Mouth of the Columbia River North Jetty Erosion Stabilization

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ABSTRACT

The Mouth of the Columbia River (MCR), located at the river’s confluence with the Pacific Ocean between Oregon and Washington, is a critical regional and national gateway for trade and commerce. The MCR is protected and stabilized by three rubble-mound jetties, all of which are in need of major rehabilitation. In 2014, rehabilitation started with construction of the North Jetty Lagoon Fill project.

Soon after construction of the North Jetty in 1917, deposition of sand caused the formation of a wide beach along the north side of the structure, which helped protect much of the north side of the jetty from ocean erosion. However, over time, a linear ‘lagoon’ feature formed adjacent to the north side of the jetty, primarily caused by erosion and piping through the jetty. This erosion was accelerated by the presence of a small stream that connected with the lagoon and drained through the jetty structure. The erosion was jeopardizing the foundation of the jetty and contributing to ongoing deterioration.

Simply filling the lagoon would not have been a long-term solution without addressing the causes of the erosion. Of the design elements included, three were key: construction of a rock filter adjacent to the jetty, construction of an erosion protection structure near the west end of the lagoon area, and construction of a weir structure to allow stream drainage through the jetty. Construction was completed in June 2015.

Keywords: Jetty, erosion, sinkhole, breach, stability, Columbia River.

1. INTRODUCTION

The Mouth of the Columbia River (MCR), or Columbia Bar, is located at the river’s confluence with the Pacific Ocean between Oregon and Washington (Figure 1) and is known as one of the most treacherous coastal inlets in the world, with its strong currents, large waves, and extreme tidal influences. The MCR has been linked to the economic future of the Pacific Northwest since settlers first began exploring the region in the late 1700s. Today, about 38 million metric tons of cargo is transported through the MCR each year, with an estimated value of $20 billion (U.S.) (USACE 2012). This level of commerce would not be possible without the deep-draft navigation channel that currently exists through the inlet and which is maintained by nearly continuous dredging operations and the presence of protective jetties at the river’s mouth.

The jetty system at the MCR consists of three rubble-mound jetties (North Jetty, South Jetty, and Jetty A) with a total length of about 15.6 km. The jetties were constructed between 1885 and 1939 on massive tidal shoals to secure consistent navigation through the coastal inlet, which historically experienced rapid shifting of sand bars. Since initial construction, these structures have been battered by storms and the jetties have undergone a number of repairs. Today, the jetties are once again in need of major repair, so in 2010, planning and design for rehabilitation began, with construction starting at the North Jetty in 2014. The rehabilitation at the North Jetty is being completed in three phases:
1. Infilling of an eroded lagoon on the landward side of the jetty,
2. Initial ‘critical’ repair of the jetty from station 85+00 to 98+50 (stationing in U.S. feet), and
3. Construction of a new head cap from station 98+50 to 101+00 and rehabilitation of the jetty truck and root from station 20+00 to 85+00.

The first two phases of the rehabilitation are complete. The third phase is currently being designed, with construction anticipated to begin in 2017. This paper focuses on the first phase of the project, stabilizing the jetty by infilling of the landward lagoon.

2. LAGOON FORMATION

The North Jetty is located in Pacific County, Washington, near the towns of Ilwaco and Long Beach. Originally, the North Jetty was about 3.7 km long, extending from Cape Disappointment west along Peacock Spit, then out to open water (Figure 2). Soon after construction, jetty induced morphological changes to the inlet resulted in the rapid deposition of sand at Peacock Spit and the formation of a wide accreted land mass along the north side of the structure (Benson Beach). This accreted land mass helped protect much of the north side of the jetty from the extreme ocean forces. Since construction, the jetty head has retreated about 610 m, with Benson Beach retreating by a similar amount, but the sand that remains to the north continues to protect the integrity of the jetty trunk and has reduced overall maintenance costs. However, over time, a linear ‘lagoon’ feature formed adjacent to the north side of the jetty (Figure 1), between station 16+00 and 59+00, primarily as the result of erosion and piping of sand caused by tidal exchange and wave surge through the deteriorated porous structure. This erosion was jeopardizing the foundation of the jetty and contributed to ongoing deterioration. Therefore, the decision was made to fill in the lagoon and construct a landward filter to mitigate for future erosion (USACE 2012).

The initial stages of sand erosion through the jetty likely started soon after formation of Benson Beach. The North Jetty was constructed almost entirely of large jetty stone, originally between 1 and 14 metric tons each. This resulted in a very porous and permeable structure, which allows the free transmission of water through the jetty void space as a result of tidal exchange, wave influence, and stormwater drainage. The tidal range at MCR between mean lower low water (0 m MLLW) and mean higher high water (MHHW) is 2.4 m, with seasonal high tides reaching 3 m MLLW. Mean sea level is at 1.1 m MLLW. During storms, ocean water level along the structure can be surcharged by 0.6 to 1.5 m (above tidal level) due to storm surge effects. Storm wave heights at the seaward extent of the MCR inlet can reach 7.2 m, while wave heights along the channel side of the jetty (within the inlet interior) can range from...
2.4 to 5.5 m depending upon water level and jetty location. The rapid transmission of water during tidal surcharge and storm wave action results in the piping of erodible material through the jetty and a net degradation of material.

Figure 2. Shoreline response north of North Jetty from 1939 to 2002

The first indication of erosion was the formation of sinkholes on the landward side of the jetty. Prior to the lagoon formation, the ground surface elevation behind the jetty generally ranged from about 4.3 to 4.9 m, which is higher than most of the significant waves measured at the south side of the jetty. As wave energy propagated through the structure, it initially eroded sands in contact with the jetty side slope below the ground surface. This resulted in development of subsurface voids within the sand deposit. Because the beach and dune sands that make up the Benson Beach complex are essentially non-consolidated and non-cohesive, the ceilings of the voids quickly collapsed, and sand filled the opening like an hour glass. Continued erosion and sand migration through the jetty continued this process until sinkhole depressions formed at the ground surface (Figure 3). The sinkholes enlarged until all the sand had been eroded from near the face of the jetty down to an elevation of approximately 1.2 to 1.5 m (North American Vertical Datum of 1988 - NGVD88), although some areas eroded down to an elevation of 0.3 m (NGVD88).

Wave overtopping contributed to the erosion and enlargement of the lagoon feature. Although actual wave overtopping was determined to be an infrequent event, the impact of such events on the size and shape of the lagoon were significant and likely played a key factor in the formation of the lagoon. Wave overtopping introduces a ‘slug’ of water into the lagoon from up to 3 m above the ground surface. This force rapidly erodes once stable sands and enters them into suspension. In addition, the slug of water increases the water elevation of the lagoon, creating a steeper hydraulic gradient between the lagoon and south channel, allowing more rapid flow and sediment transport back out into the channel.

Progressive landward recession of Benson Beach contributed to enlargement of the lagoon and undermining of the jetty foundation, primarily during storm surge events. The location of the beach is very much tied to the jetty head location. As the jetty length recedes, the shoreline is exposed to greater wave and storm energy, which impacts the beach. The structure also focuses incoming wave energy to the beach/jetty interface and generates outgoing rip current alongside the north jetty toe that has a negative effect on the stability of the trunk (Figure 4). This focused energy allows storm surge to travel farther inland and has resulted in periodic overtopping and breaching of the foredune near the jetty that separates the beach from the lagoon area. These periodic breaching events significantly accelerated the lagoon formation, especially at its western end.
Lastly, the formation of the Benson Beach complex also blocked and disrupted natural drainages north of the jetty. As a consequence, an approximately 1.8 km² (450 acre) catchment and lagoon complex formed at the location of the historic, pre-jetty shoreline at the base of McKenzie Head (Figure 5). Surface water no longer discharged directly to the MCR inlet upon reaching the base of McKenzie Head. Instead, runoff was detained in a depositional basin behind Benson Beach. The water that could not be stored or rapidly infiltrated in the basin exited the system by way of a single small stream channel that flowed from the basin south into a broad wetland complex present north of Jetty Road, then flowed south under the road embankment via a 1.2 m (48 inch) culvert towards the North Jetty root where the water simply flowed through the pervious jetty stones and into the inlet channel between Stations 18+00 and 20+00. As the lagoon formed on the landward side, the small stream channel eventually connected with it and contributed fresh water to the more saline intertidal lagoon. This exchanged accelerated the lagoon growth, especially at the south end of the lagoon.
The configuration of the lagoon and stream channel, and the elevation of the culvert, also allowed a moderate backflow to occur through the culvert and into the McKenzie Head wetland during extreme high tides (greater than 2.7 m NAVD88). This backflow provided an additional source of water to the wetland complex north of the road. One of the goals of the project was not to significantly impact the McKenzie Head wetland complex or the intertidal exchange during high tides.

3. DESIGN CONCEPTS

The lagoon fill project had a number of technical goals that needed to be incorporated into the design; these included:

- A design life of 50 years with only periodic maintenance.
- No negative impacts to the Benson Beach wetland complex north of Jetty Road.
- Fill design was to address erosion from hydraulic loading associated with: (1) tide, wave, surge, and overtopping loading from the channel side; (2) overland flow from the wetland; and (3) storm surging waves from the Benson Beach side/ocean side of the project.
- Fill design was to maintain sufficient permeability of the jetty.
- Fill design was to provide a sufficient subbase/subgrade surface adequate for future design and construction activities for jetty rehabilitation; including, staging, crane operations, and truck loading.

To achieve these goals, a number of design elements were developed that both helped protect the jetty while maintaining needed tidal exchange through the structure. These included construction of a zoned rock filter adjacent to the north jetty face; construction of a buried, dynamically stable, erosion protection structure near the west end of the lagoon area; and construction of an armored weir structure through the filter zone in the existing stream drainage area to help protect the jetty foundation from erosion while maintaining stream flow and tidal exchange through the jetty in this area. A fourth element was added later in the design process associated with development of a sand borrow pit at the eastern end of the site, which was used to reduce the quantity of import sand material for the lagoon filling. U.S. Army Corps of Engineers Engineering Manuals (EM) were heavily utilized during the design (including EM 1110-2-1100, EM 1110-2-1601, and EM 1110-2-1901).
3.1. Filter Design

To address piping of fine grained sandy fill through the jetty, a filter zone was needed between the jetty stone and the bulk lagoon sand backfill. A three-zone filter rock design was selected, with the coarsest gradation near the jetty and fining outward (Figure 6). The use of geotextile filters was initially considered but was later rejected, primarily due to environmental concerns and concerns related to its long-term performance.

Zone 1 – The first filter zone (the zone closest to the jetty) consisted of 9,072 metric tons of light loose riprap to be selectively placed on the inside face of the structure to fill major voids in the jetty armoring. A tonnage was specified, rather than a thickness, to simplify the bidding process and contractual oversight. The primary purpose of the Zone 1 riprap was to fill in large voids in the jetty face and to even out the slope, rather than acting as a true filter zone. The Zone 2 shot rock fill (described below) was sized to be able to bridge the jetty stone voids, although some shot rock may have been initially lost within the larger voids. The riprap zone helped reduce the amount of shot rock lose and helped develop a more regular face by which the Zone 2 shot rock could be placed.

Zone 2 – The second zone consisted of a 3.7 to 4.6 m wide zone of graded shot rock, ranging size from about 2 to 40 cm. The 0.9 m tolerance was allowed due to the variable nature of the slope. The purpose of this zone was to provide a filter between the larger jetty stone/Zone 1 riprap and the fine Zone 3 gravel. The shot rock zone also provided a deformable filter that settles and occupies any voids created by piping of the existing underlying fine sand in the lagoon area through the jetty (Figure 6).

Zone 3 – The final filter consisted of a minimum 1.5 m wide zone consisting of graded gravel sized material. This material generally ranged from sand size (min. 35% sand equivalent) to 3.8 cm material. This zone is intended to prevent the lagoon sand fill from piping through the jetty.

3.1.1. General Bulk Lagoon Fill

The required general bulk lagoon fill that was placed landward of the zone 3 filter was generally graded to be in the sand sized range, specifically in the range so that local beach and dune sand material could be utilized. The fill gradation was intended to satisfy filter criteria, provide a stable subbase for future jetty work, be able to support vegetation and promote drainage, and be readily available within the immediate project vicinity.

Initially, the lagoon infilling was to be coordinated with local dredging operations and the dredged sands reused as pump ashore bulk material. However, coordination between multiple contracts proved difficult, and alternative sources were investigated. There were numerous sand and gravel pits in the general vicinity that could provide the required bulk sand. However, costs to transport more than 76,000 m³ of material required to fill in the lagoon proved too excessive. Local borrow sites were then investigated, and a 14,000 m² (3.5 acre) area was identified as a sand
borrow source at the east end of the project to supplement imported sand. This borrow pit provided about 30,000 m$^3$ of sand material and reduced the total cost of the bulk sand material. Additional discussion of the borrow pit and its reclamation is provided in Section 3.4.

### 3.2. Western Erosion Protection Structure

As previously discussed, during extreme storm surge events along Benson Beach, the foredune protecting the western margin of the lagoon area periodically overtops and breaches. This exposes the lagoon area to more frequent storm induced wave attack. Wave inundation and subsequent backwash would have resulted in channel formation and downcutting along the landward side of the jetty adjacent to the beach without reinforcement. Failure to include erosion protection measures in this area would have resulted in degradation and loss of lagoon infill and filter along its western margin.

To protect the lagoon fill, an erosion protection zone was designed, as shown on Figure 7, which somewhat resembles a buried groin structure. The feature was constructed from jetty station 56+00 and extends northwest for a distance of about 76 m. The skewed angle with respect to the jetty alignment was an attempt to account for possible changes in the orientation of the Benson Beach shoreline resulting from continued recession. The feature was constructed using the Zone 2 shot rock and is intended to be dynamically stable. The stationing of 56+00 was selected, rather than the end of the lagoon fill at 58+00, to minimize disturbance of natural beach and dune deposits and transient features. Water from storm surge waves that overtop the structures would either infiltrate into the lagoon fill, flow over the filter zone and through the jetty, or backflow over the erosion protection structure with minimal erosion to the sand fill.

![Figure 7. Design section and photographs showing Erosion Protection Zone (1 ft = 0.3048 m). Section Modified from USACE (2014).](image)

### 3.3. Stream Weir

The presence of an upland drainage path into the lagoon fill project area necessitated a modified design approach in the vicinity of the discharge channel. Design concepts for this area were competing amongst several contradictory
project goals. These included maintaining upland drainage and protecting existing wetlands while eliminating erosion of lagoon formations and maintaining upland drainage while facilitating future equipment access and staging along the jetty.

Analysis of the upland catchment indicated that peak culvert discharge was expected to be about 0.6 m³/s during a 100 year storm event producing 16.5 cm of rain in 24 hours. This relatively low flow rate occurs due in large part to the vast low-lying wetland complex, which formed in the sandy Benson Beach deposits north of Jetty Road. Even in a region that receives an average of 198 cm of rainfall annually, the upstream wetland complex sufficiently dampens peaks flow rates experienced at the culvert.

To address the need for upland drainage and maintained tidal infiltration through the jetty, the lagoon fill template was stopped prior to reaching the discharge channel. In this area, a reduced height fill consisting of shot rock overlaying filter rock was selected. This design effectively created a rock weir that allowed free drainage through the jetty above the crest elevation and partially dampen flow below the crest (Figure 8). The key design considerations for this location were to minimize the mobilization of existing foundation sands underneath the rock weir and to prevent upstream water velocities, which could cause erosion.

The rock weir crest elevation was selected at elevation 1.8 m (NAVD) to

1. Mimic existing hydraulic characteristics and maintain existing wetland hydroperiods both upstream and downstream of the Jetty Road culvert;
2. Provide sufficient elevation to achieve construction vehicle passage across the weir approximately 75% of the time; and
3. Provide a sufficiently large rock section to improve weir stability.

Some excavation of the existing weir foundation sand was necessary for construction, but extensive excavation presented a high risk to jetty stability. For this reason, the project team decided to minimize excavation in favor of a shallower weir section. Ultimately, the top 0.6 to 0.9 m of sand were removed to develop a bench at elevation 0.6 m. Upon this bench, a 0.3 m thickness of filter rock was placed, overlain by an additional 0.9 m of shot rock.

The required length of the weir was calculated based on observed in-situ flow conditions. Hobo gauges placed within the existing lagoon provided historical data relating to the rate of change of the water surface within the lagoon over approximately 6 months of tidal cycles. The average rate of fall was recorded to be -0.25 cm/min with a standard deviation of 0.34 cm/min. A rate of fall of -0.91 cm/min was selected for design to ensure a sufficient margin of water exchange rate through the infiltration area of the jetty in excess of the present condition. The coefficient of permeability (K) was estimated to be 335 cm/sec. Because of the extremely large size and weight of the North Jetty armor stone, infiltration and seepage velocities are not a significant concern. As such, detailed analysis for in-situ conductivity was not considered necessary.

The additional tidally influenced area upland of the jetty resulting from the reclaimed borrow pit (see Section 3.4, below) increased the flow requirements through the weir discharge area. This condition considered the new wetland area connected to the existing culvert discharge channel with a free water surface area of up to 11,000 m² at high tide. A maximum discharge of 1.9 m³/s was calculated resulting from tidal exchange in the new wetland.

Cross-sectional area available for infiltration at the face of the jetty was calculated to be 18.6 m² based on a weir design length of 45.7 m, a crest elevation of 1.8 m, and a tide elevation of 2.3 m (per the continuity equation). An average flow area of 46.5 m² was used to estimate the flow capacity through the infiltration zone and required differential driving head. Assuming a discharge flow rate of 2 m³/s and an assumed flow path length of 15.2 m, a differential head of 19.5 cm was calculated across the North Jetty from the lagoon to the Columbia River channel.

Based on a projected area of 18.6 m², a maximum approach velocity of 10.4 cm/sec was expected. The approach velocity was used in wetland design to confirm the stability of channel features during normal conditions. Grain size analysis performed on samples from the installation of monitoring wells within the proposed borrow area indicates that in-situ sands are poorly graded sands with silt typically ranging from 0.2 to 0.4 mm. At 10.4 cm/sec, water velocities are below the Hjulstrom erosion velocity for sands having a grain size of 0.3 mm.
3.4. Borrow Pit and Reclamation into an Intertidal Wetland

The initial and primary objective of the borrow area was to provide about 30,000 m$^3$ of bulk backfill material to supplement the total volume of backfill needed for the project; this represented about 1/3 of the total lagoon fill volume. The borrow area is located landward of the jetty between station 20+00 and 26+00. This location was identified as an area where a borrow pit would not compromise the short- or long-term stability of the jetty. The borrow pit was reclaimed as a new intertidal wetland, which has a secondary benefit of improving intertidal habitat within the project site. Layout of the new wetland feature is shown on Figure 8 and was designed both to provide the maximum fill volume while maintaining stability of adjacent features and to optimize hydraulic function in conjunction with the adjacent stream and new rock weir. The new lagoon was appropriately vegetated with Carex Lyngbyei plantings within the emergent march zone (1.7 to 2 m NAVD), suitable native forbs-grass plantings and large woody debris broadcast through the upper marsh zone (2 to 2.4 m NAVD), and sedges with small native tree species within the upland perimeter bordering the new lagoon. The wetland area within the new lagoon (4,000 m$^2$, below 1.7 m NAVD) was unplanted and expected to colonize native species.

As previously discussed, the intertidal flow in/out of the new wetland is serviced by the porous rock weir that promotes intertidal exchange through the jetty. In addition to providing a secured flow path though the jetty for the new wetland drainage, the rock weir also provides vehicle access for future jetty repairs (to avoid impacting the wetland). Upland drainage (from areas north of Jetty Road) into the new intertidal wetland is serviced by a 1.2 m (48-inch), 15.2 m long culvert passing under Jetty Road.

Figure 8. Layout of borrow area reclaimed into a new intertidal wetland lagoon. Modified from USACE (2014).
4. CONCLUSIONS

The majority of the construction work was completed by June 2015, and the zoned filter, weir, erosion protection structure, and new intertidal wetland appear to be functioning as intended (Figure 9). The western end of the lagoon fill area was subsequently used as staging area for initial ‘critical’ repair efforts for the North Jetty. It is anticipated that the infilled area will be utilized more during the major rehabilitation phase of the project, which will likely start construction in 2017. The newly established intertidal wetland will remain outside the area allowed for future staging activity and will be observed to determine how well it matches a natural wetland environment and to provide data for future reclamation efforts.

5. REFERENCES

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