Reintroducing Structures for Erosion Control on the Open Coasts of America

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Introduction and Purpose

After a long hiatus, coastal managers are reconsidering the inclusion of erosion control structures along with beach nourishment and sand bypassing to maintain America's open coast beaches. Over the past 40 years, beach nourishment has been preferred (and in some states the only) method to address open coast erosion problems. Prior to that, structures had been the method of choice to protect upland properties and to attempt to hold sand on the beach. The current focus is on improving regional sediment management and not choosing sand vs. structures, but on developing cost-effective solutions that may include both.

The primary goal in erosion control projects is to provide a relatively uniform design beach along the project and adjacent areas that can be maintained at the lowest cost over time. The tools include sand bypassing at inlets, beach nourishment and structures to control and manage the erosion and sand placement in a manner that accomplishes this goal.

The purpose of this paper is to identify how structures can be used in concert with regional beach management approaches that may include beach nourishment and sand bypassing. The challenge to the coastal engineering community is to design erosion control solutions that can improve regional sediment management programs and avoid or manage downdrift consequences. Sand shortages, higher dredging costs and environmental impacts on nearby habitats are constraining designers to use less sand in beach management projects. How well designers meet these challenges will affect coastal policy for the future.

Background

There are two basic types of coastal erosion control structures:

1) Shoreline hardening structures that protect upland property (e.g. seawalls, revetments and bulkheads)
2) Sand retention structures that trap and retain sand (e.g. groins and breakwaters).

It is widely recognized that shoreline hardening structures provide no means of holding sand on the beach. The 1984 *Shore Protection Manual* (pp. 5-2 to 5-3) states that seawalls, bulkheads, and revetments "afford protection only to the land immediately behind them, and none to adjacent areas up-coast or down-coast. When built on a receding shoreline, the recession on adjacent shores will continue and may be accelerated. Any tendency toward the loss of beach material in front of such a structure may well be intensified." Seawalls and revetments, by design, are placed along the backshore as a means of absorbing or reflecting wave energy and preventing further recession of the uplands. Sand on the seaward side of such structures remains subject to erosion and can be lost, leaving no beach.

Sand retention structures, by comparison, are placed across the beach or nearshore so as to modify waves and currents, the primary processes that control sand transport, the form of the beach and the erosion or accretion of the beach. Sand becomes trapped between groins or in the lee of breakwaters, and maintains a particular section of beach. Sand retention structures do not manufacture sand but control the movement of sand along the shore and hence the amount of sand that resides in different sections of beach.

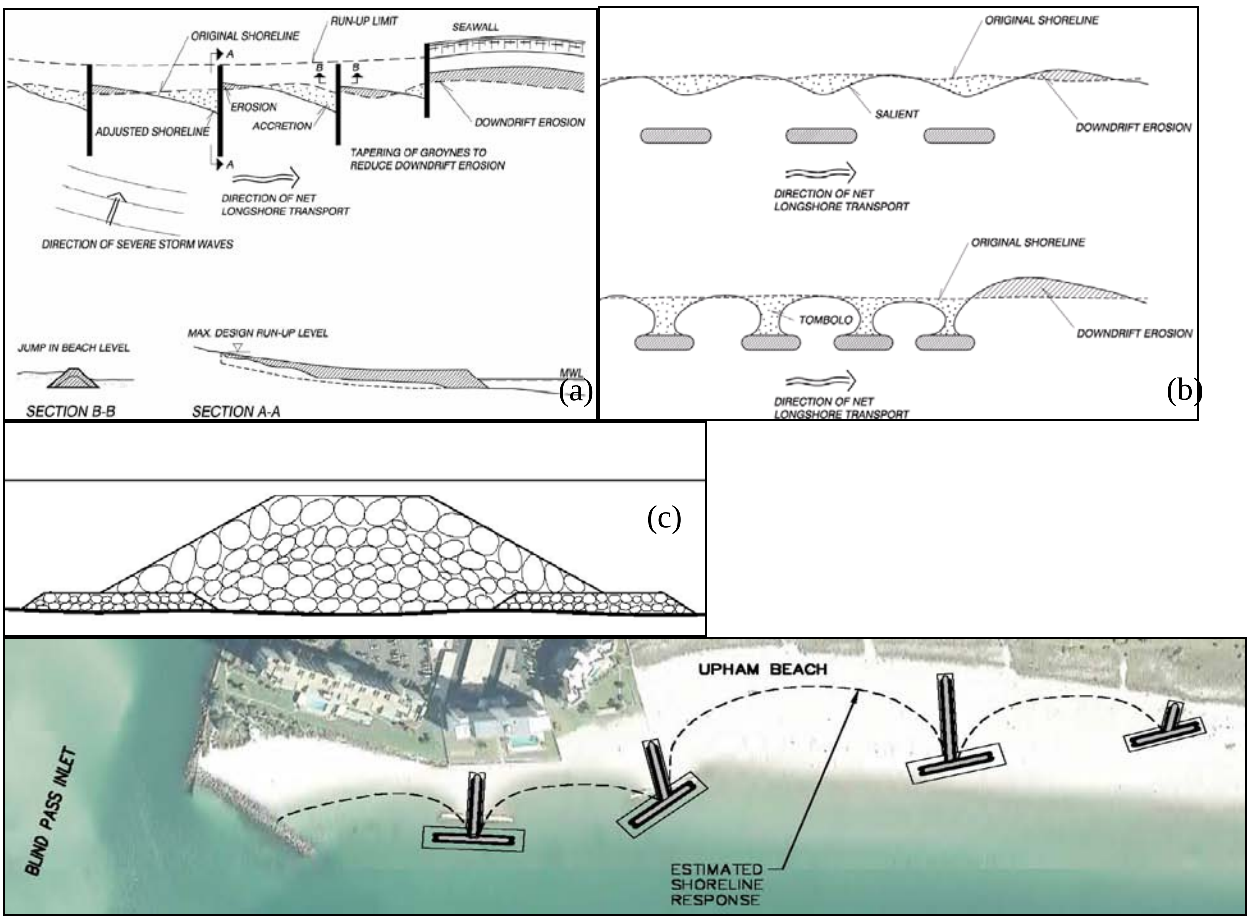

FIGURE 1: (a) Typical beach configuration with groins, (USACE, 2006); (b) Typical beach configuration with detached nearshore breakwaters, (USACE, 2006); (c) Example of a reef breakwater cross-section, (USACE, 2006); (d) Predicted shoreline response for T-head groins at Upham Beach, Florida (CPE, 2010).

When waves break at an angle with the shore, sand is moved along the shore; this sand movement is called littoral transport. Groins and breakwaters hold sand on a beach by reducing the amount of sand moving along shore. They can either be installed as single structures or as a field of multiple structures to control erosion over a broader area. Groins are generally perpendicular to the shore (see Fig. 1a) and slow the littoral transport by blocking sand movement along a portion of the active profile. Breakwaters are constructed parallel to the shoreline and slow littoral transport by absorbing wave energy coming into the shore (see Fig. 1b).

Since erosion is primarily caused by increases in littoral transport with respect to distance along the shoreline (littoral transport gradient), groins and breakwaters can counteract erosion by moderating the gradient in littoral transport along the shore. In some cases, they can reduce littoral transport to a point where they catch sand and cause accretion of the beach being protected by the structures. However, where littoral transport is slowed to reduce erosion along a section of eroding coastline, it has an effect on the adjacent beaches. The effects of coastal structures on adjacent shores can be positive or negative.

It was the proliferation of erosion control structures, primarily groins (that were not pre-mitigated with sand fill), and the ultimate realization that sand was being sequestered and not gained that led to limitation of their use by government. *Coastal zone management policy in the United States and many other countries strongly discourages the use of groins for shore protection, despite observations of good performance and their potential for maintaining beach width, increasing the longevity of beach fills, and preventing loss of sand into inlets, navigation channels , and submarine canyons.* (Kraus, 1994).

Why Consider Erosion Control Structures?

There are a number of reasons to consider the use of erosion control structures. The primary reason is to reduce beach erosion on a case-by-case basis along the open coast. There are many examples worldwide of erosion control structures that have been used to successfully retain sand and control erosion. Holly Beach, Louisiana, is an example of a breakwater field combined with a beach nourishment project in 2001 that is performing well. (See Fig. 2).

FIGURE 2. Holly Beach breakwater field, looking west from Louisiana towards Texas. The sub-aerial beach in this aerial photograph was constructed using sands buried in an offshore channel located about 3.5 miles offshore. Note the prominent salients forming in the lee of the emergent segmented breakwaters (Mann and Thomson, 2003).

Within nourishment projects, hot spot erosion areas are often good candidates for structures as they typically lose sand and storm protection well before the scheduled renourishment of the beach. This usually results in renourishing early and more frequently than planned and an increase in cost (Elko *et al.*, 2005).

Structures can be introduced to slow the erosion of a hot spot or stop it from eroding altogether. The challenge is use of the appropriate type and number of structures to slow the erosion of the hot spot area and to spread the sand deficit to a broader beach area that can be managed more effectively with less sand at an increased nourishment interval. When hot spot erosion is addressed with sand, and not a combination of sand and structures, more sand is needed to maintain the beach. This can increase the need for renourishment volumes significantly (in some cases as much as 2-3 times the net erosion of the beach).

The cost of sand for re-nourishment becomes more expensive as the sand sources get progressively further away with each renourishment. In a number of areas (such as south Florida), sand is scarce. Here, structures can reduce the loss rates from the projects, conserving sand in these areas for a longer period, thereby reducing renourishment requirements.

On the west coast of the United States, the narrow continental shelf and relatively high wave energy reaching the coast can contribute to very large sediment transport rates. Effective application of erosion control structures can retain sand in these areas for a longer period, thereby reducing renourishment requirements.

Structures can also be effective in environmentally sensitive areas where marine resource habitats are located near shore. In those areas, structures can be used to enable the placement of less sand and to have less frequent nourishment events to protect sensitive marine resource areas thus creating less impact on the environment. Structures may also be helpful in controlling sand migration in the vicinity of these sensitive habitats.

In all cases, a sediment budget should be a design component. A detailed "sediment budget" that identifies sinks and sources for sand can provide a useful starting point. Sediment budgets are approximations of the yearly balance of sand entering a self-contained coastal system (coastal cell) through rivers and shore erosion, and exiting the system through loss to deep water, entrapment by a structure or an embayment, and upland loss.

Potential Impacts on Adjacent Beaches

When structures are used to retain sand in a specific area (the design beach), they can have an effect on the adjacent beaches along the coast. Downdrift of a groin or breakwater field that reduces the erosion of the design beach on the open coast, erosion (or reduced accretion) of the downdrift beaches will be caused by the reduced sediment supply coming from the protected area.

Updrift of the stabilized area, beaches may accrete. Updrift accretion (or erosion reduction) will reduce the sand supply to the downdrift beaches and can increase the downdrift erosional effects of the groin or breakwater field. This updrift effect is sometimes not fully understood or accounted for in the design analysis. Improper consideration and planning for downdrift effects has led to the general distaste for erosion control structures in recent years.

Hot Spot/Cold Spots

On many beaches, hot spot erosion areas are adjacent to accretional areas known as cold spots. For various reasons, the littoral transport speeds up in the hot spot areas causing erosion and then slows down as it enters the cold spot area depositing sand and causing accretion. It is possible to use structures in these cases to regulate the amount of sand that moves along each segment to provide a consistent level of littoral transport along both areas, reducing or eliminating erosion of the hot spot area without causing unmanageable erosion of the cold spot area (Campbell, T.J. and Jenkins, M.G., 2002). In order to limit downdrift effects, the structural field will need to extend along the hot spot erosion area and a distance into the cold spot area to transition littoral transport to the background rates.

It may not always be possible or economically feasible to avoid all downdrift effects of coastal structures used to control erosion. However, it is often possible to reduce the net erosion by moderating the erosion in the hot spot and increasing nourishment in the downdrift areas. By keeping the entire project area on a longer nourishment interval by controlling hot spots with structures, cost savings will be realized through increased project longevity and reduced mobilization costs as well as reduced nourishment volumes.

Reducing Downdrift Effects

By limiting the amount of sand that is trapped by a structural field and allowing sand movement past the field, downdrift impacts can be reduced. The following approaches are commonly employed to mitigate downdrift effects of sand retention structures:

A. Pre-filling with Sand

Downdrift impacts can be reduced by placing sand within the structural field (series of groins or breakwaters) during or immediately after construction. This helps to limit the amount of sand removed from the littoral transport system that would otherwise be trapped or impounded by the structures over time. Pre-filling should also include the expected impoundment of sand in the fillet (accretional area) that will form updrift and downdrift (in some cases) of the structural field.

If structures are used to hold a wider beach on an otherwise stable stretch of beach, pre-filling can potentially eliminate the downdrift effect, but this is not the typical case since most erosion control structures are used to counter erosion on actively eroding beaches. When structures are placed on an eroding stretch of beach (the typical case) pre-filling reduces but does not eliminate all of the downdrift effects because any level of erosion reduction in the structurally protected and updrift areas means less sand moving to the downdrift beaches.

Downdrift beaches can also be pre-filled to counter the expected increase in erosion caused by the structures. In cases where the downdrift erosional effects cannot be avoided, pre-filling downdrift beaches should be done with the first nourishment and repeated as needed based on monitoring results and sediment budget analysis that may include numerical modeling.

B. Permeable and Low Profile Groins

The downdrift impacts of a groin field can be reduced if some sand is allowed to move over (low profile) or through (permeable) less aggressive structures. Permeable groins allow sand to move through holes or gaps in the structure as well as around the seaward ends of these structures. Permeable groins need to be longer than nonpermeable groins to retain the same volume of sand.

Low profile groins can also be built to hold the desired beach profile and allow sand to move to the downdrift beach by wave action. Permeable and low profile groins may reduce the potential for washouts (extreme concentrated erosion) experienced immediately downdrift of groin fields. This is partially because sand is moving along the entire active profile instead of just along the seaward portion of the profile (as with nonpermeable groin field) and thus creates less of a discontinuity at the interface with the last structure.

Some longer permeable structures, such as fishing piers and long permeable groins, have been shown to have both updrift and downdrift fillets which can be attributed to the wave shadowing effect of the longer structure. This wave shadowing effect also serves to limit washouts of the downdrift profile.

Detached Breakwaters

Detached breakwaters are defined by the CEM (USCAE (2006) as “small, relatively short, non-shore-connected nearshore breakwaters with the principal function of reducing beach erosion.” Breakwaters reflect and dissipate some of the incoming wave energy, which reduces wave heights in the lee of the structure and reduces the magnitude of littoral transport within the protected area. This reduction of littoral transport can stabilize or reduce the erosion of the beach within the breakwater field but can also cause downdrift problems.

The basic design parameters for breakwaters functioning as erosion control devices include their height, length, distance offshore and spacing (in the case of multiple breakwaters), structure porosity and beach sand grain size. These parameters, in addition to the resulting alteration in breaking wave height and wave angle, will determine whether a *salient* or *tombolo* will form (see Fig. 1b). A salient is the seaward protrusion of the shoreline in the lee of the structure, though the mean high tide shoreline does not physically reach the breakwater. The shoreline response is termed a tombolo if the mean high tide shoreline connects to the structure. Salient-formation is typically preferred since the littoral transport still continues in the lee of the structure(s). Several methodologies are available to predict the shoreline response and thus estimate the impoundment volume. These include but are not limited to Suh and Dalrymple (1987), and Pope and Dean (1987).

Long breakwater fields (10 or more breakwaters) will reduce both littoral transport and littoral transport gradients but may not eliminate erosion within the field (Mann and Thomson, 2003). An important consideration when designing breakwaters as erosion control structures is the longshore transport rate. Breakwaters can suppress but not eliminate longshore transport. It has been observed in long breakwater fields (where the end effects do not interact) that shoreline recession can still occur within a long breakwater field. This is because the sediment transport gradient is still positive, signifying erosion even though the net sediment transport rate is lower than the pre-structure condition. In this instance, nourishment within the breakwater field is still required.

An analysis of the sediment transport rate pre- and post-construction can also be instructive when considering downdrift impacts. The breakwater field will suppress the sediment transport so the breakwater field should be extended into the accretional downdrift area to the point that the suppressed rate equals the pre-construction sediment transport rate. The goal is to remove the peak of the sediment transport curve and not induce a second peak on the downdrift end.

For example, 85 segmented breakwaters at Holly Beach, Louisiana, reduced but did not eliminate erosion in the protected beach area. Monitoring showed that the littoral transport was reduced uniformly by the breakwaters but the littoral transport gradient was not eliminated. Therefore, erosion continued within the breakwater field, albeit at a reduced rate, and thus required nourishment.

Breakwater fields can also result in updrift erosion. Consider a scenario where the ratio of gross to net transport rate is very high (a lot of sand moving back and forth within the field but the net transport in one direction is low). In this instance, sand is moved into the breakwater field at the pre-construction transport rate. However, the reversal of sediment transport out of the breakwater field is subdued by the breakwaters. Thus, sand is moved into the breakwater field but not out, which can result in an updrift erosion signature.

Submerged Breakwaters

Submerged breakwaters or reef breakwaters can reduce wave energy by tripping waves coming into shore (see Fig. 1c). Similar to emergent breakwaters, submerged breakwaters can potentially create a lower energy zone where littoral transport and erosion are reduced. An advantage of submerged breakwaters is the potential of achieving erosion control with a structure that does not obstruct the view of the water or the horizon. Submerged breakwaters may also provide hard bottom habitat which could mitigate for impacts to the environment where nearshore rock outcrops may be affected by the project. There are a number of examples of natural submerged reef breakwaters that are effective in retaining sandy beaches in their lee. (Everts Coastal, 2000).

Ranasinghe and Turner (Ranasinghe, *et al*., 2004) demonstrated by physical and numerical modeling that submerged structures can cause either erosion (close to shore) or accretion (far from shore) based on their distance from shore. In the Town of Palm Beach, Florida, thin crested submerged breakwaters placed relatively close to the beach were found to have caused a pile up of water (wave setup) in their lee that generated a scouring current along the beach. This hydrodynamic effect resulted in increased erosion of the project beach that the structures were intended to protect (Dean, *et al.,* 1994; Dean, 1995). The structures also experienced up to 2.8 feet of settlement (Dean, *et al.,* 1994). Due to their unfavorable performance, they were eventually removed.

There are a number of challenges associated with designing submerged breakwaters that should be considered:

- Submerged breakwaters used for erosion control need to be a sufficient distance offshore to avoid wave setup, but close enough to the surface of the water and relatively wide to reduce wave energy.
- Submerged obstructions, such as submerged breakwaters, close to the surface of the water can pose a hazard to both swimmers and boaters.
- Where there is a significant tidal range, submerged breakwaters can become ineffective at high tide and potentially emergent at low tide.

If a coastal engineer can successfully address these challenges an effective design for a submerged breakwater system can be developed.

T-head Groins

T-head groins are erosion control structures that combine the features of groins and breakwaters (see Figures 1d and 6). Also called "attached breakwaters," T-head groins are better able to hold a beach than a simple groin, and limit transport on the leeward side of the breakwater. Several analytical methods have been developed to predict the shoreline shapes within the compartments of T-head groins. These methods are cataloged in Coastal Engineering Technical Note IV-36 by Hanson and Kraus (2001). Like straight groins and breakwaters, T-head groins can have updrift and downdrift effects and should be pre-filled to reduce downdrift impacts.

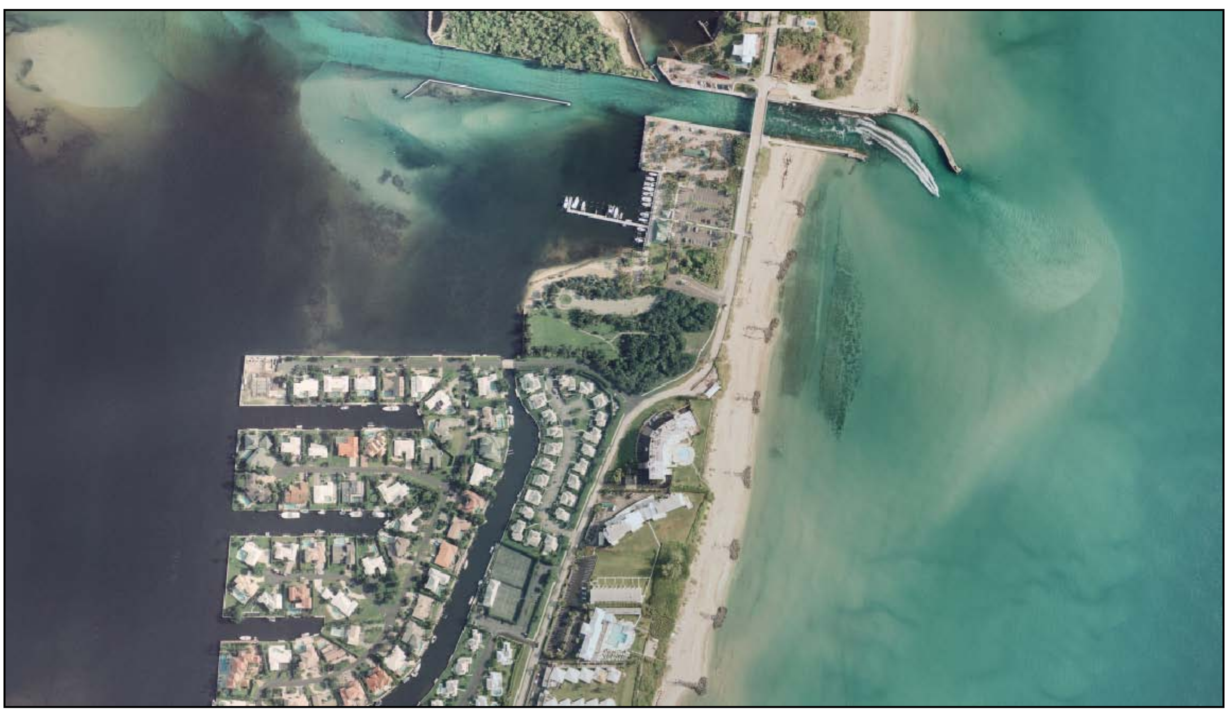

FIGURE 6: T-Head Groins near South Lake Worth (Boynton) Inlet, Ocean Ridge, FL.

Terminal Groins

Beaches adjacent to tidal inlets are often subject to accelerated erosion and much larger scale fluctuations in the shoreline compared with beaches distant from inlets. Terminal groins placed at inlets can limit the loss of sand into the inlet and moderate large-scale fluctuations of the shoreline near the inlet. (Although similar in appearance to groins, navigation jetties that are intended to maintain navigable tidal inlets should not be confused with terminal groins which have been placed to control erosion). A more thorough discussion of terminal groins is included in a separate ASBPA white paper.

Erosion Control Structures and Surfing

Erosion control structures can affect wave break and recreational surfing conditions. A separate white paper has been developed to address surfing concerns and design considerations.

Summary

Experience has shown that sand retention structures can be included with sand bypassing and beach nourishment to develop cost effective programs for erosion control and regional sediment management. The design must be based on a sediment budget such that the sand entering the protected area equals the amount leaving. Coastal engineers must carefully consider and provide for changes in the littoral transport patterns that will result from the inclusion of structures in the design of erosion control programs.

Along open ocean sandy beaches, long-term erosion is primarily caused by an increase in littoral transport along the shoreline. When less sand enters a coastal segment than leaves, the overall effect is erosion and shoreline retreat. Based on this principle, groins and breakwaters can:

- Slow littoral transport and reduce or reverse erosion of the protected areas.
- Be used to reduce hot spot erosion and the needed frequency of nourishment.
- Preserve or enhance recreational surf breaks.

Negative updrift and downdrift impacts of groins or breakwaters can be reduced by:

- Pre-filling the groin or breakwater field with the amount of sand that is expected to accumulate in the field.
- Pre-filling the updrift areas in anticipation of an updrift fillet development.
- Construction of less aggressive structures that have a low profile or are porous.
- Pre-filling downdrift areas to address anticipated impacts and nourishing downdrift areas based on physical monitoring of volume changes.
- Extending the groin or breakwater field beyond the erosion area and along a portion of the downdrift accretional (cold spot) area.

Developing a comprehensive littoral budget is critical to help coastal engineers design composite erosion control programs that include beach nourishment, sand bypassing and erosion control structures that maintain uniform storm protective and recreational beaches at lower costs. Proper coastal engineering design can avoid or manage downdrift effects of erosion control structures

As economical sources of sand become harder to find there will be increased pressure on the coastal engineer to develop erosion control projects that manage sand more efficiently. Sand retention structures combined with beach nourishment and sand bypassing can achieve these goals. The challenge for the coastal engineer is to bring beach managers, beach users, surfers and coastal regulators together, using sound scientific and engineering principles to properly manage our coastal sand resources.

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