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The Failure of the Kamaishi Tsunami Protection Breakwater

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ABSTRACT

Kamaishi is a small city located in the Iwate Prefecture on the East coast of Japan. Historically, Kamaishi was famous as a city for its steel production, but more recently is known for its fishing and shellfish production.

In March of 2009, construction was completed on the world's largest breakwater within Kamaishi Bay. The completion of the breakwater was the result of over 30 years of research and construction, and was recognized by Guinness World Records as the world's deepest breakwater at 63 meters deep and 1950 meters long. The design intention of the breakwater was to protect Kamaishi Bay from the threat of tsunamis and other significant wave action.

Two years later, Japan was devastated by the Tohoku earthquake; the most powerful earthquake known to have struck Japan and the fifth largest recorded earthquake to date at a 9.0 magnitude. An accompanying tsunami struck the breakwater at Kamaishi, where waves as tall as 4.3 meters surmounted the breakwater and proceeded to submerge the city center. The failures of this and other breakwaters on the coast of Japan have forced officials to rethink the effectiveness of the structures.

The following paper will highlight the research undertaken for the design of the breakwater, challenges met during construction, and the failure of the breakwater. In addition, this paper will address the issue of the effectiveness of breakwaters in areas known to have high seismic activity.

1 INTRODUCTION

The city of Kamaishi is located on the South-eastern coast of the Iwate Prefecture in Japan. It is located approximately 593 km North of Tokyo, as depicted in the map of Japan below.

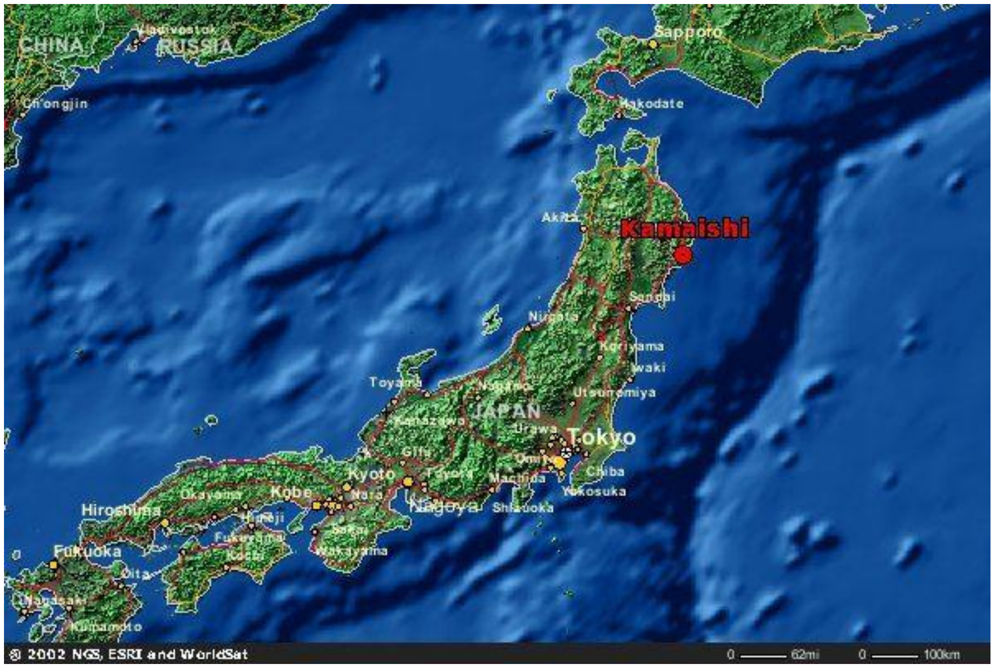

Figure 1: Map of Japan showing location of Kamaishi

(Source: http://abbot.us/DD629/book/c9.shtml)

Historically, Kamaishi was a small fishing village similar to any other on the coast of Japan until the discovery of magnetite in the surrounding area in the year 1727. Development of industry in Kamaishi was truly seen in 1857 when Japan's first small blast furnaces were constructed in the city. The lighting of these furnaces marked the beginning of modern iron production in Japan, and the date of their lighting is celebrated as "Iron Commemoration Day". At the time the primary use of the iron was the development of Western-style weapons in an arms race between the different feudal domains. Kamaishi would continue to be known as a foundry city for years to come, with fishing remaining as another dedicated industry.

The city's fishing and iron industries benefitted greatly from the access to the natural harbour, and the addition of a breakwater served to further benefit the existing geography. Breakwaters are very important to Japan due to the countries heavy reliance on port cities which benefit immensely from the protection offered by breakwaters.

2 BREAKWATERS IN JAPAN

More than a third of the coast of Japan is guarded by breakwaters or seawalls intended to protect the country from heavy storms and wave action, and even tsunamis.

The type of breakwater most commonly found worldwide is the rubble mound breakwater. However, composite breakwaters (also called mixed breakwaters) with a rubble mound foundation and a vertical caisson section have been the most common choice for design in most of Japan.

2.1 Composite Breakwaters

The advantage of the composite type is that they are more stable and faster to construct than rubble mound breakwaters, and they resist wave transmission. However, composite breakwaters also experience higher wave forces due to the wave pressure acting on the vertical section in almost the same phase from top to bottom.

The vertical section has also been known to cause reflection of waves, which has proven to be an issue in harbours near designated fishing grounds. The agitation of the water due to this reflection causes issues for small crafts typically used for fishing.

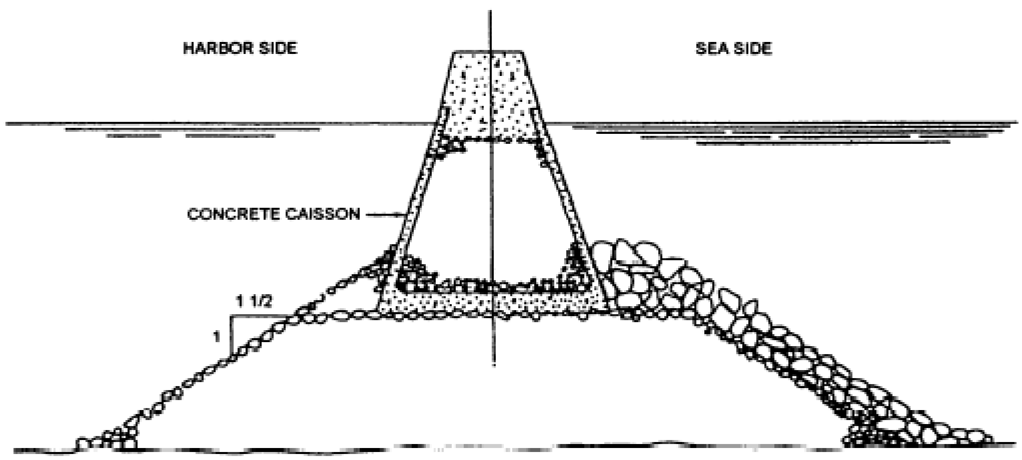

Figure 2: Sample detail of a composite breakwater

(Source: http://www.tpub.com/inteng/1f.htm)

To help reduce the effect of these disadvantages, composite breakwaters can be designed with additional concrete blocks which serve to dissipate waves against the vertical face. These blocks are more typically used in shallower areas, as the cost of construction increases drastically in deep water due to the sloped geometry of stacking the blocks.

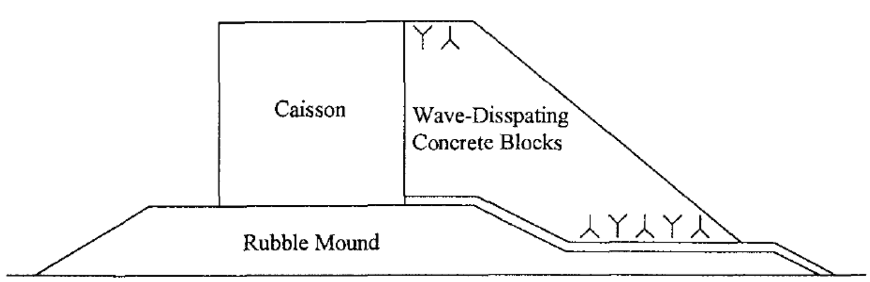

Figure 3: Geometry of wave dissipating concrete blocks against composite breakwaters

(Source: Proceeding of 25th Conference on Coastal Engineering, Orlando, Florida, 1996)

2.2 Proposed Section for Kamaishi

When originally considered, the breakwater at Kamaishi would be constructed in a location where more than 50% of its total length would be comprised of a section deeper than 50 meters. At the deepest point, the breakwater would be approximately 63 meters deep, setting the Guinness World Record for deepest breakwater. Construction of the breakwater started in 1978 and was completed in March of 2009.

Figure 4: Aerial view of the breakwater across Kamaishi Bay

(Source: http://www.mlit.go.jp)

Due to the required depth, a rubble mound breakwater was not suitable for design and a composite breakwater was instead selected. The extreme depth of the breakwater also restricted the use of wave dissipating concrete blocks as they would have been too expensive. Considerations for earthquake and tsunami resistance were still however a factor in the design, and an experimental section was researched using laboratory tests on a scale model.

The experimental composite breakwater utilized a trapezoidal cross section above the rubble base with the intention of providing extra resistance to hydrodynamic pressures during seismic activity. Atop the trapezoidal section was the vertical face of the breakwater of which two designs were tested for wave dissipation effectiveness. One design used a standard face as a reflective surface, and the other used a double horizontal slit wall to assist in wave energy dissipation.

The results of the testing showed that in terms of wave pressure, similar intensity was observed by each design. However, during sliding tests it was found that the sliding distance of the design with the double horizontal slit wall was generally less than that of the reflective surface. This was attributed to the design causing the downward wave force to act in a different location, as well as a reduction in horizontal wave force due to wave energy diffusal.

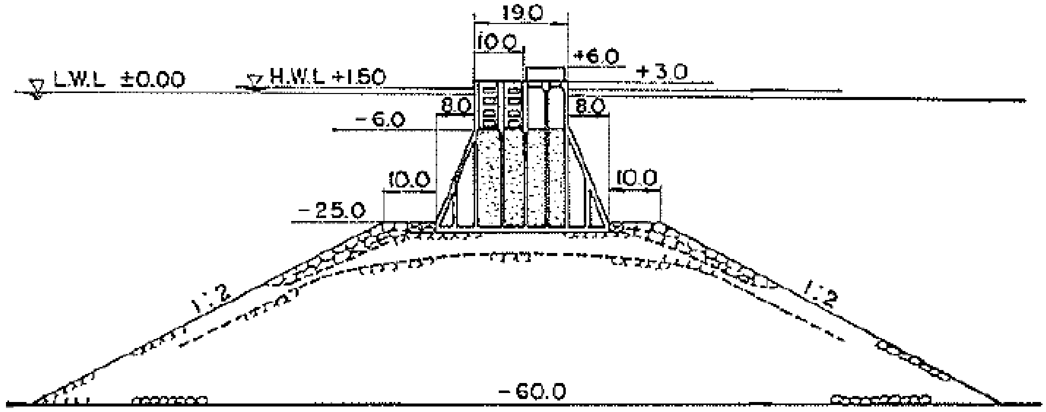

Figure 5: Originally proposed cross section of Kamaishi Breakwater

(Source: Report of the Port and Harbour Research Institute, Vol. 26, No. 5)

3 THE GREAT TŌHOKU EARTHQUAKE

On March 11, 2011, two years after the completion of the Kamaishi breakwater, Japan was devastated by one of the strongest recorded earthquakes in history. Referred to as the Great Tōhoku Earthquake, it measured a magnitude of 9.0, making it the strongest recorded earthquake to strike Japan, and the fifth strongest recorded earthquake. The epicentre of the earthquake was located approximately 130 km off the Eastern coast of Japan, to the Southeast of Kamaishi, as shown in the figure below.

Figure 6: Map showing Great Tōhoku Earthquake epicentre and severity

(Source: http://www.britannica.com)

3.1 The Resulting Tsunami

The earthquake triggered massive tsunami waves in the Pacific Ocean travelling at up to 800 kilometers per hour from the epicenter. The waves devastated the East coast of Japan, causing extensive damage to cities located on the coast. Some waves were even reported to have travelled inland as far as 10 kilometers, leaving large areas of low-lying land completely flooded.

The Kamaishi breakwater failed when it was overtopped by the first wave of the tsunami, measuring at 4.3 meters. Although the breakwater was designed with the intention of resisting the force of tsunami waves, the design simply did not account for a wave of such devastating natural force. When considering design, tsunami waves are considered to be unbroken waves and translated into a hydrostatic force on the face of the structure. In the case of Kamaishi, the design wave was simply tamer than the wave which actually struck the breakwater.

Figure 7: A section of the destroyed Kamaishi breakwater

(Source: www.nytimes.com)

3.2 The Tsunami Aftermath

In the wake of the Great Tōhoku Earthquake and accompanying tsunami, the government of Japan decided to repair the damaged breakwater. This was met with general disproval from the population, as the repairs could cost up to $650 million and the breakwater had proven to be unsuccessful in preventing a tsunami from reaching the coast. As far as the population was concerned, that amount of money should not have been spent to repair a breakwater that had failed, especially in an area beginning to see a decline in population. However, the government decided that repairs were the most cost efficient and effective choice and would encourage industry to remain in Kamaishi, as they would feel protected.

The fact remains that the breakwater was designed to withstand a smaller tsunami, but the unpredictable nature of seismic activity proved to be the true cause of failure. The extensive research into the design of the breakwater proved that the structure could withstand seismic action and tsunami forces, just not at the magnitude of one of the most powerful earthquakes in recorded history.

4 CONCLUSIONS

It can be seen from the case study that regardless of size, composite breakwaters can still be ravaged by extreme cases of earthquake forces. Such unpredictable forces can prove to be difficult when trying to design a structure to resist them, but it should not be considered impossible. At Kamaishi, the breakwater was struck by tsunami waves taller than ever expected based on historical data and failed as a result. Had the forces caused by the tsunami been within the expected limits based on recorded events, the breakwater would not have failed.

Although the population was opposed to the idea of rebuilding a failed technology, it was deemed by the government to be the best option to protect the coast from tsunami action. The government's decision was partially based on repair being the fastest solution in order to prevent industry from closing due to feeling unprotected.

The Japanese government was wise in their decision to take the fastest solution to return the port at Kamaishi to a protected state, but future endeavors should account for seismic activity of the magnitude experienced in 2011. At the time of its design the Kamaishi breakwater was a new development in breakwater engineering, and with their extensive use of breakwaters the Japanese should be able to adopt similar new innovations to protect the coast.

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