CHAPTER 187

DESIGN AND PERFORMANCE OF ARTIFICIAL BEACHES FOR THE KUWAIT WATERFRONT PROJECT

Timothy W. Kana,¹ Mohammad Al-Sarawi,² and Michael Holland³

Introduction

One of the largest recreational waterfront projects ever designed (Sasaki Associates, 1979) is located along 20 kilometers (km) of the City of Kuwait on the Arabian Gulf (Fig. 1). Planning and design were initiated in 1976, and the first phases of construction were completed in 1985. Amenities included artificial beaches, promenades, waterfront parks, and an artificial island. Extensive armoring has also been installed, ranging from 10-ton, dolosse breakwaters to large, quarry-stone revetments. Total investment in the first two phases is upwards of US \$100 million.



FIGURE 1. Location map of the Kuwait waterfront showing principal features.

- 1) Coastal Science & Engineering, Inc., P.O. Box 8056, Columbia, SC, USA 29202
- 2) Faculty of Science, Kuwait University, Safat, Kuwait
- 3) Sasaki Associates, Inc., 64 Pleasant Street, Watertown, MA, USA 02172

One aspect of the master plan--recreational beaches--required special consideration because of the moderately high tide range of 3.5 m. typical of Kuwait Bay. The present paper describes the participation of the authors since 1977 in developing design criteria [Research Planning Institute, Inc. (RPI), 1979], supervising engineering (Holland, 1981), and monitoring performance (Al-Sarawi et al., 1986) of eight pocket beaches constructed for the waterfront project.

Project Setting

The study area (Fig. 1) is located along the southeast margin of Kuwait Bay at the head of the Arabian Gulf. This is a clastic shoreline composed of sediments derived from the Shatt al-Arab mouth of the Tigris-Euphrates River approximately 50 km to the north. The natural waterfront along Kuwait City consists of a series of perched beaches and low headlands formed of intertidal coral rock. Ras al Ardh, the most prominent headland, marks the division between Kuwait Bay and The Arabian Gulf. West of Kuwait Towers is a commercial shoreline of dhow harbors which predate the rapid build-up of the oil-export industry. With a tide range varying from (est.) 3.0 m to 3.5 m from Ras al Ardh to Shuwaikh, a broad intertidal terrace is exposed at low tide.

East of Kuwait Towers, the project area forms a broad arc bounded by the headland at Ras al Ardh. Midway along the shoreline near the location of Green Island (Fig. 1) is a slight bulge produced by a less prominent headland (beach rock terrace). Between Green Island and Kuwait Towers, Bnade al Kar Sea Club divides the shoreline between recreational beaches to the northwest and a steep rubble edge to the southeast. This area is part of Phases I and II of the Kuwait waterfront (KWF) project.

Coastal Processes

Tide plays a dominant role in the shoreline dynamics along the KWF because of its moderately high range [3.5 m between mean higher, high water (MHHW) and mean lower, low water (MLLW): British Admiralty (1982)]. This limits exposure of the beach to wave action at middle and upper tide levels only. The principal driving force for currents in the Arabian Gulf are the tides which enter through the Strait of Hormuz, 950 km southeast of Kuwait. Local winds play an important secondary role in establishing circulation patterns. Galt et al. (1983) report a net surface flow which is counterclockwise at the head of the gulf under the northwest and southeast winds which are most common. This produces a net ebb-directed flow (time-averaged) in the nearshore area of the KWF project.

Coastal processes and longshore transport are highly variable, being dependent on local winds, nearshore bathymetry, and wave-refraction patterns. Hayes et al. (1977) found that wave energy and longshore transport are low in magnitude along the developed waterfront of Kuwait City. Waves at the shoreline in Kuwait Bay average less than 15 centimeters (cm) and thus produce net sand transport rates on the order of 10^3 - 10^4 cubic meters per

year (m^3 /yr). Longshore transport is higher along the Arabian Gulf shoreline of Kuwait where inshore waves are typically 20-30 cm high. Kana et al. (1986) estimate net southerly rates of 5 x 10⁴ m³/yr for a site 70 km south of Ras al Ardh.

Long-term erosion rates are unavailable but, based on site-specific data for the Kuwait City shoreline (Hayes et al., 1977), rates are low because of:

- 1) Protection by the rocky. low-tide terrace.
- 2) The compartmentalized nature of the shoreline.
- 3) Low wave energy.

Lacking tropical storms and associated storm surges, beach erosion is limited to periods of highest tides and infrequent shamal winds from northerly components.

Sediments and Beach Morphology

Sediments along the KWF are a mixture of sand, building blocks, rock, and other debris (Hayes et al., 1977). Gravel-sized sediment was found to occur at the base of eroding scarps, the upper swash line (limited small sizes), at the toe of the beach, and at various positions on the low-tide terrace depending on exposure or mining of the beach platform. Sand was found to occur as a thin veneer over the mid-beach face and also as intertidal sand bars on the low-tide terrace. Most remaining beaches prior to construction of the KWF project had moderately to poorly sorted sand ranging from 0.25 millimeters (mm) to 1.0 mm diameter. The principal mode occurs at the break between medium and fine sand (Hayes et al., 1977).

With low wave energy, the active beach slope tends to be steep where beaches exist along the KWF. Hayes et al. (1977) found that slopes ranged from 0.08 to 0.13, or roughly 1 on 10. Berms were widest between Shuwaikh Port and Bnade Al Kar. Typical high-tide berm widths in 1977 were 20-30 m. From a recreational standpoint, Kuwait City beaches are normally usable for bathing only during higher tide stages because of exposure of the low-tide terrace.

Design Planning

A field-monitoring program was initiated in 1977 (Hayes et al., 1977) in order to provide basic criteria for design of improvements to the waterfront edge. These measurements became the basis for a set of design criteria and recommendations for artificial beaches as well as larger-scale structures such as a 400-m-diameter artificial island. Beaches were designed to accommodate the high tide range and high-density recreational use.

A key aspect of the early, field-survey program was measurement of littoral processes over ten days, every quarter for two years at six representative stations along the KWF. Beach profiles were also measured at over 30 stations every quarter (Fig. 2). For the most part, Kuwait coastal processes are exceedingly weak and changes in the beach profile are minimal (Hayes et al., 1977). However, Kana and Sexton (1978) measured storm processes during a moderate shamal in February 1978 and found that this one event accounted for 25 percent of the gross annual longshore transport. It also produced 2-4 m³/m of erosion along the active profile where sand beaches existed. These field data provided confirmation of the predominance of northwesterly winds and waves along the waterfront.



FIGURE 2. Coastal process and selected beach profile stations monitored along the Kuwait waterfront.

Wave-refraction models were developed for Kuwait Bay and the waterfront shoreline by RPI (1979) and Al-Sarawi et al. (1986). Galvin (1979) prepared the original estimate of design waves, using standard hindcasting procedures which were applied in the earlier refraction analysis. The models provided guidance on local longshore transport rates and directions, and the presumed stable configuration of artificial beaches into the incident wave field. Example regional and inshore diagrams are given in Figure 3. These were prepared with a program written by S.J. Siah using a finite-element grid scheme (Al-Sarawi et al., 1986).





FIGURE 3. Regional (upper) and example inshore refraction diagram (lower) for the area around Green Island. Input parameters are $H_{1/3} = 1.37$ m. $T_{1/3} = 4.6$ s. Tidal elevation approximates MHHW.

It was found that limited reaches of the Kuwait City shoreline would accommodate recreational beaches. Some areas were considered unsuitable because of exposure or proximity to tidal channels. Other areas were eliminated from consideration because of alternative land use such as a marina or aquarium which were integral parts of the master plan. RPI (1979) recommended 6-8 pocket beaches bounded by groins which could double as pedestrian promenades and outfall jetties for upland drainage. Sand compatibility analyses indicated that an inland source would be required since nearshore deposits were considered unsuitable for environmental reasons. Sasaki Associates (1979) incorporated these conceptual designs into the final master plan. Final design proceeded through 1981 with construction of Phase I beginning that year.

Construction

Phases I and II of the KWF project (Kuwait Towers to Doha Marina, Fig. 1) were essentially complete by late 1986. Infrastructure and the major design elements--retaining groins, the artificial island, and the "hook" at Kuwait Towers--were completed before placement of sand in each artificial beach.

Figure 4 illustrates a typical pocket-beach design and postconstruction configuration in December 1985 (Fig. 4b). Given the local orientation of the shoreline oblique to predominant waves refracting from the northwest, a typical configuration consisted of a broad downdrift end with the widest part of the berm measuring 150* m. Typical length of each beach was 500 m. Each beach is backed by a revetment designed to +6.5* m Kuwait Land Datum (KLD). The datum approximates local MLLW, thus placing the crest of each structure about 2.5 m above highest still-water levels. Design berms were set at +4.5 m KLD.

Figure 5 illustrates various stages of sand placement by land-based equipment. The fill was placed in accordance with the design planform of each beach to minimize losses. The beach face and lower part of the profile were allowed to adjust naturally to an equilibrium slope (Fig. 5c).

Comparative profiles (Fig. 6) show the final configuration of two representative beaches in relation to the original profile. Sediment sampling by the authors in 1985 indicated the nourishment sand from upland matched the native sand very well (Fig. 7).

Innovative Features

Two innovative design elements of the KWF project are shown in Figures 8 and 9. The first, Green Island, consists of a 400-m-diameter artificial "island" armored with dolosse and connected to the mainland by a "tombolo" beach. Originally, the master plan called for a tidal channel between the island and shore, but this concept was abandoned in favor of recreational beaches. This design imitates the natural tendency of a shoreline to develop an isthmus (tombolo) in the lee of an offshore island where sediment supply is plentiful.

A second, unusual design element was the "hook" built on the exposed, low-tide terrace adjacent to Kuwait Towers (Fig. 9). This feature anchors a pocket beach facing west into the principal fetch direction.

Postconstruction Monitoring

Postconstruction surveys have been initiated by Al Sarawi et al. (1986) in order to develop preliminary estimates of erosion and changes in local coastal processes produced by the KWF project. These surveys include quarterly rod-and-level measurements and coastal process measurements over ten-day periods. Additional measurements have been taken to monitor inshore turbidity levels adjacent to the beach fill. Surveyed profiles have been analyzed to compute sediment budgets for several compartments along the shoreline.





FIGURE 4. (a) Typical pocket beach designed for the KWF project. Alignment is into the predominant wave direction to minimize longshore sand losses. Retaining structures double as promenades and outfalls. (b) Pocket beach nearing completion on 12 December 1985 along the KWF project.



FIGURE 5. Stages of beach construction by land-based equipment beginning with spreading along the profile (top), natural adjustment of the beach face (middle), and final completion in an equilibrium planform (bottom). Photos taken at low tide in March 1985 by T.W. Kana.



FIGURE 6. Comparative profiles from two representative artificial beaches showing the fill in relation to the preconstruction profile (see Fig. 2 for station location).



FIGURE 7. Frequency-size curves for composite samples of artificial and natural beach sediments along the KWF study area. Note the slightly better sorting of natural deposits, but generally very good correspondence between the two curves.

COASTAL ENGINEERING-1986



FIGURE 8. Conceptual plan for Green Island (Sasaki Associates, 1979) and an aerial photo of the feature nearing completion on 12 December 1985. Note the connecting beaches shaped into a tombolo. Kuwait Towers is in the upper right corner.



FIGURE 9. Conceptual plan for the artificial beach at Kuwait Towers and an aerial photo of construction on 12 December 1985. The beach is oriented into the primary fetch direction from the west. The jetty shown extending from the hook in the photo is a temporary feature for loading rock imported from Oman for the project.

The typical unit-fill volume for artificial beaches was 50-85 m³/m. Interestingly, this volume was less than might be expected because each of the new beaches was "perched" on a low-tide terrace. This eliminated much of the profile adjustment normally associated with profile renourishment. On the other hand, the high-tide range required construction of the berm at elevations much higher than typical for beach nourishment. Total quantities of beach fill were unavailable at the time of this writing because some of the beaches had not been completed by the time of the most recent survey (July 1985). However, through that date, approximately 300,000 m³ of sand had been added to the KWF project in the beach zone. For beaches which had been in place for at least one year, the extent of profile movement (sweep zone) was typically less than 5 m³/m, or about 6-10 percent of the average, unit-nourishment volume. This compares with typical adjustments of 50 percent or more of the initial fill volume during other beach nourishment projects in order to build up subtidal portions of the profile.

Compared with the 1977-1979 period, measurements of coastal processes indicated little change in wave-energy flux at three monitoring stations (P3 just west of Green Island; P2 at the easternmost pocket beach; and P1, 3 km from Ras al Ardh along the hardened, existing shoreline). Only one station monitored (P4, 1 km southwest of Kuwait Towers) experienced a significant decrease in wave energy, with mean breaker heights decreasing by 40 percent. This is probably a result of construction of the hook at Kuwait Towers which tends to shift incident waves refracting around the headland further downdrift.

Despite the similarities in wave-energy flux at most stations, there was measurably reduced net longshore transport at P3 near Green Island and at P2 near AI Shaab Sea Club (the only two sites where processes were routinely measured along new beaches for comparison with the 1977-1979 surveys). This could be attributed, in part, to sheltering by Green Island during winds from easterly components. Westerly component winds produced comparable wave heights as the 1977-1979 data set, but lower longshore transport rates because of the realignment of the pocket beach into the predominant approach direction. At the other pocket beach, P2, the new shoreline alignment is offset about eight degrees from the strandline, reducing the incident wave angle into the compartment. Thus, net longshore transport has also decreased.

Although long-term monitoring is needed to determine the ultimate success and longevity of each artificial beach. preliminary evidence suggests the fill has rapidly adjusted to an equilibrium planform and profile. Aerial overflights in December 1984 and December 1985, as well as periodic ground inspections, showed no evidence of large sediment plumes, sand spits, or other geomorphic indicators of rapid longshore transport. This contrasts with a situation documented by Hayes et al. (1977) in which a small-scale nourishment project at Al Shaab Sea Club experienced rapid loss of fill because of improper sediment size (too fine) and a design which presumably was out of equilibrium with a natural planform into the predominant wave direction.

Conclusions

Early surveys after construction of artificial beaches along the Kuwait waterfront indicate:

- 1) It is possible to construct artificial beaches in high tide-range settings (up to 3.5 m) which are usable for swimming throughout most of the tidal cycle.
- 2) Orientation of artificial beaches should be aligned into the predominant wave approach to minimize sand transport. Wave-refraction models using appropriate hindcast wind frequencies is a minimum design requirement. However, site-specific littoral process measurements should be made to confirm local sand transport patterns, especially where inshore bathymetry is subtle and irregular such as Kuwait's shoreline.
- 3) Retaining structures were necessary in the Kuwait situation because of other design elements which required separation from recreational beaches. The design of shore-perpendicular structures in this case was modified to incorporate stormwater outfalls, pedestrian promenades, and decorative lighting. Onshore amenities were sited at the downdrift end of each beach where more people would be likely to congregate along the wide part of the berm.
- 4) Construction of perched beaches on a stable, low-tide platform is facilitated in low-energy, mesotidal areas if the fill is placed at an equilibrium planform and profile slope. Nearby natural beaches provide the best guidance for berm elevations and slope. Provided beach quality fill is used, this reduces turbidity in the nearshore zone and allows artificial beaches to achieve a natural look much faster. Construction by land-based equipment also reduces turbidity levels in comparison to a dredging operation.

Recommendations for Further Study

Given at least eight discrete and independent beaches constructed for the KWF project, it will be possible to develop a controlled data base on each one's response to the prevailing wave and tide regime. Additional profile survey stations should be set up and monitored 2-4 times each year to develop sediment budgets for each compartment. Such surveys will demonstrate whether each beach seeks an equilibrium planform, is retained within the control structures, or tends to shift in the longshore direction under seasonal wave patterns. The low-energy shoreline along Kuwait Bay and the compartmented beach system also provide a workable prototype setting to conduct experiments of onshore/offshore sand transport and the role of natural low-tide sills in stabilizing the profile (i.e., a perched beach). Experience gained from the KWF project beaches should be useful in the design of artificial beaches in other high, tide-range settings.

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