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Case Study of a Successful Beach Restoration Project

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ABSTRACT

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A numerical model and two physical models were used to investigate shoreline erosion problems at Buhne Point (Humboldt Bay), California. Initially, a numerical tidal circulation model was utilized to determine the tidal current field adjacent to Buhne Point. Maximum flood and ebb tidal currents were identified and used as test conditions for the physical models. A 1:100-scale physical model of central Humboldt Bay was used to determine the local wave climate in the vicinity of Buhne Point from hindcast data propagated through the Humboldt Bay entrance for various water levels and tidal flow conditions. The wave and tidal information obtained from these models was used in a 1:50-scale physical model to simulate shoreline changes at Buhne Point, and to develop a shoreline stabilization plan for the site. An optimum plan was developed to insure that the beach fill would not erode. The plan entailed a 510-m-long groin and a 259-m-long shore-connected breakwater. It was constructed at Buhne Point in 1984 and has functioned as intended to this point, as predicted by the model investigations.

ADDITIONAL INDEX WORDS: *Hydraulic models, beach stabilization, coastal structures, engineering research, physical and numerical modeling, coastal engineering, shoreline erosion control, beach restoration.*

INTRODUCTION

In 1982 Congress authorized funds to the Federal Highway Administration for a "demonstration project" in the prevention of erosion to shoreline highways. State-of-the-art research methods were to be applied to determine the best method of repairing and protecting highways at Buhne Point, Humboldt Bay, California. Knowledge gained as a result of the project would be applied to other shoreline highways experiencing erosion. The Federal Highway Administration asked the San Francisco District, South Pacific Division, Corps of Engineers to take charge of design and construction of the project. Technical support was provided by the Los Angeles District. As part of the investigation, a sequence of model studies was agreed upon to provide data that would determine the most suitable plan for shore protection and restoration of Buhne Point. The model investigations were conducted by the Coastal Engineering Research Center of the U.S. Army Engineer Waterways Experiment Station (WES).

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Background

Humboldt Bay is a natural harbor located on the northern California coast about 418 km north of San Francisco (Figure 1). The entrance to the bay is protected by two rubble-mound jetties about 0.8 km apart extending from the ends of two long, narrow sand spits separating the bay from the ocean. The bay is 22.5 km in length and varies in width from 0.8 km to about 6.4 km. The entrance channel is dredged to 12.2 m and the interior channels (7.9-10.7 m deep) extend north and south, respectively.

Buhne Point is located within Humboldt Bay directly opposite the jettied entrance, about 4.8 km south of the city of Eureka, California (Figure 2). It is a prominent bluff about 23 m high. To the southwest of Buhne Point is a sand spit known as Buhne Spit (sometimes referred to as Buhne Point). A small community known as King Salmon, was developed shoreward (eastward) of Buhne Spit. King Salmon, with a population of about 400, is a small fishing village, camping/recreational site, and home for retired persons (U.S. ARMY CORPS OF ENGINEERS, 1979). King Salmon Harbor consists of slips developed in the Buhne Spit Shoal. The

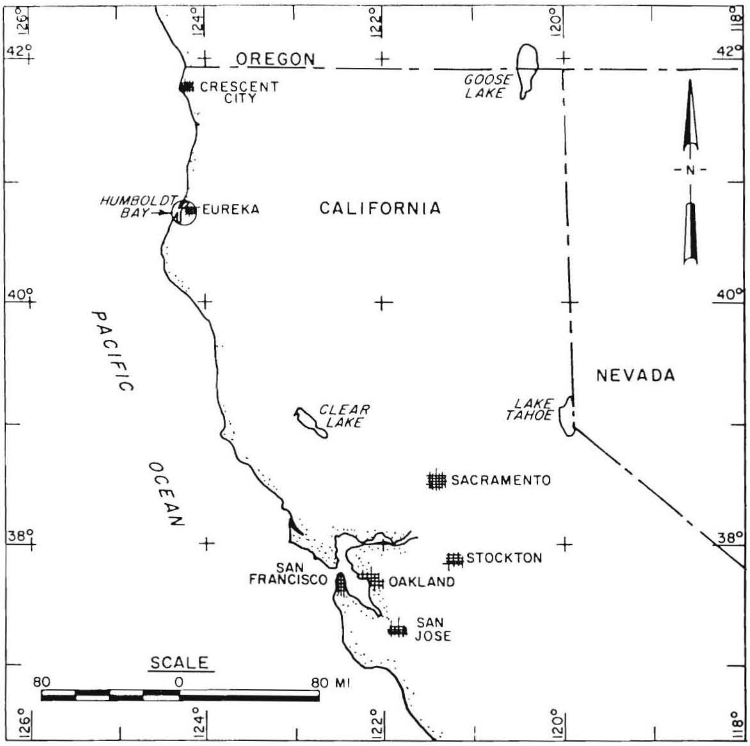

Figure 1. Location of Humboldt Bay.

entrance to the harbor (Fisherman's Channel) is also the entrance to the Pacific Gas and Electric's (PG&E) cooling water intake channel. Fisherman's Channel is a berthing area for the deeper draft boats moored within/along the channel.

Buhne Point Road, the bayside boundary of King Salmon, is the main transportation link to the area and also carries all the underground utilities, including the main sanitary sewer line. The road has been protected by emergency placement of rock along its entire length.

Wave energy entering through Humboldt Bay entrance and impinging upon Buhne Spit has created severe erosion of the spit and shoaling of the navigation channels. Sediment is transported southerly into the main navigation channel and around the southern tip of Buhne Spit into PG&E's cooling water intake channel (Fisherman's Channel). This shoaling of Fisherman's Channel occasionally closes the entrance to small-boat navigation and safe mooring. Additionally, it reduces the capacity of the cooling water intake supplying PG&E's steam power plant. Continuous dredging is required to provide adequate channel clearance and cooling water. Historical erosion of the spit is depicted in Figure 3.

The bay side of Buhne Point Road has been revetted with large rock to protect the road and underlying utilities (water lines, natural gas lines, and the main sewer line) from destruction by wave action. However, this emergency rock revetment was not designed as a permanent structure to withstand large breaking waves, and consequently, has been overtopped during severe storms resulting in waves breaking onto the roadway, disrupting traffic and causing localized flooding of homes and resort facilities. During severe storms, smaller rocks from the revetment have been carried into the roadway and cascaded into nearby homes, breaking windows and causing minor structural damage. The revetment has settled and unravelled at various locations, and Buhne Point Road has been undermined by wave wash-through and

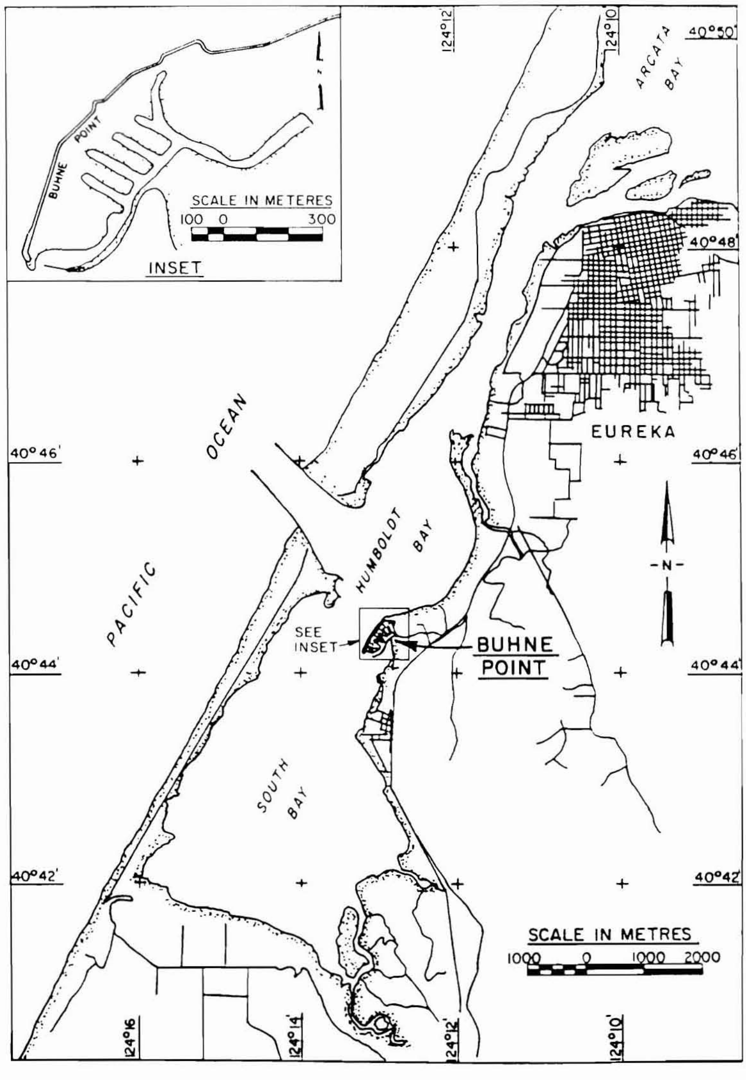

Figure 2. Location of Buhne Point.

collapsed in numerous instances. These conditions have created an extreme safety hazard during moderate to large storm wave conditions. Potentially, the large rocks on the revetment may become dislodged and roll onto the roadway, thus blocking access to King Salmon for emergency vehicles and the public. Also, as the remaining spit recedes (both horizontally and vertically), increasingly large waves will break farther up the rock revetment and the present condition will be worsened (DEPARTMENT OF BOATING AND WATERWAYS, 1983).

THE NUMERICAL MODEL

The numerical tidal circulation model used for this study was the WES Implicit Flooding Model (WIFM). WIFM (BUTLER, 1978) solves the vertically integrated time-dependent equations of fluid motion for a two-dimensional Eulerian system. The finite difference solution

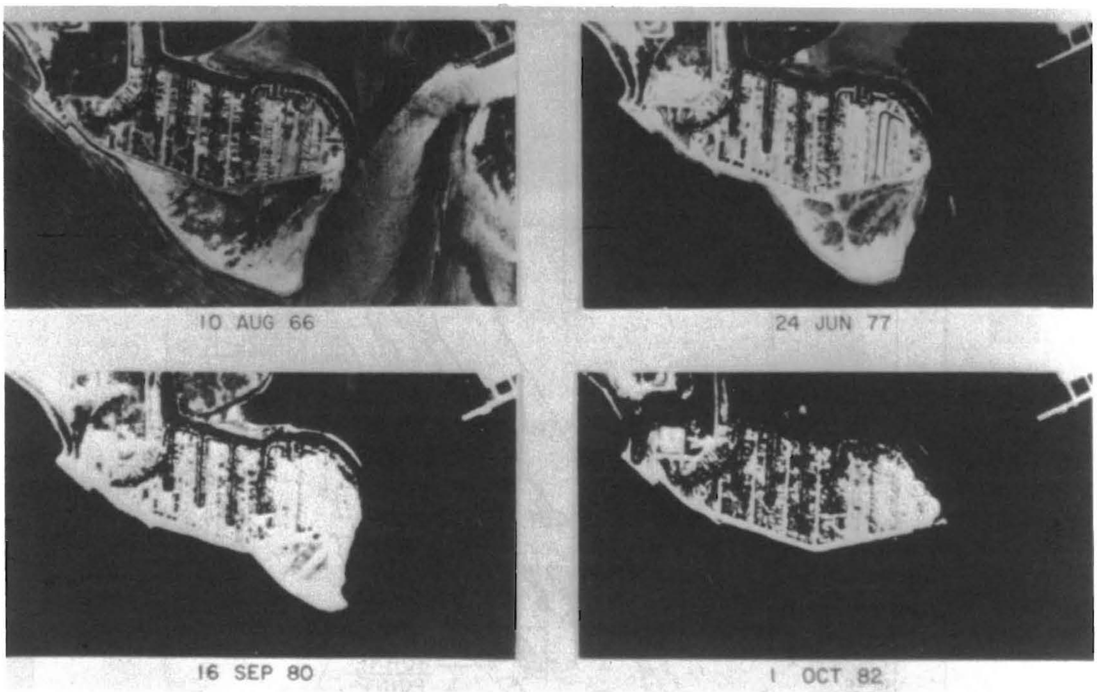

Figure 3. Historical erosion of Buhne Point spit.

in WIFM uses an alternating-direction-implicit (ADI) method. The computation scheme accounts for flooding and drying of low-lying coastal terrain due to fluctuations in water elevation. WIFM employs a spatially variable stretched finite difference grid to minimize costs and provide detail in areas of high gradients or particular study interest. Figure 4 shows the grid relative to the shorelines of Humboldt Bay. The grid axes were aligned roughly parallel to the jetties and the Buhne Point shoreline. The cell sizes ranged from 95 by 95 m near Buhne Point, to 935 by 822 m in the northwest corner of the grid.

Bathymetric and tidal elevation, and current data for Humboldt Bay were available from Corps studies (U.S. CORPS OF ENGINEERS, 1981; COSTA and STORK, 1984) and National Ocean Survey (NOS) tide records. Tidal elevations were used as boundary conditions for all open-water cells at the edges of the computational grid, and the numerical model for Humboldt Bay was calibrated by matching computed tidal signals (tidal elevations and currents) within the grid to prototype measurements (Figure 5). Eight-constituent tide signals, representing 90% of the total tide amplitude, were used on the model boundaries. Verification was achieved by simulating tide elevations and currents for a period of time different than the calibrated period and comparing the computed and measured tidal elevations and currents. Results of the tidal circulation numerical model were used to determine maximum flood and ebb tidal currents and corresponding water levels at the boundaries of two physical models.

THE PHYSICAL MODELS

Two geometrically undistorted physical models were constructed at WES at scales of 1:100 and 1:50 (Figures 6 and 7). Following selection of the linear scales, the models were designed and operated in accordance with Froude's model law (STEVENS, 1942). The scale relations used for design and operation of the models are shown in Table 1. Monochromatic wave generators were used to simulate wave conditions and circulation systems to reproduce steady-state ebb and flood tidal flows. Model wave heights simulated the prototype significant wave height.

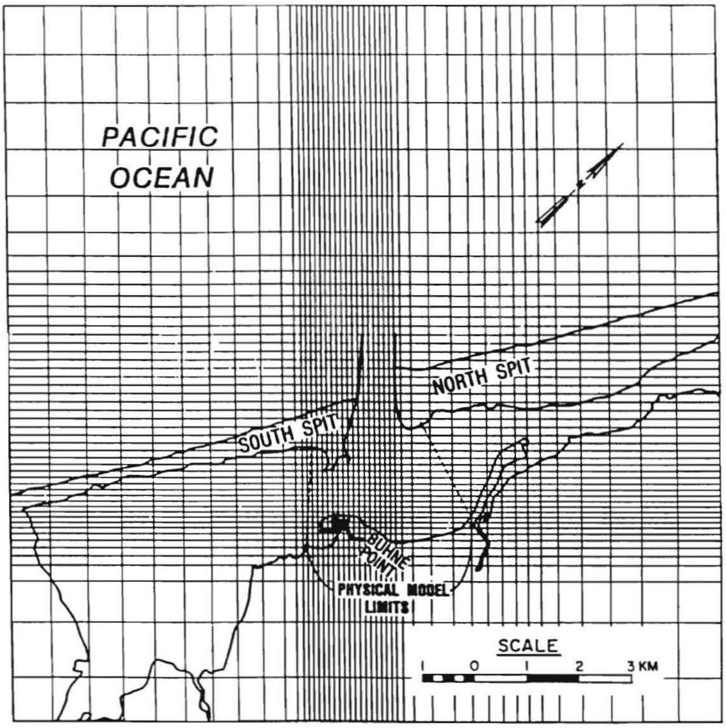

Figure 4. Finite difference grid for the numerical model.

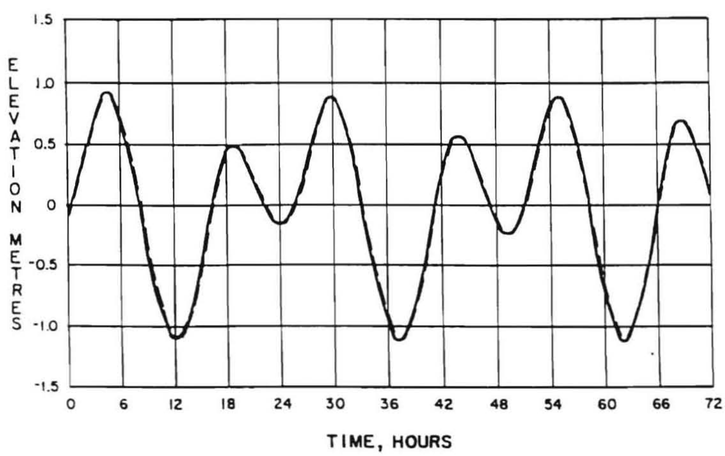

Figure 5. Comparison of computed tidal signal (solid line) versus prototype tide (dashed line) inside Humboldt Bay after calibration.

Figure 6. General view of 1:100-scale central Humboldt Bay model prior to modifications.

A crushed coal tracer material (specific gravity = 1.3, D_{50} = 0.80 to 1.62 mm) was used in the 1:50-scale model to qualitatively determine shoreline movement at Buhne Point for historical conditions and the stabilization plans. The tracer was chosen in accordance with the scaling relations (NODA, 1972) that indicate a relation or model law among the four basic scale ratios, *i.e.*, the horizontal scale λ ; the vertical scale μ ; the sediment size ratio, η_D ; and the relative specific weight ratio, η_Y (Figure 8). These relations were determined experimentally using a wide range of wave conditions and bottom materials and are valid mainly for the breaker zone. Several types of movable-bed tracer materials were available, however, previous studies at WES (BOTTIN and CHATHAM, 1975) indicate that crushed coal in a physical model can satisfactorily reproduce aspects of the movement of prototype sand. A detailed discussion of modeling sediment transport in movable bed models is given in KAMPHUIS (1982).

Wave heights in the models were obtained with parallel-rod, resistance-type wave gages and current magnitudes were determined by timing the progress of an injected dye relative to known distances on the model floor. In addition, overhead photographs were used to document wave and sediment patterns.

Still-water levels of 0.0 m (mean lower low water), +0.98 m (maximum flood tidal el) +1.13 m (maximum ebb tidal el), +2.04 m (mean higher high water) and +2.9 m (extreme high water) were used during model testing. Vertical datum for both models was mean lower low water (mllw). The tidal circulation systems were used only for the flood and ebb water levels.

The 1:100-Scale Physical Model

The 1:100-scale model reproduced the jettied entrance to Humboldt Bay, approximately 5,486 linear m of shoreline inside the bay (including Buhne Point), and underwater con-

Figure 7 General view of 1:50-scale Buhne Point model with a groin and offshore breakwater plan installed.

Table 1. *Scaling Characteristics of the Physical Models.*

Characteristic	Dimensions*	Model:prototype relation (1:100)	Model:prototype relation (1:50)
Length	L	1:100	1:50
Area	L^2	1:10,000	1:2,500
Volume	L^3	1:1,000,000	1:125,000
Time	T	1:10	1:7.07
Velocity	L/T	1:10	1:7.07
Discharge	L^3/T	1:100,000	1:17,680

*Dimensions are in terms of length and time.

tours throughout the central portion of the bay and the area between the jetties. The total area reproduced in the model was approximately 1,858 sq m, which represented about 18.6 sq km in the prototype. The model was used to determine the wave climate (angle of wave front and wave heights along this front) in the vicinity of Buhne Point.

Comprehensive statistics of deep-water wave conditions in the Humboldt Bay area were not available, so hindcast data (NATIONAL MARINE CONSULTANTS, 1960; DEPARTMENT OF NAVIGATION AND OCEAN DEVELOPMENT, 1977) were used for the study. A linear wave refraction analysis (DOBSON, 1967) computed refraction and shoaling coefficients required to convert the deep water data into shallow-water values at the bay entrance. From these analyses representative shallow-water wave characteristics from three incident directions were selected for model testing.

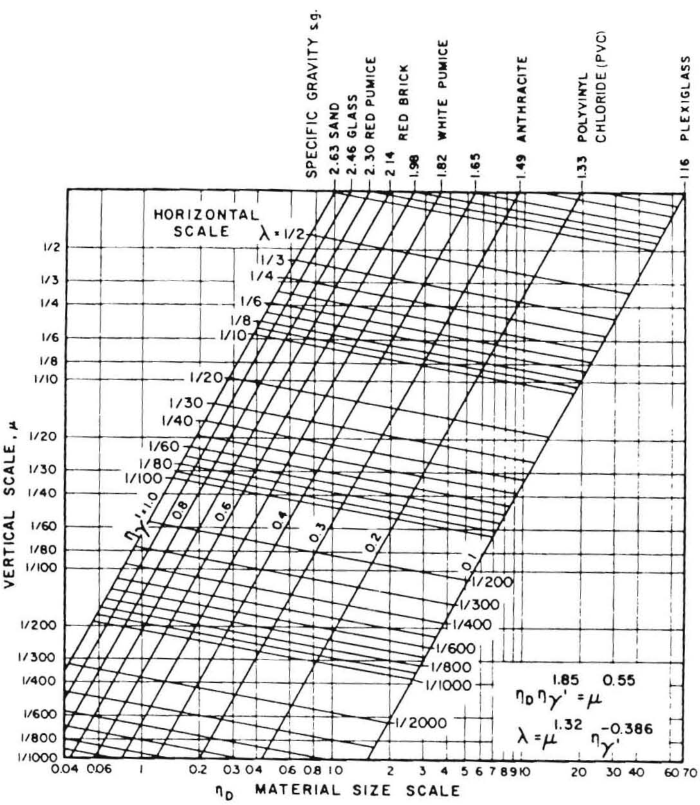

Figure 8. Graphic representation of model law (NODA, 1972).

Wave pattern photographs obtained for selected test waves from north, northwest, and west were analyzed to determine the shape and direction of wave fronts in the vicinity of Buhne Point. A composite wave front was selected since the resultant wave shape and direction were essentially the same for all test directions. Wave height data for 185 test conditions were obtained along the wave front location and used as input data for the 1:50-scale model. Test waves from northwest (waves approaching more directly down the axis of the channel) resulted in significantly larger wave heights in the vicinity of Buhne Point than test waves from north and/or west. Typical wave patterns approaching Buhne Point are shown in Figure 9.

The 1:50-Scale Physical Model

The 1:50-scale model reproduced approximately 2,800 linear m of shoreline within the inlet adjacent to the Buhne Point area and the immediate underwater contours in Humboldt Bay. The total area reproduced in the model was approximately 1,600 sq m which represented about 4 sq km in the prototype. This model was used to determine the causes of erosion at the point and the effectiveness of various structures proposed for shore protection under various wave, water level, and steady-state tidal current conditions. It also optimized the locations, lengths, crest elevations, and type of structures required to prevent erosion. The model was constructed at a 1:50-scale because wave breaking and sediment transport are important in the area, and scale effects can become significant for small scale models with shallow water depths (*i.e.*, depths and wave heights in a 1:50-scale model are twice those in a 1:100-scale model).

Model waves were generated by a 26-m-long

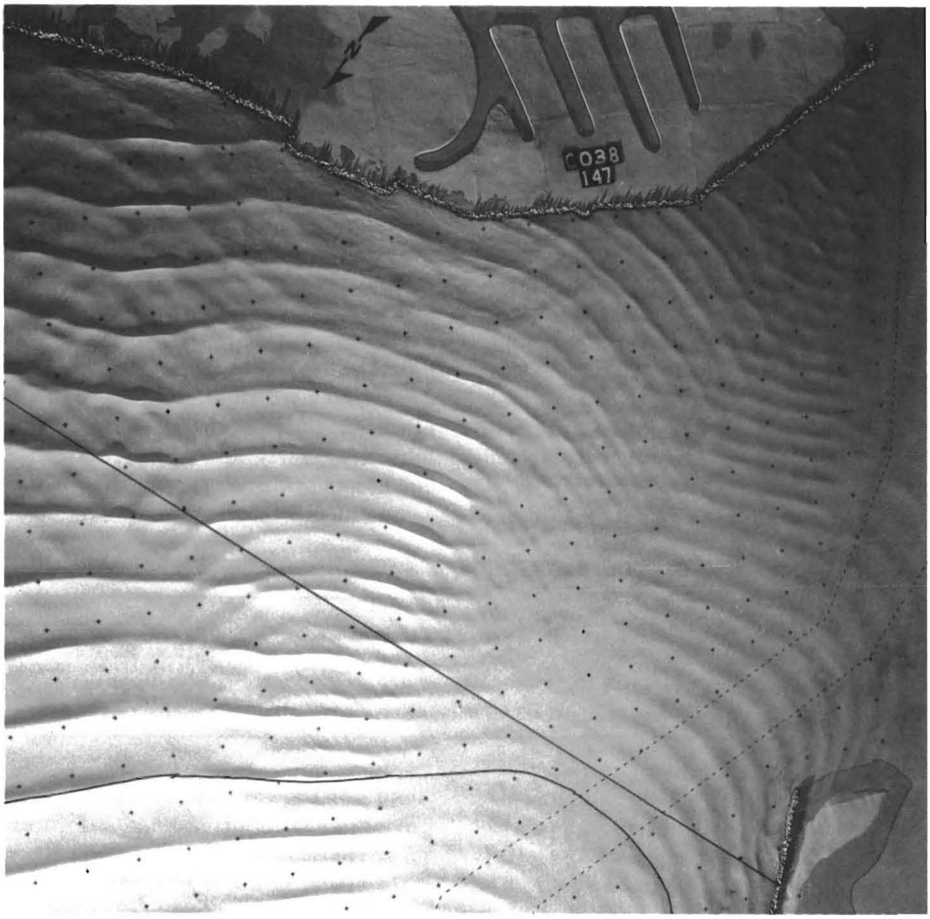

Figure 9. Typical wave patterns approaching Buhne Point in the 1:100-scale model prior to construction of the project.

curved plunger type wave generator. The length of the stroke and the frequency of the vertical motion were variable over the range necessary to generate waves with the required characteristics. Different stroke settings at various locations along the wave plunger resulted in variable wave heights along the wave front as determined by the 1:100-scale model test results.

Prior to testing of various improvement plans, historical erosion tests were conducted to determine the causes of erosion at Buhne Point. Shoal formations were constructed in the model representing spits similar to those existing in the prototype in prior years (as determined from aerial photographs). Various test waves resulted in erosion of the northeastern portion of the spit and accretion in the navigation channel southwest of Buhne Point. Wave conditions entering through the Humboldt Bay entrance and impinging onto Buhne Point created longshore currents in a southwesterly direction.

Test waves with the higher water levels, in particular, eroded the spit and the currents moved material southwesterly into the dredged channel. Erosion patterns, evidenced by aerial photographs, thus were verified with those severe test wave conditions in conjunction with the higher water levels. Tidal currents had only minor impacts on the movement of sediment.

The original improvement plan for the project (Figure 10) consisted of a 381-m-long timber-pile groin parallel to and 122 m east of the navigation channel to King Salmon Harbor. The groin extended northwesterly into the bay from the southern end of Buhne spit. A rubble wave absorber rising to an elevation (el) of 4.2 m was placed adjacent to the channel side of the groin and a rubble-mound head protected the bay end of the timber piles. The plan also included a large sand fill (el +3.7 m) adjacent to Buhne Drive that extended bayward. When subjected to extreme test conditions, erosion occurred at the eastern portion of the fill with sediment migrating in a westerly direction and accreting against the groin (Figure 11). Initially, only the finer particles moved around the head of the groin toward the navigation channel; however, as tracer material accreted bayward against the head of the dike, the larger sediment-size particles migrated around the head of the groin toward the navigation channel. Some material also penetrated through the voids of the rubble-mound head section of the groin. As erosion continued along the upcoast end of the fill, significant overtopping of the existing revetment was observed, particularly with high water levels and large test waves.

A series of groins were installed in the model perpendicular to the shoreline in an effort to decrease the magnitude of the longshore currents and hold the northern end of the fill in place. Material between each groin, however, moved westerly and accreted adjacent to the downcoast groin. As the beach profiles changed, sediment migrated westerly around the heads

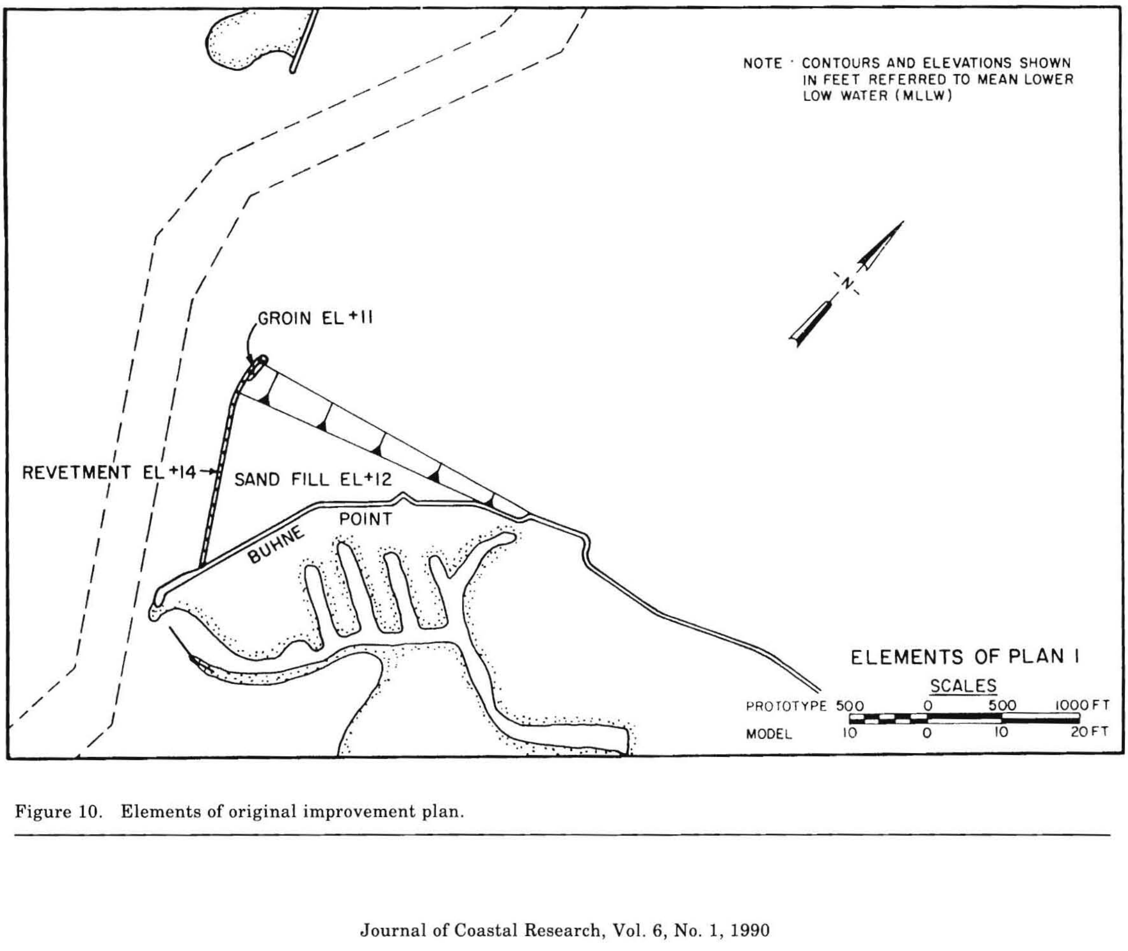

Figure 10. Elements of original improvement plan.

Figure 11. Shoreline configuration showing erosion and accretion for the original test plan.

of the groins and eventually toward the navigation channel. Overtopping of the existing revetment along Buhne Drive also occurred for the groin plan for the higher water levels, after the northeast corner of the sand fill eroded.

Twelve additional improvement plans were tested that consisted of shore connected or offshore breakwaters. Variations consisted of changes in the lengths, alignments, and/or cross sections of the various structures. Erosion occurred in the lee of some of the breakwaters for extreme high tide conditions, which indicated their crest elevations had to be raised. Some of the offshore structures also resulted in erosion of the sandfill due to diffracted wave energy around their heads. The optimum improvement plan consisted of a 260 m shore connected breakwater with a +4 m crest el. A reverse curve in the breakwater where it originated from the Buhne Point revetment minimized wave convergence and runup in this area. Also included was a 130-m-long extension of the original groin. The shoreline configuration was subjected to all test conditions. Some test waves slightly rearranged the shoreline (based on the shape of the incoming wave front) but, in general the shoreline remained stable (Figure 12) for all combinations of waves, tidal currents, and water levels. Slight erosion of the shoreline did occur where the sand fill was not protected by the breakwater and accretion against the groin head occurred until the shoreline stabilized.

Based on model test results, the Corps of Engineers completed modifications at Buhne Point in 1984. The completed project and beach configuration during March 1985 is shown in Figure 13. The project has been monitored since construction and, similar to the physical model test results, the shoreline receded slightly in the center and accreted along the inside of the south groin until it stabilized. The project has

Figure 12. Stable shoreline resulting for optimum improvement plan.

performed successfully, as the study indicated, and has resulted in eliminating the threat to Buhne Drive.

SUMMARY AND CONCLUSIONS

This investigation simulated the combined erosional forces of wave climate, tidal currents, and water level fluctuations to predict shoreline response at Buhne Point, California. Large test waves at high water levels were the major cause of erosion, whereas tidal currents had only minor impacts on sediment movement. Erosion of the historical shoreline most likely occurred during the winter storm seasons along the coast of California, due to the combined storm effects of high water levels with large waves.

The approach used in this investigation, the joint application of numerical and physical models to predict coastal erosion patterns caused by complex hydrodynamic forces, can be economically applied to many areas where shoreline erosion problems exist. The study took about six months to complete, from design to final tests. Approximately one month was needed to build the physical models which were constructed simultaneously. The numerical modeling efforts were done concurrently with construction of the physical models. The joint use of numerical and physical models allows for a cost effective and accurate plan of study (*i.e.*, relatively inexpensive numerical modeling of tidal effects and accurate physical modeling of the nonlinear interactions among short-period waves, tidal currents, and sediment).

ACKNOWLEDGEMENTS

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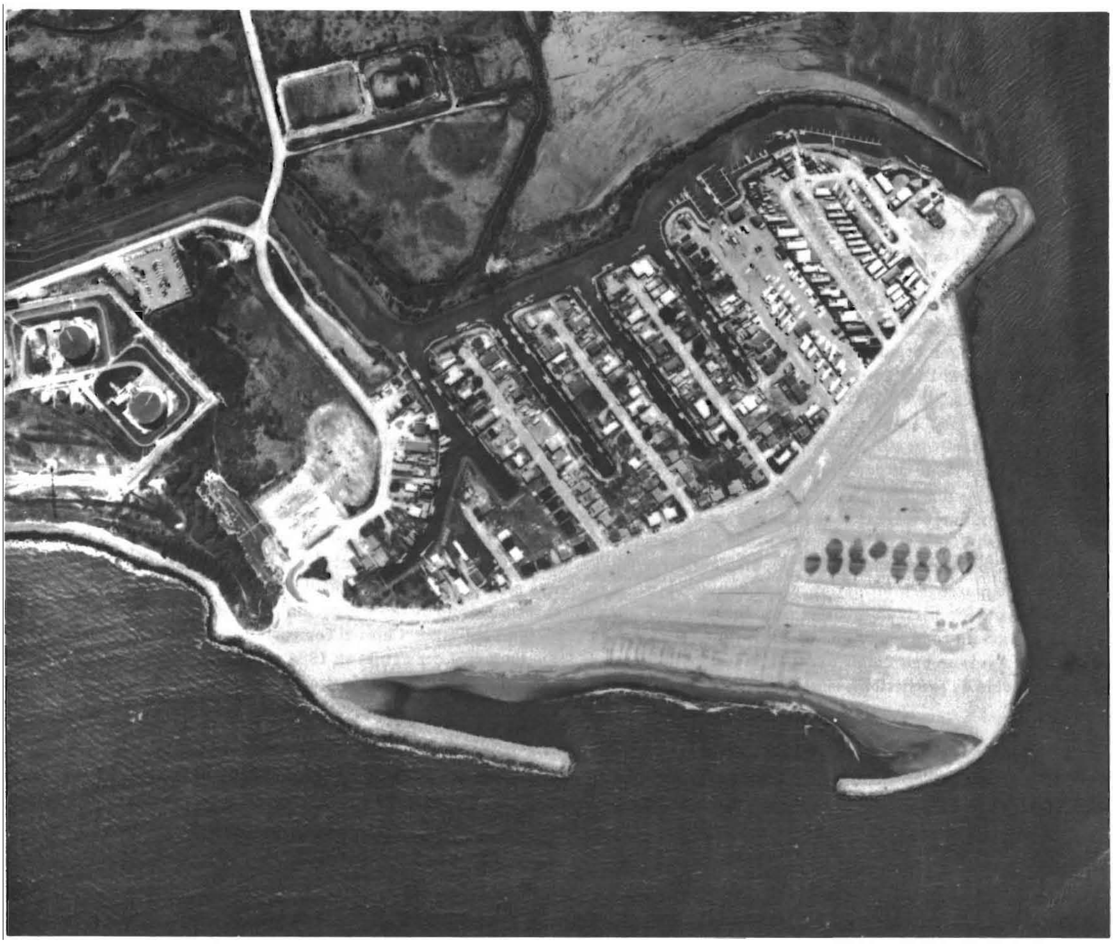

Figure 13. Completed project at Buhne Point and shoreline configuration during March 1985.

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□ ZUSAMMENFASSUNG □

Um Probleme von Küstenerosionen bei Buhne Point (Humboldt Bay-Californien) zu untersuchen, wurden ein numerisches und zwei physikalische Modelle betrieben. Mit dem numerischen Modell konnten die Tideströmungen in der Umgebung des Untersuchungsgebietes ermittelt werden. Die gewonnenen Daten dienten der Eichung des physikalischen Modells (Baßstab 1 : 100) für den zentralen Teil der Humboldt Bay. Mit diesem Modell wirde das lokale Wellenklima für verschiedene Wasserstände und Strömungsbedingungen im Nahbereich von Buhne Point bestimmt. Diese Daten wurden in einem weiteren physikalischen Modell (Maßstab 1 : 150) verwendt, um Veränderungen der Küstenlinie bei Buhne Point zu simulieren und daraus geeignete Maßnahmen zur Stabilisierung der Küste abzuleiten. Als Planungsziel galt die Verhinderung von Erosionen an einer Strandaufspülung. Aus den Untersuchungen ergab sich die Notwendigkeit, eine 510 m lange Buhne und einen 259 m langen Wellenbrecher mit Uferanschluß zu bauen. Die Baumaßnahmen wurden 1984 durchgeführt und haben bisland die erwünschten und durch die Modellversuche vorhergesagten Effekte gehabt.—*Reinhard Dieckmann, WSA Bremerhaven, West Germany (FRG).*

□ RÉSUMÉ □

Un modèle numérique et deux modèles physiques ont été utilisés pour étudier les problèmes d'érosion à Buhne Point (baie de Humboldt, Californie). Initialement, un modèle numerique de circulation de la marée a servi à déterminer les champs de courants à l'entour de Buhne Point. Les maxima de flot et de jusant ont été identifiés et utilisés comme conditions test des modèles physiques. Un modèle au 1/100ème de la baie de Humboldt a permis de définir l'onde locale climatique au voisinage de Buhne Point. On est parti de données sur la propagation depuis l'arrière à travers l'entrée de la baie de Humboldt, ce, pour diverses profondeurs et conditions de marée. L'information sur la houle et la marée obtenue par ces modèles a été utilisée pour créer un modèle physique au 1/50ème qui simulait la modification du rivage à Buhne Point, et a permis de développer un plan de stabilisation du rivage. La non érosion du remplissage de plage devait être assurée par un plan optimum. Celui-ci comportait une jetée de 510 m de long et attenant à lui, un brise lame parallèle à la côte de 259 m de long. Ils furent construits en 1984 et jusqu'à ce jour fonctionnèrent selon le modèle de prédiction.—*Catherine Bressolier, Labo. Géomorphologie E.P.H.E., Montrouge, France.*

□ RESUMEN □

El análisis de los problemas de erosión en Bunhe Point (Humboldt Bay) California, ha sido realizado por medio de un modelo numérico y dos modelos fisicos. Inicialmente, y con objeto de determinar el campo de corrientes adyacentes a Bunhe Point, se utilizó un modelo numérico de circulación de marea. Con este modelo se identificaron las corrientes máximas de vaciante y llenante, que fueron posteriormente usadas como condiciones de ensayo de los modelos fisicos. Para determinar el clima maritimo en los alrededores de Bunhe Point se utilizó un modelo fisico escala 1:100 de la zona central de la Bahia de Humboldt, propagando diversos oleajes a través de la entrada de la Bahia de Humboldt con varios niveles de agua y condiciones de flujo de marea. La información de oleaje y marea obtenida de estos modelos fue usada en otro modelo fisico escala 1:50 que simulaba los cambios de la linea de costa en Bunhe Point, para asi poder desarrollar un plan de estabilización costera de la zona. Como resultado de estos modelos se obtuvo unplan óptimo que aseguraba que el relleno de la playa no se erosionaria. El plan consistia en un dique de 510 m de largo conectado con otro dique de 259 m de largo. El citado plan fue llevado a cabo en 1984 y ha funcionado hasta el momento según se predijo en los modelos desarrollados.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*