*Eider Barrage and Lock*

# PART III

## COASTAL STRUCTURES AND RELATED PROBLEMS

*Light House, Weser Estuary*

# COASTAL STRUCTURES' EFFECTS ON SHORELINES

by Ronald M. Noble*

## ABSTRACT

Coastal structures have caused significant impacts to adjacent shorelines, especially when these shorelines are composed of sand. Many times, these shoreline impacts have not been expected due to improper planning prior to the design and construction of these structures. Consequently, excessive erosion and/or deposition of sediment as a result of these structures has necessitated costly, and in some cases, continuous maintenance operations.

This paper reviews the expected shoreline effects for an offshore pier-trestle and breakwater system for an LNG marine terminal. Coastal structures originally proposed for the LNG marine terminal consisted of a 4,600-foot-long pile supported "T" head pier/trestle system and a 1,000-foot-long detached rubble-mound breakwater. This investigation involved field and historical aerial photographic examination of 30 structures in the Southern California Bight and a literature review of similar structures in other environments. Also, a review of theoretical and physical model studies applicable to structures within the coastal marine environment was conducted.

The results of this investigation of existing structures, in conjunction with theory and model studies, indicate that within the study region, pile-supported piers have no appreciable impact of the adjacent shoreline. This investigation also indicates that detached breakwaters produce only minimal impact when the offshore distance of the structure is greater than six times the breakwater length. Of course, consideration was also given to the structure's position relative to the littoral zone, to the depth of water at the shoreward face of the structure, and to the wave climate approaching the structure.

This study included a review of such factors as the local topography, nearshore bathymetry, beach processes, shoreline configuration, beach materials, range of water levels, and local wave climate. The controlling parameters identified in this study are discussed, and the final recommendations presented. This paper illustrates the importance of proper advance shoreline planning before the final design and construction of shoreline facilities.

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## INTRODUCTION

The construction of, or the nonconstruction of, coastal structures have resulted in significant impacts along our shorelines. It works both ways; structures built for inlet stabilization or for providing protection such as jetties and breakwaters, and for shoreline stabilization such as groins, bulkheads, revetments, etc. which have not properly considered the existing wave climate and shore processes taking place have resulted in costly maintenance operations; whereas, shoreline developments at other locations have not considered the potential erosion of shorelines from coastal processes and therefore, have not provided adequate coastal structures in the form of shoreline protection or the proper setback and floor elevation for development.

This paper discusses the assessment of the potential impact of a proposed marine terminal on the longshore movement of sand. This study was a preliminary assessment performed in a short time frame in order to ascertain whether the proposed marine terminal posed a significant impact to the adjacent shoreline and if more detailed studies were required.

Included in this study was a review of the site baseline conditions, the effects existing similar structures have had on adjacent shorelines, and theoretical and model studies pertaining to the effects of coastal structures on the littoral environment.

## COASTAL STRUCTURES

A liquefied natural gas (LNG) facility has been proposed for construction at Point Conception, California (Figure 1) by Western LNG Terminal Associates. The original[1] proposed coastal structures for the LNG marine terminal consisted of a 4,600-foot-long pile supported "T" head pier/trestle system for LNG carrier offloading and a 1,000-foot-long detached rubble-mound breakwater for support boat and barge mooring.

The 4,600-foot main trestle and the 1/2-mile "T" head pier were to be supported by 60-inch-diameter piles placed four to a bent across the 50-foot pier/trestle width with bents placed approximately 130 feet on centers. The water depth at the pier head would be to approximately -60 feet mean lower low water (MLLW). The proposed rubble-mound breakwater would be located adjacent to the main trestle

[1]The design specifications for the proposed coastal structures have been subsequently modified.

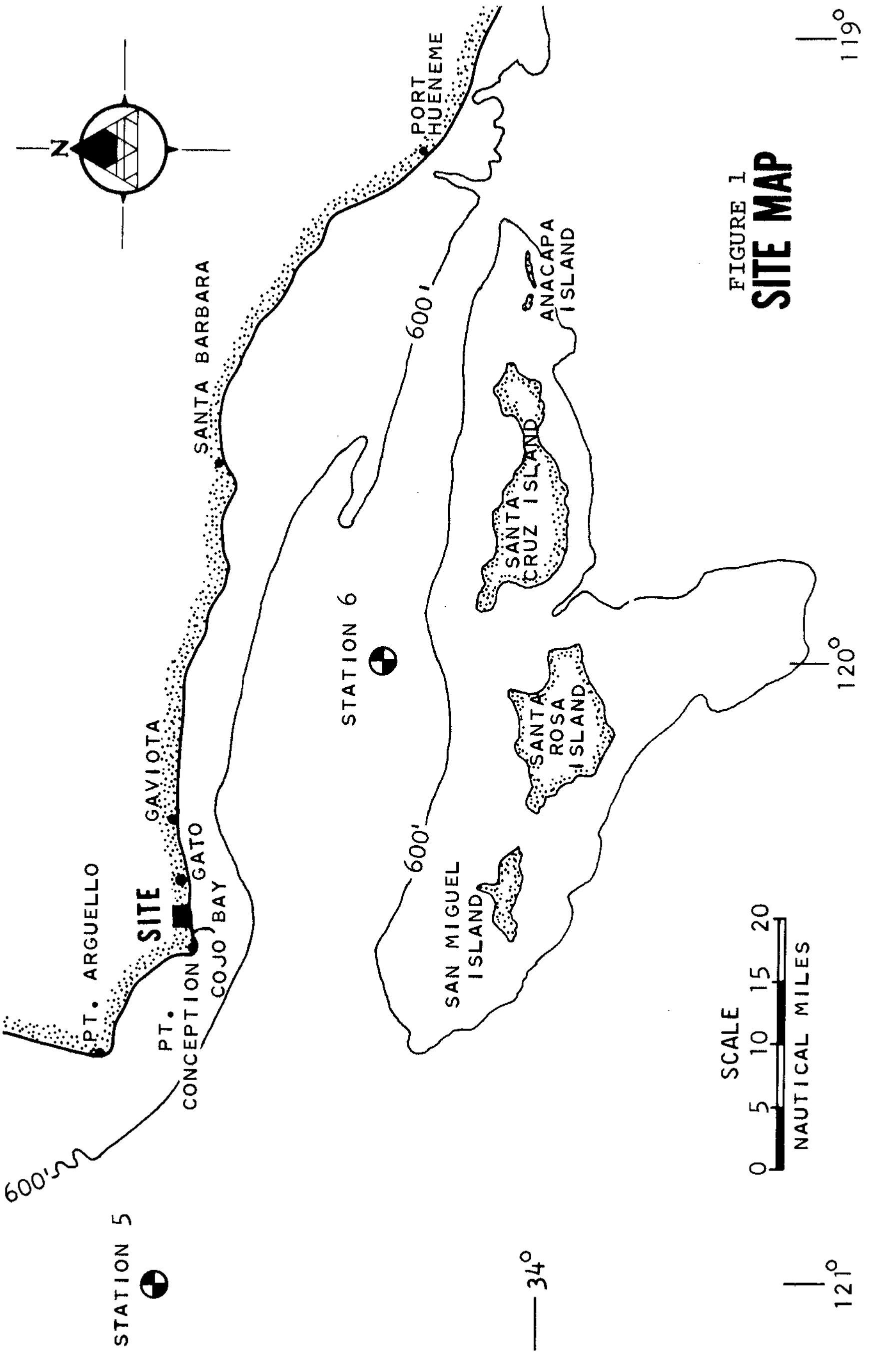



FIGURE 1
SITE MAP

on the trestle's east side and extend 1,000 feet from the trestle aligned approximately parallel to the shoreline along the -20-foot MLLW water depth contour.

The potential effect these proposed structures could have on the adjacent shoreline was assessed by considering the following:

- o Limited site field investigation
- o Review of existing similar structures
- o Review of literature on theoretical and model studies

In review of the above, a good understanding of the shore processes taking place in the site area is required, especially concerning wave climate, sediment transport volumes and sediment transport directions of movement.

## EXISTING CONDITIONS

Longshore sediment transport is dependent on such physical conditions as wave climate, beach profile, shoreline configuration, sediment budget, currents, offshore bathymetry, and existing shoreline structures. Waves are the primary driving force controlling the longshore movement of sediment. Therefore, these physical conditions were investigated for the site area.

The proposed site is located at the west end of the Santa Barbara Channel in Santa Barbara County (see Figure 1). This location is approximately 2 miles east of Government Point within what is known as the Southern California Bight. Due to the abrupt change in orientation of the coastline in the Point Conception area, the coastline within the Southern California Bight is sheltered from wave approach out of the northwest. Additionally, eight offshore islands within this region intercept a portion of the incoming open ocean wave energy from the west, southwest, and south. Consequently, this portion of the coastline may be thought of as a "semiprotected" open ocean coast.

The proposed LNG terminal site is exposed to wave activity from directions southeasterly clockwise through westerly. It is directly exposed to deepwater ocean wave conditions from directions southerly clockwise through westerly directions. Deepwater waves approaching from directions northwesterly through northerly will be refracted toward the east up the Santa Barbara Channel. Due to significant refraction effects and the natural protection provided to the site by Government Point, these waves do not significantly affect the site. Deepwater ocean waves approaching the site from directions southeasterly clockwise through southerly directions will undergo the effects of diffraction and refraction around the Santa Barbara Islands before reaching the site area. Waves generated within the Santa Barbara Channel can also reach the site from these directions. Several wave hindcast and refraction studies performed in the vicinity of Point Conception were used to verify these findings.

Stations 5 and 6 from National Marine Consultants (1960) deepwater hindcast wave statistics are located in the Point Conception area as shown on Figure 1. There also presently exists wave gages both offshore and in the site area.

The coastline in the vicinity of the proposed site trends in a westward direction and turns northward upcoast from Point Arguello. Sedimentological studies conducted in this area have established the direction of net longshore sediment movement as west to east or downcoast and have also verified the fact that some sediment does move southward around the rocky promontories of Point Arguello and Point Conception. Additionally, investigations by Bowen and Inman (1966) and the U.S. Army Corps of Engineers (1965) have attempted to quantify the sediment transport rate along this portion of California coast. At present, estimates range between 50,000 and 100,000 cubic yards annually. Field and literature investigations suggest that most of this volume of sediment moves downcoast inside of the surf zone. Field studies conducted during the present investigation indicate that the effective boundary of the littoral zone at the site may be approximated by the -20-foot MLLW contour. Seasonal onshore/offshore migration of sand deposits and the redistribution of deposits during a storm event may move the position of the boundary seaward.

## SHORELINE PIERS

To effectively assess the potential impact of the proposed pier on the longshore movement of sediment in the site area, case histories of existing piers were investigated and a review of the theory and model studies applicable to pile-supported structures was performed. In all, 20 piers were involved in this study, all situated within the Southern California Bight. The pier locations investigated are shown on Figure 2. The wave climate south of Point Conception, as previously mentioned, is strongly

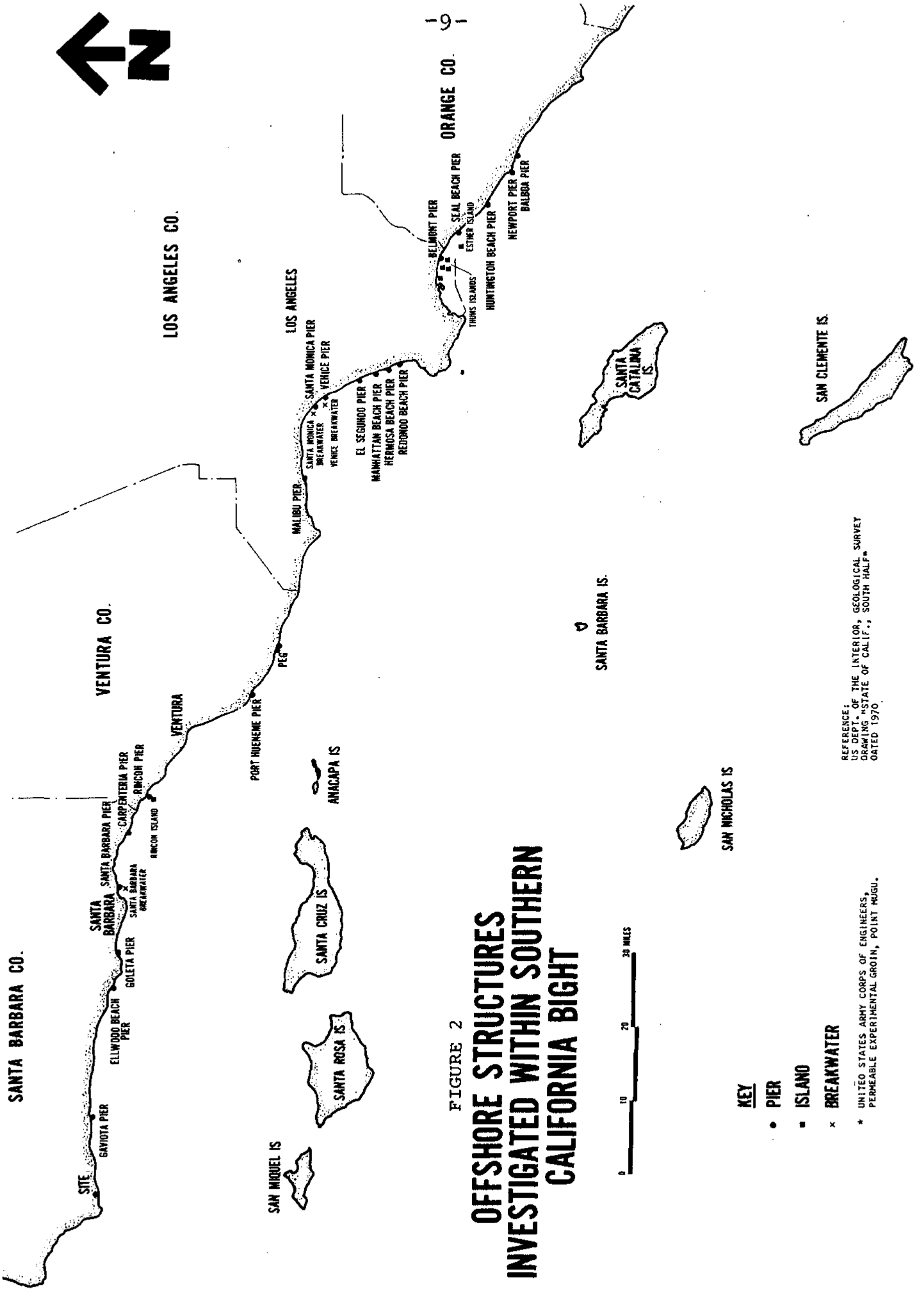



FIGURE 2
OFFSHORE STRUCTURES INVESTIGATED WITHIN SOUTHERN CALIFORNIA BIGHT

influenced by the change in orientation of the coastline and the presence of the offshore islands. Similarities between each of the pier environments are afforded by this regional physiography.

Factors reviewed for each pier structure are shown in Table I and were as follows:

- o Environment

  Location of structure
  Wave exposure
  Physiographic setting
  Configuration of pier
  Net longshore transport

- o Structural Characteristics

  Pile diameter
  Number piles per bent and pile spacing
  Bent spacing
  Length of structure
  Width of structure

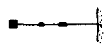
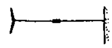
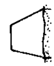
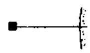
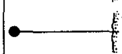
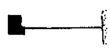
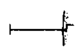
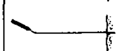
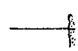
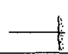
- o Effects on Adjacent Shoreline

The piers in this study were all pile-supported structures with evenly spaced pile bents. The foot of each pier was located shoreward of the mean high water level, and the pile-supported structures extended seaward through the nearshore zone. Pile diameters were uniform over the length of each pier as were the bent spacings, and with few exceptions, the number of piles per bent was consistent over the length of the piers.

Although similarities existed between the various piers, the observed ranges in dimensions and configurations were large. The piers ranged in length from 625 to 2,500 feet and in width from 15 to 300 feet. Designs varied from straight "finger-type" piers to complex "U-shaped" or "Dog Leg" piers. Pile diameters ranged from 12 to 30 inches and exhibited a transverse, on center spacing of 4 to 28 feet. The 20 piers also exhibited a minimum bent spacing of 15 feet and a maximum of 60 feet.

Field inspections and historical aerial photographs provided the necessary information for evaluation of the impact on littoral sand transport for each of the structures. Field observations and review of the aerial photographs indicated that these piers have had a negligible effect on the adjacent shoreline. In two cases, where

# TABLE I
# PIERS INVESTIGATED WITHIN THE SOUTHERN CALIFORNIA BIGHT

| | ENVIRONMENT | | | | |
|---|---|---|---|---|---|
| NAME OF STRUCTURE | LOCATION OF STRUCTURE | WAVE[1] EXPOSURE | PHYSIOGRAPHIC SETTING | CONFIGURATION OF PIERS | NET LONGSHORE TRANSPORT (cubic yds/year) |
| Balboa Pier | Newport/Balboa Penninsula, Orange County | Open | Long continuous beach |  | > 200,000 |
| Newport Pier (McFadden Wharf) | Newport/Balboa Penninsula, Orange County | Open | Long continuous beach |  | > 200,000 |
| Huntington Beach Pier | Huntington Beach, Orange County | Open | Long continuous beach |  | > 200,000 |
| Seal Beach Pier | Seal Beach, Orange County | Semi Restricted | Long continuous beach |  | Not determined |
| Belmont Pier | Long Beach, Los Angeles County | Restricted | Long continuous beach |  | Little or no |
| Redondo Pier | Redondo Beach, Los Angeles County | Semi Restricted | Long continuous beach |  | Not determined |
| Manhattan Fishing Pier | Manhattan Beach, Los Angeles County | Open | Long continuous beach |  | > 100,000 and < 270,000 |
| Hermosa Beach Pier | Hermosa Beach, Los Angeles County | Open | Long continuous beach |  | > 100,000 and < 270,000 |
| El Segundo Pier | El Segundo, Los Angeles County | Open | Long continuous beach |  | > 100,000 and < 270,000 |
| Venice Pier | Venice Beach, Los Angeles County | Open | Long continuous beach |  | 270,000 |
| Santa Monica Pier | Santa Monica Beach, Los Angeles County | Semi Restricted | Long continuous beach |  | 270,000 |
| Malibu Pier | Malibu Beach, Los Angeles County | Semi Restricted | Long continuous beach |  | > 200,000 |
| USACE PEG[2] Point Mugu | Point Mugu, Ventura County | Open | Long continuous beach |  | > 500,000 |
| Port Hueneme Pier | Port Hueneme, Ventura County | Open | Long continuous beach |  | > 1,000,000 |
| Ventura Pier | Ventura Beach, Ventura County | Semi Restricted | Long continuous beach |  | > 500,000 |
| Rincon Pier | Rincon Point, Ventura County | Open | Headland |  | 270,000 |
| Carpenteria Pier | Carpenteria Beach, Santa Barbara County | Open | Pocket beach |  | 270,000 |
| Santa Barbara Pier | Santa Barbara, Santa Barbara County | Restricted | Long continuous beach |  | > 100,000 |
| Goleta Pier | Goleta, Santa Barbara County | Semi Restricted | Long continuous beach |  | > 200,000 |
| Ellwood Pier | Ellwood Pier, Santa Barbara County | Open | Long continuous beach |  | > 200,000 |
| Gaviota Pier | Gaviota Beach, Santa Barbara County | Open | Pocket beach |  | > 200,000 |

[1] Initially most of the Southern California coastline is partially protected from the offshore islands.

[2] U.S. Army of Engineering, Permeable Experimental Groin, Point Mugu.

## TABLE I (Continued)
## PIERS INVESTIGATED WITHIN THE SOUTHERN CALIFORNIA BIGHT

| | STRUCTURAL CHARACTERISTICS | | | | | |
|---|---|---|---|---|---|---|
| NAME OF STRUCTURE | PILE[3] DIAMETER (inches) | NUMBER[3] PILES PER BENT AND PILE SPACING (feet on center) | BENT[3] SPACING (feet on center) | LENGTH OF STRUCTURE (feet) | WIDTH OF[3] STRUCTURE (feet) | EFFECTS ON ADJACENT SHORELINE |
| Balboa Pier | 16 to 18 | 4 piles/bent 7 foot spacing | 20 foot spacing | 925 | 30 | None |
| Newport Pier (McFadden Wharf) | 16 | 4 piles/bent 6 foot spacing | 20 foot spacing | 1,025 | 24 | None |
| Huntington Beach Pier | 24 | 3 piles/bent 8 foot spacing | 22 foot spacing | 1,950 | 25 | Minor scour at foot of structure |
| Seal Beach Pier | 18 | 4 piles/bent 6 foot spacing | 20 foot spacing | 1,650 | 24 | Minor upcoast erosion, Minor downcoast accretion |
| Belmont Pier | 20 | 4 piles/bent 8 foot spacing | 60 foot spacing | 1,350 | 32 | None |
| Redondo Pier | 15 | 4-5 piles/bent 10 foot spacing | 15 foot spacing | 500 | 40-50 | None |
| Manhattan Fishing Pier | 30 | 2 piles/bent 14.5 foot spacing | 25 foot spacing | 660 | 20 | None |
| Hermosa Beach Pier | 18 | 3 piles/bent 7.5 foot spacing | 32 foot spacing | 875 | 20 | None |
| El Segundo Pier | 22 | 3 piles/bent 5.5 foot spacing | 18 foot spacing | 700 | 16.5 | None |
| Venice Pier | 22 | 1 pile/bent | 16 foot spacing | 935 | 30 | None |
| Santa Monica Pier | 15 | 30 piles/bent 6-8 foot spacing | 18.5 foot spacing | 875 | 300 | Minor accretion at foot of pier |
| Malibu Pier | 12 to 14 | 5 piles/bent 2-8 foot spacing | 15 foot spacing | 815 | 30 | None |
| USACE PEG[2] Point Mugu | 14 inch square | Variable | Variable | 700 | 15 | None |
| Port Hueneme Pier | 14 | 4 piles/bent 4-10 foot spacing | 18 foot spacing | 850 | 20 | None |
| Ventura Pier | 12 to 16 | 5 piles/bent 6 foot spacing | 15 foot spacing | 1,750 | 30 | None |
| Rincon Pier | 16 | 1-2 piles/bent 12 foot spacing | 40 foot spacing | 3,500 | 14 | None |
| Carpenteria Pier | 30 | 2 piles/bent 28 foot spacing | 30 foot spacing | 600 | 28 | None |
| Santa Barbara Pier | 12 | 7 piles/bent 4 foot spacing | 8 foot spacing | 2,200 | 30 | None |
| Goleta Pier | 12 to 16 | 3 piles/bent 6 foot spacing | 15 foot spacing | 650 | 15 | None |
| Ellwood Pier | 12 | 3 piles/bent 6 foot spacing | 16 foot spacing | 2,000 | 20 | None |
| Gaviota Pier | 16 to 18 | 4 piles/bent 7 foot spacing | 16 foot spacing | 625 | 22 | None |

[2]U.S. Army of Engineering, Permeable Experimental Groin, Point Mugu.
[3]Characteristic pertaining to the inshore portion of pier.

substantial accretion effects were observed, it was apparent that the presence of structures other than the pile-supported piers had been the cause.

The results of these "similar structure" observations for piers are supported by the result of two previously conducted studies, one by J.W. Johnson in 1973 and another by C.H. Evert and A.E. DeWall in 1975. Johnson inspected approximately 34 piers along the California coast and found no discernible effects on the adjacent shorelines as a result of pier installation. Everts and DeWall, in a beach survey conducted in North Carolina, likewise found that out of five fishing piers inspected, none had a significant effect on accretion or erosion along adjacent shorelines.

Theoretical/analytical studies have been conducted to determine the effects of pile-supported structures on the transmission of wave energy. Most of the studies have attempted to identify the factors which control or greatly influence the transmission losses as waves pass through pile structures. The purpose of these particular studies has been to evaluate the use of closely spaced piles as a breakwater (Wiegel, 1961; Macknight and Thomas, 1973) and to predict wave transmission losses through pile arrays (Costello, 1952, van Weele and Herbich, 1972). In these studies single rows and multiple rows of piles were considered. Both longitudinal and transverse pile spacings were varied along with diameter and total number of piles. Considerations were given to incident wave height and steepness and diffraction effects as the wave passed through the pile arrays. Results of these studies indicate that within a range of incident wave steepness, when pile spacing is greater than four times pile diameter, reflection and eddy losses are of minor importance and the ratio of transmitted wave height to incident wave height should approach unity. This holds true for both transverse and longitudinal pile spacings.

Predominant swell conditions within the Southern California Bight fall well within the wave steepness boundaries established in these investigations. In the case of the surveyed piers, both the longitudinal and the transverse pile spacing were beyond the "four-diameter" range. It would be expected from theory that transmissibility should be very close to unity for all of the structures examined; consequently, as wave energy losses are negligible, there should be a minimal impact on the littoral environment.

## OFFSHORE STRUCTURES

To effectively assess the potential impact of the proposed breakwater on the longshore movement of sediment in the site area, case histories of nine existing offshore structures were investigated and a review of the theory applicable to these structures was performed. The structures examined included three detached breakwaters and six artificial islands, all located within the Southern California Bight. The offshore structure locations investigated are shown on Figure 2.

Factors reviewed for each offshore structure are shown in Table II and were as follows:

- o Environment

    Location of structure
    Wave exposure
    Physiographic setting
    Configuration of structure and adjacent shoreline
    Net longshore transport

- o Structural Characteristics

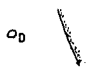
    Structure type
    Depth at shoreward face of structure
    Offshore distance to structure
    Length of structure
    Ratio: $\frac{\text{distance offshore}}{\text{length of structure}}$

- o Effect on Adjacent Shoreline

Like the piers, the detached structures may be defined by a set of measurable parameters. For the breakwaters, these parameters included the longshore length, the distance from the shoreline, and the depth of water at the shoreward face of the breakwater. Similarly, the measurable parameters for the artificial islands included the distance from shore (measured parallel to the predominant wave approach direction), the structural length (measured perpendicular to the predominant wave approach direction), and the depth of water at the shoreward face of the structure.

The detached breakwaters ranged in length from 600 to 2,800 feet, in distance from the shoreline from 600 to 1,850 feet, and in water depth at the shoreward face from 6

## TABLE II
## DETACHED BREAKWATERS AND ARTIFICIAL ISLANDS INVESTIGATED WITHIN THE SOUTHERN CALIFORNIA BIGHT

| | ENVIRONMENT | | | | |
|---|---|---|---|---|---|
| NAME OF STRUCTURE | LOCATION OF STRUCTURE | WAVE[1] EXPOSURE | PHYSIOGRAPHIC SETTING | CONFIGURATION OF STRUCTURE AND ADJACENT SHORELINE[2] (not to Scale) | NET LONGSHORE TRANSPORT (cu. yds/year) |
| Venice Breakwater | Venice Beach, Los Angeles County | Open | Long continuous beach |  | 270,000 |
| Santa Monica Breakwater | Santa Monica Beach, Los Angeles County | Open | Long continuous beach |  | 270,000 |
| Santa Barbara Breakwater | Santa Barbara Harbor, Santa Barbara County | Open | Headland |  | 270,000 |
| Island Esther | Long Beach, Los Angeles County | Semi Restricted | Long continuous beach |  | Little or no longshore movement of sediment |
| Thums Islands Island "A" | Long Beach, Los Angeles County | Semi Restricted | Long continuous beach |  | Little or no net longshore movement of sediment |
| Thums Islands Island "B" | Long Beach, Los Angeles County | Restricted | Long continuous beach |  | Little or no net longshore movement of sediment |
| Thums Islands Island "C" | Long Beach, Los Angeles County | Semi Restricted | Long continuous beach |  | Little or no net longshore movement of sediment |
| Thums Islands Island "D" | Long Beach, Los Angeles County | Restricted | Long continuous beach |  | Little or no net longshore movement of sediment |
| Rincon Island | Long Beach, Los Angeles County | Open | Headland |  | 270,000 |

[1] Initially most of the Southern California coastline is partially protected from the offshore islands.

[2]  Areas of accretion.

TABLE II (Continued)
DETACHED BREAKWATERS AND ARTIFICIAL ISLANDS
INVESTIGATED WITHIN THE
SOUTHERN CALIFORNIA BIGHT

| | STRUCTURAL CHARACTERISTICS | | | | | |
|---|---|---|---|---|---|---|
| NAME OF STRUCTURE | STRUCTURE TYPE | ORIGINAL DEPTH MLLW AT SHOREWARD FACE OF STRUCTURE (feet) | ORIGINAL OFFSHORE DISTANCE[3] (D) TO O' MLLW (feet) | LENGTH OF STRUCTURE (d) (feet) | RATIO D/d DISTANCE OFFSHORE/ LENGTH OF STRUCTURE (Dimensionless ratio) | EFFECTS ON ADJACENT SHORELINE |
| Venice Breakwater | Rubble Mound | 16-18 | 1,000 | 600 | .60 | Pronounced shoreline accretion (formation of tombolo) |
| Santa Monica Breakwater | Rubble Mound | 23-25 | 1,850 | 1,800 | 1.02 | Pronounced shoreline accretion (formation of tombolo) |
| Santa Barbara Breakwater | Rubble Mound | 6-8 | 600 | 2,800 | .21 | Pronounced shoreline accretion |
| Island Esther | Sand filled core with armor rock perimeter | 41-43 | 8,400 | 380 | 22.11 | No discernable effect |
| Thums Islands Island "A" | Sand filled core with armor rock perimeter | 26-28 | 1,547 | 1,172 | 1.32 | Shoreline accretion (May be due to an adjacent fill project - see text) |
| Thums Islands Island "B" | Sand filled core with armor rock perimeter | 26-28 | 2,604 | 1,085 | 2.40 | No discernable effect |
| Thums Islands Island "C" | Sand filled core with armor rock perimeter | 26-28 | 5,555 | 1,085 | 5.12 | Shoreline accretion |
| Thums Islands Island "D" | Sand filled core with armor rock perimeter | 39-41 | 6,614 | 868 | 7.62 | No discernable effect |
| Rincon Island | Sand filled core with armor rock perimeter | 41-44 | 5,500 | 535 | 10.28 | No discernable effect |

[3]Distance to shore parallel to predominant wave approach direction.

to 25 feet. The artificial islands ranged in length from 380 to 1,172 feet, in distance from the shoreline from 1,547 to 8,400 feet, and in water depth at the shoreward face from 26 to 44 feet.

Comparison of historical aerial photographs provided most of the information needed to assess the impact of the breakwater and artificial island structures on the littoral environment. These photographs indicated appreciable sediment buildup in the lee of each breakwater. Aerial photography of the artificial islands, before and after construction, showed that some of these structures also may have produced accretionary effects along the adjacent shorelines.

Previous case studies and field investigations have been conducted to evaluate the impact of offshore structures on the littoral zones. Most of these studies have acknowledged one or more of the following parameters as being important in performing this evaluation:

- The length of the structure relative to its offshore distance
- The incident wave length relative to the offshore distance of the structure
- The depth of water at the shoreward face of the structure
- The incident sector of wave approach at the structure and the resultant wave shadow in the lee of the structure
- The position of the structure relative to this active littoral zone

Inman and Frautschy (1965) observed that along the southern California coast, pronounced accretion occurs if a detached breakwater is located offshore a distance of less than three to six times the length of the breakwater. Dames & Moore (1974) investigated the effects of artificial islands along the southern California coast on the inshore littoral processes. Through aerial photographic analysis they attempted to document what, if any, effects had occurred on the adjacent shoreline since the time of island construction. This study generally confirms the basic guideline put forth by Inman and Frautschy.

Theoretical and model studies conducted by Harms and others (1973) along with the investigations by Savage de

Saint Marc and Vincent (1968) indicate that a region of reduced wave energy will develop in the lee of an offshore structure. Further, the study by Savage de Saint Marc and Vincent indicates that the effect of an offshore structure on a given shore is dependent mainly on the length of the structure relative to its distance from the shoreline.

The detached structure case studies established distance to shore/length of structure relationship as being the controlling parameter in evaluating the impact of an offshore structure on the adjacent shoreline. Model study investigations supported this finding.

## RESULTS

The proposed LNG terminal pier, like all of the piers investigated, is a pile-supported structure. Although the proposed pile diameter is larger than the pile diameters measured for existing piers, the pile density (pile area/total pier area) for the proposed structure is at the low end of pile densities for the surveyed piers. The longitudinal spacing is 20D (20 pile diameters) and the transverse spacing is 4D (4 pile diameters).

Potential impacts associated with the proposed pier are a function of pile density, pile spacing, and incident wave steepness. Pile densities for the piers investigated along the southern California coast produced no discernible impacts on the net longshore movement of sediment. These piers exist in an environment similar to that found at the proposed site, both in terms of wave exposure and longshore sediment transport rates. Because the pile density of the proposed LNG pier is lower than 90 percent of all the piers investigated, it is expected that this pier would have a negligible impact on the longshore movement of sand. Consideration of incident wave steepness and pile spacing from theoretical and model studies also supports the conclusion that the proposed pier would not significantly affect the longshore transport of sand.

Potential impacts associated with the proposed breakwater were found both in the similar structure/similar environment and the model studies to be primarily a function of the distance to shore/length of structure ratio. Of course, consideration was also given to the structure's position relative to the littoral zone and the wave climate approaching the structure. The proposed breakwater's distance to shore/length of structure ratio was approximately two, and its location was in the proximity of the effective littoral boundary. This could cause a substantial reduction in wave energy reaching the littoral zone in the lee of the breakwater and, therefore, diminish the sediment transporting capacity of waves and currents in this area with a resultant deposition of sediment.

According to the findings of both the case studies and the model studies, at the proposed site, the distance offshore at which the breakwater would be expected to have no discernible impact on the adjacent shoreline would be 6,000 feet (6:1 ratio).

It was felt that the shoreline impact associated with the proposed breakwater would be significantly reduced, for a particular distance offshore, if the structure's length was shortened. In this manner, the ratio of 6:1 offshore distance/length of structure, established in both the similar structure/similar environment investigations and supported by the findings of model studies, could be maintained. However, it would still be important to verify if there would be any wave energy reduction in the effective littoral zone due to wave shadow effects caused by the breakwater.

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