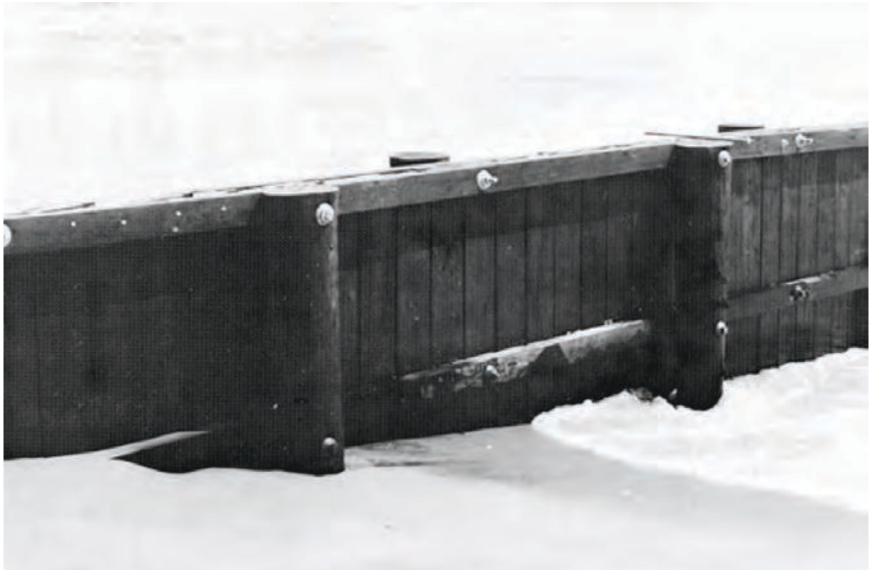

Figure 11-18. Timber Pile Groin

11.6.5.2 *Alignment*

The conventional alignment of groins is normal to the shore. The obvious factors that might influence alignment are:

- effectiveness in retaining or detaining littoral drift, and
- protection of the groin itself from damage by wave action.

The seaward end of groins have been finished in various configurations. For stone, there is typically an enlarged head to reduce the slope. Timber, concrete, and steel have been frequently constructed with a “T”, “L”, or angle at the end of the section.

11.6.5.3 *Permeability*

Permeability of a groin may be a desirable characteristic but has not generally been considered to be a necessary element in the design of groins. Currently, more consideration is being given to groin permeability to allow downdrift movement of sediment (*4*).

11.6.6 Breakwater Systems

A breakwater is a structure lying parallel to the shoreline generally not attached to land. Often, several are constructed in a series parallel to the coast to form a breakwater system as shown in Figure 11-19. Breakwaters, being located beyond the surf zone, are usually exposed to large wave conditions and are therefore usually massive structures. They are frequently constructed of rock with an armor stone or concrete armor protective layer. Segmented breakwaters reduce total wave energy reaching the project shore, and they may cause net accretion in the protected region. The individual breakwaters and gaps cause a longshore variability in wave energy which, in plan form, results in a sinuous beach of alternating zones of accretion and erosion. Improperly designed breakwaters systems can have a negative effect on the downdrift shoreline similar to a groin field.

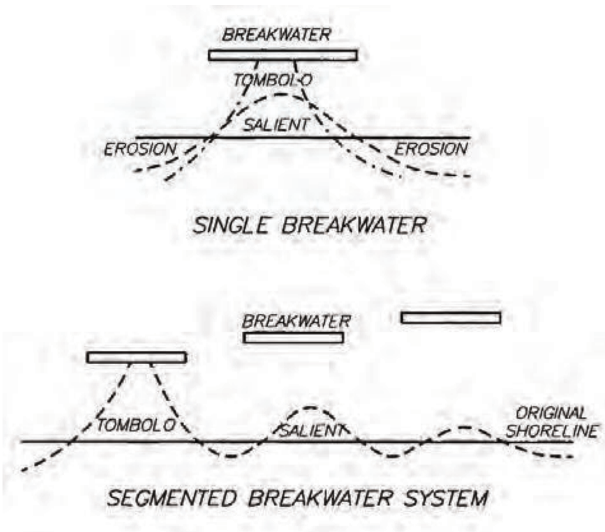

Figure 11-19. Schematic of the Response of the Shoreline to an Offshore Breakwater System

In contrast to seawalls or revetments, breakwaters parallel to the shore, separated into segments, are intended to protect the shore by attenuating the incident wave energy through sheltering and causing accretion of the beach. A single breakwater can provide protection to a short stretch of beach; however, a segmented breakwater system is required for a lengthy section of shoreline, similar to the requirement for groins. Figure 11-20 shows an offshore breakwater under construction at Holly Beach, Louisiana.

Figure 11-20. Offshore Breakwater System at Holly Beach, Louisiana

11.6.7 Bulkheads

Bulkheads are vertical structures that are designed primarily to prevent land slip failures and act as retaining walls. A secondary purpose is to protect upland areas against damage from wave action. In shore protection, a bulkhead is a structure designed to retain the highway embankment, to resist earth pressures, and to protect it from erosion from wave action.[5]

Examples of materials used for bulkheads in highway practice include:

- concrete gravity walls,
- timber pile-supported walls, and
- steel sheet piling with a concrete cap as shown in Figure 11-21.

Alignment of a bulkhead should be parallel to the shoreline. However, on occasion, the bulkhead is aligned with the roadway, structure, or shoreline. The height of bulkheads is usually established at an elevation above wave runup or incident wave height including runup to prevent overtopping.

Shape of a bulkhead is very important as the shape and slope of the face may create one or more of the effects:

- concentrate the power of the wave as a horizontal load on the wall,
- throw back a major part of the wave to dissipate its energy,
- deflect part of the wave downward causing toe scour, and
- deflect part of the wave over the top of the bulkhead.

Frequently, toe stone is added to the bulkhead to prevent scour and to dissipate some of the reflected wave energy.

Figure 11-21. A Steel Bulkhead Showing Tierod Connections and Concrete Cap

[5] In some geographic locations, bulkheads are called “seawalls” incorrectly according to the nomenclature developed and published by USACE. Seawalls generally refer to massive structures and not the lightweight structures that comprise most bulkheads.

11.6.8 Beach Nourishment

A very effective method to cope with an eroding shoreline that threatens a highway is to add sand to the system to compensate for that lost either due to longshore drift or offshore transport. An example of beach nourishment to protect the shoreline in northern New Jersey is shown in Figure 11-22. Beach nourishment is accomplished by dredging sand from a suitable inshore or offshore site and placing it on the beach in a predetermined profile. For some sites, the material is trucked from an inland source. To be effective, the "borrow" material must be compatible with the "native" material. Additional information is provided in Chapter 18 of the MDM (*1*) and in the USACE *Engineering Design Manual* (*13*). It is currently thought that a combination of beach nourishment with a system of coastal structures, such as groins or offshore breakwaters, is more effective to slow longshore transport. This in turn minimizes the need to renourish the beach in response to the background erosion.

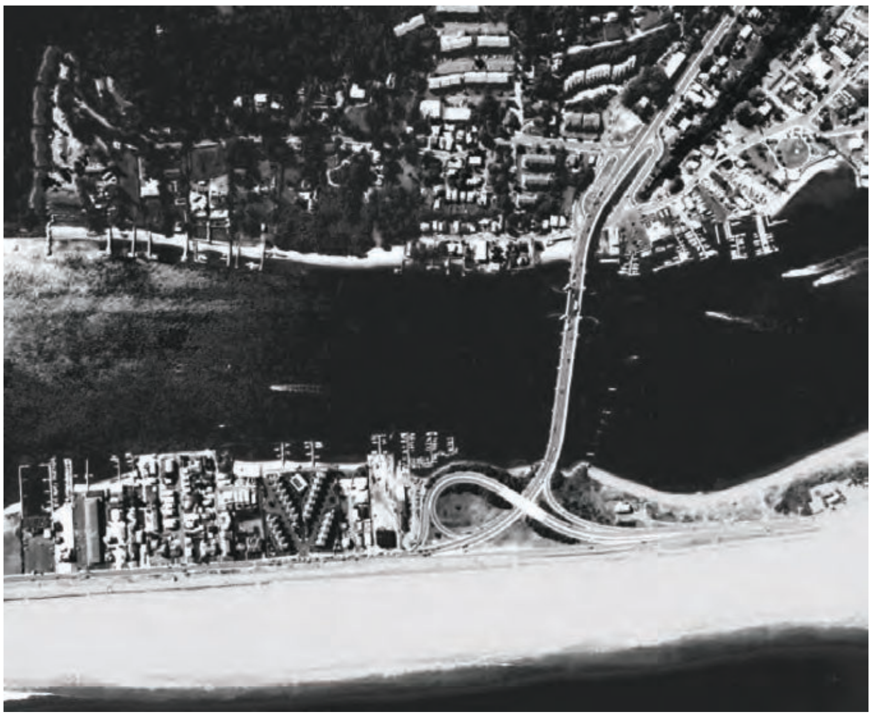

Figure 11-22. Nourished Beach Providing Protection for the Roadway and Fronting Seawall in Northern New Jersey

11.7 PLANNING FOR SHORELINE CHANGES

Many of the considerations presented below apply to the shorelines of large lakes and reservoirs and coastal environments.

11.7.1 Shoreline Changes

Shoreline changes can be considered as long-term or short-term. Short-term changes are usually the result of a combination of relatively large waves and high water due to a storm. Sediment is moved offshore and the width of the beach decreases. In the case of a more extreme event, there may also be some dune or bluff erosion. In time, after the storm has passed, the beach and dunes will rebuild. On many shorelines, the net loss of sediment from a single storm may be relatively small. From a planning perspective, the potential for short-term periods of storm-generated erosion imply that the transportation project be protected even though the post-storm beach is relatively wide. These short-term changes usually extend over a period of weeks.

Long-term changes in shoreline position occur over periods of years or even decades. These long-term changes are a consequence of a combination of factors:

- changes in sea level,
- wave climate and related coastal processes,
- type of land forms adjacent to a coastal area,
- type and volume of sediment supplied to the shore, and
- impact of man-made shoreline and navigation projects along the coast.

The human presence may play an important role by altering natural processes through navigation works and construction of dams on streams and rivers that supply sediment to the coast. On sandy shores, each wave and any variation in sea level alter, to some degree, the shoreline. Beach sands are transported offshore, onshore, and in the direction of prevailing longshore currents. Beaches constantly adjust elevation and shape to accommodate different tide, wave, and current conditions. On rocky coasts, erosion may be slower than on sandy coasts, but the effect of the continuous action of waves on the shoreline causes the coast to erode. Periods of erosion and accretion are superimposed on a longer trend of worldwide rising sea level. This long-term rise submerges the coast, causes shoreline recession and forces the beach landward.

11.7.2 Rate of Shoreline Change

There have been a number of national surveys of long-term shoreline change including Dodd, et al., (*5*) and a report of the H. John Heinz III Center (*9*). Most State coastal zone management agencies have more detailed and current shoreline change data suitable for project planning. Long-term shoreline change data indicate that there are some coasts with erosion rates greater than 5 m/yr (15 ft/yr) or larger and other shorelines that are stable or even accreting.

11.7.3 Sea Level Rise

Historically, most engineers have neglected sea level rise in the design and planning for transportation projects. Recent studies have suggested that it is no longer appropriate to ignore the potential impacts of a rising sea level (*6*). The sea level rise illustrated in Figure 11-23 shows a clear trend based upon tide gage records. While this trend is relevant, a greater concern is the potential for higher rates of rise as a result of man's activities and global warming.

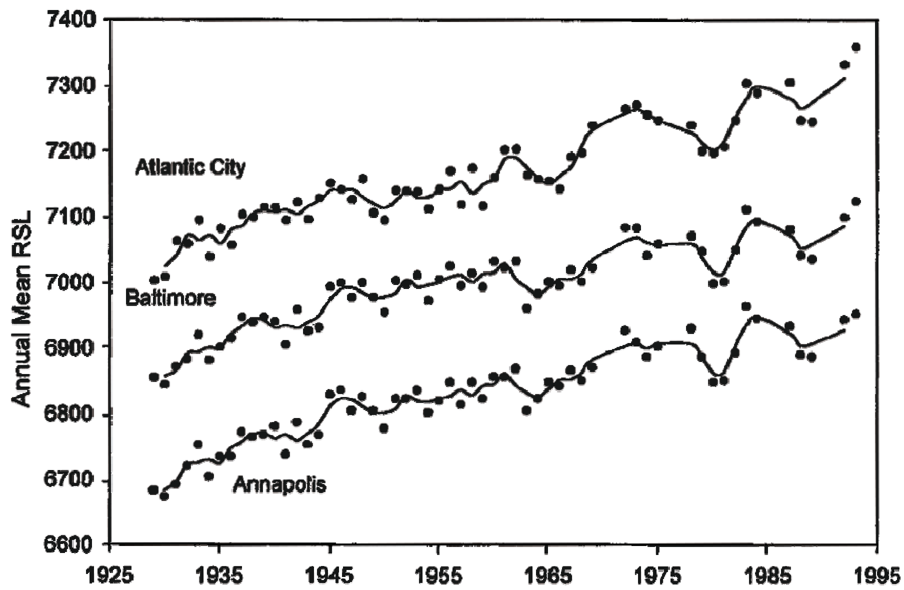

Figure 11-23. U.S. Mid-Atlantic Annual Mean Relative Sea Levels (Douglas et al. (*6*))

11.7.4 Considerations in Planning for the Future

11.7.4.1 *Condition Assessment*

In the United States, there are many kilometers [miles] of highways adjacent to shorelines. Due to a combination of ocean, storm, and engineering design factors, these roadways are being damaged. The long-term expectation of continued highway damage requires comprehensive and continuing studies of highway vulnerability. Decisions to repair, protect, or relocate these highways can be accomplished in a cost-effective manner based on these studies.

11.7.4.2 *Objectives of a Vulnerability Study*

The decision to repair, protect, or relocate highways in a shoreline area requires an assessment of a large number of variables, including the erosion potential, present and future transportation needs and repair, protection, and construction costs. It is desirable to develop a systematic method to anticipate future erosion problems along coastal highways and to evaluate responses for their repair and protection. The following objectives should be addressed by such a study:

- Identify the relative vulnerability of highway actions in the coastal zone to long-term erosion that includes the effects of seasonal storms and hurricanes and sea level rise.
- Evaluate feasible engineering solutions for protecting and repairing the coastal highways.
- Review and document prior highway damages, causes, remedial actions, costs, and effectiveness.
- Develop and test a methodology for matching repair and protection strategies to highway sections for different vulnerability scenarios.
- Use the methodology to estimate the locations of vulnerable sections and protection actions and cost for a predefined planning period.
- These objectives will produce a plan covering a prescribed period of time that addresses the identified vulnerable roadway sections and the appropriate mitigation actions and costs.

11.7.4.3 *Coastal Highway Vulnerability Model*

The effectiveness of a vulnerability model is based on its fundamental concepts and assumptions. The development of the model rests heavily on the assumption that long-term erosion rates are a good predictor of the future position of the shoreline. In a deterministic sense, it is impossible to locate the position of the shoreline precisely at any future point in time. One reason for this is that the short-term variation and the position of the beach can be different than that predicted by the long-term rate and can include periods of both erosion and accretion. The long-term erosion rate is, however, a good indicator of the historical temporal ranges in shoreline position and is generally used in coastal management as a way to identify areas of potential erosion. See Figure 11-24.

Figure 11-24. Road Loss Due to Erosion in Jefferson County, Texas

The term vulnerability means that the coastal highway is susceptible to excessive overwash and possible undermining of the highway base. The shoreline gradually moves landward toward the coastal road. In that process, the beach and dunes are gradually depleted until undermining of the road becomes a problem. Transportation officials usually perceive a vulnerability problem when maintenance crews are required to remove sand from overwash several times within one year. When overwash occurs, highway access is interrupted and costly sand removal is required.

A coastal zone vulnerability model is built from three essential databases:

- a digitized map showing the shoreline topography and coastal highway position,
- long-term erosion rates, and
- short-term shoreline change impacts from storms.

If the storms used in the analysis are characterized by their respective probabilities (return periods), the combination of these three databases can be used to develop a statistical model for future highway vulnerability. The model results can be presented in a GIS format showing the locations and probabilities of future problems.

11.7.4.4 *Emergency Evacuation Plan*

Transportation planners should work with coastal zone management agencies to develop an emergency evacuation plan. In many instances, isolated communities or recreation areas rely on a single transportation corridor for egress and ingress to their area. During a major storm event, this corridor may be severed preventing evacuation of the residents and preventing delivery of emergency services to them. Highways are usually the major transportation facility serving these areas.

Hurricane evacuation is an important function of highways in many coastal areas. Evacuation route grades must be designed to allow for access of coastal areas prior to peak storm conditions. Grades required for evacuation will also affect the hydraulics in the coastal area. Without adequate drainage, elevated coastal highways may allow increased flooding in the immediate vicinity of the coast.

The hydraulics engineer may be called upon for advice in the development of the emergency plan based on his/her expertise and understanding of coastal hydraulics. A great deal of valuable information may be gained by monitoring a major storm event along the coastal area. A procedure, similar to identifying highwater marks in upland flood situations, should be instituted in the coastal zone. Post-storm visits can also be valuable in assessing the performance of hydraulic designs.

11.8 CONSTRUCTION AND MAINTENANCE CONSIDERATIONS

The hydraulics engineer should be able to anticipate the more significant problems that are likely to occur during the construction and maintenance of a shoreline facility. So far as possible, the design should be adjusted to eliminate or minimize those potential problems.

11.8.1 Construction-Related Considerations

The logistics of the construction activity such as access to the site, on-site storage of construction materials, time of year restrictions, and sequence of construction should be carefully considered during the project design. The shoreline morphology and its response to the construction activity are integral parts of this planning process. Communication between the hydraulics engineer and those responsible for contract administration and actual construction must be maintained. Any special or unique construction requirements should be communicated to the hydraulics engineer early in the plan development process. It is equally important that the hydraulics engineer be notified of any unexpected difficulties or revisions that may be encountered during construction. In addition, attention must be given to environmental issues that may impact construction schedules such as migration of anadromous fish.

11.8.2 Maintenance-Related Considerations

Hydraulic structures along the shoreline require periodic maintenance, inspection, and repair as needed. Where practicable, provisions should be made in the design of a facility to provide access for maintenance.

11.8.2.1 *Maintenance during Construction*

Hydraulic structures are usually constructed early in the construction operation. The highway agency should provide for maintenance by the contractor during the term of the contract, requiring inspection, interim protective measures, and necessary corrective actions.

11.8.2.2 *Perpetual Maintenance*

While most hydraulic structures are designed to minimize the need for frequent maintenance, it is necessary to conduct periodic inspections so that deterioration or damage can be detected. Corrective action taken when a problem first develops can usually forestall more serious and costly remedial action at a later date. Conditions that appear to require extensive repair or that require frequently recurring maintenance should be referred to the hydraulics engineer for review. Investigation may reveal that a complete redesign is necessary rather than repetitive repair. Reports by the maintenance forces of both effective and ineffective hydraulic installations aid the engineers in future designs. The corrosive effect of saltwater is a major concern for hydraulic structures located in coastal zones. The long-term effectiveness of special coatings should be monitored. With reservoirs, rapid drawdown (particularly in flood control reservoirs) can present serious maintenance problems. Embankment or shoreline protection damage from unbalanced pore pressures requires a design by the hydraulics engineer for any remedial work.

The dynamics of wave action, currents, and wind setup and setdown exert an impact on shore protection, hydraulic structures, and the adjacent environment. Such occurrences also affect roadway gradelines and the determination of the upper extent for shoreline protection.

Hazardous splash and spray, particularly in freezing conditions, is also a concern. The installation of shoreline armor, bulkheads, groins, splash and spray deflectors, and similar features may achieve the desired result of protecting a local area, but such actions may result in undesired responses in adjacent areas.

11.9 REFERENCES

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11.9.2 Additional Publications

In addition to the references that are cited above, there are numerous sources of information on planning and engineering in the coastal zone. Below are listed some important works in print and some web sites where additional information may be found.

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