-spined starfish	<i>Pisaster brevispinus</i> (Stimpson)
Giant starfish	<i>Pisaster giganteus</i> (Stimpson)
Common starfish	<i>Pisaster ochraceus</i> (Brandt)
Sunburst starfish	<i>Solaster dawsoni</i> Verrill
Red sea urchin	<i>Strongylocentrotus franciscanus</i> (Agassiz)
Purple sea urchin	<i>Strongylocentrotus purpuratus</i> (Stimpson)

Chordata: This group of animals contains a diversity in size from the gray whale down to the tiny sea squirts and provides some of the more interesting forms around the island. The simple tunicates, the numerous kinds of fishes, birds, and marine mammals compose this phylum. The construction of this island has made possible the diversity of chordates now found in the area. This diversity of life again emphasizes the maturity of the reef and the ecological enhancement provided by this structure.

In listing those species of chordates which have been collected or observed around the island we have broken them down into classes to provide an easier understanding of the types of these organisms in this major phylum.

Table 9. Chordates at Rincon Island

Class	Common Name	Scientific Name
Tunicata	Simple sea squirt	<i>Boltenia villosa</i> Stimpson
	Simple sea squirt	<i>Chelyosoma productum</i> Stimpson
	Compound sea squirt	<i>Cystodytes lobatus</i> (Ritter)
	Simple sea squirt	<i>Styela montereyensis</i> (Dall)
Chondrichthyes	Swell shark	<i>Cephaloscyllium ventriosum</i> (Garman)
	Horn shark	<i>Heterodontus francisci</i> (Girard)
	Bat ray	<i>Myliobatus californica</i> (Gill)
	Blue shark	<i>Prionace glauca</i> (Linnaeus)
	Shovelnose guitarfish	<i>Rhinobatos productus</i> (Ayes)
	Smooth hammerhead shark	<i>Sphyrna zygaena</i> (Linnaeus)
	Spiny dogfish	<i>Squalus acanthias</i> (Linnaeus)
	Leopard shark	<i>Triakis semifasciata</i> Girard
	Round stingray	<i>Urolophus halleri</i> (Cooper)
Osteichthyes	Island kelpfish	<i>Alloclinus holderi</i> (Lauderbach)
	Barred surfperch	<i>Amphistichus argenteus</i> Agassiz
	Calico surfperch	<i>Amphistichus koelzi</i> (Hubbs)
	Sargo	<i>Anisotremus davidsoni</i> (Steindachner)
	Smoothhead sculpin	<i>Artedius lateralis</i> (Girard)
	Topsmelt	<i>Atherinops affinis</i> (Ayes)
	Jacksmelt	<i>Atherinopsis californiensis</i> Girard
	Kelp perch	<i>Brachyistius frenatus</i> Gill
	Black croaker	<i>Cheilotrema saturnum</i> (Girard)

Table 9. Chordates at Rincon Island-Continued

Class	Common Name	Scientific Name
Osteichthyes- Continued	Blacksmith	<i>Chromis punctipinnis</i> (Cooper)
	Pacific sanddab	<i>Citharichthys sordidus</i> (Girard)
	Mosshead sculpin	<i>Clinocottus globiceps</i> (Girard)
	Pacific herring	<i>Clupea harengus pallasii</i> Valenciennes
	Blackeye goby	<i>Coryphopterus nicholsi</i> (Bean)
	Shiner surfperch	<i>Cymatogaster aggregata</i> Gibbons
	White seabass	<i>Cynoscion nobilis</i> (Ayres)
	Striped seaperch	<i>Embiotoca lateralis</i> Agassiz
	Black surfperch	<i>Embiotoca jacksoni</i> Agassiz
	Northern anchovy	<i>Engraulis mordax</i> Girard
	Striped kelpfish	<i>Gibbonsia metzi</i> Hubbs
	Crevice kelpfish	<i>Gibbonsia montereyensis</i> Hubbs
	Opaleye	<i>Girella nigricans</i> (Ayres)
	California moray	<i>Gymnothorax mordax</i> (Ayres)
	Rock wrasse	<i>Halichoeres semicinctus</i> (Ayres)
	Giant kelpfish	<i>Heterostichus rostratus</i> (Girard)
	Walleye surfperch	<i>Hyperprosopon argenteum</i> Gibbons
	Silver surfperch	<i>Hyperprosopon ellipticum</i> (Gibbons)
	Rockpool blenny	<i>Hypsoblennius gilberti</i> (Jordan)
	Rainbow surfperch	<i>Hypsurus caryi</i> (Agassiz)
	Garibaldi	<i>Hypsypops rubicunda</i> (Girard)
	California grunion	<i>Leuresthes tenuis</i> (Ayres)
	Bluebanded goby	<i>Lynthrypnus dalli</i> (Gilbert)
	Halfmoon	<i>Medialuna californiensis</i> (Steindachner)
	Ocean sunfish	<i>Mola mola</i> (Linnaeus)
	Coho salmon	<i>Oncorhynchus kisutch</i> (Walbaum)
	Lingcod	<i>Ophiodon elongatus</i> Girard
	Señorita	<i>Oxyjulis californica</i> (Günther)
	Painted greenling	<i>Oxylebius pictus</i> Gill
	Kelp bass	<i>Paralabrax clathratus</i> (Girard)

Table 9. Chordates at Rincon Island-Continued

Class	Common Name	Scientific Name
Osteichthyes- Continued	Spotted sand bass	<i>Paralabrax maculato-fasciatus</i> (Steindachner)
	Barred sand bass	<i>Paralabrax nebulifer</i> (Girard)
	California halibut	<i>Paralichthys californicus</i> (Ayres)
	White surfperch	<i>Phanerodon furcatus</i> Girard
	California sheephead	<i>Pimelometopon pulchrum</i> (Ayres)
	Starry flounder	<i>Platichthys stellatus</i> (Pallas)
	Smooth ronquil	<i>Rathbunella hypoplecta</i> (Gilbert)
	Rubberlip surfperch	<i>Rhacochilus toxotes</i> Agassiz
	Pile perch	<i>Rhacochilus vacca</i> (Girard)
	Pacific sardine	<i>Sardinops sagax</i> (Jenyns)
	Chub mackerel	<i>Scomber japonicus</i> Houttuyn
	Monterey Spanish mackerel	<i>Scomberomorus concolor</i> (Lockington)
	California scorpionfish	<i>Scorpaena guttata</i> Girard
	Cabezon	<i>Scorpaenichthys marmoratus</i> (Ayres)
	Kelp rockfish	<i>Sebastes atrovirens</i> (Jordan and Gilbert)
	Brown rockfish	<i>Sebastes auriculatus</i> Girard
	Greenspotted rockfish	<i>Sebastes chlorostictus</i> (Jordan and Gilbert)
	Greenstriped rockfish	<i>Sebastes elongatus</i> Ayres
	Vermilion rockfish	<i>Sebastes miniatus</i> (Jordan and Gilbert)
	Blue rockfish	<i>Sebastes mystinus</i> (Jordan and Gilbert)
	Bocaccio	<i>Sebastes paucispinis</i> Ayres
	Grass rockfish	<i>Sebastes rastrelliger</i> (Jordan and Gilbert)
	Flag rockfish	<i>Sebastes rubrivinctus</i> (Jordan and Gilbert)
	Olive rockfish	<i>Sebastes serranoides</i> (Eigenmann and Eigenmann)
	Treefish	<i>Sebastes serriceps</i> (Jordan and Gilbert)
	Pacific barracuda	<i>Sphyræna argentea</i> Girard
	California tonguefish	<i>Symphurus atricauda</i> (Jordan and Gilbert)

Table 9. Chordates at Rincon Island-Continued

Class	Common Name	Scientific Name
Osteichthyes- Continued	Kelp pipefish	<i>Syngnathus californiensis</i> Storer
	Albacore	<i>Thunnus alalunga</i> (Bonnaterre)
	Jack mackerel	<i>Trachurus symmetricus</i> (Ayres)
Aves	Spotted Sandpiper	<i>Actitis macularia</i> (Linnaeus)
	Western Grebe	<i>Aechmophorus occidentalis</i> (Lawrence)
	Mallard	<i>Anas platyrhynchos</i> Linnaeus
	House Finch	<i>Carpodacus mexicanus</i> (Müller)
	Willet	<i>Catoptrophorus semipalmatus</i> (Gmelin)
	Wildeer	<i>Charadrius vociferus</i> Linnaeus
	American Coot	<i>Fulica americana</i> Gmelin
	Common Loon	<i>Gavia immer</i> (Brünnich)
	Red-throated Loon	<i>Gavia stellata</i> (Pontoppidan)
	Black Oystercatcher	<i>Haematopus bachmani</i> Audubon
	Herring Gull	<i>Larus argentatus</i> Pontoppidan
	California Gull	<i>Larus californicus</i> Lawrence
	Ring-billed Gull	<i>Larus delawarensis</i> Ord
	Heermann's Gull	<i>Larus heermanni</i> Cassin
	Western Gull	<i>Larus occidentalis</i> Audubon
	Bonaparte's Gull	<i>Larus philadelphia</i> (Ord)
	Marbled Godwit	<i>Limosa fedoa</i> (Linnaeus)
	Belted Kingfisher	<i>Megasceryle alcyon</i> (Linnaeus)
	Black Scoter	<i>Melanitta nigra</i> (Linnaeus)
	Surf Scoter	<i>Melanitta perspicillata</i> (Linnaeus)
	Common Merganser	<i>Mergus merganser</i> (Linnaeus)
	Long-billed Curlew	<i>Numenius americanus</i> Bechstein
	Whimbrel	<i>Numenius phaeopus</i> (Linnaeus)
	House Sparrow	<i>Passer domesticus</i> (Linnaeus)
	Brown Pelican	<i>Pelecanus occidentalis</i> Linnaeus

Table 9. Chordates at Rincon Island-Continued

Class	Common Name	Scientific Name
Aves - Continued	Double-crested Cormorant	<i>Phalacrocorax auritus</i> (Lesson)
	Pelagic Cormorant	<i>Phalacrocorax pelagicus</i> Pallas
	Brandt's Cormorant	<i>Phalacrocorax penicillatus</i> (Brandt)
	Eared Grebe	<i>Podiceps nigricollis</i> Brehm
	American Avocet	<i>Recurvirostra americana</i> Gmelin
	Starling	<i>Sturnus vulgaris</i> Linnaeus
	Common Murre	<i>Uria aalge</i> (Pontoppidan)
Mammalia	Gray whale	<i>Eschrichtius glaucus</i> (Cope)
	Steller sea lion	<i>Eumetopias jubatus</i> (Schreber)
	Harbor seal	<i>Phoca vitulina</i> (Linnaeus)
	California sea lion	<i>Zalophus californianus</i> (Lesson)

V. SUMMARY

The construction of Rincon Island has seen the development of a mature and balanced reef out of an area which might well have been considered to be a biological desert. The total number of species present before construction probably numbered no more than 25 to 30 species (by count only 14 species were observed). After construction was completed and sufficient time elapsed for a climax community to be established, 298 species were recorded (probably even more are present), representing all of the major marine phyla. The major phyla recorded are composed of numbers of species as follows:

Table 10. Major Phyla at Rincon Island

Phylum	No.	Phylum	No.
Cholorophyta	7	Nemertea	3
Rhodophyta	11	Annelida	10
Phaeophyta	9	Arthropoda	21
Porifera	14	Mollusca	65
Coelenterata	19	Bryozoa	8
Ctenophora	1	Echinodermata	15
Platyhelminthes	4	Chordata	118

Two major advantages have made possible this climax marine community: (1) the establishment of a substrate conducive to the attachment of various marine forms, and (2) the island's position one-half mile off the coast

which prohibited the destruction of life by the public. Rincon demonstrates the potential that an offshore structure can have in establishing biological communities with diverse and sometimes rare forms of life. Such a structure can be used to study the various marine forms and to provide "seeding" ground for the distribution of these forms to adjacent areas. The need of such structures is basic to the conservation of this segment of our marine resources.

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