

CHAPTER 244

ST. PAUL BREAKWATER, PHASE 1

The Project, the Failure and the Subsequent Investigations

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Abstract

The St. Paul Phase 1 berm breakwater was destroyed by two storms within approximately two months of its completion. Investigations made after the failure demonstrate that the cause of the failure was that the breakwater was built from material that was vastly undersized as compared to the recommended minimum rock gradation, and heavily contaminated by fines and overburden from the quarry.

Original Design and Hydraulic Studies

In 1982, the City of St. Paul, Alaska commissioned an American consulting engineering firm (the Consultant) to design a fishing harbour on St. Paul Island, one of the Pribilof Islands in the Bering Sea approximately 450 km north of the Aleutian Islands. The Consultant subcontracted the Danish Hydraulic Institute (DHI) to perform scale model tests and other hydraulic studies to support the design of the project. These studies resulted in the recommendation of a conventional rubble-mound breakwater to be constructed from locally available quarry rock material.

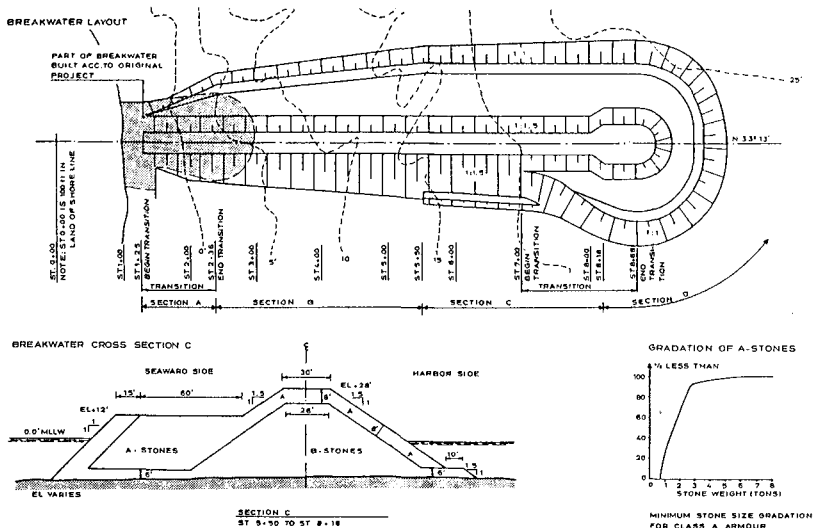
Construction and Revised Design

Construction of the breakwater started early May 1984 under the supervision of the Consultant. Soon after commencement of construction, it became clear that the contractor was unable to produce the stones required for the breakwater armour as designed.

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On the basis of detailed information of quarry yield reported to have been obtained DHI, in response to an inquiry from the Consultant, suggested consideration of a berm type breakwater, including suggestions for a trunk cross-section that might be used with the available stone sizes.

On 20 July 1984, DHI was authorized to perform a model test programme to be executed during the first two weeks of August 1984. This is to be seen on the background that Phase 1 of the breakwater, i.e. the first approximately 900 ft of a 2050 ft long breakwater, should be completed before the start of the winter, presumably before November 1984. The revised breakwater design (Fig. 1) involved only two stone gradations, called A and B-stones. The A-stones, also called the "1-8 t" gradation, were the armouring with a prescribed minimum gradation curve and the B-stones were 0 to 0.5 t quarry run. DHI's final report of September 1984 states the following with respect to the A-stones: "It is recommended that the coarse "1-8 t" gradation used in the tests is made a minimum requirement for construction, understood so that the material built into the breakwater should at no point have a gradation curve below (with smaller stones) than the "1-8" t stones".



Due to the planned interruption of construction during the winter 1984/85, a temporary protection of the outer end of the Phase 1 breakwater was required.

Having been informed that large armour stones were not available for the temporary breakwater head, DHI suggested the use of a berm type roundhead as a temporary protection using the same "1-8 t" A-stones as used on the trunk of the breakwater. However, DHI cautioned the Consultant that "it is expected that the provisional round-head will suffer severe damage in the coming winter, but that the damage will not hamper the progression of construction work on Stage II in the spring of 1985, since the stones displaced from the roundhead will be deposited on the harbour side where the inner breakwater is to be constructed. It is thus expected that the stones can be directly incorporated in the inner breakwater" (which formed part of the envisaged construction under Phase 2 of the project). For reasons of time and costs, no three-dimensional model tests with the temporary breakwater head were made prior to construction.

During construction, the Consultant's "Construction Manager" on the site repeatedly complained that the contractor was deviating from the specifications using too small stones and stone material mixed with overburden and fines. However, neither the Consultant nor the contractor apparently ever made any measurements by weighing or by any other means to determine the actual gradation of material being placed in the breakwater profile. At least, no such measurements were ever presented or found during the subsequent litigation. Similarly, it appears that none of the undersized rocks was ever removed from the breakwater.

The Breakwater Failure

The Phase 1 breakwater was completed 2 October 1984 and was severely damaged during two storms in November and December the same year. At the end of the December storm, the length of intact crest of the breakwater was reduced from its original approximately 800 ft to less than 300 ft (Fig. 2).

Various surveys of the A-stone gradations used for construction were made after the damage. Fig. 3 shows the results of all of these surveys. It appears clearly from the various surveys that the average weight of the A-stones used for construction was generally very much smaller than what was recommended by DHI.

Model Tests

During "discovery" under the subsequent litigation, model tests were made both by DHI (defendant) and by ARCTEC for plaintiffs (the Consultant and its insurance company). These tests were three-dimensional model

tests with a structure modelled in compliance with DHI's recommendations regarding profiles and stone material. The wave conditions used in these tests represented those of the two storms that destroyed the breakwater built at St. Paul and were determined by numerical hindcasting made in-house by DHI and by OCTI on behalf of plaintiffs.

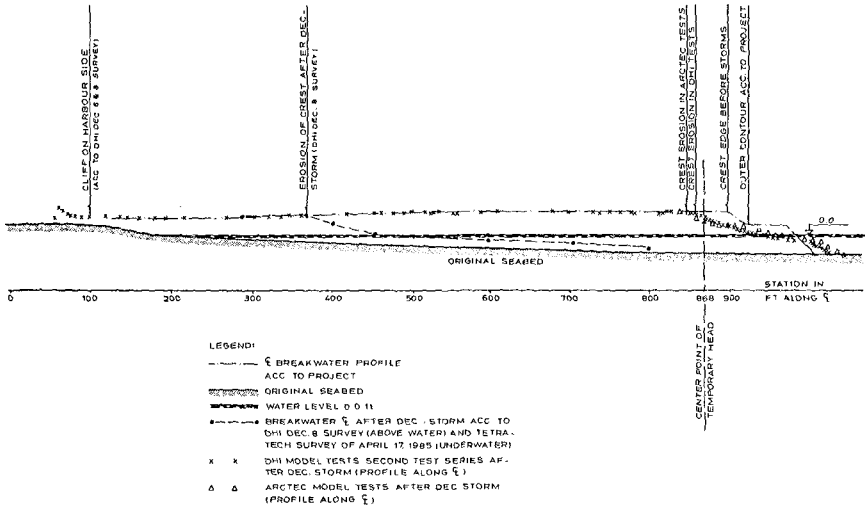


Figure 2. Comparison of Model Test Results and In-Situ Damage.

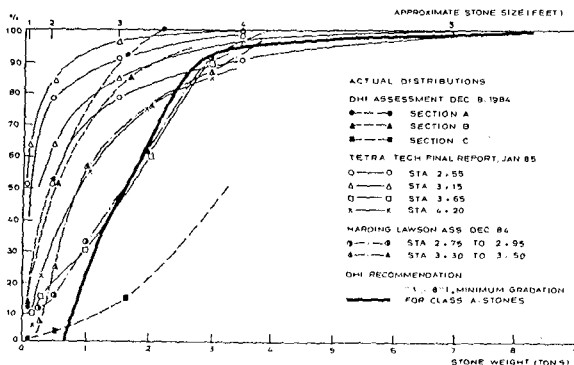


Figure 3. Estimates of A-Stone Gradations As-Built.

In spite of a number of differences between the two sets of model tests, both in the hindcast wave conditions and in the physical modelling, the results of the two sets of tests were remarkably similar. In both tests, the damage observed in the models had no resemblance whatsoever to that experienced in nature. In the models, the damage was limited to the temporary breakwater head proper and fell well within what was predicted in DHI's final report of September 1984, whereas in the nature the breakwater had suffered virtually total destruction (Fig. 2), chiefly through the process of crest erosion caused by excessive overtopping.

In both sets of model tests, overtopping was insignificant and did not at any point cause damage to the crest of the breakwater. This is in sharp contrast to what was observed in nature where photographs taken during the storms show violent overtopping, and photos taken after the storms show extensive damage in the form of crest erosion over the entire outer portion of the breakwater.

The difference in overtopping between models and nature is entirely consistent with the assumption that the rocks used for construction were much smaller (and contaminated with fines and overburden) than corresponding to those used in the model tests and recommended by DHI. This assumption is also supported by numerous photographs taken during and immediately after construction.

Conclusion

DHI considers the identical results of the two sets of model tests as conclusive engineering proof that the St. Paul Phase 1 breakwater was built from stones that were generally very much smaller than those recommended by DHI. Smaller stones combined with extensive contamination with fine material would cause both highly accelerated erosion from the end and drastically increased overtopping resulting in heavy damage to the crest and the rear side - i.e. exactly those processes that destroyed the breakwater in nature as seen from the surveys and the photographs.