



North Breakwater in Otaru Port

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Abstract

North Breakwater in Otaru Port is Japan's first full-fledged concrete block breakwater faced to outer sea and has total extension length 1,289 m. Investigation, planning, designing and construction of this breakwater were carried out under the initiative of Dr. Isami Hiroi. This breakwater was put into construction in 1897 and completed in 1908.

North Breakwater constructed in Otaru Port by Dr. Hiroi's far-reaching perspective seeing of the future sufficiently fulfills its functions also nowadays after its completion about 100 years ago.

1 Introduction

Hokkaido is an island located in the northern part of Japan and occupying about 22% of the territory of Japan. Full-fledged development of this island started about 130 years ago. Along with progress in development of Hokkaido, Otaru Port as a port for shipment of the coal yielded in Ishikari Coalfield has been developed and improved in full scale for these 100 years or so, and up to now it has been fulfilling its function as a northern front door of Japan since it had been opened in 1899.

Otaru Port is located in the northwest of Sapporo City, which has 5-th largest population in Japan, and is faced to Sea of Japan (Fig. 1).

North Breakwater in Otaru Port is Japan's first full-fledged concrete block breakwater faced to outer sea and has maximum water depth about 14 m and total extension length 1,289 m. Investigation, planning, designing and construction of this breakwater were carried out under the initiative of Dr. Isami Hiroi. This breakwater was put into construction in 1897 and completed in 1908.

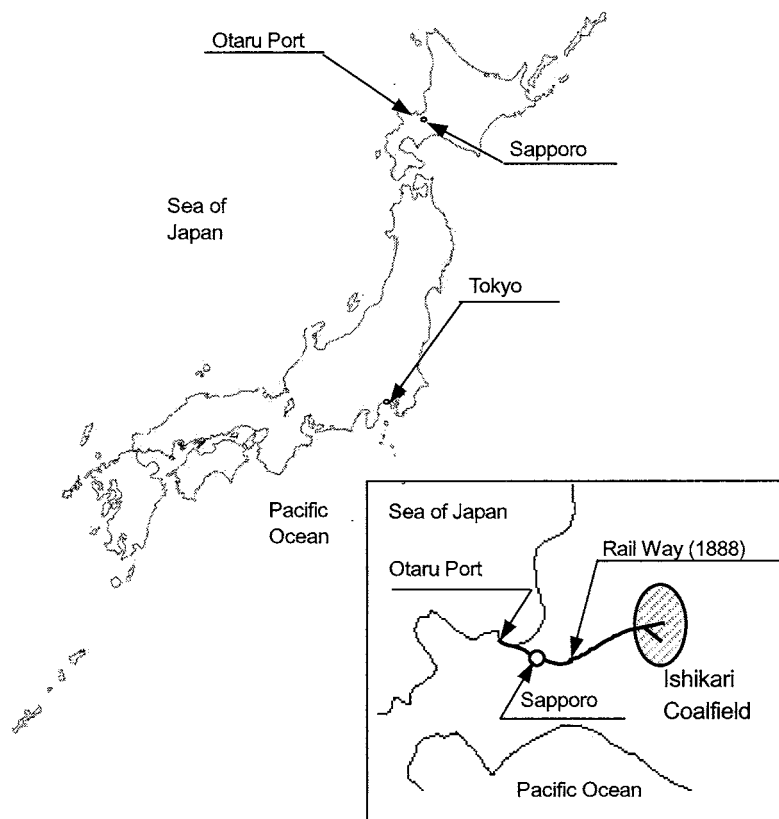


Figure 1. Location map of Otaru Port.

2 Investigations and test construction

2.1 Brief historical review on concrete block breakwater construction in Japan

Japan's first concrete block breakwater was constructed in Yokohama Port in 1889. This composite breakwater designed by and constructed under the supervision of an English engineer H. S. Palmer suffered from concrete cracking during construction. It took 8 months to accomplish detailed investigation of causes for cracking.

Under severe conditions for construction of breakwater using concrete blocks, Dr. Isami Hiroi addressed himself to breakwater construction for Otaru Port.

2.2 Harbor survey

Prior to construction of North Breakwater, Dr. Hiroi and his staff conducted survey and investigation of the harbor in 1894 with an aim to confirm and fix a design for construction. Survey activities carried out there covered bottom sounding, observation of tide level, observation of water and ambient air temperature, submarine geological survey, observation of wind direction and velocity, observation of wave crest height and wave force as well as observation of tidal current.

Bottom sounding started in May and finished in September 1894. Geological survey started in June and finished in October of the same year. Measurements of wind direction and velocity were conducted at 2 points, wave crest height at 4 points and wave force at 3 points. During survey period there was measured wave pressure value 23.8 t/m^2 at wind velocity 22 m/sec and wave crest height 3.5 m.

2.3 Test construction

Test construction was carried out in 1895 after completion of the harbor survey. Purpose of the test construction was to construct a part of the breakwater. This construction work was to employ rubble mound as foundation at point with water depth 7.8 m, on which to pile up concrete blocks each about 6 t in weight to form breakwater body with base area 7.2 m x 7.2 m and height 7.5 m. Regarding test construction, there were conducted survey and investigation on the items necessary for breakwater design and construction work. Survey items and major results were as described below:

- (1) Bearing capacity of sea bottom ground;
- (2) Movement of rubbles;
- (3) Action of waves on sea bottom;
- (4) Height, length, velocity and pressure of sea waves;
- (5) Resistive properties of concrete block against seawater;
- (6) Disengaging force caused in individual concrete blocks under the action of rough sea waves.

Sea bottom ground proved to have enough bearing capacity for construction of the breakwater. Foundation rubbles proved not to overturn or move under the action of sea waves. However, sea bottom nearby the toe of mound slope was scoured 6 to 30 cm in depth.

Each concrete block was prepared according to the predetermined mix proportion and manufacturing method anticipated for practical use and was settled down on the rubble mound more than 2 months later after its preparation. It was found that the concrete blocks piled up on the rubble mound had increased their strength and had not suffered from an adverse effect of seawater. The piled-up concrete blocks with weight each 5 to 8 t did not move under the action of sea waves.

The results obtained from investigation by the test construction gave great contribution to construction of the breakwater.

3 Construction of North Breakwater

3.1 Concrete using volcanic ash

Use of volcanic ash for the purpose of early development of concrete strength and reduction of construction cost was suggested by the test conducted in Germany (former Preussen) in 1898. Dr. Hiroi applied this idea to preparation of concrete blocks used for construction of the breakwater. This was the first case in utilization of volcanic ash for concrete in Japan. He prepared 4 kinds of mortar test pieces with various mixing ratio of cement – sand – volcanic ash to be used for tests on tensile strength. These test pieces were kept under the sea and put to strength tests for 4 years. Fig. 2 shows the results of tensile strength tests. These tests proved effectiveness of volcanic ash for submarine works. So the initial mixing ratio for concrete [cement1: sand 2: gravels and crushed stones 4 in volume ratio] was altered to new ratio [cement1: volcanic ash 0.8: sand 3.2: gravels and crushed stones 6.4 in volume ratio] in 1902 and thereafter.

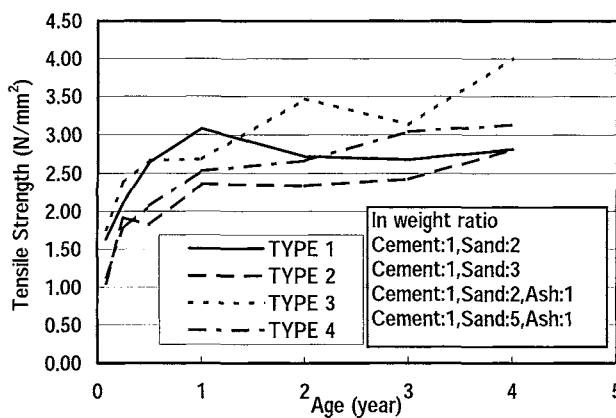


Figure 2. Results of tensile strength tests on mortar using volcanic ash.

3.2 Structural configuration of breakwater

North breakwater has the structure in which concrete blocks with weight 14 to 23 t each, width 7.2 m each and height 7 m each are piled up on the rubble mound at an angle of gradient $71^{\circ}34'$ to the horizontal line, cast-in-place concrete is placed on the piled-up blocks and another type of concrete blocks each 12 t in weight are set aside of the breakwater in order to protect rubbles (Fig. 3).

This construction method had been already applied in Madras, Colombo, etc., but found the first application in Japan at that time.

This structural configuration was adopted with the aims, on one hand, to prevent any concrete blocks at the breakwater end from dropping off during construction work, and, on the other, to let adjacent blocks be engaged more tightly with each

other as the rubbles settled and to disperse local wave force widely.

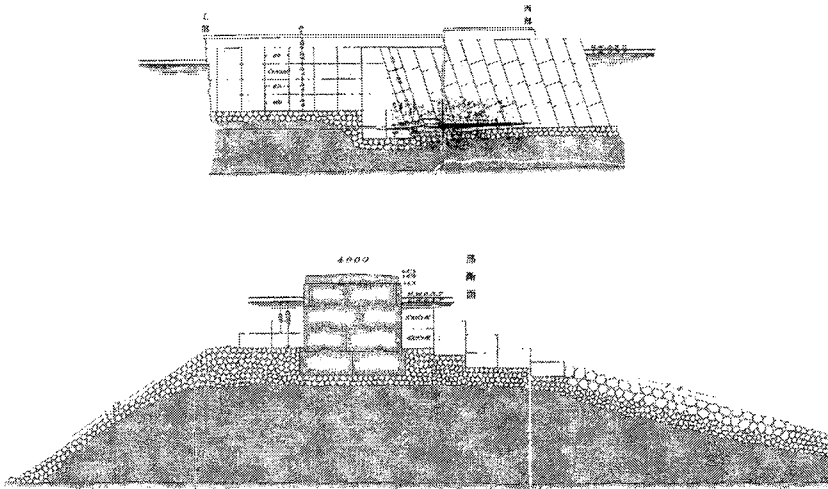


Figure 3. Longitudinal- and cross-sectional views of North Breakwater.

3.3 Construction of North Breakwater

One of the causes for cracks in the concrete blocks used for breakwater in Yokohama Port was formation of voids. With such finding taken into consideration, preparation of the concrete blocks used for North Breakwater in Otaru Port was performed under elaborative compaction and control of water volume. Owing to strict quality control there was no defective concrete block found among total 13,000 and more blocks manufactured.

In order to secure stability of rubble mound against sea waves, further piling-up of concrete blocks was implemented at least 1 year later after setting of the rubble mound. This work was carried out by use of the machine shown in Fig. 4 at usual pace of 16 blocks a day. Construction of North Breakwater was completed in 1908.

A test for concrete strength got under way concurrently with construction of this breakwater in order to make secular change of the strength clear. This test has been continued periodically still at present. Recent test results show that tensile strength of the test pieces aged 90 years is approximately as much as 75 to 95% of that of those aged 10 years. In view of number of the remaining test pieces it is possible to continue the test hereafter for 100 years.

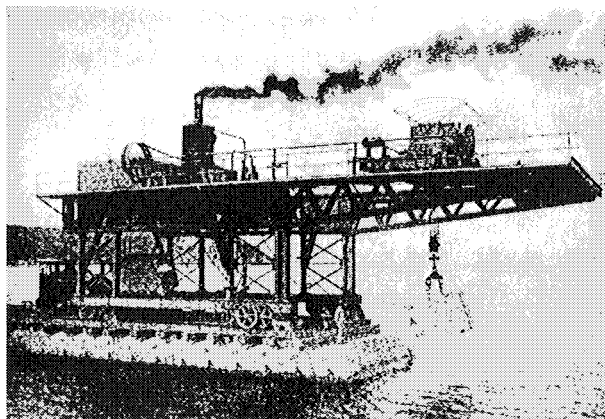


Figure 4. View of construction work.

4 Construction of Otaru Canal

4.1 Brief historical review on construction of Otaru Canal

Following North Breakwater completed in 1908, South Breakwater and Island Breakwater were constructed in 1921. As mentioned above, outlying facilities of the port were developed and improved surely and steadily. Also, in parallel with progress in additional construction and improvement of breakwaters, cargo-handling facilities and wharves were developed and improved. Wharf system planned in 1908 was changed to reclaimed canal system according to the comment given by Dr. Hiroi who returned home in 1909 from abroad. Otaru Canal was put into construction in 1914 and completed at the end of 1923 as the canal 40 m wide and 1,324 m long. Completion of this canal made it possible to moor simultaneously 40 barges with laden weight 100 t each and to use the whole port shore for store housing (Fig. 5).

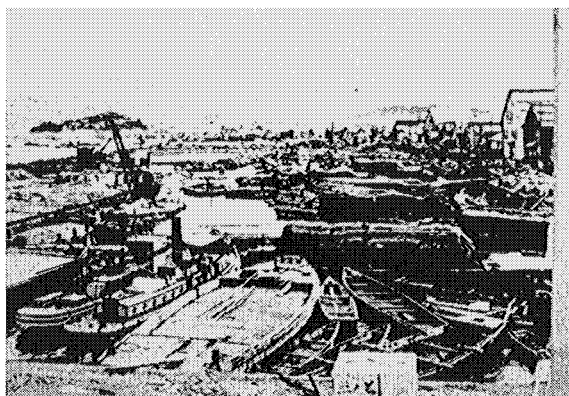


Figure 5. Otaru Canal at the time of construction (photo contributed by Otaru Museum).

4.2 Present Otaru Canal

As vessels had been getting larger and cargo-handling facilities had become further mechanized, Otaru Canal terminated its function of wharf and cargo-handling facility, and so there was raised a plan for reclamation of it. However, as the canal was very attractive on account of its spectacular scene, it was rearranged and maintained on a reduced scale. Also the streets around the port and museum have been improved and restructured in response to increasing number of tourists visiting Otaru. As shown in Fig. 6, number of tourists visiting Otaru has been increasing and especially Otaru Canal has been enhancing its nationwide popularity as a famous sight spot in Otaru.

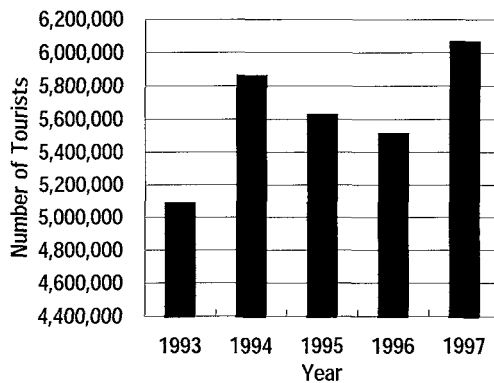


Figure 6. Number of tourists visiting Otaru.

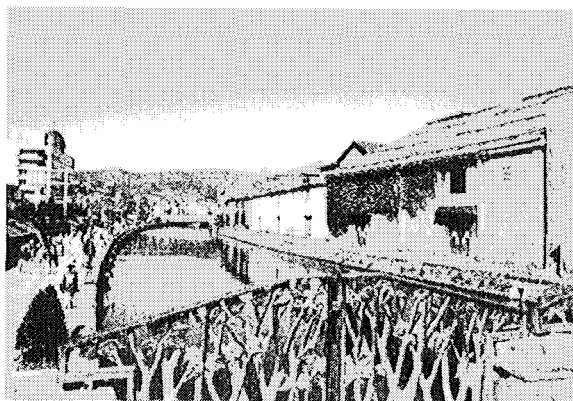


Figure 7. Otaru Canal at present.

5 Growth of Port and secular change of amount of cargo handled

Otaru Port, having started initially as a port for coal shipment, recently has been favored with smooth growth of amount of cargo handled, making active use of advantage that it is located in a large business area centered at Sapporo. Fig. 8 shows secular change of amount of cargo handled in Otaru Port during the period from 1912 through 1995.

Meanwhile, up to now major kinds of cargos have shifted from coal to industrial products and cargos transported by ferries. And, to cope with upsizing of vessels, mooring facilities have come to meet needs for mooring such vessels, namely the wharf with water depth 7.5 m started its operation in 1972 and the wharf with water depth 14 m got in service in 2000 with provisional water depth 13 m (Fig. 9 and Fig.10).

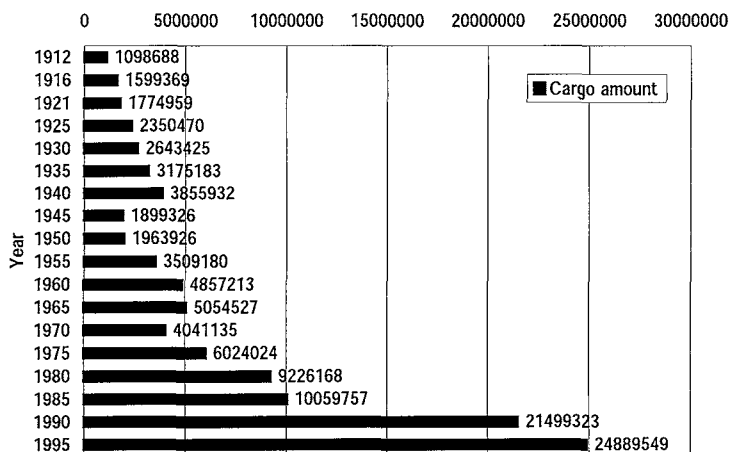


Figure 8. Secular change of amount of cargo handled in Otaru Port.

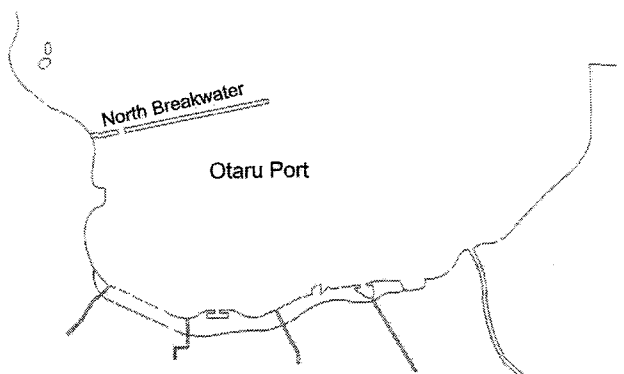


Figure 9. Historical comparison of Otaru Port development (in 1907 or so).

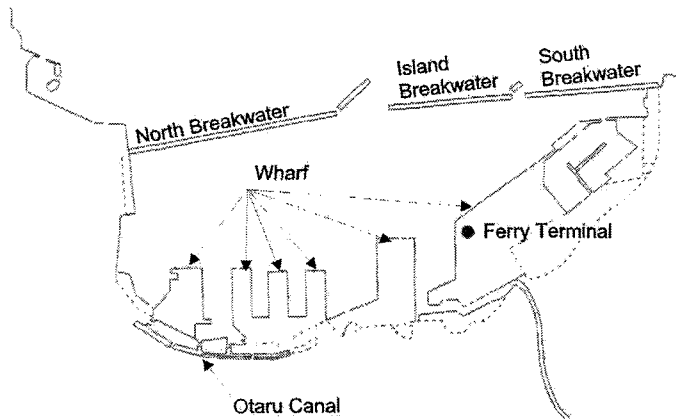


Figure 10. Historical comparison of Otaru Port development (recently).

6 Conclusions

North Breakwater in Otaru Port constructed on thoroughgoing survey and investigation, and design adopting up-to-date construction method at that time and strict construction supervision under the initiative of Dr. Hiroi is also now fulfilling enough its function as a breakwater.

In 2000 North Breakwater was certified by JSCE (Japan Society of Civil Engineers) as a “Heritage-2000 of civil engineering certified and recommended by JSCE” which is to be acknowledged for the civil engineering structure. It remains highly evaluated after half a century passed since its completion. Thus, North Breakwater in Otaru Port can be called Japan’s representative marine structure having historical value.

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