Chapter 4

Development of Tsunami Engineering

Field of expertise: Tsunami Engineering

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Summary

Let us review the role of tsunami engineering in the Great East Japan Earthquake, its challenges, and its progress in the past 10 years. Why was there a huge tsunami? What was the status of the observation and warning systems at the time? What was the actual damage of this huge tsunami? How can we reduce damage and how can we predict tsunamis in the future? We would like to introduce the creation of a new academic field to reduce human casualty.

Keywords: tsunami engineering, numerical analysis, cascading disaster, comprehensive disaster prevention measures

Introduction

The experience of the 1933 Sanriku tsunami and the 1960 Chilean tsunami led to the development of tsunami observation and warning systems as well as structural facilities, which have since contributed to tsunami disaster prevention. However, the Great East Japan Earthquake revealed a number of problems, and a new fusion of humanities and sciences started in tsunami engineering in order to mitigate future damage.

1: Problems Revealed by the Great East Japan Earthquake

The Tohoku region has been experiencing various types of tsunamis for a long time. The 869 Jogan Tsunami recorded about 1,000 victims. The 1611 Keicho-Oshu Tsunami hit from Hokkaido to the Kanto region and caused great damage in the Tohoku region. The 1896 Meiji Sanriku tsunami caused more than 20,000 casualties, despite the fact that only small tremors were caused by the "tsunami earthquake." The 1960 Chilean tsunami was an earthquake on the other side of the world and was not felt in Japan, yet a tsunami arrived in the Sanriku region 23 hours later, claiming about 140 lives. In our research field, we have assessed the risk of tsunamis in the past using geological methods, cooperated with governments to estimate tsunami inundation areas using numerical analysis techniques, promoted tsunami disaster prevention in local communities, and conducted evacuation drills and educational support activities. However, the Great East Japan Earthquake had an impact never experienced before. The magnitude of the earthquake was 9, a number that had never been predicted or assumed in Japan. The earthquake ruptured a wide range of faults from off the coast of Aomori Prefecture to off the coast of Ibaraki Prefecture. Because of this, tsunamis reached a height of more than 10 meters in the Sendai Plain and up to about 40 meters in the Sanriku area. In addition to the ground shaking and liquefaction caused by the massive earthquake, the tsunami caused damage to structures and buildings. There was a massive amount of land subsidence, debris, and fires. Long-term health damage, environmental damage, ecological impact, and damage caused by the accident at the Fukushima Daiichi Nuclear Power Plant occured as well. We believe that all of the currently conceivable damage occurred in one chain. The direct damage and indirect damage (including harmful rumors) were catastrophic.

2: Paradigms Destroyed by the Earthquake

In the past, structural measures such as seawalls were used to prevent tsunami damage, and non-structural measures such as tsunami warnings, evacuation systems, and hazard maps were also created. After the 1933 Sanriku Tsunami, the tsunami warning system was put into operation in 1941, and it has been improved with each subsequent tsunami disaster. At the time of the Great East Japan Earthquake, the first warning was issued about 3 minutes after the earthquake occurred. The system was designed to build a database of the numerical analysis results of tsunamis caused by earthquakes. When an earthquake occurs, the database is used to retrieve the expected tsunami height and arrival time based on the magnitude of the earthquake. However, this could not be applied to the Great East Japan Earthquake. Previously, we did not expect to experience earthquakes with a magnitude of 9, and because of this, the system underestimated the expected height of the tsunami. Some offshore stations confirmed a massive tsunami and the warning level was raised, warnings were issued, but the first wave of the tsunami had already reached the coast by this time. The scale of this tsunami was larger than what was assumed at the time the hazard map was created, and the failure to evacuate appropriately was one of the reasons for the large number of casualties, in addition to the issues mentioned about the tsunami warning and observation system.

Structural measures such as seawalls, breakwaters, and floodgates have been developed mainly in the Sanriku region since the 1960 Chilean tsunami, and this mitigated damage caused by the 2003 Tokachi-oki tsunami and other tsunamis. However, the huge tsunami of the Great East Japan Earthquake was much larger than the height of these structures and this caused significant damage. On the other side of these structures, the tsunami flow velocity increased and scouring occurred, which caused significant damage to the structures as well. In addition to this, not all of the structure openings (land locks) were remotely operated or automatically controlled, and there were reports of casualties among firefighters who tried to close them manually.

3: A New Approach

This section introduces a new approach based on the experiences and lessons learned from the Great East Japan Earthquake.

1. Offshore observation and warning systems after a huge tsunami

At the time of the Great East Japan Earthquake, a limited number of GPS wave stations (Figure 4-1) were used, but in addition, about 200 submarine tsunami sensors were installed by the Seafloor Observation Network for Earthquakes and Tsunamis along the Japan Trench (S-net). The

Japan Meteorological Agency (JMA) can observe tsunamis offshore in real time before they reach the coast, and this information is useful for sending quick tsunami warnings, updates, and cancellations of these warnings. In addition, the JMA is also developing a new method (Tsunami Forecasting based on Inversion for Initial Sea-Surface Height, or tFISH) to predict coastal tsunamis by estimating their location and magnitude based on the waveform data observed offshore.

In our research field, we are focusing on the optimal use of observation networks using genetic algorithms, and are investigating ways to improve the efficiency of this method. In the case of tsunami warnings, when there is a suspicion of a huge earthquake, the first tsunami warning is issued using the maximum magnitude expected in the area. However, when the maximum magnitude expected is used, qualitative expressions such as "huge" are used instead of numerical expressions until the exact magnitude of the earthquake is determined. In addition, the levels to express expected tsunami height were changed from 8 levels to 5, and we now announce the higher level to the public.

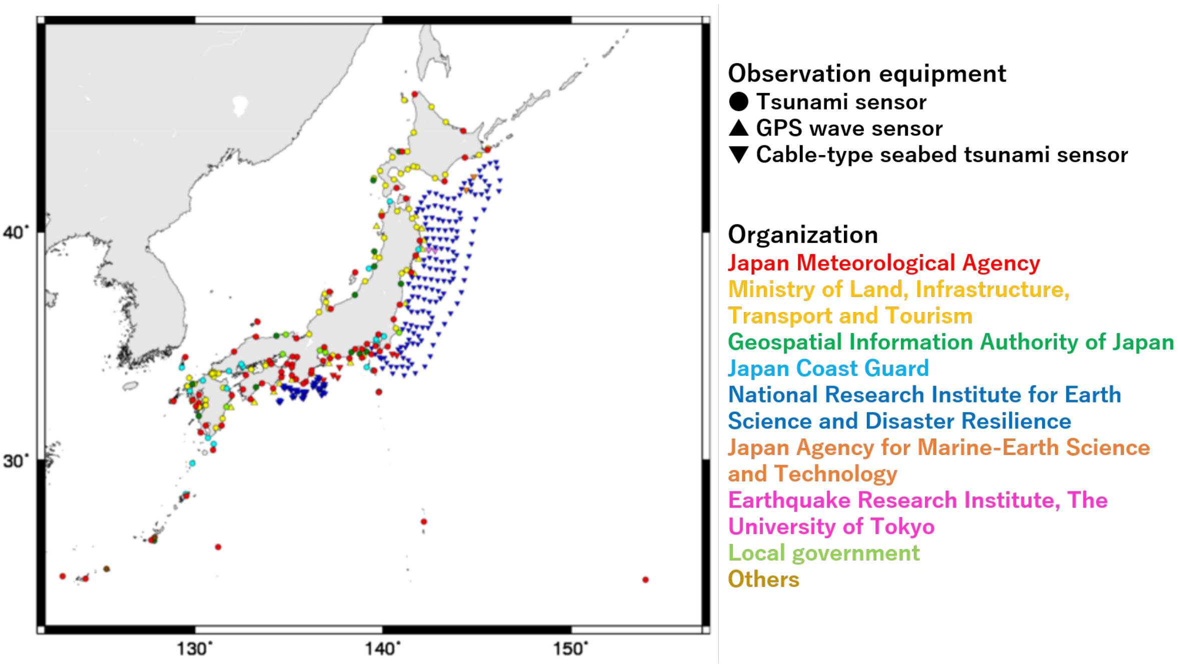

Figure 4-1. Current tsunami observation points (Japan Meteorological Agency, 2022)

2. Disaster prevention facilities to prevent or reduce inundation by a huge tsunami

Level 1 and Level 2 tsunami countermeasures were discussed and proposed by the Japan Society of Civil Engineers (JSCE) and other organizations. Level 1 tsunamis are the largest in modern times (with a probability of occurring once in 100 years). It is a structural measure of disaster prevention, and is expected to protect not only human life, but also property and economic activities. On the other hand, Level 2 tsunamis are the largest (with a probability of occurring about once in 1,000 years). It is a comprehensive measure that is expected to protect human lives, reduce economic loss, prevent major secondary disasters, and enable early recovery. The concept of tsunami disaster prevention facility design has changed accordingly. In the past, disaster prevention measures were based on a single design level and they were considered unbreakable. Today, disaster prevention and mitigation measures have features for multiple design levels, a stable performance, as well as functions and stability performance that change depending on priority.

As a result, it has become necessary to improve the technical standards of tsunami disaster prevention facilities and promote technology development. For example, the damage patterns of disaster prevention facilities were identified and through research and development, the damaged areas will be repaired so that they become resilient structures

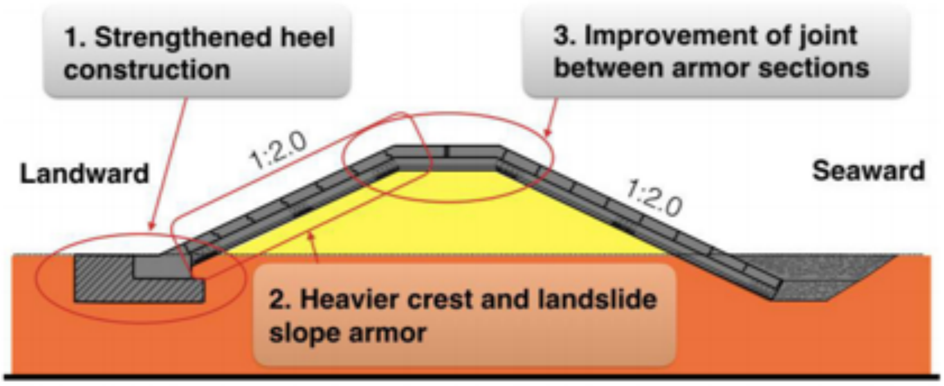

Figure 4-2. Example of a resilient structure (Suppasri, et al., 2016)

3. Predicting damage from a huge tsunami

After the Great East Japan Earthquake, data from more than 250,000 damaged buildings were collected, including the type of structures, number of floors, building function, etc. to analyze damage (indicating the relationship between the external force of the tsunami and damage to buildings, etc.). In addition to buildings, we have also developed a wide range of tsunami damage analysis for fishing boats, coastal embankments, road bridges, and aquaculture facilities to improve the prediction of more complex tsunami damage. In recent years, advanced computational science and personal computers have made it possible to reproduce detailed tsunami flows and drifts, and to perform detailed structural analysis, thus improving the accuracy of tsunami damage prediction.

4. New research on science of human survival from disaster

New research to protect human lives from various natural hazards that are likely to occur in the future has started. Our institute has received information from the Miyagi Prefectural Police Headquarters on approximately 9,000 victims who died in the tsunami that followed the Great East Japan Earthquake, and we are currently analyzing this information. In this analysis, forensic medicine, disaster medicine, tsunami engineering, fluid mechanics, and others are collaborating to reorganize the causes of death in tsunami disasters and to clarify the actual damage and characteristics in each region. In the future, the results of these studies will be linked to rescue and evacuation methods, so that people can survive even if they are caught in a tsunami. This is the first research to utilize the vast amount of information on the victims of the Great East Japan Earthquake, and it is expected to make a significant contribution to the mitigation of human suffering.

5. Newly established organizations

New initiatives have begun worldwide. The Sendai Framework for Disaster Risk Reduction 2015-2030, the resulting document of the Third UN World Conference on Disaster Risk Reduction of 2015, is the successor to the Hyogo Framework for Action of 2005, and as a guideline for international disaster reduction efforts. Based on the Sendai Framework for Disaster Risk Reduction, other countries around the world have begun making changes as well. The Global Centre for Disaster Statistics (GCDS) was established at the same time, mainly in collaboration with the United Nations Development Program (UNDP) and other disaster reduction-related organizations, to provide support for improving disaster reduction capacity in developing countries through the collection, analysis, and utilization of disaster damage statistics, including those on tsunamis.

4: Achievements and Future Prospects

Even now, the offshore observation stations are giving us useful reference data for confirming tsunami generation and issuing tsunami warnings immediately after an earthquake. Before a tsunami arrives on land, it is possible to determine the fault parameters of an earthquake in real time, calculate and visualize the tsunami inundation area, and announce the expected inundation map and damage prediction through analysis. As for the construction of survival science as a discipline to fundamentally reduce human casualty, the cause of death in the Great East Japan Earthquake was classified in detail, including address, place where the body was found, regional characteristics, leading to the relationship between these factors and the cause of death (drowning, unknown, burning, hypothermia) being found. In addition to the external forces of the tsunami, we would like to make proposals to protect lives through detailed studies. Finally, the newly established international organizations are in the process of data collection and analysis, and we can look forward to international guidelines based on the results.

Conclusion - From the authors

In the future, the basic principles of tsunami risk assessment, observation and prediction, damage estimation and mitigation, as well as community development, including tsunami disaster prevention culture, will remain unchanged. Tsunami engineering aims to provide technologies that contribute to practical damage reduction, but its development is based on the fusion of academic fields and basic science, and we will continue to move forward through collaboration.

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