100-YEAR DURABILITY TESTS OF CONCRETE AT OTARU PORT

Far-Reaching Long-Term Exposure Tests on Stability of Concrete in Seawater

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1 North Breakwater at Otaru Port

Toward the end of the 19th century, it became imperative to improve Otaru Port to ensure steady development of the Hokkaido region. The Meiji Government passed a budget for the work through the Imperial Diet in 1896 and then implemented the port development project. Construction of the north breakwater began in 1897 as one of the large national projects. Dr. Isami Hiroi, a civil engineer, was appointed head of the Otaru Port Construction Office to supervise the project. The work was carried out in two phases; that is, a 1,289m long section from 1897 to 1908 and a subsequent 419m section from 1908 to 1921. After completion of the breakwater, construction work began on the south breakwater and the coal shipping wharf, forming the port as it is known now.
Dr. Hiroi began developing innovative civil engineering techniques and theories including a formula for calculating the wave force acting on a breakwater, a method of oblique stacking of concrete blocks for the breakwater body, and the mixing of volcanic ash for strengthening concrete. Among them, the long-term durability tests of concrete that he initiated [1,2] are worthy of special mention.

2 Long-Term Durability Tests

Concrete technology was still young at the time. Just before the construction project began, a number of incidents involving concrete in a marine environment had been reported, including the appearance of many cracks in concrete blocks at Yokohama Port in 1892 and water seepage at a concrete dock at Sasebo Port in 1895. Similar problems were also being frequently reported in Europe. In an effort to overcome these problems, investigations had been carried out by many researchers and it had been found that volcanic ash had potential for use in concrete because of its stability in seawater. In addition, domestic cement production had recently begun in Japan in 1875; accordingly Dr. Hiroi had concerns about quality and the amount of cement production. To evaluate the durability of concrete, he decided to initiate long-term durability tests in the actual environment.
The objectives of the test were to determine mix proportions and to evaluate the durability of the concrete to be used for the breakwaters. Dr. Hiroi started producing gourd-shape test pieces (the mortar briquettes shown in Fig. 1) for use in tensile strength tests. The test method entailed applying a tensile force by pulling on the two ends of the test piece. Production of the mortar specimens started in 1896, a year before the project began, and continued for 40 years until 1937, when Mr Chouemon Ito, 2nd Head of the Office, took over the work. The following test parameters were implemented: 13 kinds of cement produced by different manufacturers; 19 kinds of volcanic ash (different kinds and locations); 10 kinds of fine aggregate (different locations); and 4 kinds of mixing water (seawater, salted water, and two fresh water). The total number of test pieces reached approximately 60,000 of 491 varieties, of which about 4000 still remain for future tests. It can be inferred that Dr. Hiroi originally intended to carry on testing for 50 years. However, another series of tests was started during Taisho Period (1912-26), so the test became called the “100-year durability test” somewhere down the line.
Based on the results of tests with these mortar specimens, Dr. Hiroi concluded in 1902 that volcanic ash would be effective in the strength development as well as the durability enhancement of concrete when mixed in suitable proportions. He made the first attempt to use it in breakwater concrete. The unmodified concrete mix proportion by volume ratio was 1 (cement): 2 (sand): 4 (gravel). Based on the tests, this was eventually modified to 1:0.8(volcanic ash):3.2:6.4. By this modification, the amount of

cement used was reduced by about 38% and great reduction in construction cost was achieved because, initially, the purchase of cement accounted for about 30% of the total cost.

Fig. 1 Mortar briquettes

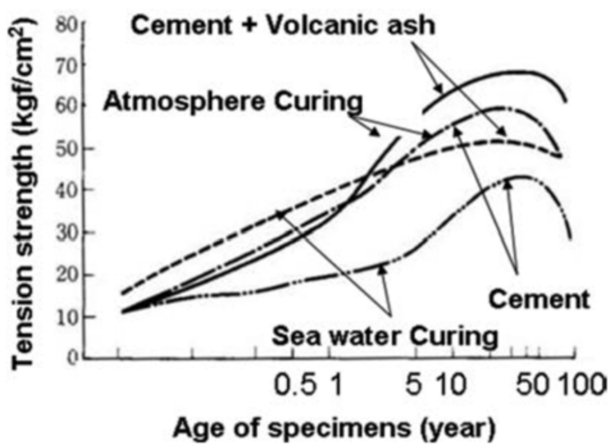

Fig. 2 Change in tensile strength over about 100 years[3]

Figure 2 shows the results of the 100-year durability test to date with four different principal test parameters: with and without volcanic ash and curing conditions. The results show that the strength is greatest with atmosphere curing. Test specimens cured in the atmosphere exhibit smaller variations in strength whether with or without volcanic ash, while those cured in seawater with volcanic ash tend to become strong earlier. Since mortar with volcanic ash has higher strength than that without, this proves that volcanic ash contributes to enhancing concrete durability in seawater. Though a decline in strength is found after 30-50 years, one of the reasons for this may be considered to be an interruption of the planned curing regime due to world wars. Further examination and discussion of this point are needed.

3 What Can Be Learned from the Tests

Dr. Hiroi mentioned in his book that whether to honor or humiliate an engineer, a question which would re- main open for one thousand years, depends on the design made. Preparation for the design must be thorough and based on far reaching plans. The tests he initiated not only provide us with valuable evidence on the long-term durability of concrete but also embody the archetypal essence of an engineer’s attitude toward infrastructure that will remain in service for a long time.

4 References

[1] Otaru Port Construction Office, Hokkaido Development Bureau: Outline of the 100-Year Durability Tests of Concrete Conducted at Otaru Port.

[2] Sarukawa, Y., Sakai, K. and Kubouchi, A.: Japan’s 100-Year-Long Otaru Port Breakwater Durability Test, Concrete International, 16(5), 25-28, 1994.