

CHAPTER 64

MOVABLE-BED MODEL STUDIES OF PERCHED BEACH CONCEPT

by

C. E. CHATHAM, JR.

U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION, VICKSBURG, MISSISSIPPI

ABSTRACT

Hydraulic model studies were conducted to aid in ascertaining the technical feasibility and optimum design factors of the perched beach concept. Among these were two-dimensional, movable-bed studies to determine an estimate of the amount of sand which would be lost seaward over the submerged toe structure by normal and storm wave action, the optimum elevation of the submerged toe structure, and the length of a stone blanket required to reduce seaward migration of sand to a minimum. The model beach was subjected to test waves until equilibrium was reached for a wide range of wave conditions for both the existing beach and the perched beach. Test results indicate that (a) little or no beachfill material will be lost seaward of the toe structure for normal wave conditions but the larger storm waves may cause erosion of the perched beach, (b) the installation of a stone blanket shoreward of the toe structure will reduce the amount of beach erosion, (c) if the beach fill is extended a sufficient distance seaward, the toe structure serves no useful purpose, and (d) a three-dimensional movable-bed model study is feasible and is necessary to determine the final design features of a perched beach.

INTRODUCTION

The concept of building a perched beach, that is, extending the berm of an existing beach seaward of its original position, has received favorable attention in recent years for the purpose of expanding or creating recreational areas and providing more coastal area for development. Since the beach profile in a given area is governed by the wave climate in that area, in a beach-fill project the existing profile must be reproduced for a considerable distance seaward if the fill is to be stable. The basic concept of the perched beach is to reproduce the existing beach profile to some convenient seaward point and then intersect this profile with a submerged toe structure to retain the beach in a perched position (see figure 1). Since turbulence induced by the oncoming waves as they travel over the submerged toe structure could transport quantities of beach material seaward, a stone riprap apron might be needed along the shoreward edge of the toe structure crest to reduce seaward migration of sand. In order to be effective, a perched beach must allow the natural littoral processes to continue without being supplemented by excessive beach replenishment.

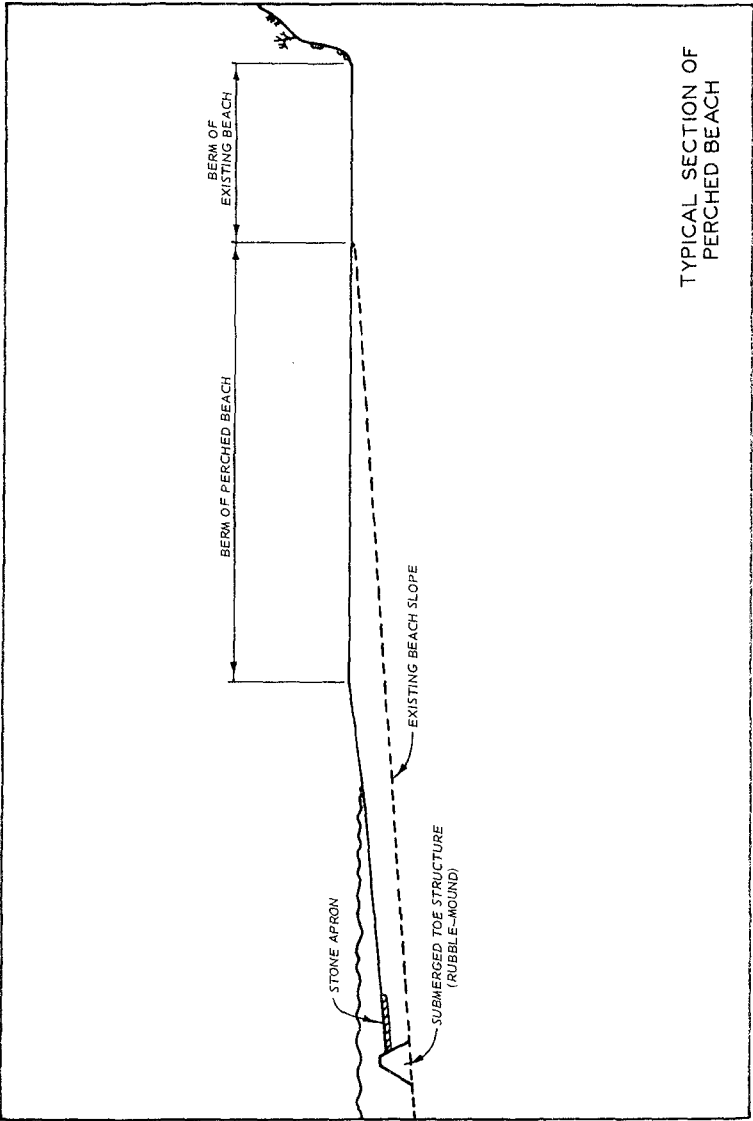


Figure 1

Hydraulic model studies were conducted to aid in ascertaining the technical feasibility and optimum design factors of the perched beach concept for a site in Santa Monica Bay, California. Among these were two-dimensional movable-bed studies to determine an estimate of the amount of sand which would be lost seaward over the toe structure by normal and storm wave action, the optimum crown elevation of the submerged structure, and the length of the stone riprap apron required to reduce seaward migration of sand to a minimum.

Scale models of hydraulic phenomena are essentially a means of replacing the analytical integration of the differential equations governing the process, including initial conditions and boundary conditions. However, before reliable information can be derived from scale models, the physical laws which cause the processes must be understood so that the relative magnitude of the forces involved remains the same.

A movable-bed model study guided by proper similitude relations and procedures can offer quantitative results which are vitally important in seeking an efficient engineering solution. In addition, by observing the display of the model, an investigator can develop a more concrete feeling of the nature of the problems which could not be achieved otherwise.

SELECTION OF SCALES

The perched beach movable-bed model was designed in accordance with the scaling relations developed by Noda (1971) which indicate a relationship or model law among the four basic scale ratios; the horizontal scale, vertical scale, sediment size ratio, and the relative specific weight ratio. These relations, which are valid mainly for the breaker zone, were determined experimentally using a wide range of wave conditions and beach materials. To determine the validity of the experimentally derived model law, Noda modeled a prototype dimension beach profile in the laboratory and comparisons of test results showed good correlation.

Using the scaling relations of Noda and the physical characteristics of the prototype sand at the perched beach site, a search was made of all readily available model beach materials, and possible model scales based on the characteristics of these materials were computed. Preliminary model tests were conducted using polystyrene (specific weight = 1.05) but this material proved to be too light and serious operational problems were encountered. Polystyrene was therefore abandoned and a quantity of crushed coal (specific weight = 1.30) was obtained. The model scales were computed as follows:

$$\gamma_w = 1.00 = \text{specific weight of water}$$

$$\gamma_s = 2.65 = \text{specific weight of prototype sand}$$

$\gamma_c = 1.30 = \text{specific weight of coal}$

$$\gamma'_s = \frac{\gamma_s - \gamma_w}{\gamma_w} = \frac{2.65 - 1}{1} = 1.65 = \text{apparent specific weight of prototype sand}$$

$$\gamma'_c = \frac{\gamma_c - \gamma_w}{\gamma_w} = \frac{1.30 - 1}{1} = 0.30 = \text{apparent specific weight of coal}$$

$$\eta_{\gamma'} = \frac{\gamma'_c}{\gamma'_s} = \frac{0.30}{1.65} = 0.182 = \text{ratio of apparent specific weight}$$

$D_{\text{proto}} = 0.4 \text{ mm} = \text{median diameter of prototype sand}$

$$\eta_D = \frac{D_{\text{model}}}{D_{\text{proto}}} = \text{ratio of median diameters}$$

$\lambda = \text{horizontal scale}$

$\mu = \text{vertical scale}$

$D_{\text{model}} = 0.55 \text{ mm} = \text{median diameter of available coal}$

$$\eta_D = \frac{0.55}{0.40} = 1.375$$

$$\mu^{0.55} = \eta_D \eta_{\gamma'}^{1.46} = 1.375 (.182)^{1.46} ; \mu = 0.0192 = 1/52 \text{ say } 1/50$$

$$\lambda = \mu^{1.32} \eta_{\gamma'}^{-0.35} = (.0192)^{1.32} (.182)^{-0.35} = .0098 = 1/102 \text{ say } 1/100$$

$$\Omega = \frac{1/50}{1/100} = 2 = \text{model distortion using coal}$$

To check the validity of the computed scales, equilibrium profile tests were conducted using coal as the beach material and the test results were compared with data from full scale tests run at the Coastal Engineering Research Center using natural sand as the beach material. Since these data were generally in good agreement, the computed scales were considered adequate for the movable-bed tests.

The two-dimensional movable-bed model was constructed in a 2-ft wide, 4.5 ft deep, 148-ft long wave flume. A flap-type wave generator capable

of generating waves with the required characteristics was positioned at the seaward end of the flume. Using coal as the beach material and the computed scales, average beach slopes were constructed between elevations of +20 and -60 ft.

SELECTION OF TEST CONDITIONS

Still-water levels (swl) for wave action models are selected so that the various wave-induced phenomena that are dependent upon water depths are accurately reproduced in the model. These phenomena include the refraction of waves, the overtopping of structures by the waves, the reflection of wave energy, and the transmission of wave energy through porous structures. The primary purpose of the movable-bed model was to determine the amount of beach fill material which would be lost seaward over the toe structure. Since the waves would break further seaward for lesser depths probably causing greater losses of material, a model (swl) of 0.0 mean lower low water (mllw) representing a low water stage was selected for these tests.

Measured wave data on which a comprehensive analysis of wave conditions could be based were unavailable for the Santa Monica Bay area. However, hindcast wave data were secured from deepwater stations 7 (National Marine Consultants) and A (Marine Advisers). The locations of these stations are shown in fig. 2. The data prepared by National Marine Consultants were computed in accordance with the theory of wave spectra and statistics as presented by Pierson, Neumann, and James. The data prepared by Marine Advisers were in accordance with Bretschneider's modification of the Sverdrup-Munk theory. Data for stations 7 and A were analyzed to establish the characteristics and estimated duration of deepwater sea and swell approaching the problem area from all directions clockwise from south to west. The deepwater wave data were then converted to shallow water data for use in the model by application of refraction and shoaling coefficients, and the results of this conversion are presented in table 1 for a depth of 60 ft. Since waves were to be generated from one direction (that normal to the beach) table 1 shows the estimated duration and magnitude of shallow water waves approaching the problem area from all directions combined. The following test waves were selected as being representative of those approaching the study area:

<u>Selected Test Waves</u>	
<u>Period, sec</u>	<u>Height, ft</u>
7	5
7.9	10
10	3
10	8
10	14
11.3	12
16	4
16	8

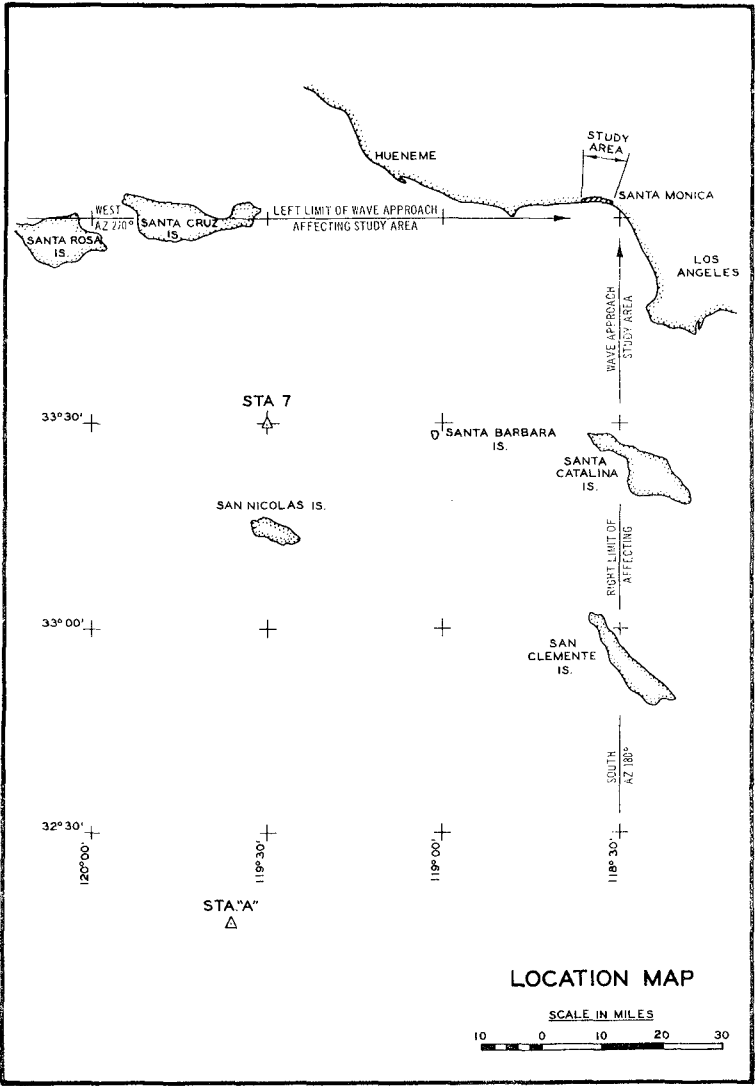


Figure 2

Table 1

Estimated Duration and Magnitude of Shallow-Water Waves (60-ft depth)
Approaching Santa Monica Bay from all Directions (South to West)

Wave Height (ft)	Duration, hr/yr, for the Various Wave Periods (sec) at Station A										Total
	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	
0-0.9	395		27	47	10	612	342				1433
1-1.9	245		2	28	55	1387	982	100	29	11	2839
2-2.9		132	1	1	27	583	492	204	30	18	1488
3-3.9		159			3	91	151	118	10	2	534
4-4.9		64				13	46	99	12		234
5-5.9			22								22
6-6.9			71		9	1	3	18	1		103
7-7.9			20					9			29
8-8.9			18					1	2		21
9-9.9			1						1		2
10-10.9				3							3
11-11.9				2							2
12-12.9				1							1
TOTALS	640	355	162	82	104	2687	2016	549	85	31	6711

Wave Height (ft)	Duration, hr/yr, for the Various Wave Periods (sec) at Station 7								Total
	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18+	
1-1.9	106	2	63	20	2	4			197
2-2.9	202	115	196	103	56	31	10	2	715
3-3.9	49	89	86	48	31	2	10	2	317
4-4.9		100	52	22	22	22			218
5-5.9		21	33	36	11	6	4		111
6-6.9		20	33	28					81
7-7.9			27	39	22	4			92
8-8.9			26		14	9			49
9-9.9			10	23					33
10-10.9					2	6	2		10
11-11.9				15					15
12-12.9					8				8
13-13.9				4					4
TOTALS	357	347	526	338	168	84	26	4	1850

MODEL TESTS AND RESULTS

The term "base test" as used herein denotes a test performed with existing prototype conditions installed in the model. Movable-bed tests were conducted for base test conditions and 8 variations in design elements of the proposed perched beach. Brief descriptions of the plans are given in the following subparagraphs.

- a. Plan 1 consisted of a 700-ft wide perched beach (measured from the toe structure centerline to the 0.0 milw contour) with the submerged toe structure located at the -25 ft contour and a crown elevation of -15 ft.
- b. Plan 1A was the same as plan 1 with a 100-ft stone apron installed shoreward of the toe structure.
- c. Plan 2 consisted of a 350-ft-wide perched beach with the submerged toe structure located at the -22-ft contour and a crown elevation of -10 ft.
- d. Plan 2A was the same as plan 2 with a 100-ft stone apron installed shoreward of the toe structure.
- e. Plan 3 consisted of an 1100-ft-wide perched beach with the submerged toe structure located at the -28-ft contour and a crown elevation of -20 ft.
- f. Plan 3A was the same as plan 3 with a 100-ft stone apron installed shoreward of the toe structure.
- g. Plan 4 consisted of a 700-ft-wide perched beach with no toe structure.
- h. Plan 4A consisted of an 1100-ft-wide perched beach with no toe structure.

The movable-bed tests were conducted in the following manner. The movable-bed material (coal) was installed in the flume to correspond to one of the test plans. The wave generator was then started and allowed to run continuously until the beach profile had reached an equilibrium condition. The length of time required to reach equilibrium varied from 3 hours (model time) for the smaller waves to as much as 13 hours (model time) for some of the larger waves. Profiles were measured at regular intervals (usually hourly) to determine the bed evolution. Since initial tests indicated that

considerable wave energy was reflected from some of the steeper profiles, a wave filter was installed in front of the flap-type wave generator to dampen re-reflected waves.

The results of movable-bed tests with base test and plans 1 through 4A installed are presented in fig. 3-9. These data indicate that normal wave action on the perched beach caused no appreciable loss of beach fill, but for some of the larger storm waves, severe erosion of the perched beach occurred.

Tests to determine the effect of a 100-ft stone apron installed shoreward of the toe structure reveal that installation of such a structure in conjunction with a 700-ft perched beach (plan 1A) significantly reduced the amount of beach fill lost seaward. When installed with a 350-ft perched beach (plan 2A) however, the stone apron had little or no effect on beach erosion. When installed with an 1100-ft perched beach (plan 3A), the stone apron had a slight beneficial effect on reducing erosion, however, from a comparison of the data for base test, plan 3, and plan 3A, it appeared questionable whether the toe structure itself was beneficial in this location. Tests were therefore conducted with the toe structure removed (plan 4A) and these test results, when compared with those of plans 3 and 3A, indicated that the toe structure would have little or no beneficial effect on reducing beach erosion when located 1100-ft seaward of the 0.0 contour. Tests with the toe structure removed for the 700-ft perched beach (plan 4) revealed that beach erosion increased significantly without the toe structure.

From a comparison of all the data in fig. 3-9, it appears that plan 1A (700-ft perched beach, toe structure crown elev of -15 ft, and 100-ft stone apron) offers the greatest degree of protection to the perched beach fill of any of the plans tested.

While the overall test results using coal as a movable-bed material appear satisfactory, there are two inconsistencies which bear further discussion. The first of these is the behavior of the coal in the area above the swl. As can be seen from fig. 3-9, the amount of shoreward erosion between the 0.0 and +20 contours is inconsistent for several of the plans tested (especially for the larger waves). In addition, in some cases the profile at the shoreward limit of erosion is characterized by a vertical (or possibly undercut) bank as much as 20 ft high. This is probably due to a discrepancy in the moisture content of the coal above the water line as compared to the prototype sand (the coal appears to be more cohesive in this area). This inconsistency should be kept in mind when examining the data in fig. 3-9 and a more accurate evaluation can probably be drawn by considering only that portion of the profile which is below the swl. The second inconsistency is the formation of a series of bars seaward of the toe structure for the 16 second test waves (fig. 8 and 9). It was known, prior to the use of coal in the present study, that it had a tendency to form unrealistic ripples or waves

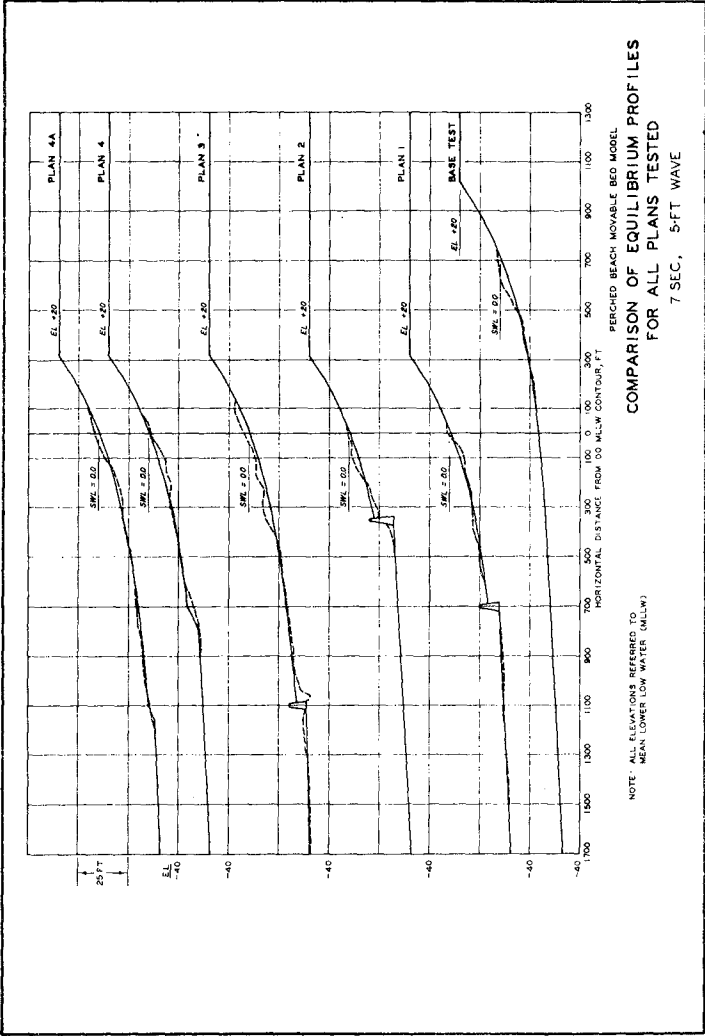


Figure 3

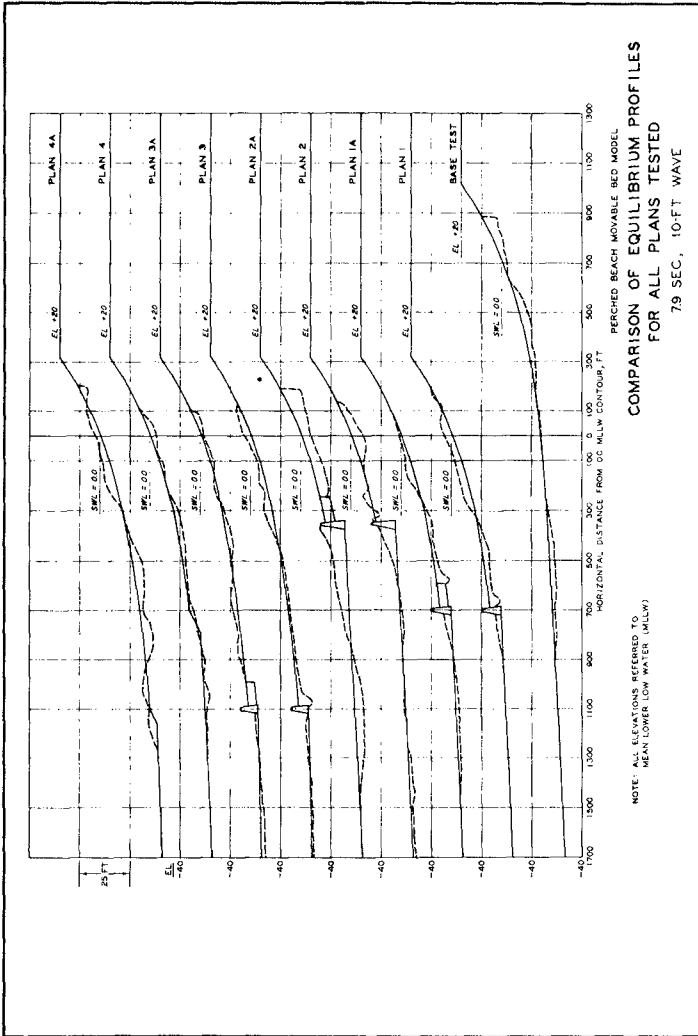


Figure 4

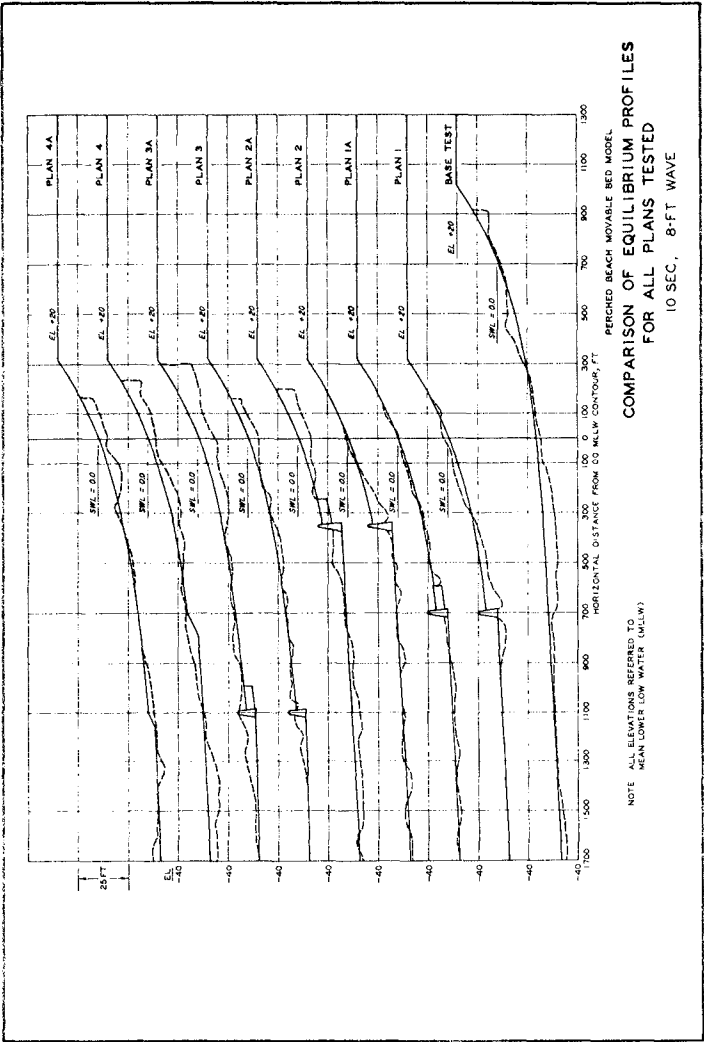


Figure 6

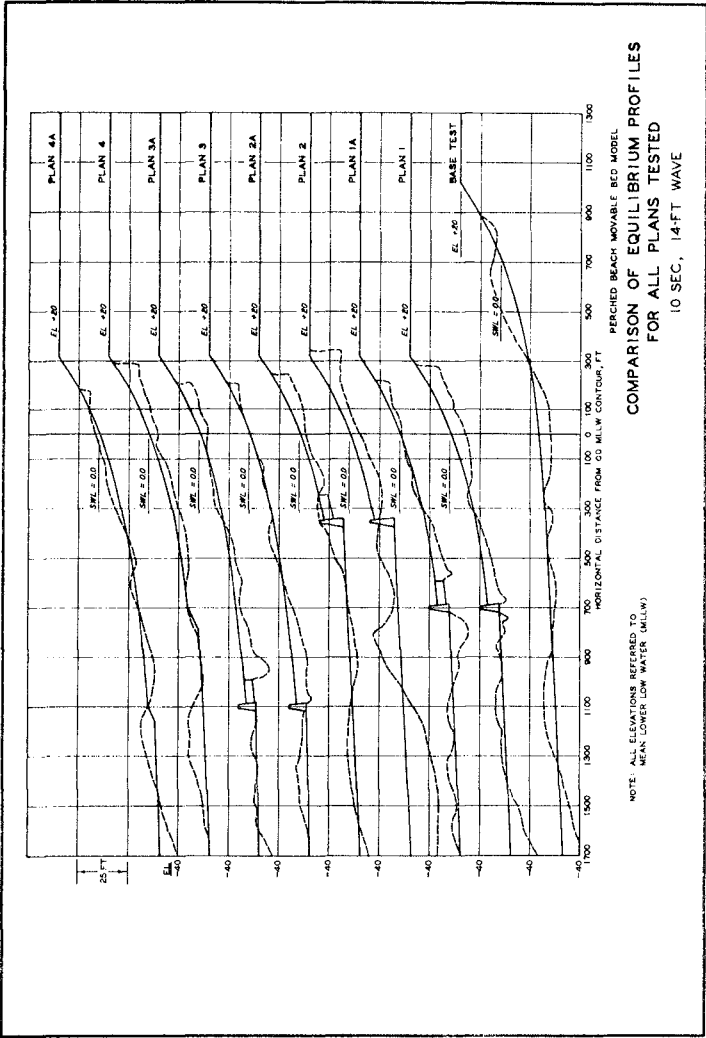


Figure 7

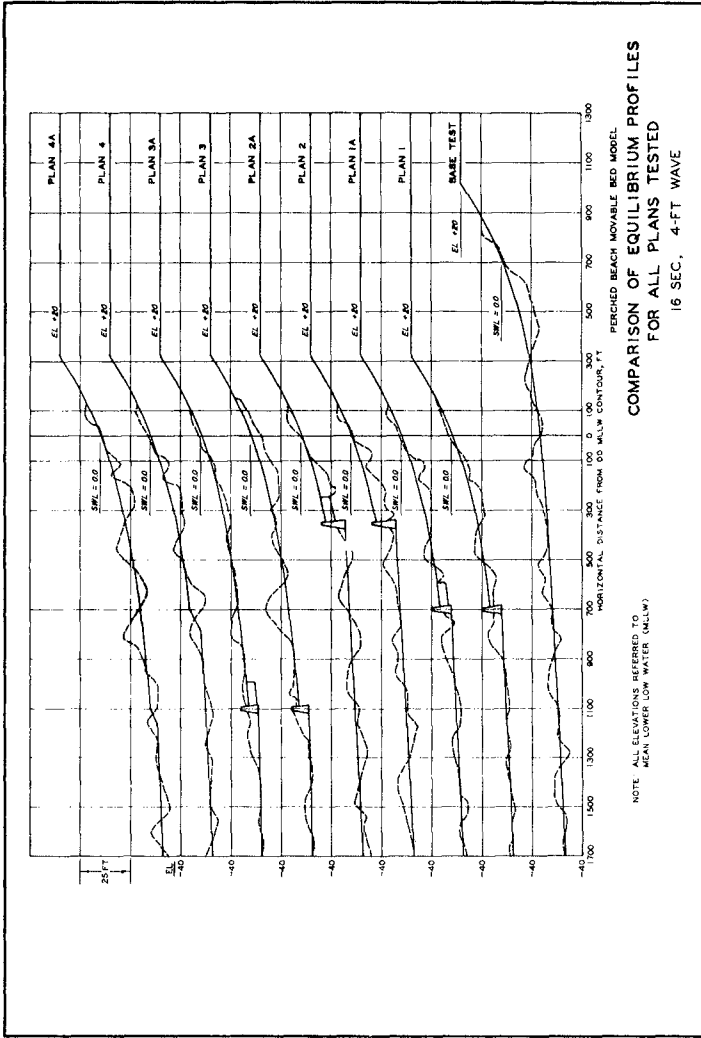


Figure 8

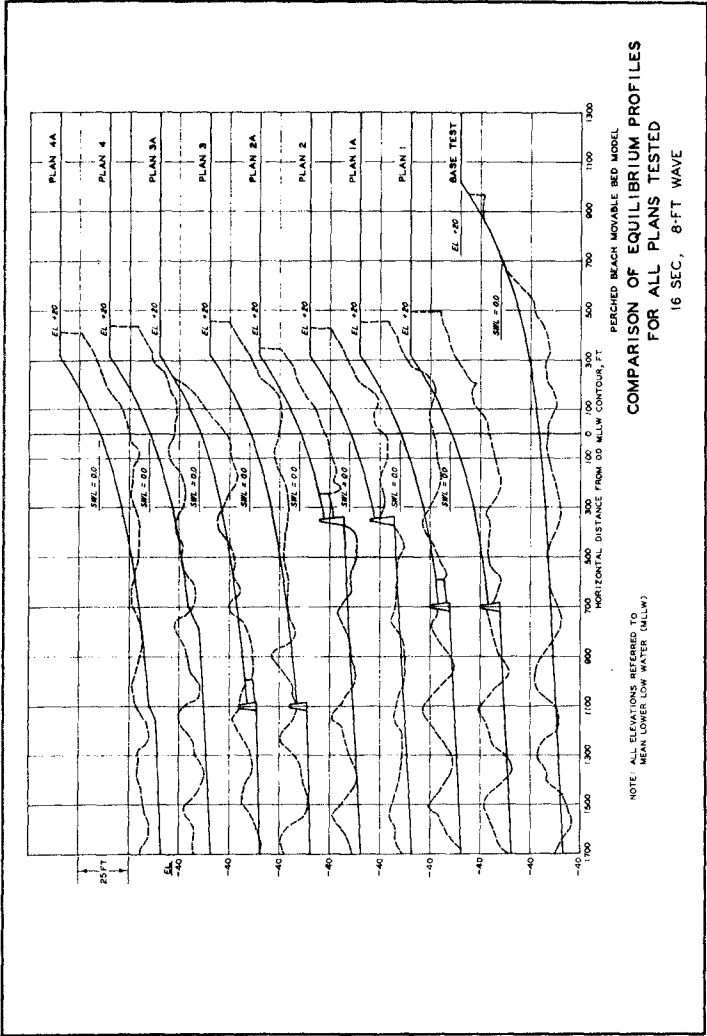


Figure 9

for higher velocity oscillatory flow (longer period, larger amplitude waves); however, the wave statistics at the Santa Monica location reveal a relatively mild wave climate, and since coal was available it was an expedient choice for the present study. It was found that coal would be satisfactory except for the longer period waves which have a low frequency of occurrence.

THREE-DIMENSIONAL MOVABLE-BED MODELS

Prior to performing a three-dimensional movable-bed model investigation, additional wave-flume tests are needed using various materials with a specific gravity range from 1.3 to 1.6 to aid in the selection of a suitable beach material. Another problem which must be analyzed during the two-dimensional tests is the size distribution of the model material. If Noda's scale relations are accepted without modification, any appreciable size distribution in the prototype will be difficult to scale correctly in the model (at certain scales) due to the sensitivity of the calculated model scales to variations in particle size. This means that one must either show that the size distribution is essentially a delta function or else the particle size distribution in the prototype has a negligible effect on the onshore-offshore transport as well as the littoral transport. It is believed that the answer to the problems lies somewhere in between these two elements. That is, the scale relations should not be quite so sensitive to particle size and, hopefully for a specific location, the size distribution will not have a large effect on the erosion and accretion characteristics of the beach.

It is well known that quantitative three-dimensional movable-bed model investigations are difficult to conduct and each area where such an investigation is contemplated must be carefully analyzed. The following computations and prototype data are considered essential for such investigations:

- a. A computation of the littoral transport based on the best available wave statistics.
- b. An analysis of the sand size distribution over the entire project area (offshore to a point well beyond the breaker zone).
- c. Simultaneous measurement of the following items over a period of erosion and accretion of the shoreline (this measurement period should be judiciously chosen to obtain the maximum probability of both erosion and accretion during as short a time span as possible):

(1) Continuous measurements of the incident wave characteristics. This means enough sensors to obtain accurate estimates of the directional spectrum over the entire project area and a detailed analysis of these data.

(2) Bottom profiling of the entire project area using the shortest time intervals possible.

(3) Nearly continuous measurements of both littoral and onshore-offshore transport of sand. This is especially important over the erosion-accretion period. A wave forecast service is essential to this effort in order to be prepared for full operation during the erosion period.

Upon verification of the model based on the data acquired, one should then be prepared to evaluate the effectiveness of various project plans. A quantitative three-dimensional movable-bed model investigation of littoral transport is feasible and should be successful provided it is approached in the manner prescribed and provided adequate prototype data are acquired. Insofar as is known, prototype data to the extent described above have never been acquired; however, it is certainly within the state of the art to obtain such data. Admittedly the measurement of littoral and onshore-offshore transport will be most difficult, but it is felt that such measurements can be made with sufficient accuracy for model verification. It should be noted that the prototype data acquisition would include measurements of the size and intensity of rip currents in the prototype area and, if they persevere to any appreciable degree, measurements of the amount of material moved seaward in the rips would be obtained as a part of the overall data.

CONCLUSIONS

Based on the results of the two-dimensional hydraulic model studies, it is concluded that:

- a. Normal wave action on the perched beach will cause no appreciable loss of beach fill.
- b. For the larger storm waves, severe erosion of the perched beach may be expected.
- c. The installation of a 100-ft stone apron in conjunction with a 350-ft perched beach (plan 2A) will have little or no effect on reducing beach erosion.
- d. The installation of a 100-ft stone apron in conjunction with a 700-ft perched beach (plan 1A) will significantly reduce the amount of beach erosion.
- e. If the beach fill is extended as far as 1100 ft seaward of the 0.0 mllw contour, the toe structure itself will have little or no beneficial effect on reducing beach erosion.

- f. Of all plans tested, plan 1A (700-ft perched beach with -15-ft toe structure crown elev and 100-ft stone apron) appears to offer the greatest degree of protection against erosion of beach fill material.
- g. Additional wave flume tests are needed in the specific gravity range from 1.3 to 1.6 prior to performing a three-dimensional movable-bed model investigation.
- h. Provided adequate prototype data are available for use in model verification, a three-dimensional movable-bed model investigation of the perched beach is feasible and should result in a valid indication of the relative merits of various project designs.

ACKNOWLEDGEMENTS

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