Response Summary:

On November 7 and November 8, 2022, Spencer Harper (CESPN-ECE-W), Jeffrey Melby (CEERD-HNH), Dylan Robinson (CEERD-HNC) and Chad Bounds (CEERD-HNH) provided a walkover inspection of the north jetty at Noyo Harbor, CA in response to a DOTS request. SPN requested a site visit from the ERDC team to understand the conditions of Noyo Harbor, and the failing north jetty. A previous inspection of Noyo Harbor's jetties, conducted by SPN on August 11, 2021, described a large depression in the jetty crest on the leeward (north) side of the concrete monolith approximately 10 feet deep at some locations. The report also noted minor ejection of armor stone along the channel side of the jetty. Additionally, local stakeholders have observed large stone armoring displaced from the structure within the existing channel reducing the navigability of the channel. During the site visit, the DOTS response team observed waves breaking along the channel side of the concrete monolith creating a jet-like flow at low tide that could potentially dislodge poorly interlocked stones and move them into the channel. At high tide, the team observed waves breaking over the concrete monolith adjacent to the observed depression on a day where wave conditions were smaller than typical storm conditions in the area.

Because the incident waves are highly oblique with respect to the jetty long axis and the waves breaking along the concrete monolith generate relatively high momentum, typical equations are not applicable. The DOTS response team suggests the use of a physical model, possibly in combination with numerical models.

Figure 1: Noyo Harbor north jetty

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Structure Background

Noyo Harbor's north jetty, originally constructed in 1931, extends 345 feet west from the north wall at the mouth of Noyo River. The structure is located just south of Fort Bragg, CA. The jetty consists of a concrete monolith surrounded by stone filter and armor layers. There is a traditional rubble mound head, and the multi-layer stone extends down the north side of the jetty. On the channel side of the jetty, there is a narrow berm consisting of both loose and grouted armor stone at crest varying elevations from near the base of the monolith towards the head to the crest of the monolith towards the shoreward end (Figure 2). Due to the narrow nature of the channel, the head of the jetty does not protrude into the channel and therefore provides little reduction in wave energy along the channel side of the structure. The crest width is 21 feet at an elevation of 13 feet MLLW. Based on a repair in 1990, the design wave height at the head of the structure is 16.1 feet (SPN, 1990).

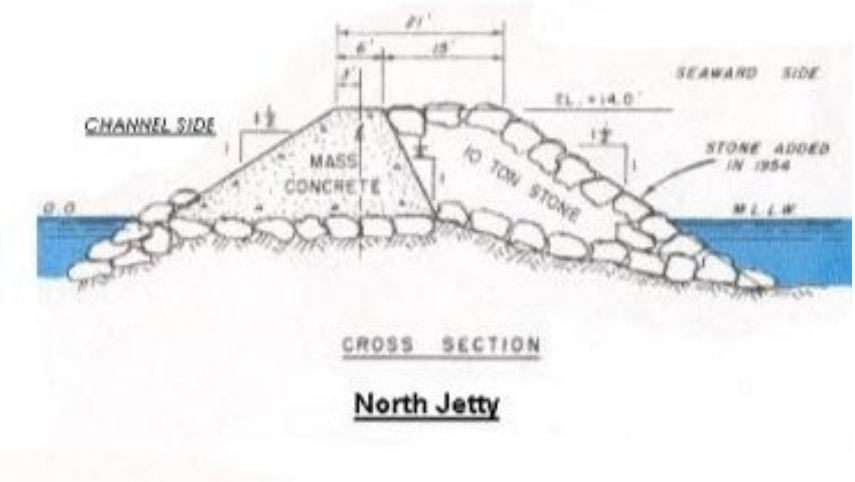

Figure 2: Noyo Harbor north jetty cross section (SPN, 2001)

Noyo Harbor's north jetty has been repaired numerous times, most recently in 2019. This repair involved placement of 10-ton armor stones along the channel side of the concrete berm, while removing and reusing displaced rocks already in the channel (SPN, 2018). During this repair, a 40 to 50 foot-long cavity along the channel side of the concrete monolith at MLLW level was filled with 6-inch rock and grout.

In the 2021 jetty inspection conducted by SPN, the jetty was considered to be in fair to poor structural condition. A depression at the crest of the jetty upwards of 10 feet deep was observed, as well as poor stone size consistency along the remaining crest (SPN, 2021). Aside from a small depression where an estimated 2 to 3 stones were missing, the head of the structure remained in good condition. However, it was also observed that armor stone on the channel side of the jetty along the concrete monolith was displaced, and the base of the monolith was exposed. Stone armoring displaced from the channel side of the monolith has entered the channel and is now a navigational hazard as reported by locals. Some of this damage was attributed to a storm in January 2021, with waves reported by the local coast guard to be greater than 20 feet at the entrance to the harbor on a king tide that was near the jetty crest.

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Period of Performance & Site Conditions:

11/7/2022 – 11/8/2022

The DOTS Response team was on site between 1430 and 1600 on November 7, 2022. At the time, NDBC Station 46014 (located approximately 16 miles southwest of Noyo Harbor) recorded a wave height of H_{m0} = 17.1 feet with a peak period of T_p = 15 seconds propagating from the west-northwest. Wave heights at the head of the north jetty were estimated to be approximately 3 to 5 feet based on visual observation. See the predicted tidal elevation from NOAA gauge 9417426 Noyo Harbor, CA and tidal elevations during the site visit in Table 1. Weather conditions were partly cloudy with light winds out of the south.

Table 1: Nov 7, 2022, Predicted tidal elevations at Noyo Harbor, CA (NOAA 9417426)

Time	Event	Tidal elevation (MLLW)
0943	High Tide	6.67 ft
1430	Start Site Visit	1.05 ft
1600	End Site Visit	-0.30 ft
1634	Low Tide	-0.42 ft

The team returned to the north jetty the following morning November 8, 2022, to observe the site at high tide. Wave heights of H_{m0} = 14.1 feet out of the northwest with peak period of T_p = 14 seconds were recorded at station 46014 during this trip to the site. Wave heights at the head of the north jetty were estimated to be approximately 2 feet based on visual observations. See the predicted tidal elevations from NOAA gauge 9417426 in Table 2. Weather conditions were overcast with light winds out of the south.

Table 2: Nov 8, 2022, Predicted tidal elevations at Noyo Harbor, CA (NOAA 9417426)

Time	Event	Tidal elevation (MLLW)
1014	High Tide	6.69 ft
1030	Start Site Visit	6.67 ft
1200	End Site Visit	5.62 ft
1714	Low Tide	-0.66 ft

Observations

The structural condition of the north jetty was similar to that described during the August 11, 2021 inspection. A large depression existed on the jetty crest along the leeward side of the concrete monolith (Figure 3). During the 2019 north jetty repair, the contractors placed small stones along the jetty for construction equipment access. During the site visit, few of these stones remained on the structure, while similarly sized stones were found along the beach north of the structure. The stones along the beach were possibly from the jetty's construction access, and these stones may have been moved by wave forces from the crest of the structure to the beach. The crest depression may simply be the void left by movement of these stones.

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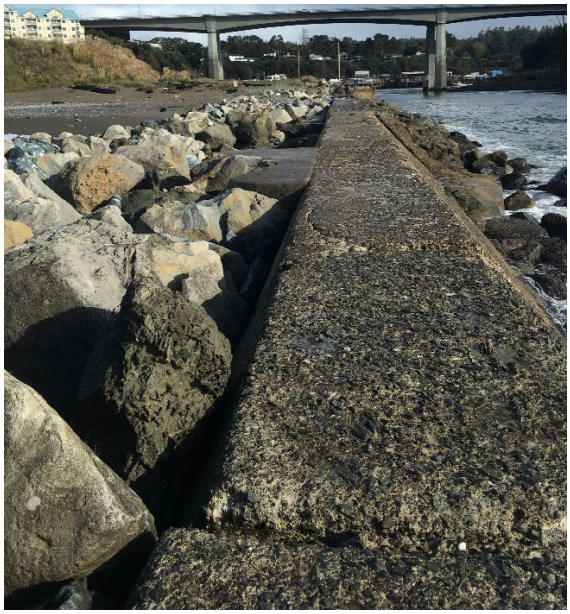

Figure 3: Depression on leeward side of concrete monolith

Although the head of the structure appeared to be in good condition, the stone armoring along the channel side of the concrete monolith appeared to be displaced from the concrete monolith and towards the center of the channel (Figure 4a and 4b). Some of the stones nearest the monolith appeared to be grouted to the structure, but there was limited evidence of interlocking with the concrete monolith keeping the remaining stone in place.

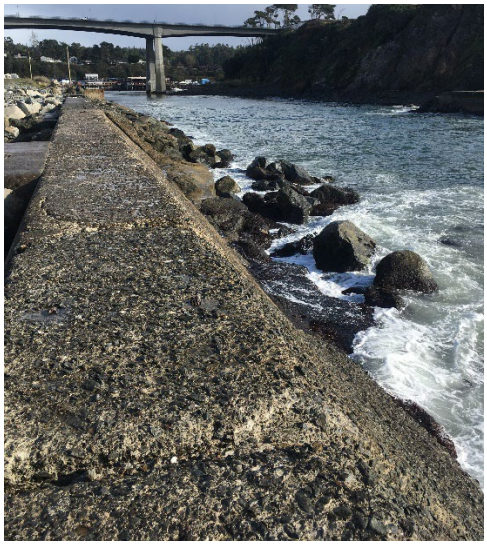

Figure 4a (left) stone armoring on channel side of concrete monolith looking seaward; Figure 4b (right) stone armoring looking landward

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The site was first observed at low tide with the incident wave crests perpendicular to both the channel axis and the long axis of the north jetty (Figure 5). As waves passed the head of the structure, the wave refracted, diffracted and broke around the south side of the head. The wave continued to break and wrap around the head resulting in wave focusing into the seaward end of the berm that runs along the channel side of the concrete monolith (Figure 6). As the wave continued along the structure, this process continued in a mach stem, amplifying the broken wave momentum along the berm at the base of the concrete monolith. This created a jet-like flow that ran along the concrete monolith and could exert large forces on the remaining berm stone armoring (Figure 7). This could be what is pushing the berm stone off the structure and into the channel and may be the primary failure mode for this part of the structure. Also, there appeared to be large voids under the monolith. At low tide, water undercut the concrete monolith in some locations with a significant amount of water flowing out of the gap under the monolith after each wave passed. From the crest of the jetty, it could not be determined if stone armoring or grout from previous repairs still existed beneath the concrete monolith.

Figure 5: Wave entering channel at low tide (November 7, 2022)

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Figure 6: Refraction of wave along concrete monolith (Google Earth Pro, 2022)

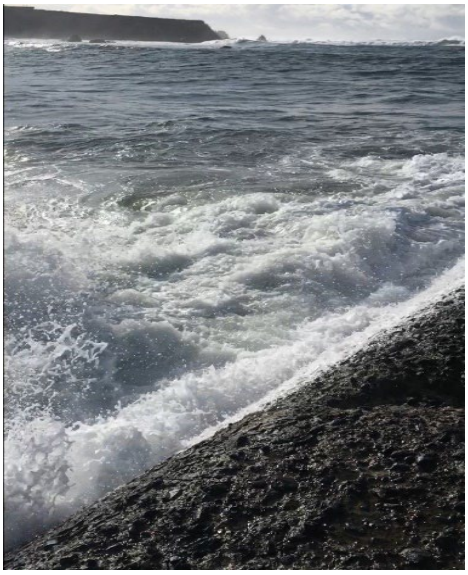

Figure 7: Jet-like flow along concrete berm at low tide (November 7, 2022)

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Waves at high tide also propagated directly into the channel perpendicular to the jetty long axis. Again, as waves travelled along the southside of the north jetty, wave focusing from refraction, diffraction and breaking occurred towards the berm. Because the concrete monolith reflected the wave without dissipating large amounts of the wave energy, the wave height increased at the monolith (Figure 8). The wave was then observed to overtop the concrete monolith from south (channel side) to north. The location where the overtopping occurred during the site visit corresponded to the depression in the stone armoring on the north side of the jetty. Therefore, in larger wave conditions than observed at the site the morning of November 8, 2022, it could be hypothesized that greenwater overtopping occurs at this location along the jetty. This potentially destabilizes smaller stone on the north side of the jetty and is most likely causing the crest depression observed at the site.

Figure 8: Wave overtopping concrete monolith at high tide (November 8, 2022)

Benefits of the Response to the USACE Dredging/Navigation Program:

The DOTS response site visit gave members of ERDC and SPN a chance to meet and gain a better understanding of the field conditions and the current state of the structure. Maintaining navigational capacity of Noyo Harbor is critical since it is the only improved harbor between Bodega Bay (100 miles south of Noyo Harbor) and Humboldt Bay (130 miles north of Noyo Harbor). The port is locally critical for both commercial and recreational activities, is a harbor of refuge and is home to a US Coast Guard Station. Channel reliability is directly dependent on the north jetty condition.

The team discussed possible models that could describe the wave and structure interactions and armor stability. The observed physics that are likely causing stone instability along the channel side berm are complex and highly nonlinear.

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There are no known armor stability formulae for this specific case. However, there are several modeling tools that could be applied to define a long-term solution to the berm mobility problem. Given the observed jet-like flow along the concrete berm and oblique angle of the overtopping waves, existing calculations, such as toe stability and stone armor sizing, cannot account for the observed conditions. In addition, it was not clear what hazards are causing the berm armor instability. The site is exposed to storm wave conditions over a wide range of water levels due to the large tide range. Waves strongly refract and diffract into Noyo Cove and so the wave height, period, direction and water level combination that results in the worst-case momentum along the berm is unknown. Therefore, the team suggests that a small-scale three-dimensional physical model study be conducted. The model would scale both fluid dynamics and armor stability. A range of different hazards (different incident wave conditions and various tidal levels) would be modeled, and the behavior of the jet-like flow along the concrete monolith and stone stability would be measured.

Additionally, a CFD model could be created using, for example, the Proteus Toolkit or CMS-Wave and CMS-Flow. This CFD model would have the capability to simulate the jet-like flow and determine the loads applied along the channel side of the jetty. The computed flow could be combined with simplified armor stability criterion like armor sliding and overturning to determine berm armor failure. The downsides of this method would be that the model requires validation, which would still support the need for a site-specific physical model study.

The DOTS response team plans to meet with other ERDC personnel to discuss the feasibility of the various options. Then the team will meet with the SPN personnel to finalize ERDC involvement with the Noyo project.

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References

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