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"The parties have concluded that they cannot readily come to a mutual agreeable settlement in the mediation / arbitration process and have agreed (which is required) that they will proceed directly to litigation and at the same time avail themselves of judicial mediation / settlement services offered by the Superior Court. Therefore, the necessity of protecting the integrity and confidentiality of the mediation / arbitration process as called for in the Dispute Resolution Clause is no longer present nor the requirement of confidentiality. Therefore, the report is attached and is now available to the public."

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To: Edward O'Connell and Tracy Collins, Waller, Smith & Palmer, P.C.

From: Sean Kelley, P.E. and John Ramsey, P.E.

Subject: Niantic Bay Overlook Revetment

Applied Coastal has reviewed the design documentation of the Niantic Bay Overlook revetment provided by Bill Sheer (Town Engineer for East Lyme), and has concluded that the wall failure was due primarily to inadequate construction specifications. A series of improper assumptions used in the development of the wall design also contributed significantly to the poor performance of the wall. The following discussion presents the preliminary findings of the review of the information made available to Applied Coastal at the present time. The discussion points are presented in the order of their importance, relative to the failure, from construction specifications (greatest importance) to the design wave analysis.

A. Construction Specifications

It is Applied Coastal's opinion that the riprap armor stone requirements were incorrectly specified in the project specifications (CTE, 2003), and that this error is the primary cause of the wall revetment failure that commenced with the December 16, 2005 storm. A "***nominal diameter***" of 26 inches was incorrectly specified. The term "***nominal diameter***" has a precise meaning (Bates and Jackson, 1987). "***Nominal diameter***" indicates that the stone size used for the revetment is based on a spherical volume. This specification disagrees with the design guidance for average stone weight provided by the design engineer (Welti, 2001), where the characteristic armor unit size (again 26 inches) is based upon a cubic volume.

Because the riprap specifications are based upon a spherical volume, the armor stones used to construct the revetment are significantly undersized, and do not meet the requirements established by either Clarence Welti, P.E. or the design review by Ocean and Coastal Consultants (OCC, 2003). As a result of utilizing the "***nominal diameter***" in the project specifications, the average stone size in the revetment armor layer is 880 lbs. Clarence Welti specified a median stone weight of 1770 lbs which is approximately two times the weight allowed by the construction specifications as written.

Another major problem arises from the use of the Connecticut Department of Transportation Form 814A as the basis of the riprap specification. This generic specification presents a stone gradation based on the ***average diameter*** of the material

used to construct the revetment. The ***average diameter*** is computed as the average diameter by weight of all the stones in the revetment armor layer.

The method selected by the design engineer (USACE , 1995) as the basis for the stone sizing calculations results in a ***median*** stone weight. Stones are typically selected for placement in a revetment based on the ***median weight*** of the design, not their diameter. The ***median weight*** represents the typical weight of the armor stone, where half the stones in the revetment would have a weight less than the ***median weight*** and the other half of the stones would have a weight greater than the ***median weight***. This method for developing appropriate stone size in the revetment yields significantly different results than the ***average diameter by weight*** method incorporated into the specifications. Coastal revetments are typically not constructed of graded riprap, according to procedures outlined by the US Army Corps of Engineers (USACE, 1995).

As and example of the difference between average and median weights, a section of a stone revetment with a specified ***average*** stone weight of 1770 lbs could be constructed using a single 48-inch stone (allowed per the project specifications) and five 6-inch stones, which would result in an average weight of 1770 lbs. In contrast, for a stone revetment with a specified median weight, for every stone larger than the median weight, only one stone smaller than the median would be allowed. The ***median*** specification therefore would prevent the utilization of too much undersized material in the wall.

A third problem results from the allowable re-use of any stones that were on-site, regardless of size or dimension. For coastal revetments, a minimum acceptable stone size and a maximum aspect ratio are usually specified to prevent excess use of undersized and oddly shaped material in the wall, in order to maximize wall stability and design life expectancy. The construction specifications did not provide any limits regarding minimum stone size or maximum aspect ratio for the armor layer.

B. Design Analysis

There are irregularities in the design procedures used to determine the weight of the armor stone for the Niantic Bay revetment that do not follow best engineering practices. The first problem is that the design engineer specified a "graded riprap" revetment (Welti , 2001), which is typically not utilized in coastal shore protection projects. It remains unclear why the Niantic Bay Overlook revetment was designed as a graded riprap revetment. According to procedures outlined by the US Army Corps of Engineers (USACE, 1995) and utilized by Clarence Welti for the design, graded riprap is not recommended where wave heights exceed 5 feet. According to the design calculations, the 25-year significant wave height incorporated into the design was determined to be 5.7 feet. Graded riprap is less stable than well-sorted stone, and therefore more prone to movement and failure.

A second issue concerning the design is the wave height used in the calculations. The design engineer utilized the significant wave height (H_s) provided by Ocean and Coastal Consultants (OCC, 2001) in his calculations of stone size. The significant wave height represents the average of the largest 33% of waves approaching the project area. For the method utilized by the design engineer (i.e., the Hudson equation) the U.S. Army Corps of Engineers (USACE, 1984) recommends that the H_{10} wave height be used. The H_{10} wave height represents the average of the largest 10% of waves approaching the

project area, and is approximately 1.3 times greater than the significant wave height (per USACE, 1995). Using an estimate of the H_{10} wave height (7.2 feet, or 1.3 times 5.7 feet), the median armor stone weight would be calculated as 3560 lbs, rather than the 1770 lbs median armor stone weight computed by Clarence Welti, P.E. and reviewed by Ocean and Coastal Consultants (OCC, 2003)

C. Wave Analysis

There are additional irregularities in the design wave height analysis performed by OCC (2001). The use of 75 mph hurricane wind speeds as the basis of the design wave calculations should have resulted in a very conservative design. However, assumptions used by OCC in their analysis resulted in wave heights that do not reflect the wave conditions for the design return period event (25-year), and are likely greatly underestimated. If wave heights are computed incorrectly, then the armor stone weight of the revetment will not be computed correctly either.

The first issue with the wave analysis is the duration of the storm utilized in the ACES computations of wave height. ACES is a software application, developed by the USACE (CERC, 1992), which is widely used in the development of design conditions for coastal structures. OCC used a storm duration of only one hour in their computations. This short duration does not result in fully developed sea conditions, the point where wave heights are limited by the wind speed and fetch length (i.e., the distance over water which the wind blows).

It can be easily demonstrated that the storm duration has a tremendous impact on the computed design wave height and resulting armor stone size. By only increasing the storm duration to two hours (a better assumption), and using all the same inputs used by OCC in their original analysis, the computed wave height is 8.4 feet or 1.5 times greater, and would result in a 5650 lbs armor unit weight. By using a three-hour storm duration, the result is a 10.1 foot wave height and 9830 lbs armor stone.

The second issue with the wave analysis is that it is based on only winds blowing from due south of Niantic Bay. This wind fetch is the shortest of all sectors approaching the project site, and is therefore the least conservative assumption as far as wave growth is concerned. The OCC analysis should have included a range of wind directions to determine from which sector the waves would be largest. Considering the scale and cost of the Niantic Bay revetment project, it would have been prudent to perform a more thorough wave refraction analysis to determine the significance of storm waves propagating from western Long Island Sound to the project site.

Since the 25-year wave heights were under-predicted for the Niantic Bay Overlook revetment, it is likely that the revetment will experience storm waves in the range of 5-to-6 feet on a more frequent basis than the 25-year return period initially computed by OCC.

D. Summary Points of Design Review

The review of the Niantic Bay Overlook revetment design documentation has revealed a series of errors in the design process that have contributed to the failure of the structure. The errors include:

- Improper specification of "nominal diameter" of armor stone size, based on a spherical volume;
- Improper specification of armor stone size based on average diameter by weight (as apposed to median weight);
- Inclusion of a construction specification that allows reuse of all existing on-site material for the revetment armor layer, regardless of size or aspect ratio;
- Inappropriate specification of graded riprap for the armor layer;
- Inappropriate use of significant wave height in armor design calculations (as apposed to maximum wave height);
- Unsound assumption in the wave analysis of a one hour storm duration, which lead to sea conditions that are not fully developed;
- Invalid assumption in the wave analysis that storm winds blow only from the south to the project site.

Generally, assumptions used in the design were not representative of best engineering practice, and lead to a non-conservative design that could not withstand a storm which is more likely representative of an annual-level event than it is of the design 25-year return period event.

E. General Requirements for Revetment Repair

Since the existing revetment was constructed of undersized armor stone that consists of a wide range of stone weights, repair/reconstruction of the revetment will be costly. If nothing is done to repair the revetment, it will continue to degrade and allow future washouts of the walkway.

Repair/reconstruction of the revetment basically will require disassembling the existing revetment, sorting the stone to determine what stone can be reused for the armor layer and what stone could be appropriate for the underlayer, bringing in additional armor stone of appropriate size for the armor layer, and reconstruction of the structure to appropriate design standards. There is no easy temporary repair that would not add significantly to future reconstruction costs. Based on our initial review of the structure, only a small percentage of the stones within the existing revetment would be appropriate for the armor layer. Therefore, much of the stone within the existing revetment would either be used as an underlayer or would be removed from the site.

At this time, Applied Coastal has not performed detailed calculations to determine design wave conditions and the appropriate armor stone weight for the revetment. However, much of the existing armor stone is undersized and it is likely that an appropriate armor stone weight would be larger than the design armor stone weight provided by Clarence Welti.

F. References

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