

BATTLING THE BERING SEA: ST. GEORGE ISLAND'S BERM BREAKWATER

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St. George Island, Alaska is located in the Bering Sea more than 320 kilometers (200 miles) north of the nearest Aleutian Island. During original design and construction of the fishing harbor at St. George Island in the early 1980's, stone large enough for a conventional breakwater was not available to quarry on the island, so the project utilized a berm breakwater approach with the available local stone. The long-term performance and service life of the berm breakwaters is reviewed in this paper. Construction of the berm breakwater was completed in 1987 and the breakwaters remained functional for nearly 20 years with little maintenance. In the winter of 2015/2016, approaching 30 years since initial construction, significant damage occurred during a winter storm. Repairs utilized a berm breakwater approach similar to the original design. Repairs were completed in 2 phases due to the short construction seasons at the project site.

Keywords: Alaska; berm breakwater; Bering Sea; Aleutian Islands; Pribilof Islands

INTRODUCTION

St. George Island, Alaska, is part of the Pribilof Islands, located in the Bering Sea (Figure 1) near 56.6° N latitude, approximately 1,300 kilometers (800 miles) southwest of Anchorage and 350 km (220 miles) north of Unalaska. The island is more than 320 kilometers (200 miles) north of the nearest Aleutian Island.

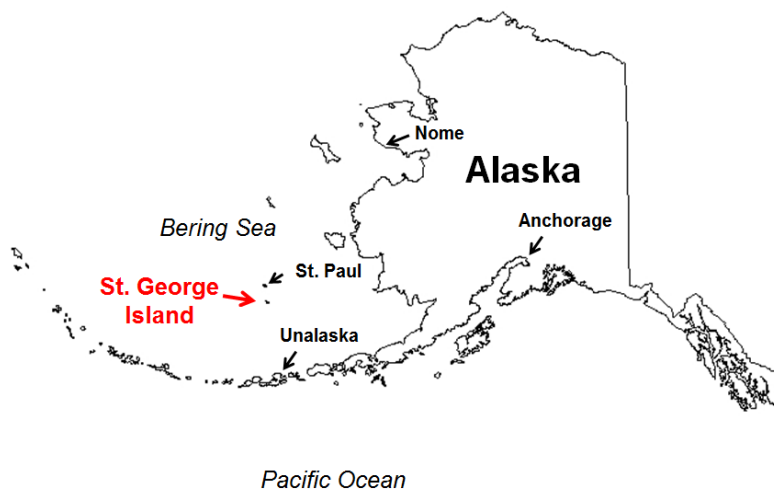


Figure 1. Location map.

For nearly two centuries, St. George's primary economy was based on commercial fur seal harvesting. In the early 1980s when commercial fur seal harvesting was halted, the community turned to a fishing economy. Despite being surrounded by productive fishing grounds, the community did not have a permanent boat harbor suitable for commercial fishing vessels, and the geography of the island offered no naturally-sheltered areas from the severe Bering Sea wave climate where boats could be consistently and reliably anchored or docked.

In 1982 the City of St. George received assistance from the State of Alaska to begin harbor design and develop initial design alternatives. In 1984 the City engaged a private engineering firm to continue development of the design, and cost-reduction measures resulted in the outer breakwater being shifted into shallower water and incorporation of a berm breakwater. The design condition for the breakwater was determined to be a significant wave height of 34 feet at peak spectral period of 18 seconds. Because a conventional breakwater at St. George would have required larger armor stone than was obtainable on the island, a berm breakwater was selected to utilize locally quarried basalt rock, significantly reducing project costs and allowing the project to move forward within the available

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funding (“St. George,” 1986). The berm breakwater design called for armor stone ranging from 1 to 10 tons, with a median stone size of 4 tons (Bloomberg, 1988).

Construction of the breakwaters was completed in 1987. The harbor consists of two outer breakwaters and one inner breakwater. Figure 2 shows a 2013 aerial photograph of the harbor.



Figure 2. St. George Harbor Aerial (Alaska Mapped, 2013).

BREAKWATER PERFORMANCE

Damage and Repair Timeline

A strong indication of the success of the berm breakwaters at St. George is the minimal maintenance and repair work performed in the approximately 30 years since construction. Figure 3 shows a timeline of the documented damage occurrences and the associated repairs. The first documented damage to the breakwaters occurred in 2004, approximately 17 years after construction (PND, 2008). This damage event displaced stone from the breakwater cross-section, but review of survey drawings from the repairs design shows minimal to no loss of the breakwater crest elevation, therefore leaving the harbor functioning (PND, 2007). Repairs for the 2004 damage were constructed in 2006 and consisted of placing 18,000 tons of 6 to 12 ton armor stone on the south breakwater. The next, and most recent, documented damage occurred during the winter of 2015 and 2016 when the crest of the south breakwater arm was displaced. This event was approximately 27 years after construction and displaced approximately 29,300 tons of armor stone on the south breakwater (HDR, 2017).

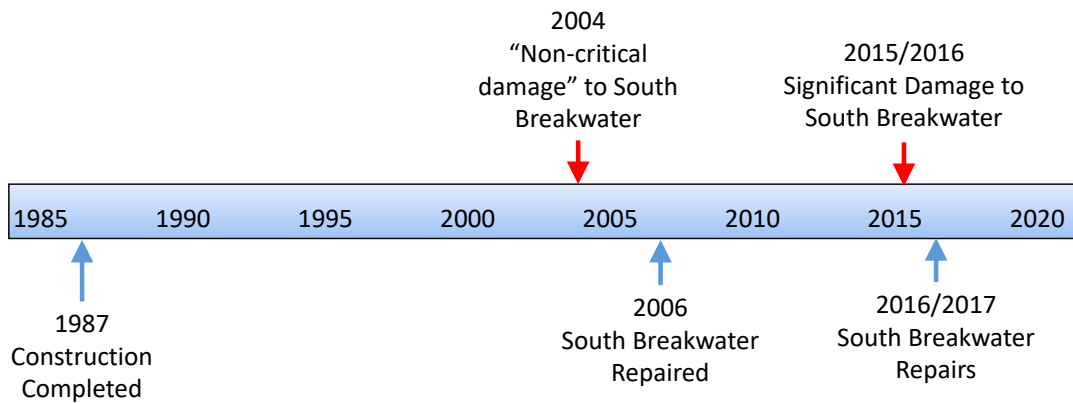


Figure 3. Timeline showing St. George breakwater damage and associated repairs.

Cross-section Comparisons

Although somewhat limited in availability, historical survey data and plots were gathered to perform comparison of the breakwaters over time. The most comprehensive survey data were available from 2013 and 2016. In addition, construction drawings for the original design and survey plots from the 2006 damage repairs were obtained and digitized. Figure 4 shows a comprehensive comparison of a representative cross-section through the south breakwater arm for all of the data obtained.

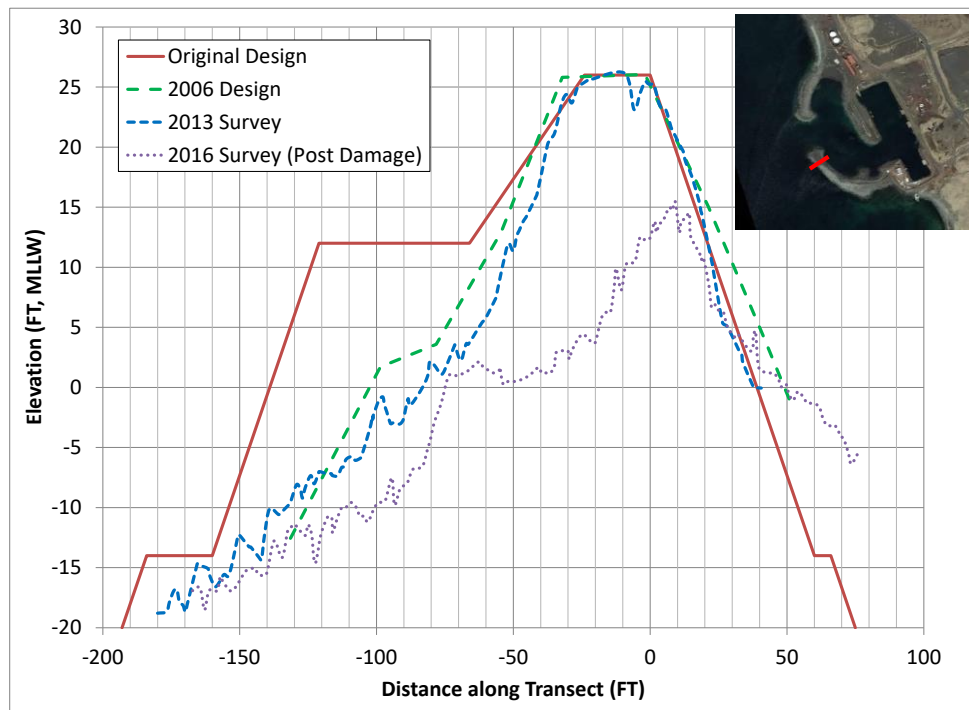


Figure 4. Breakwater cross-section comparison of original design (digitized from PND, 1984), 2006 survey data (data digitized from PND, 2007), 2013 survey data (HDR, 2013), and 2016 data (HDR, 2017). Inset on right shows the location of the survey cross-sections.

Numerous conclusions can be deduced from Figure 4. Of most significance is that the berm portion of the breakwater only appears in the design template, but not in any of the subsequent surveys. It is important to note that the first post-construction survey section is from 2006, almost 20 years after construction. One potential explanation for loss of the berm armor stone is longshore transport of the stone. Movement of the berm stone over the project life was expected as the project was designed to be dynamically stable (or "reshaping"). It is expected that the basalt armor stone degraded over time with constant wave forcing and undergoing freeze and thaw cycles. Reduction in size of the stone by degradation would have increased potential for armor stone movement. Therefore berm material may

have been pushed southward during large wave events due to the oblique orientation of the south breakwater arm. Armor stone accumulation was apparent on some southern portions of the south breakwater in the 2013 survey and analysis (HDR, 2013) and in aerial photographs. Armor stone movement may also have resulted in displacement of stone further offshore. Another possible explanation for the loss of berm material is settlement into the sand bottom. As the armor stones were continuously impacted by waves, movement of some of the stone may have gradually caused them to settle deeper and deeper into the seafloor. In reality it is likely a combination of these damage mechanisms that occurred.

Additional armor stone from the central portion of the breakwater section appears to have been lost between the 2006 and 2013 cross-sections, and then ultimately the 2016 survey cross-section shows loss of the breakwater crest. The intended design function of the berm breakwater requires the presence of the berm to allow for some reshaping of the breakwater and to dissipate wave energy prior to waves impacting the remainder of the structure. From the information available it is unclear how quickly the berm portion of the breakwater was lost, but based on the lack of documented damage prior to 2004 it is expected that the berm was present to some degree for over a decade after construction.

One additional and noteworthy observation from Figure 4 is that the crest elevation of the breakwater remained relatively stable until the 2016 storm event. The crest elevation of the breakwater is imperative to prevent significant wave energy from overtopping into the harbor and creating hazardous conditions. The stability of the breakwater crest for approximately 27 years is a significant achievement for the project and lends to the success of the design.

WINTER 2016/2017 DAMAGE AND REPAIRS

A strong winter storm in December 2016 displaced a large number of armor stones from the breakwater crest on the south breakwater arm (see Figure 4). The displaced stone resulted in a breach of the crest elevation in the area shown in Figure 1 which would allow wave energy to more frequently overtop the breakwater. The resulting condition resulted in increased navigation hazards, and the City acquired funding from the Federal Emergency Management Agency to perform emergency repairs.

Phase 1 Repairs

Repair design began immediately after the December 2016 storm as part of an emergency repair effort to return the harbor to an operating condition. Initial assessments of damage were based on rudimentary survey methods and observations until more time and weather permitted modern surveys to be performed. The results of the assessments determined that approximately 9,500 tons of armor stone would be required to return the breakwater to its pre-storm condition, but later surveys showed the damage to be more extensive (discussed below in *Phase 2 Repairs*). The initial assessment volume provided enough stone to rebuild the breakwater crest to the pre-storm elevation.

The design analysis for Phase 1 identified that the remaining stone in the breakwater cross-section was focused on the leeward side of the original structure. This was attributed to the damage mechanics and larger wave forces on the seaward slope. To reduce volumes necessary to complete the Phase 1 repairs, the centerline of the breakwater crest was shifted landward to center over the remaining armor stone.

Phase 1 repairs applied a composite breakwater slope on the seaward side with a 4H:1V slope in the lower portion of the breakwater below the +12 ft MLLW contour and a 1.5H:1V slope on the upper section. The composite slope allowed for greater stability in the lower portion of the breakwater cross-section while still meeting the elevation requirement for the crest. Figure 5 shows a cross-section of the Phase 1 and Phase 2 repair design.

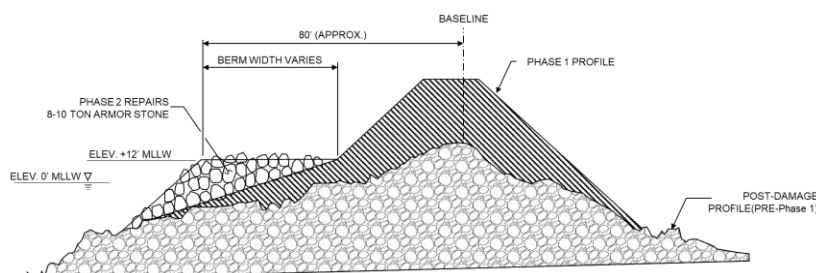


Figure 5. Comprehensive cross-section of Phase 1 and Phase 2 repairs to the south breakwater at St. George Harbor.

The repairs placed 6 to 10 ton armor stone partially sourced from a local quarry on the island and also imported from Kodiak Island, AK and Rainier, WA. Construction of Phase 1 was completed in September 2016. An aerial photograph of the completed repairs is shown in Figure 6.



Figure 6. Aerial photograph of completed Phase 1 repairs. (Photo courtesy of Brice Construction).

Phase 2 Repairs

Surveying performed simultaneously with the Phase 1 repairs identified a large amount of displaced armor stone beyond the Phase 1 assessment. The additional displaced stone was below the water line, beyond where the rudimentary survey methods were employed during the winter. The new assessment increased the total displaced stone from 9,500 tons to 29,300 tons. This information became available during construction of the Phase 1 repairs, but due to the short summer construction window in the Bering Sea, the decision was made to complete the repairs in two phases with the first phase focused on rebuilding the crest of the breakwater.

The Phase 2 repairs focused on increasing the overall stability of the breakwater rather than just restoring the crest elevation. Design alternatives for both a composite slope and a berm breakwater were considered and ultimately a berm breakwater was chosen, largely based on the success of the concept from the original construction. The berm would be constructed on the seaward side of the damaged breakwater section and serve to dissipate wave energy in its porous section before the energy impacts the remainder of the structure.

The original design of the St. George breakwaters used a dynamic berm concept in which the berm would be reshape in the wave conditions at the site. Although the berm was intended to ultimately be stable despite the reshaping, the repair work was able to utilize larger stone to create a more stable berm. In the stable berm concept, large enough stone is used so that it is not intended to reshape. This approach is expected to provide a more robust breakwater system. The construction of the stable berm was only possible by importing larger armor stone, whereas the original breakwater construction utilized local-quarried armor stone from St. George Island. For Phase 2 armor stone was imported from Shackmanoff Quarry on Kodiak Island, AK. Figure 5 shows a comprehensive cross-section of the Phase 1 and Phase 2 repairs. Construction of the Phase 2 repairs was completed in July 2017. A ground-level photograph of the constructed berm is shown in Figure 7. Approximately 32,000 tons of armor stone were placed in total between Phase 1 and Phase 2 for a total construction cost of approximately \$17M.



Figure 7. Ground level photograph of completed Phase 2 repairs (Photo courtesy of Brice Construction).

SUMMARY

St. George Island is located in the Bering Sea and is exposed to the raw energy of powerful, frequent winter storms. The island hosts a harbor constructed in 1987. The harbor breakwaters utilized a berm breakwater concept to incorporate the smaller basalt armor stone obtainable at local quarries on the island. Ultimately the berm breakwater concept provided significant cost savings and made construction of the harbor feasible. The harbor breakwaters were considered successful, suffering the first documented damage (and associated repairs) approximately 17 years after construction, and finally suffering more significant damage almost 20 years after construction. Repairs to the most recent damage were constructed in two phases over two summer construction seasons. The repairs utilized the berm breakwater concept with larger imported armor stone to improve the stability of the breakwater.

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