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Gabions, A Poor Design for Shore Hardening: The Puerto Rico Experience

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ABSTRACT

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Gabions are low-cost shoreline engineering structures in common use in Puerto Rico to combat coastal erosion. They consist of individual wire cages or baskets filled with rocks and stacked on top of one another to construct shore-stabilization structures. Gabions are not traditionally used in open ocean or high-energy coastal environments. They are more commonly used to stabilize slopes, as levees for streams and rivers, and as retaining walls. However, the low-cost and ease of assembly on the construction site make gabions an attractive alternative to other shore-hardening structures. As a result, coastal communities in Puerto Rico, often with limited resources, have opted for gabions in shore-hardening construction, even if they are not ideal. In Puerto Rico, the following problems with gabions on open-ocean shorelines have been observed: (1) gradual failure by degradation, (2) instantaneous failure during a storm, (3) rock leakage onto the beach, (4) protruding wire on the beach, and (5) loss of the recreational value of the beach. Failure or ineffectiveness of gabions has resulted in their replacement, reconstruction, or encasement in other materials, defeating the initial economy of the gabion structure and illustrating their ineffectiveness on ocean shorelines. In at least two cases the gabion structures were unnecessarily built on public swimming beaches where no development was at risk. Four stages of gabion life have been identified: (1) emplacement - newly emplaced gabions can cause active, passive, or placement loss of the beach, similar to seawalls and revetments, (2) initial weakening - piping, wire deterioration and rupture, and gabion slumping signal the eventual failure of the gabion structure, (3) failure - the gabions leak rock content and/or collapse onto the beach, and (4) replacement - failed gabions are replaced by more substantial hard structures or covered in place with concrete. The alleged low-cost of gabions is misleading and more than offset by their high failure rate, negative environmental impact, and threat to the safety of beach users. The Puerto Rico experience indicates that even with regular maintenance, gabions are a poor choice for open-ocean shoreline protection.

ADDITIONAL INDEX WORDS: *Coastal erosion, coastal management, coastal engineering, hard structures.*

INTRODUCTION

Puerto Rico is plagued by shoreline retreat of its sandy coastal reaches (BUSH *et al*., 1995; MORELOCK, 1978; 1984; MORELOCK and BARRETO, 2003; THIELER and DANFORTH, 1994; THIELER *et al.*, 1995). Coastal communities in Puerto Rico have historically opted for various types of shore-hardening structures in order to prevent further shoreline retreat, even though such structures may enhance lateral shoreline erosion and disrupt natural beach cycles (JACKSON *et al.*, 2001). The seawall/revetment option is usually expensive to design and emplace, leading coastal engineering and construction companies to tout low-cost solutions. One cost-cutting measure is to substitute the use of gabions for rip-rap or other heavy-duty construction materials such as solid concrete walls.

Gabions are essentially wire cages or baskets, resembling cubes, filled with rocks, which then are stacked on top of one another and connected in rows to construct traditional shore-stabilization designs. The cages are usually made of heavy-duty wire, and can be galvanized or PVC coated (corrosion resistant). Traditionally, gabions have been used to stabilize slopes, as levees for streams and rivers, and as retaining walls. The low-cost and ease of assembly on the construction site make gabions an attractive design alternative to other shore-hardening structures. In the past twenty years, coastal communities in Puerto Rico, with limited resources, have opted for gabions in shore-hardening construction, even though the U. S. Army Corps of Engineers states that gabions should not be used in high-energy shoreline environments (USACE, 1986). In short, gabions are very poor choices for oceanfront construction because they deteriorate rapidly in the salt air. The end result is a beach narrowed in front of the seawall, and one ultimately littered with gabion debris that is both unsightly and dangerous to beach users.

In four case studies of gabion use for ocean or lacustrine shoreline stabilization (Kotzebue and Ninilchik, Alaska; Geneva, Ohio; and Cape May Canal, New Jersey) the USACE (1986) reported that all ended in failure. Similar gabion failures are reported in the sparse literature on gabion use for coastal stabilization (TEME, 1990), and no reports of monitored successful gabion shoreline projects were found in the literature.

There are examples in Puerto Rico, however, of gabions being used more conventionally and successfully. The Piñones Trail, for example, along Route PR-187, is a bicycle/walking trail. In places an elevated boardwalk crosses over wetlands where gabions are used to stabilize the banks of tidal creeks, low-energy, brackish to fresh-water environments.

Since the 1980s, the lives of several gabion structures have been observed along the Puerto Rico shore (e.g., Aguada Parque de Colón; Balneario de Rincón; Balneario de Carolina, San Juan; Old San Juan; near Puerto Nuevo; Playa de Humacao; and near the mouth of the Río Guayabo; Figure 1). The following range of problems has been noted: (1) gradual failure due to the same problems associated with other shore-hardening structures (e.g., piping; undercutting; sagging); (2) complete failure of a structure during a storm with subsequent loss of the design protection; (3) significant damage due to wave erosion, corrosion, and abrasion resulting in the failure of individual "baskets" and rock leakage; (4) structures that have become beach hazards due to protruding wire and rock leakage; and (5) structures that have resulted in the loss of the recreational value of the beach due to initial wall placement, the passive-wall effect (PILKEY and WRIGHT, 1988), obstruction of beach access, and the noted injury hazard.

Failure or ineffectiveness of gabion structures have resulted in their replacement (Rincón), reconstruction (Balneario de Carolina), or encasement in other materials (Aguada); defeating the initial economy of the gabion structure and illustrating their

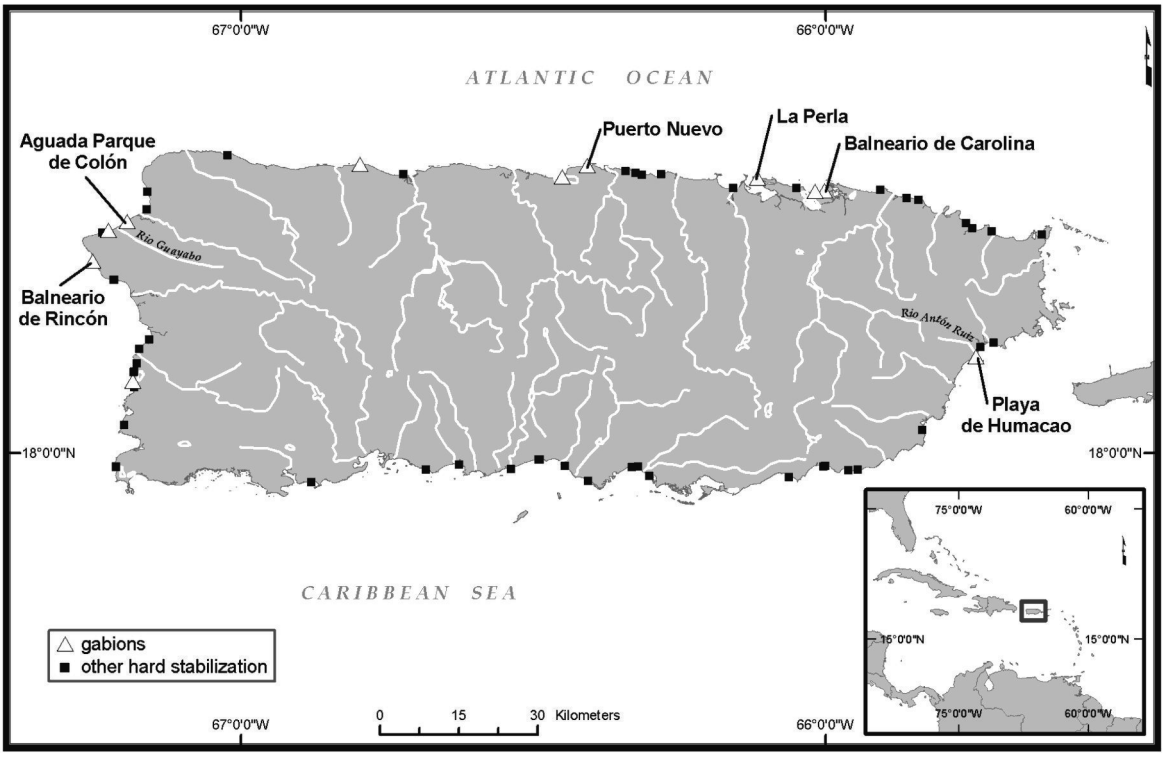

Figure 1. Location of Puerto Rico's sandy shorelines engineered with seawalls, revetments, and gabions. The gabion locations represent the more recent engineering projects

ineffectiveness on ocean shorelines.

To date, none of the localities have abandoned the shore-hardening "solution." At some of these localities, the gabion structures were unnecessary because beach retreat was not threatening significant property loss (e.g., public parks in Rincón and Carolina), and the beach recovered naturally after storms (e.g., Playa de Humacao). In all of these examples the beaches were degraded with spilled gabion fill rocks and deteriorated wire mesh.

PUERTO RICO COASTAL SETTING

Puerto Rico is the easternmost and smallest of the Greater Antilles Islands (Figure 1). It is roughly rectangularly shaped, approximately 160 km long (east-west) and 50-60 km wide (north-south). The insular shelf surrounding the island ranges in width from less than 0.5 km on the northern shelf to over 25 km on the western shelf, and the shelf break occurs at about 80 m water depth. The eastern shelf faces the Puerto Rico-Virgin Islands Platform.

Puerto Rico is highly developed with a population density of about 400 people/km2. Much of the population and associated development is constrained to the coastal zone. The coast is highly varied with sandy beaches, dune fields, rocky shores, cliffs, bluffs, mangrove, and artificial shores (MORELOCK, 1978; BUSH *et al.*, 1995).

Most coastal development took place without knowledge or regard for the geologic hazards which affect the coastal zone. The predictable results are recurring disasters with increasing total property damage losses. Major coastal disasters occurred with the passage of Hurricanes Hugo, 1989 (BUSH, 1991), and Georges, 1998 (FEMA, 1999).

To combat beach loss due to coastal erosion, Puerto Rico has a long history of shoreline engineering, including emplacement of seawalls. Mining of sand from beaches, dunes, and rivers has increased the erosion problem. One interesting aspect of Puerto Rico's shoreline engineering history in open ocean settings is the frequent use of gabions, instead of typical seawalls or revetments. By all accounts, gabions are not suitable for such uses.

EXAMPLES OF GABIONS ALONG OPEN-OCEAN SHORELINES IN PUERTO RICO

Gabions, as well as more traditional seawalls, can be found along many beaches in Puerto Rico (Figure 1). Several important points to consider in using gabions in the coastal environment are spelled out in detail by USACE (1986); most of which have been completely diregarded in Puerto Rico. For example, it is suggested that gabions not be used in high energy wave environments, in the active surf zone, nor on public beaches where injury to bathers from protruding wire is possible. Moreover, the final suggestion given is that inspection and maintenance plans must be established. Failure to follow these suggestions has resulted in not only a dollar cost, but also a loss of aesthetics and compromising of safety for beach users.

Balneario de Carolina

Balnearios are public swimming beaches maintained by local governments. Balneario de Carolina (Figure 2; previously named Balneario de Isla Verde) is certainly the most popular and heavily used public beach in the San Juan metropolitan area. The shoreline here has been experiencing erosion for many years. Note the remnants of a beach boat launch just offshore in Figure 2-A. Swell from a January, 1988, North Atlantic winter storm formed an approximately 1-meter high erosion scarp (Figure 2-A). The passage of Hurricane Hugo in September 1989 caused further erosion. To combat the persistent erosion problem, a gabion wall was emplaced soon thereafter.

By 1994, a gabion had been built and already begun to deteriorate (Figure 2-B). Filter cloth had been used behind the gabion to prevent washout of sediment by downward water movement, but it seemed to have little positive effect. The gabion began to fail almost immediately by undermining and piping, eventually collapsing onto the recreational beach (Figure 2-B). Continued erosion along with deterioration of the gabions has led to several generations of modifications and repairs to the gabions. Ultimately the gabions have failed, spilling rock and wire debris onto the recreational beach.

Figure 2. Balneario de Carolina (previously known as Balneario de Isla Verde). Balnearios are public swimming beaches with amenities and maintained by a local government. Major erosion caused by swell from a January, 1988, winter storm, and the passage of Hurricane Hugo in September, 1989, resulted in the emplacement of gabions. Continued erosion along with deterioration of the gabions has lead to several generations of modifications and repairs to the gabions. Ultimately the gabions have failed, spilling rock and wire debris onto the recreational beach. (a) Immediately after the January, 1988, winter storm swell erosion. View to the east. The boat ramp marks the shoreline previous to the mid-1970's. (b) Similar view as (a), but in 1994 after gabion has been built and begun to deteriorate. Note filter cloth behind gabion. (c) A wooden observation deck was added and threatened by erosion by 2001. View to the west. (d) Major monument structure built on the retreating shoreline and already deteriorating by January 2002. View to east.

By 2001 (Figure 2-C), a wooden observation deck had been built and threatened by erosion. The gabion was almost completely destroyed and was not protecting the platform, but was creating hazards for beach users. Not content in realizing this as a high-hazard erosion area, more coastal "improvements" were made in the form of a concrete and steel monument structure built right on the shoreline, seen in this January, 2002, photo (Figure 2-D). Notice the deteriorated gabion collapsing and leaking rocks onto a narrowing beach. Also, the monument had sand and loose rock washed up onto it, and was rusting noticeably.

Aguada Parque de Colón

Even though it may seem much calmer on any typical summer day, the west coast of Puerto Rico can experience the largest waves to impact the island in the form of far-traveled swell from major North Atlantic winter storms. A gabion was built in the late 1980s along part of the Aguada shoreline, near the Parque de Colón (Figure 3). By 1992, the wall was already deteriorating. The steel-wire mesh has ruptured and the stone fill dispersed by waves (Figure 3-A). Rusting wire and stones litter the beach creating a hazard to beach users. Ultimately a cement covering was added an unsightly attempt to hold the wall together (Figure 3-B). This material was eventually undercut by storm waves, creating an even bigger mess on the beach. Further south, just down the beach from Parque de Colón, a long stretch of gabion limits access to the beach from the moderate-elevation bluff (Figure 3-C). By 2000, much of this stretch of gabion was failing (Figure 3-D). The sloping Aguada gabion wall also is a debris catcher, littered with driftwood and flotsam, further detracting from beach aesthetics.

Playa de Humacao

On the east coast, at the northern end of Playa de Humacao and a few blocks north of a small pier, there is a gabion wall, approximately 2 meters high, with a stepped vertical front and a gently sloping rear (Figure 4). The gabion was a response to coastal erosion and property damage caused by the passage of Hurricane David in 1979. Built about 1983 at a cost of over $200,000, the gabion is over 100 meters long and extends north to the small river, Río Antón Ruíz. In 1988, the wall was basically intact, but showing signs of deterioration (Figure 4-A). The passage of Hurricane Hugo in 1989 did not severely damage the wall, but highlighted some spots of previous deterioration, spilling some fill rocks onto a narrowed beach (Figure 4-B). By 1991, several of the wire cages were failing and fill rocks were spilling out onto the beach (Figure 4-C). By January, 2002, the gabion wall was still standing without major deterioration (Figure 4-D). It was overgrown with small trees and spot failures had not been repaired.

Sediment input from the Río Antón Ruíz helps maintain this shoreline stretch, and it is questionable that any stabilization structure was needed here. Although this beach is not used a great deal for swimming, the continued gabion deterioration

Figure 3. Gabion wall near Aguada's Parque de Colon, built in the late 1980s. (a) and (b) By 1992 the wall had already deteriorated and been "improved" with a concrete covering, which in turn had been broken by storm wave action. Fill rock from the failed gabion was observed to be washed several tens of meters up into the small drainageway visible in (a). (c) Just to the south the entire bluff was covered with a sloping gabion, visible in this 1992 photograph. Note that the wire mesh traps driftwood and flotsam. (d) By summer of 2000, the gabion in (c) was severely compromised.

and leaking rocks have degraded the beach.

Gabion Miscellany

Even without a time-series of photographs, several examples of gabions as a poor design choice for shoreline stabilization are evident around the coast of Puerto Rico. For example, in the La Perla urbanization of Old San Juan, a gabion "protects" a road running along the coast and facing directly into the North Atlantic Ocean (Figure 5-A). The hillside is Pleistocene eolianite, so a solid rock wall to protect the road would have more closely matched the natural setting. Another candidate for future replacements is the multi-tiered gabion that faces into the high-energy North Atlantic Ocean near Puerto Nuevo on the north coast about 30 km west of San Juan (Figure 5-B). The gabion had only recently been emplaced when the photo was taken in summer, 2000. Near the northern corner of the west coast, just northeast of the mouth of Río Guayabo, a gabion was emplaced to protect the road. When visited in 1992, the gabion was failing by piping and undercutting, and modified by covering with a concrete cap and installation of a riprap wall in front of the gabion (Figure 5-C). In the end, the low-cost engineering approach ultimately led to costly continued maintenance and improvements, resulting in a more expensive structure. A better approach would have been to either build a better-designed seawall in the first place, or avoidance of the problem if possible by relocating the road. Further south on the west coast, Balneario de Rincón is an example of a "wall for no reason" (Figure 5-D). Recall that balnearios are public swimming beaches, so there should be nothing to "protect." The gabion (shown in a 1992 photo) merely adds a structure, dividing the recreational beach, and limiting access to the ocean. By 2002, the gabion had been replaced by a solid concrete wall. Balneario de Carolina (Figure 2) is another example of a wall with no reason, on a public swimming beach with nothing to protect.

CONCLUSIONS

Four stages of gabion life have been identified in Puerto Rico: (1) emplacement - newly emplaced gabions can cause active, passive, or placement beach loss, similar to seawalls and revetments (PILKEY and WRIGHT, 1988), (2) initial weakening-piping, wire deterioration and rupture, and gabion slumping or toppling signal the eventual failure of the gabion structure, (3) failure - the gabions leak rock content and/or collapse onto the beach, and (4) replacement - failed gabions are replaced by more substantial hard structures or covered in place with concrete. The alleged low-cost of gabions is misleading and more than offset by their high failure rate, negative environmental impact, and threat to the safety of beach users. The Puerto Rico experience indicates that even with regular maintenance, gabions are a poor choice for open-ocean shoreline protection.

A better management alternative is to identify high erosion risk zones (BUSH, *et al.*, 1996; 2001; THEILER and DANFORTH, 1994), and enforce set-back regulations as well as to develop retreat/relocation strategies. If shore-hardening structures are warranted as a last resort, communities should opt for the best design and strongest materials. The latter is not likely to fall into the "low cost" category and will result in loss of the recreational beach (JACKSON *et al.*, 2001).

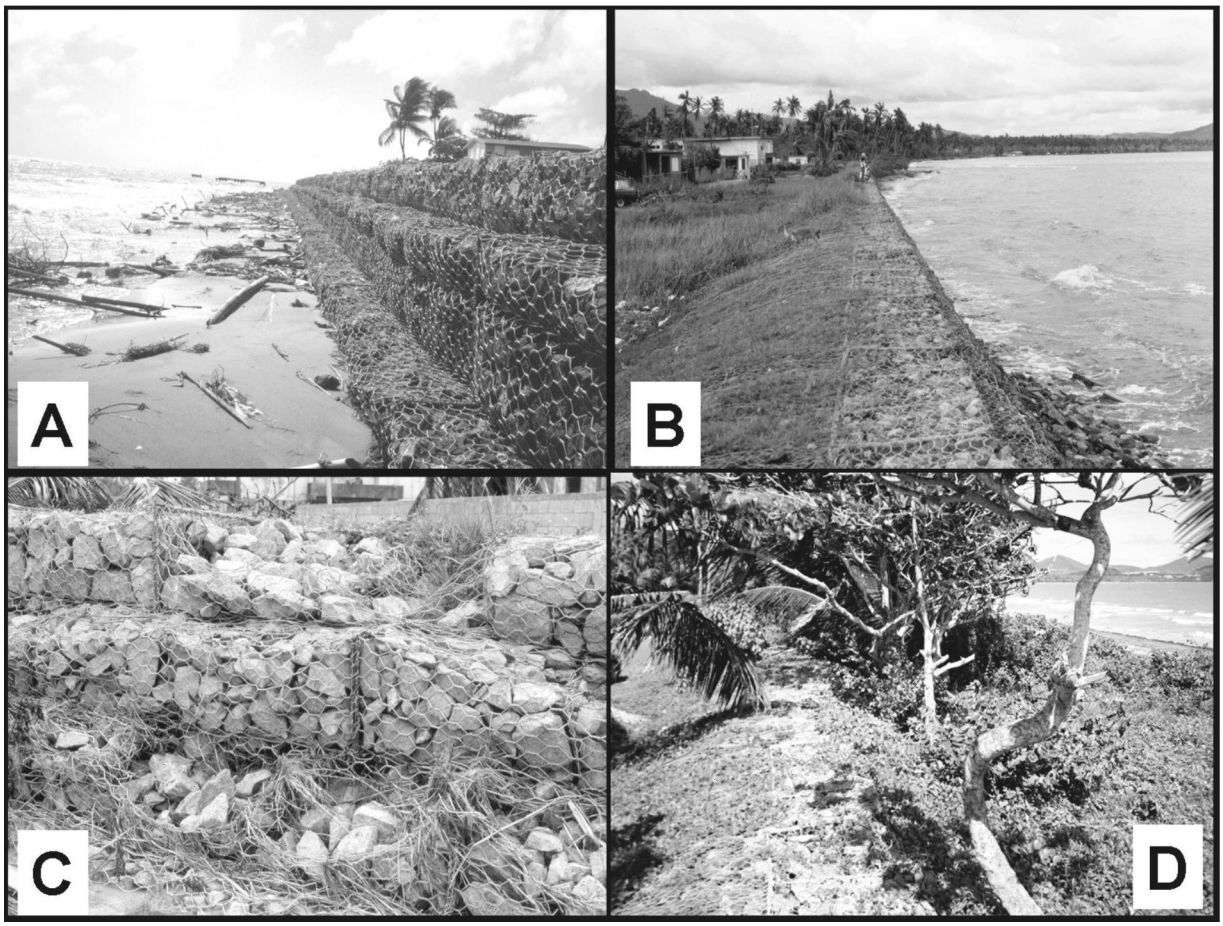

Figure 4. After erosion caused by Hurricane David in 1979, a gabion was emplaced along a 100-meter stretch of the Playa de Humacao shoreline just south of Rio Anton Ruiz. (a) Only a few years old in 1988, the wall was already beginning to show signs of deterioration. (b) Hurricane Hugo (1989) did not cause major damage to the wall, but narrowed the beach for a short time. Some rocks were spilling onto the beach. (c) By 1991 the wall was failing is several places. (d) The gabion wall was allowed to become overgrown by 2002, and was not being maintained.

The authors are not familiar enough with the inner workings of permitting and construction of coastal engineering structures in Puerto Rico to know why gabions came into such favor as the structure of choice. Certainly relatively low initial cost plays a part. It may also be that an enterprising contractor convinced the decision makers that gabions are the best choice for combating shoreline erosion in Puerto Rico, although they clearly are not the best choice.

It is particularly distressing that the number one authority on coastal engineering in the United States, the U. S. Army Corps of Engineers, has made it well known that gabions are not a viable alternative for high energy coastal settings, and yet gabions continue to proliferate in Puerto Rico. Several important points to consider in using gabions in the coastal environment are spelled out in detail by the Corps (USACE, 1986). Several of those points are completely disregarded in Puerto Rico. For example, it is suggested that gabions not be used in high energy wave environments, in the active surf zone, nor on public beaches where injury to bathers from protruding wire is possible. Moreover, the final suggestion given is that inspection and maintenance plans must be established. Clearly, none of these suggestions is followed in Puerto Rico, resulting in not only a financial loss, but also a loss of aesthetics and compromising the safety of beach users. The future of recreational beaches is dim if degraded gabions continue to litter rock and debris and cause increased hazards for swimmers and other beach users.

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Figure 5. Gabion Miscellany. (a) La Perla urbanization of Old San Juan, view to west, January, 1988. (b) Near Puerto Nuevo on the north coast, summer 2000; the endpoint of an urbanized shore. (c) Near Rio Guayabo, on the west coast of Puerto Rico, in 1992. (d) A "wall for no reason" at Balneario Rincon, on the west coast of Puerto Rico, in 1992. This structure was removed and replaced with a solid bulkhead wall sometime prior to 2002.

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