Chapter 10

Coastal & Marine Environment

Shore Protection

Mazen Abualtayef
Assistant Prof., IUG, Palestine
Coastal engineering and management in the past consisted of providing protection against shore erosion and flooding.

Critics of shore protection will say that all shore protection is temporary - so why build it and interfere with nature?

In any case, economic considerations decide if a coast should be protected. Particularly with the increase in tourism everywhere and demand for a lifestyle that includes the sea, it is unlikely that countries will permit their highly valued shorelines erode.
If we do nothing, the shore will become ugly and dangerous through erosion and in time it will not be accessible. *We do not want that.* But to resist the sea successfully, shore protection must be massive and will often be ugly. *Perhaps we also do not want that.*

Given the necessity of shore protection, *we should do it right.* Unfortunately, there are few guidelines on how to build shore protection. *As a result, much shore protection is built without adequate knowledge or appropriate design.*
Three questions that need to be asked are:

- Do we need shore protection?
- What are the available alternatives?
- How can we implement protection and leave the coast as natural and attractive as possible?
Previously, we distinguished between alongshore and cross-shore sediment transport. Most protection schemes do not function well with too much cross-shore sediment movement. In particular if the main cause of shoreline recession is systematic movement of sand offshore, the design of protection becomes difficult.

Incident wave angle is probably the most important ingredient in determining sediment movement, since it determines alongshore sediment transport rates and cross-shore sediment transport patterns.
1. Groins

- Groins are structures that are almost perpendicular to the shore. An individual groin interrupts the sediment transport forming accretion on its updrift side, and erosion downdrift.
- Groins change the alongshore sediment transport rates. This will result in accretion updrift of the groins and within the groin field and erosion downdrift.

\[ \begin{align*}
Q_g & : \text{sediment through the groin field} \\
Q_u & : \text{sediment outside the groin field}
\end{align*} \]

Figure 15.1 Groin Field
Chapter 10

1. Groins

- The **length** and **spacing** of groins is based on the mean shoreline orientation (Fig. 15.1) and the extreme orientations (Fig. 15.2).
- It is important that groins are placed well back into the existing shore to prevent the waves from flanking the groins (breaking through around the landward end of the structure). Flanking will result in deep scour trenches, landward of the groins and will compromise their stability.

Figure 15.2 Extreme Beach Orientations
1. Groins

- Because the sediment transport rate past the groins ($Q_g$) is less than the rate in unprotected area outside the groin field ($Q_u$), such a groin field will act like a wide, single groin and cause local accretion, updrift and local erosion downdrift as in Fig.15.1b.

- The erosion-accretion process will continue until all the groins are filled to capacity, so that they bypass all the sediment that arrives from updrift. In the time that it takes to fill the groins, extensive damage can be caused downdrift of the groins.
1. Groins

• Combining the groin construction with *artificial beach nourishment* as in Fig. 15.3, providing the sand for the filling of the groin field and the updrift accretion area from elsewhere, can prevent such damage. That is a common method to integrate a groin field into its surroundings.
1. Groins

- Cross-shore sediment transport can rapidly add or remove sediment from the groin field. When offshore sediment motion resulting from high water levels and storm surge empties a groin field of sand and removes the accretion volumes collected updrift of the groins, downdrift erosion depicted in Fig 15.1 will begin to take place.

- If the offshore movement of sand is severe, the shore will erode back far enough that the groins will flank, and the shore behind the groins will be damaged.

- Obviously, when the erosion is a result of a steep beach and foreshore, causing a net offshore motion of sand, groins will not help. Artificially filling the groins will also not work when there is a possibility of large temporary offshore transport rates or when there are large fluctuations in mean water level or in areas of large storm surge.
1. Groins

- Thus, groins can only be applied in areas where erosion is a result of predominantly alongshore sediment transport.

- It is clear from Figs. 15.1 to 15.3 that the incident wave angles cannot be too large for groins to be effective, otherwise they would need to be either very long, or very closely spaced.

- And protection by groins is not effective when there are large long-term water level fluctuations. The method has therefore a very restricted window of application.

- The fact that the use of groins is so ubiquitous reflects a general misunderstanding about their functioning.
1. Groins

- Damage by the groin field to the surrounding shore is a function of the rate of sediment bypassing.
- When the groin field is not filled, long, high groins will stop all sediment transport for a long time and cause much damage.
- Shorter, lower groins will cause less damage but will still affect the surrounding shore, until they are filled to capacity.
- Groins also generate offshore current as in Fig. 15.4. These currents move sediment offshore and can be a hazard to bathers.
- Most groins are short and will only obstruct the beach section where sediment transport takes place primarily by beach drifting.

Figure 15.4 Offshore Currents near Groins
1. Groins

Effect of groins for alongshore transport control
1. Groins

- Groins are mostly constructed out of armor stone or sheet pile.
- To minimize downdrift erosion, their height should only be just enough to contain the design beach profile.
- Their spacing are 2~3 times their length.
- A wave climate that is not predominantly in one direction can produce much different erosion-accretion patterns.
- Groins impact the surrounding environment and habitat.
- A discontinuity will arise where the groin field meets the surrounding area. To minimize damage to adjacent downdrift areas, sometimes the end groins are shortened to form a transition.
1. Groins

Figure V-3-32 Transition from groin field to natural beach
1. Groins

Armor stone groins
1. Groins

Sheet pile groins

Wooden

Steel and concrete
2. Seawalls

- A seawall is a protection wall, built along to the shore (Revetment).
- It is the protection method of choice for locations where further shore erosion will result in excessive damage, for example, when roads or buildings are about to fall into the water.

- Most seawalls are much smaller and many seawalls are close to vertical. They range from steel sheet-pile walls to concrete barriers, to rubble mound structures, to brick or block walls to gabions (wire baskets filled with rocks) Fig.15.5.
- Seawall impact on the alongshore sediment transport is small.
2. Seawalls

Types of Revetments

- **Quarrystone**: Uniform-sized armor stone or graded riprap

- **Field Stone**: Large, rounded field stone armor

- **Concrete**: Cast in place concrete slab on grade

- **Bags**: Sand or concrete fill in fabric bags

- **Gabions**: Rock-filled gabion baskets

- **Vegetation**: Beach and upland species above the intertidal zone, marsh species in the intertidal zone
2. Seawalls

• The primary design condition for seawalls is that they are stable and structurally sound.

• They are located at the top of the shore and will be out of reach of the water during good times (at low water).

• During times of stress (at high water), they will be exposed to direct wave action.

• Most seawalls are under severe stress.

• The waves will attack the structure, move sand offshore and alongshore away from the structure.
2. Seawalls

• The wave action reflected off the seawall causes disturbed water near the wall that can promote deep scour holes immediately offshore of the seawall.

• The disturbed flows and scour areas can be dangerous and the scour may even excavate the supporting sand from under the structure, compromising the stability of the wall.
2. Seawalls

- Water levels control the design environment for seawall design. High water levels allow higher waves to come closer into shore, subjecting the structure and its foreshore to high forces and high rates of erosion.

- Very high water levels will cause waves to overtop the seawall resulting in erosion at the back of the structure.

- Trapping of water behind the seawall, may cause drainage problems resulting in erosion and structural instability.

- The design of a seawall is not simple.
Additional design considerations for seawalls are:

- They are dangerous during times of high water and storm. People on or near structure may be injured or swept out to sea.
- For near-vertical structures, there will be much overtopping, sending salt water spray inland, resulting in accelerated corrosion.
- They form a physical barrier to cross-shore movement of people and wildlife.
- The ends of a seawall are difficult to design. There will also be local accelerated erosion, damaging the adjacent shore. To prevent undermining and flanking of the seawall at its ends, the structure needs to be built well back into the existing shore.
3. Headlands

- When headlands occur naturally along a shore with some sand, they will contain pocket beaches.
- It is possible to emulate this on a smaller scale with artificial headlands as in Fig 15.6.
- Its larger size can withstand extensive cross-shore transport of sediment during periods of high water and storm surge.
3. Headlands

- The approach has been used extensively, for example, along the Toronto shore where attractive multi-purpose projects host parks, wildlife areas, marinas and bathing beaches.
- Downdrift erosion is a major consideration and hence such large structure can only be used if $Q_{\text{net}}$ is small or erosion can be readily mitigated.
4. Offshore breakwaters

- Offshore breakwaters have been used as beach protection, particularly in **tourist areas**, where seawalls and groins are not attractive alternatives.
- They can be used in areas with substantial cross-shore transport.

Salient: an accretion formation that does not reach the breakwaters

Tombolo: attached to a breakwater.
4. Offshore breakwaters

- Offshore breakwaters intercept much of the incident wave energy, resulting in reduced wave action behind the structures.
- The waves enter through the breakwater gaps and then diffract as they travel toward the shore.
- The diffracted waves change the beach shape from a relatively straight shore to an attractively curved shoreline with salient or tombolo.
- In general, breakwaters that are longer or placed close to shore form tombolo.
- Salient form when the breakwaters are further from shore and there are substantial gaps between the breakwaters.
4. Offshore breakwaters

- Salients are usually preferred, because they do not block the currents behind the breakwaters, thus enhancing water quality in the swimming areas.
- However, they are essentially unstable beach form between a straight beach and a tombolo.
- Small changes in conditions can convert a salient into a tombolo, which means that incident wave and water level conditions must be constant in order to produce salients.
- The diffracted wave crests and currents in the diffraction zone behind the breakwaters shape the salients and tombolos.
4. Offshore breakwaters

• Beach material to form the salients and tombolos is swept from adjacent areas of the original beach, causing areas of local erosion.

• Combination of these structures with artificial nourishment is ideal. The artificial nourishment prevents the erosion and the structures serve to keep the artificial nourishment in place.
4. Offshore breakwaters

- The design of offshore breakwaters is quite complex.
- Waves overtopping → Mass transport of waves decreases the currents behind the structure.
- High breakwater crests form tombolos.
- Lower breakwater crests form salients.
- Applications of offshore breakwaters, particularly to form salients are mainly found in the Mediterranean Sea.
4. Offshore breakwaters

- The currents behind breakwaters can be dangerous to swimmers, during storm periods. Because the waves behind the breakwaters are benign, people are not aware of the strong currents.
10 Chapter

4. Offshore breakwaters

- Careful lifeguard patrol during storms must keep people away from areas of strong current activity, such as near the ends of the structures and off the tips of the salients.
4. Offshore breakwaters

Shoreline Response

**Shoreline configuration** is essentially parallel to the **diffracted wave crests**.

**Longshore transport** is again zero.

A condition of no longshore transport.

The incident wave crests are parallel to the original shoreline.
4. Offshore breakwaters
4. Offshore breakwaters

Figure 4-13. Aerial photograph of wave diffraction at Channel Islands Harbor breakwater in California. Reprinted with permission from US Army Corps of Engineers (USACE), 1984, Shore Protection Manual. (Full citing in references).
4. Offshore breakwaters

Tidal Range Effects

Low tide: double tombolo

High tide: no tombolo
4. Offshore breakwaters

<table>
<thead>
<tr>
<th>Emergent structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditions for formation of</td>
</tr>
<tr>
<td>Tombolos</td>
</tr>
<tr>
<td>$L/X \geq 1.5$</td>
</tr>
<tr>
<td>$L/X &gt; 1$</td>
</tr>
<tr>
<td>$L/X &gt; 0.9$ to 1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Submerged structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditions for formation of</td>
</tr>
<tr>
<td>Tombolos</td>
</tr>
<tr>
<td>$L/X &gt; (1.0$ to 1.5)/(1 $- K_t)$</td>
</tr>
<tr>
<td>$G/L_s &gt; 0.5(1 - K_t)$</td>
</tr>
</tbody>
</table>

$K_t = 0.1 \sim 0.2$

The width of the gap is usually according to Pilarczyk (2003)

$$L \leq G \leq 0.8 \: L_s$$

where $L = T \: (g \cdot h)^{0.5}$, $T$ being the wave period and $h$ the water depth at the structure.
4. Offshore breakwaters

Submerged breakwater at Rockley Beach
4. Offshore breakwaters

Figure 3.3.10 Differences in distribution of living organisms with and without a detached breakwater on Kochi Coast
5. Artificial nourishment

- The concept of artificial nourishment is based on simulating natural dune-beach formations.
- The artificially placed material has a profile that is different from the stable profile and it has a limited length (along the shoreline).
- The nourishment will tend toward a stable profile shape in the cross-shore direction.

![Artificial Beach Nourishment](image)
5. Artificial nourishment

- It is environmentally the most friendly protection alternative.
- It has the least impact on adjacent properties and the environment, and instead of harming the surroundings, a beach fill will benefit adjacent eroding properties.
- Artificial nourishment in most areas becomes a beach maintenance solution, based on annual cost benefit figures.
5. Artificial nourishment

- The placement method is a function of the equipment used.
- In general, because of the large volumes of sand required, beaches are nourished by hydraulic fill from dredges.
- Some nourishments have been executed by placing sediment on the shore face, in the breaking zone or seaward of the breaker bars. The material is then placed in 5 to 10m of water.
- At shore face nourishment, the sand does not redistribute itself very much and forms an offshore sandy reef that protects the shore.

Placement is easy on the shore face, since hopper-suction dredges can come over the fill areas, so that no re-handling of the material is required.
5. Artificial nourishment

- The new offshore mass of sand will **prevent** further beach **erosion**, because the waves break further offshore and the beach slope to deep water is decreased.
- Since a major objective of nourishment schemes is to provide **protection and recreational beach**, most nourishments are placed as beach fills sometimes in combinations with shore face nourishment.
5. Artificial nourishment

- Beach fill requires re-handling of the sand, which it can be placed by pipeline dredge and perhaps be reshaped by land-based earthmoving equipment.
5. Artificial nourishment

Land-based earthmoving equipment
5. Artificial nourishment

- Once the fill has been re-adjusted by the waves to form a beach profile, a steep scarp may have formed at the top of the beach.
- The finer nourishment sand will be winnowed out and lost.
- Nourishment sand of larger mean diameter than the native sand will armor the beach.

Unfortunately, most readily available source of nourishment sand is usually offshore sand, which is considerably finer than the native beach material.
5. Artificial nourishment

Other aspects of design of nourishment are:

- Where will the nourishment material come from and is there sufficient material?
- The end effects discussed above, along with lower unit costs for placing large volumes of dredged material lead to the general impression that long beach fills are more effective than short ones.
- Several authors state that the longevity of a project is a function of individual storms, but beach fills at Ocean City, USA that were exposed to storms of totally unexpected severity seems to disprove this.
5. Artificial nourishment

- Combination of artificial nourishment with structures such as groins or offshore breakwaters will help contain the fill material.
- Structures also provide an opportunity to use beach fills in areas, which would never be stable with artificial nourishment alone.
- **Water levels are a very important design parameter in determining the stability and longevity of a beach fill.**
- A beach is biologically relatively unproductive. There are indications that any benthic communities covered by a beach fill re-establish quite quickly after nourishment. The surrounding ecosystem, however, will need to be carefully considered.
6. Sand bypass

New South Wales and Queensland, Australia
What type of coastal structure is best?

- Objective
- Coastal processes (e.g. groin is only practical when there is significant quantity of sand moving alongshore)
- Environmental concerns (nearshore fringing reefs, vegetation in back beach)
- Cost
  - Modeling costs
  - Construction costs (e.g. use of barge to build breakwater)
Design Process
(Industrial Engineer)

1. Analyze wave data
2. Determine long-term statistical trends
3. Determine Extreme Events (e.g. the storm wave which has a return period of 50 or 100 years)
4. Design Structure (usually for 50 yr. return event)
Gaza Shore – Case study

Coastal & Marine Environment

Chapter 10

New land

Erosion

500 m

500 m
Gaza Shore – Case study

Remote sensing findings

- The impact has extended to about 2.5km to north and south the harbor.
- The waterline advanced at the south of harbor by 0.75 m year$^{-1}$ and treated at the north of harbor by 1.15 m year$^{-1}$.

Accretion and erosion rates for the study area

<table>
<thead>
<tr>
<th>Image period</th>
<th>Erosion</th>
<th>Accretion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>area $\times 10^3$ [m$^2$]</td>
<td>rate $\times 10^3$ [m$^2$ year$^{-1}$]</td>
</tr>
<tr>
<td>1972-1984</td>
<td>180</td>
<td>15</td>
</tr>
<tr>
<td>1984-1998</td>
<td>200</td>
<td>14</td>
</tr>
<tr>
<td>1998-2003</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>2003-2010</td>
<td>143</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>531</td>
<td>14</td>
</tr>
</tbody>
</table>
Gaza Shore – Case study

**Sediment transport rates**

- The net annual rate of wave-induced alongshore sediment transport range from minimum $160 \times 10^3$ to maximum $220 \times 10^3$ m$^3$, and the average annual rate of $190 \times 10^3$ m$^3$, northward.
- The annual sand volume of accretion was estimated $80 \times 10^3$ m$^3$. 
## Gaza Shore – Case study

The wave scenarios for the study area

<table>
<thead>
<tr>
<th>Wave scenario</th>
<th>Significant wave height, $H_s$ [m]</th>
<th>Peak period, $T_o$ [s]</th>
<th>Wave direction [deg. North]</th>
<th>Wave duration [days]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H \leq 1.0$</td>
<td>0.5</td>
<td>6.3</td>
<td>284</td>
<td>289.0</td>
</tr>
<tr>
<td>$1.0 &lt; H \leq 2.0$</td>
<td>1.3</td>
<td>7.1</td>
<td>295</td>
<td>63.0</td>
</tr>
<tr>
<td>$2.0 &lt; H \leq 3.0$</td>
<td>2.4</td>
<td>8.0</td>
<td>293</td>
<td>10.0</td>
</tr>
<tr>
<td>$3.0 &lt; H \leq 4.0$</td>
<td>3.4</td>
<td>8.8</td>
<td>292</td>
<td>2.7</td>
</tr>
<tr>
<td>$H &gt; 4.0$</td>
<td>4.2</td>
<td>9.4</td>
<td>305</td>
<td>0.3</td>
</tr>
</tbody>
</table>

H: wave height

![Wave Height](image)

---

1985-1990

2003-2005
Gaza Shore – Case study

Detached breakwater model test
Gaza Shore – Case study
Submerged breakwaters model test
Gaza Shore – Case study

Groins model test
### Environmental impact of various alternatives

<table>
<thead>
<tr>
<th>Mitigation alternative</th>
<th>Annual rate [m$^3$ km$^{-1}$]</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relocation of harbor</td>
<td>$+4\times10^3$</td>
<td>Accretion</td>
</tr>
<tr>
<td>Detached Breakwater</td>
<td>$-23\times10^3$</td>
<td>Erosion</td>
</tr>
<tr>
<td>Submersed Breakwater</td>
<td>$+28\times10^3$</td>
<td>Accretion</td>
</tr>
<tr>
<td>Groins field system</td>
<td>$-22\times10^3$</td>
<td>Erosion</td>
</tr>
</tbody>
</table>