The Great Eastern Japan Earthquake and Tsunami

Facts and implications for flood risk management

Edited by
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Photo of the front page
Overturned building in Onagawa (photographed by Bas Kolen, June 2012)

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SUMMARY

The Great Eastern Japan Earthquake and Tsunami of March 11, 2011 can be characterized as a catastrophe. It inundated over 560 km^2 of land, devastating a large number of coastal communities, causing over 19,000 casualties and huge economic damage in the Tohoku region. Due to the relatively high frequency of tsunamis, the region was considered well prepared against extreme coastal events. Yet the event of March 11 exceeded all previous expectations and overwhelmed the Japanese disaster protection system.

This book constitutes a Dutch perspective to the Japanese tsunami disaster. Its main objective is to provide a comprehensive overview of the devastating events, their impact and the implications of this catastrophe for flood risk management in Japan, in the Netherlands, and ultimately worldwide. It is in fact the outcome of an effort to derive lessons for flood risk management based on the record of a natural disaster with a magnitude that has never been recorded before.

First a brief chronicle of the events of March 11 2011 is presented, followed by the consequences and actions that took place in the aftermath of the disaster. Subsequently some insight into the damage and casualties is provided through the description of field observations in September 2011. Using this information the response of the Japanese flood countermeasures to the tsunami of March 2011 is analysed from a flood risk management perspective. The book continues with an overview of the recovery efforts, and it concludes with some future challenges for developments in disaster management, including the potential of Dutch-Japanese collaborations in the field of flood risk management.

SAMENVATTING

De zware aardbeving en tsunami in Japan (Great Eastern Japan Earthquake and Tsunami) van 11 maart 2011 zijn een catastrofe voor het land geweest. Meer dan 560 vierkante kilometer overstroomd land heeft een groot aantal kustgebieden verwoest met 19,000 dodelijke slachtoffers en een enorme economische schade in de regio van Tohoku tot gevolg. Deze regio was goed voorbereid tegen extreme natuurrampen, doordat tsunami's hier relatief frequent voorkomen. De omvang van de tsunami van 11 maart ging alle voorgaande verwachtingen te boven en overdonderde het Japanse rampenbeschermingsysteem.

Dit boek beschouwt de tsunami ramp in Japan vanuit een Nederlands perspectief. Het boek heeft tot doel een volledig overzicht te geven van verwoestende natuurramen, hun impact en de consequenties van deze ramp voor overstromingsrisicomanagement in Japan, in Nederland en uiteindelijk wereldwijd. De 'lessons learned' voor overstromingsrisicomanagement zijn in feite het uiteindelijke resultaat en zijn gebaseerd op een verslag over een natuurramp met een omvang dat nog nooit eerder is waargenomen.

Het boek presenteert allereerst een kort overzicht in de tijd van de ramp op 11 maart 2011, waarna de gevolgen en de nasleep van de ramp worden belicht. Enig inzicht in de schade en slachtoffers volgt uit de observaties van veldbezoek dat in september 2011 heeft plaatsgevonden. Aan de hand van deze informatie zijn de Japanse hoogwaterbeschermingsmaatregelen tegen de tsunami van maart 2011 vanuit een overstromingsrisicomanagement perspectief geanalyseerd. Tenslotte geeft het boek een overzicht van de herstelwerkzaamheden en sluit af met enige toekomstige uitdagingen ten aanzien van de ontwikkeling van de rampenbeheersing, waarbij de potentie van de Nederlands-Japanse samenwerking het werkveld van overstromingsrisicomanagement ook is betrokken.

概要

2011年3月11日に発生した東日本大震災は世界最大規模の災害だった。海添いの560平方キロメートルにわたる社会インフラが破壊され、19,000名を超える被害者を出し、多大な経済的損害をもたらした。津波の発生頻度が高い東北地方において、災害対応力のある海岸整備がなされているはずだったが、この震災は国の予想をはるかに超えていた。

本書は、昨年の東日本大震災をオランダからの観点で分析結果をまとめている。目的は、震災に伴って何が起こったかを紹介し、日本・オランダ・それで世界の防災・防水システムへの影響を述べ、近代に起こったことのない規模の自然災害の記録から教訓を提案することである。
まずは、震災当日の時系列と、その後の影響と対策を紹介する。次に、2011年9月に被害地域を訪問したオランダの関係者が見た被害状況を報告し、リスク分析観点からみて津波対策を分析する。最後に、震災後1年にわたる復興計画や対策を紹介し、人を守る防災システムの今後のチャレンジと日蘭協力の可能な防水関連分野を提案する。

PREFACE

On 11 March 2011, Japan was shaken by an earthquake that was followed by a tsunami. To make matters even worse the Fukushima nuclear power plant was affected by the flood, causing a major nuclear disaster. This book contains an analysis of data and impressions that the lead author has collected within one year after the catastrophic event. You will be impressed by huge damage to the society. More than 19,000 people lost their life, and the economic damage was more than 200 billion USD. The world economy was also shaken by the event, since the production chains are worldwide connected. The economic damage was not only in Japan, but also all over the world.

Which lessons should be learned from this book? First, economic damage of a flood is not restricted to the flooded area, but are in a far bigger region, sometimes even all over the world. This means that protection against flooding is not only a national issue, but it should be part of the agenda of the international community. Second, protection against flooding is extremely important, especially of critical infrastructure, as nuclear plants. The failure probability of this type of infrastructure should be thoughtfully determined, taking into account the risk of flooding in flood-prone areas. Third, the recovery of the flooded areas will take years and years, and it is an important question whether the approach to assess the damages do take this timescale into account.

My wish is that this book is an essential contribution to the sense of urgency of reducing the flood risk, in the Netherlands, but also in other parts of the beautiful Delta's. It is a major challenge to design creative and challenging solutions!

Sybe Schaap

Chairman Netherlands Water Partnership;
Professor Water Governance, Delft University of Technology

ACKNOWLEDGEMENTS

The idea to bundle this book was born when the authors were in Japan in September 2011, during the International Conference on Flood Management, held in Tokyo. This project was an initiative of HKV Consultants, after a visit of the lead author to Kyoto University, and her participation in a survey of the devastated coastal zone of Tohoku, which was organized by the Disaster Prevention Research Institute of Kyoto University. Similar initiatives have been taken place in the recent past in the Netherlands. In particular HKV Consultants have published two books about Hurricane Katrina in New Orleans in 2005, and one book about Cyclone Xynthia that hit the Atlantic coast of France in 2010. In 2012 the Dutch Expertise Network for Flood Protection (ENW) published another similar book about the severe flooding in central Thailand in 2011.

The lead author would like to thank all contributors and reviewers for their voluntary collaboration, and especially those that organized her visit in Kyoto University and Tohoku in September 2011: dr. Tomohiro Yasuda, and dr. Bas Jonkman.

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The tsunami that hit the north pacific coast of Japan on March 11, 2011 can be characterized as a catastrophe based on the definition of Quarantelli (1997). It inundated over 560 km^2 of land, devastating a large number of coastal communities, causing over 19,000 casualties and huge economic damage in the Tohoku region. As many catastrophic tsunamis have been recorded in the history of Tohoku and seismologists had remarked the high probability of a major earthquake that could generate a big tsunami in Japan, the region was considered highly prepared against tsunami. However the event of March 11 exceeded all previous expectations and overwhelmed the Japanese disaster protection system.

This book constitutes a Dutch perspective to the Japanese tsunami disaster. Its main objective is to provide a comprehensive overview of the devastating events, their impact and the implications of this catastrophe for flood risk management in Japan, in the Netherlands, and ultimately worldwide. It is in fact the outcome of an effort to derive lessons for flood risk management based on the record of a natural disaster with a magnitude that has never been recorded before. Given that the assessment of the nuclear catastrophe and recovery projects are still in progress, the overview presented in this book cannot be complete, and it might take several years until a complete analysis of the disaster can be made. The intended audience of this book is flood risk management specialists and researchers, and parties involved in coastal zone management of flood-prone coastal areas, such as coastal engineers, spatial developers and decision-makers. A big part of the book is only informative, which makes it easily comprehensible by general audience, i.e. anyone interested in the topic.

In order to achieve its objective, the book begins with the chronicle of the disaster in chapter 2, starting from the earthquake and tsunami events and continuing with the consequences and actions that took place in the aftermath of the disaster. In chapter 3, an overview of the damage and casualties is presented, based on field observations in September 2011 and information provided by various Japanese institutes. Using this information the response of the Japanese flood countermeasures to the tsunami disaster is assessed from a flood risk management perspective (chapter 4). Based on this assessment, some lessons are derived for flood risk management in the Netherlands, and for the concept of multi-layered safety as being developed in the Dutch flood risk management. In chapter 5 the recovery efforts that have been taking place since the tsunami attack are presented. The book ends with chapter 6, where some future challenges for developments in the Japanese disaster management are presented, and the potential of Dutch-Japanese collaborations in the field of flood risk management.

2 CHRONICLE OF THE DISASTER

2.1 Disastrous events

2.1.1 The earthquake

On March 11, 2011 at 14:46 local time, a large earthquake occurred 130 km offshore the north-eastern coast of Japan. According to estimates, this earthquake was of magnitude 9.0 on the Richter scale, which makes it the largest earthquake ever recorded in Japan. The rupture area was 400 km long from north to south and 200 km from east to west. The same day a large amount of strong aftershocks of up to magnitude 7.4 on the Richter scale were recorded in Iwate, Miyagi, Fukushima and Ibaraki prefectures (figure 2.1).

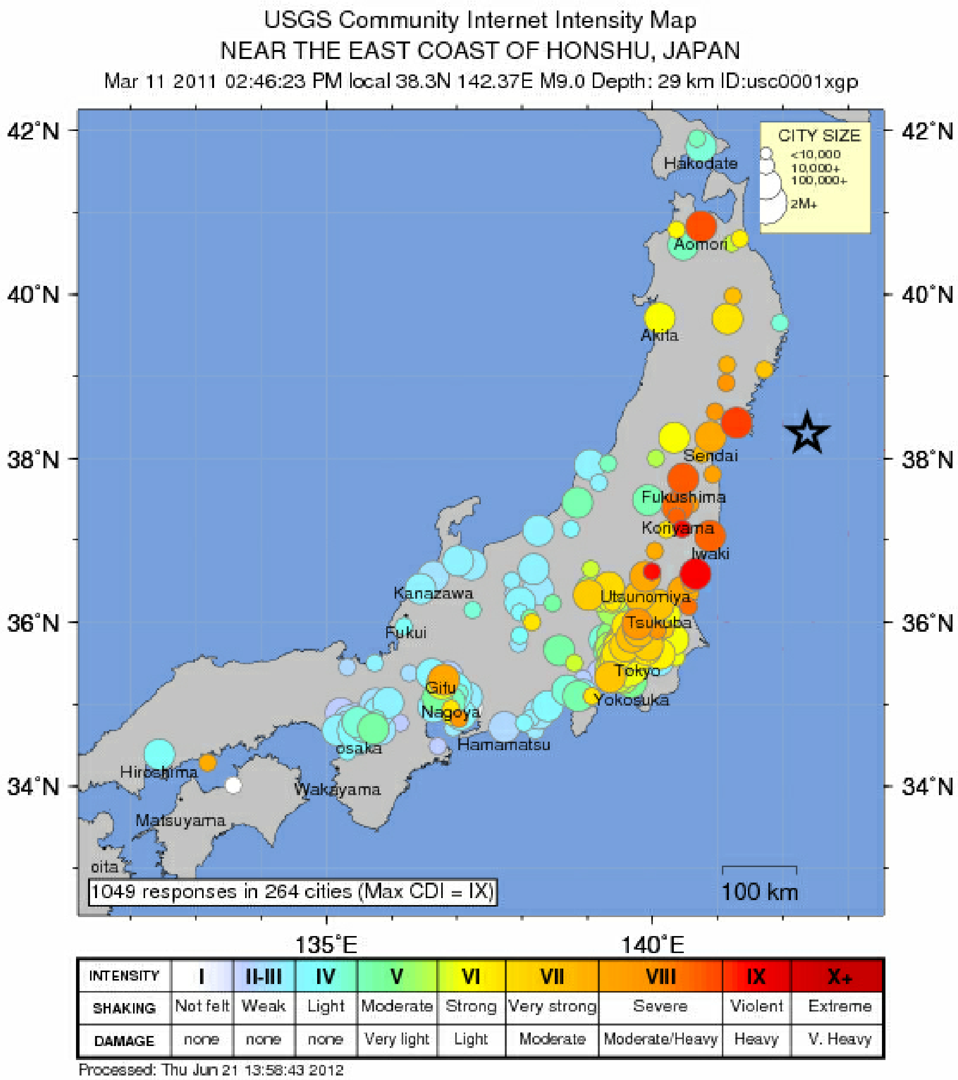

Figure 2.1: Map of earthquake intensity (USGS, 2011; http://earthquake.usgs.gov/)

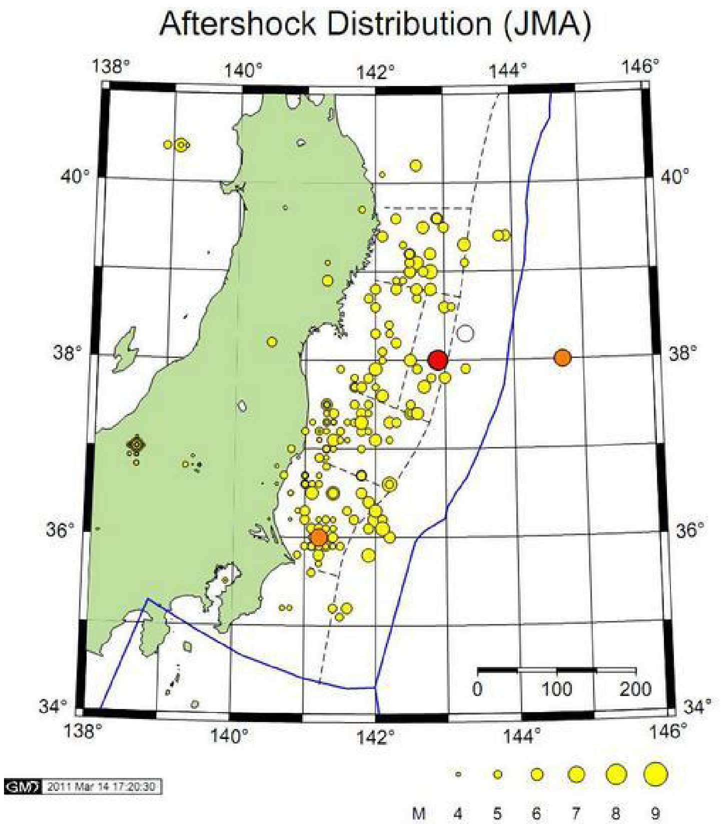

Figure 2.2: Aftershock distribution (Japan Meteorological Agency, 2011; http://www.jma.go.jp)

2.1.2 The tsunami

Three minutes after the main earthquake, the Japan Meteorological Agency issued a tsunami warning, and soon after that the GPS mounted buoys at a spot of 100-200 m in water depth off the Tohoku coast recorded a 2.6 to 7.7 m high tsunami (Kawai et al. 2012). Due to shoaling, a deep-water wave of this magnitude is expected to exceed 10 m in height when reaching coastal waters, while its exact value is very much dependent on the local bathymetry and morphology of the coast. A few minutes later those huge waves were indeed reaching the north-eastern Japanese coast, starting from Miyagi, Iwate and Fukushima prefectures, and expanding gradually to the entire north-eastern Japanese coast from Hokkaido in the north to Chiba in the south, affecting approximately 1300 km of the coastline. The rupture area where the tsunami was generated and the coastal tsunami characteristics in Iwate, Miyagi and Fukushima, as reported by Takahashi et al. (2011), are shown in figure 2.3.

In the meantime tsunami warnings were also issued in Taiwan, Indonesia, Russia, Philippines, the Pacific islands, and as far away as Hawaii, Mexico, Colombia and Chile, while extensive evacuation operations were taking place in Japan. The evacuation operations will also be discussed later.

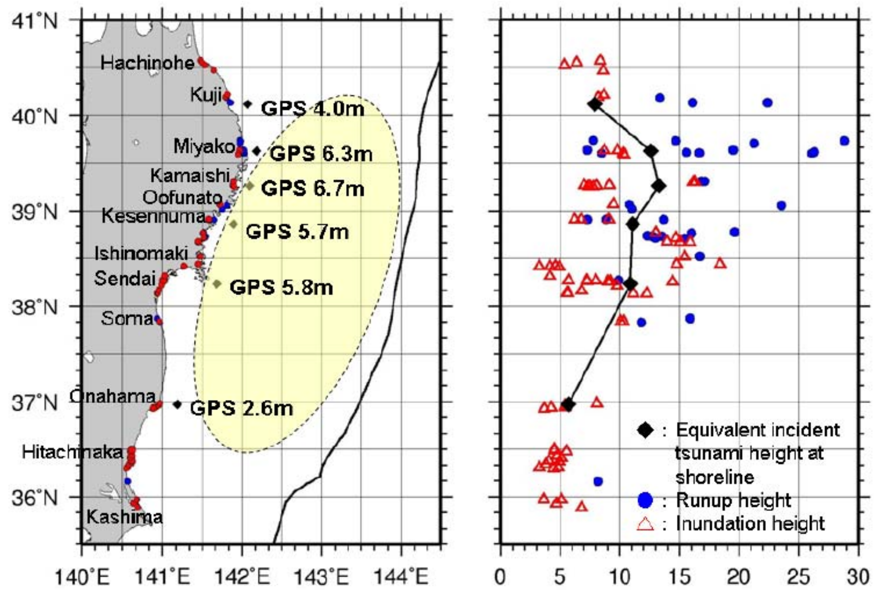

Figure 2.3: Left: Source region and GPS offshore wave records; Right: Estimated incident tsunami and measured tsunami watermarks (Takahashi et al. 2011, Courtesy of Port and Airport Research Institute, all rights reserved)

2.1.3 The nuclear disaster

Six hours after the earthquake of March 11, the International Atomic Energy Agency reported a nuclear emergency at Fukushima Daiichi nuclear power plant. Due to the strong earthquake, the process of shutting down the three operating reactors was automatically initiated. This process requires some diesel generators to power the water pumps that are supposed to supply water to the fuel rods in the reactors in order to cool them down. The operation of the diesel generators failed on the 11th of March, which should have prompted a system of back-up generators to activate. Due to the tsunami inundation, the back-up generators were damaged, and they did not work. As a consequence, the fuel rods were not sufficiently cooled, and resulted in high pressures in the reactors. On March 12 and at 15:30 local time, a first hydrogen explosion took place, which was followed by two more explosions on the 14th and 15th of March, and a large fire event in a reactor that the empty fuel rods were stored.

Those events resulted in a large emission of radiation that reached 400 millisievert per hour, which is 1.5 million times more than the radiation that a human being is supposed to be exposed per hour. After the first explosion the area in a radius of 20 km from the nuclear plant was evacuated. After the second and third explosions an exclusion zone was established in a radius of 30 km around Fukushima Daiichi nuclear power station, and the Japanese authorities took immediate action to cool down the overheated reactors, and to protect contamination of the surrounded region.

2.1.4 Fires

Apart from the nuclear emergency, the earthquake and the tsunami caused many fire accidents. By the 18th of March 325 fire events were reported to the Japan Police Agency, with most severe being the one at the Cosmo Oil Company refinery in Ichihara.

2.2 Disruption in the aftermath

The events of March 11 caused significant disruption in vital social and economic functions in Japan. The most important immediate effects, as reported by the Disaster Prevention Research Institute of Kyoto University one week after the disaster, are summarized below (Kyoto University 2011).

2.2.1 Transportation

Following the earthquake and tsunami, extensive damage was caused to the national transportation systems. The Earthquake Quick Alarm System (EQAS) was successful to reduce the speed of Shinkansen bullet trains in Tohoku region immediately after the earthquake occurrence, and consequently no passenger was injured. In the Northeast of the country, as well as in Tokyo area, train services were suspended, hindering the transport of millions of commuters. Many people had to spend nights in their offices or hotels, while most bike shops sold out. Due to extensive damages, many parts of the national road network were blocked. Meanwhile Sendai airport and many major seaports in Tohoku had to suspend their operations, impacting the global supply of goods and international trade. Many manufacturers had to suspend their operation too, due to the lack of row materials. The problems in transportation caused by the tsunami also hindered the supply of aid to the victims in Tohoku area.

2.2.2 Power supply

The accident at Fukushima Daiichi nuclear power station induced severe problems in the power supply throughout the country. Its main operator, Tokyo Electric Power Co. Inc (TEPCO), which was responsible for power supply in Kanto region, including Tokyo metropolitan area, was unable to supply sufficient energy to Tokyo and the surrounding prefectures. One week after the event TEPCO's electricity supply capacity was roughly 30% below normal peak demand for that time of the year (Fesharaki & Hosoe 2011). In particular a supply shortage of 25% was reported in Kanto region the first week after the disaster (Kyoto University 2011), halting the operation of many industries, and causing significant economic losses. The company was only able to buy electricity from other utilities in limited amounts, since Japan's power grid operates on two different frequencies. Eastern Japan, including Tokyo and Tohoku, runs on 50-hertz power, while western Japan, including Kansai and Chubu, is on 60-hertz. When power is sent to Tokyo from the west, it has to pass through frequency conversion facilities, whose capacity was rather limited (Fesharaki & Hosoe 2011).

According to Tohoku Electric Power Corporation (Tohoku-EPCO) that is responsible for power supply in Tohoku region and its own power plant in Onagawa was not affected by the tsunami, as of March 20 more than 240,000 households in Tohoku region were left without electricity. Some measures to reduce power consumption were necessary. For the first time in Japan's history power rationing was implemented. It is remarkable that Miyagi prefecture allowed the burial of victims without cremation due to fuel scarcity.

2.2.3 Water supply

The earthquake caused damage to the fresh water supply system in 17 prefectures. More than 1,4 million households were left without fresh water the first week after the earthquake in an extensive area, including parts of Tokyo. The deployment of fresh water was one of the major priorities for the emergency teams as the risk of epidemics in shelters was quite high.

2.2.4 Solid waste

Reaching the Japanese coast, the tsunami induced significant inundation in large areas, and swept away a huge amount of objects such as trees, boats, buildings and cars, whose total mass has been estimated to 5 million tones (Government of Japan 2012). The volume of debris made the access and work of emergency teams very difficult. According to members of the Kyoto University group that visited the area immediately after the disaster, it was even hard to identify their location, as the landscape had been totally changed. It is remarkable that in many settlements there was very little evidence of human activity six months later, after most of the debris had been collected.

2.2.5 Social infrastructure

The most important effect on social infrastructure was the closing of schools due them suffering severe damage or their temporary use as shelters for the evacuees. According to first estimations, about 60% of the schools in Miyagi prefecture had to suspend their function the first week after the earthquake (Kyoto University 2011). In order to have education restored as fast as possible, the Government took some urgent measures to facilitate transfer of students to other schools. Many local governments offered to host students in families and accept them in their own schools.

2.3 Emergency response

Following the earthquake and tsunami, the Japanese Government established immediately an emergency response team headed by the Prime Minister, in order to organize all emergency actions, i.e. search and rescue operations and the establishment of shelters. The international community also responded quickly. As of October 2011 163 countries and 43 international organizations had sent aid to Japan (Government of Japan 2011).

2.3.1 Search and Rescue

The first order of the Government was the deployment of 100,000 Japanese troops, 190 aircrafts and 45 boats, in order to immediately start the search and rescue operations (Kyoto University 2011). Within one week more than 70,000 Japanese and 2,000 international search and rescue personnel were deployed in Tohoku, consisting mainly of soldiers, fire fighters, doctors and engineers (Ministry of Defence 2011). Some groups specially trained to work in radio-contaminated environment were also present, as well as groups for humanitarian and environmental assessment. Most effort focused on life saving, but there were also groups that worked on the re-establishment of essential community functions. In order to increase efficiency, many teams made use of rescue dogs, electronic gear and lifting and cutting machinery. The entire operation was seriously disturbed by continuous and strong aftershocks and tsunami warnings, while the weather conditions were not helpful, due to rain or snow, which caused delays in the access of aid workers. Nevertheless it was reported that within three days more than 20,000 victims were saved (Kyoto University 2011).

2.3.2 Shelters

The sheltering of evacuees has been a major issue in Japan. More than 360,000 people lost their houses and needed to be sheltered (Government of Japan 2011). Within one week about 4,200 shelters were established, while after two months their number was planned to exceed 30,000 (Government of Japan 2011). The Government conducted the delivery of food and other relief items with the assistance of municipalities and the private sector. After the first critical couple of weeks that electricity in some areas had been restored, and transportation networks started to be rehabilitated, the conditions of shelters were improved, as many evacuees were able to return to their houses and others left the shelters to move to houses of relatives or friends in unaffected areas. In the meantime the government requested private companies to provide 30,000 prefabricated houses to accommodate evacuees in the longer term.

2.4 Scientific response

Following the disaster, the Japanese scientific society took immediate action by organizing the 2011 Tohoku Earthquake Tsunami Joint Survey Group (Mori et al. 2012). The purpose of the group was to survey the tsunami inundation and run-up along the affected coast. This is the largest ever-assembled tsunami survey group consisting of academics, engineers and governmental officials. More than 300 members of the coastal engineering committee of Japan participated in the surveying effort, while there was support of local authorities and governmental agencies (Mori et al. 2012). Most of the collected data are accessible on the website of the Japanese Coastal Engineering Committee, while there are already some publications about the surveys in scientific journals, such as the special issue of Coastal Engineering Journal. An overview of the results of all surveys along the Japanese coast is shown in figure 2.4.

Inundation was induced all along the Eastern coast of Japan, while the highest inundation and run-up heights were encountered along the coast of Tohoku. In particular, the height of inundation exceeded 20m in about 200Km of coastline, while along 530 km the height of inundation was over 10m. The maximum-recorded run-up height is 40 m, which exceeds the historical highest run-up record of 38.2 m, during the Meiji tsunami of 1886 (Mori et al. 2012).

The remarkable efforts of the 2011 Tohoku Earthquake Tsunami Joint Survey Group to record the physical aspects of such a catastrophic event are of great importance for the derivation of lessons and the advance of science and risk management concerning natural disasters. The Japanese scientific response can be considered as a good example of practice not only for the Dutch, but also for all nations that face similar risks.

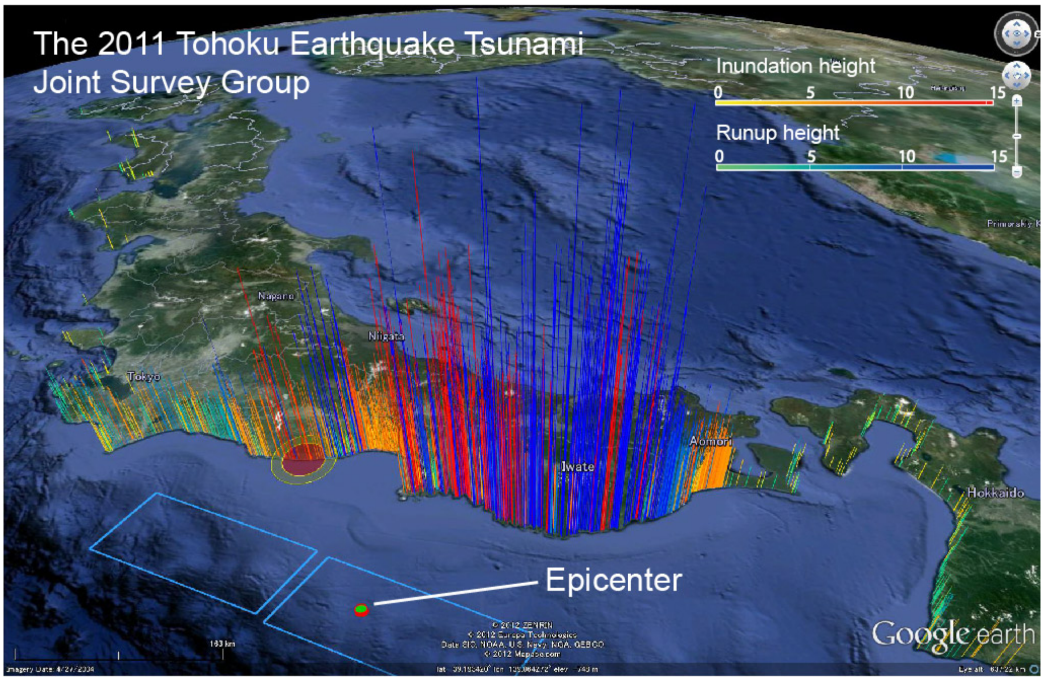

Figure 2.4: Overview of the tsunami survey results (Source: The 2011 Tohoku Earthquake Tsunami Joint Survey Group; www.coastal.jp/tsunami2011)

3 FIELD INVESTIGATION

3.1 Field trip in Tohoku

Teams of the Disaster Prevention Research Institute of Kyoto University have surveyed Tohoku area several times since April 2011. In September 2011 a small group of the same institute, including the lead author of this book, visited the devastated coastal areas of Tohoku, in order to assess and survey the recovery process six months after the tsunami, and following that some preliminary conclusions regarding the event had been drawn. The areas visited are presented in this chapter, aiming at providing some insight into the nature of the damage and casualties that took place, and ultimately into the magnitude of the disaster. The field trip was a three-day drive, starting on September 20, 2011. The team drove 300 km from North to South along the most severely affected part of the coastal zone of Tohoku, which encompasses the coastline of the South of Iwate and the entire Miyagi prefecture, and also along a small part of the northern coast of Fukushima prefecture. Further to the South access was prohibited, because of the exclusion zone due to the excessive radiation after the nuclear accident at Fukushima Daiichi nuclear power station. Both urban and rural areas were visited, as well as the commercial port of Soma in Fukushima prefecture (figure 3.1).

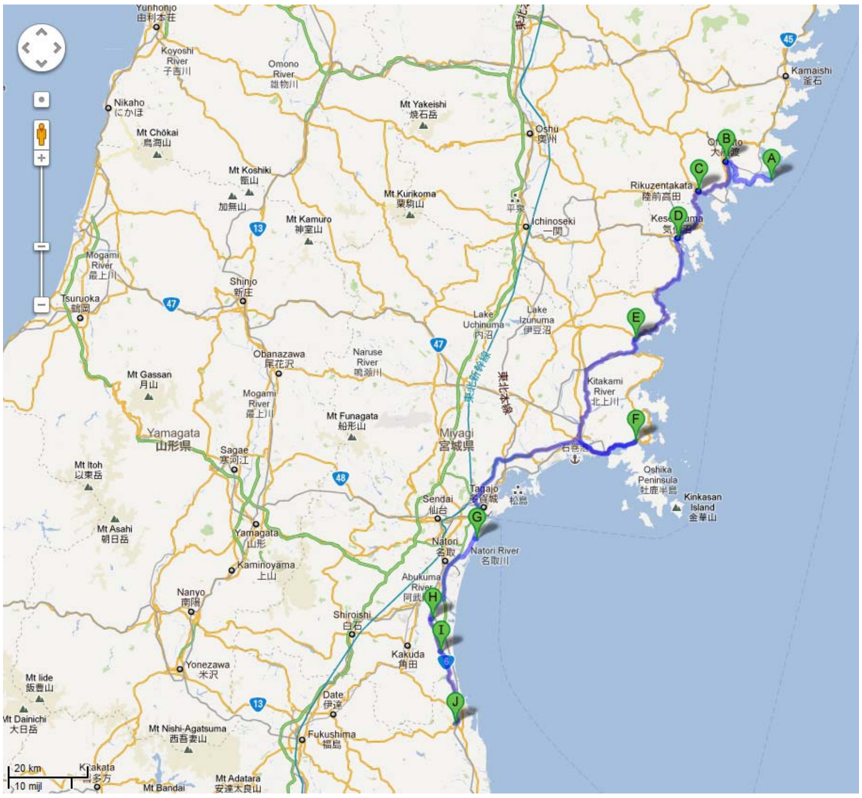

Figure 3.1: Field trip itinerary (Source: Google maps; www.maps.google.com)

The sites visited are listed below from North to South.
A. Ryori
B. Ofunato
C. Rikuzentakata
D. Kesennuma

E. Minamisanriku
F. Onagawa
G. Arahama Wakabayashi-Ward
H. Watari
I. Yamamoto
J. Soma.

Unfortunately the weather conditions did not allow for detailed observation of all visited areas, as the trip overlapped with the pass of Typhoon Roke over Tohoku, on the 21st of September. Yet the information provided below has been revised and enhanced after a second field investigation in June 2012, when a joint survey of Japanese and Dutch scientists was realized, including the lead author and four other contributors of this book.

3.2 Classification of Tohoku coastline

In order to comprehend the tsunami behaviour and disaster patterns in the coastal areas presented in this chapter, it is important first to consider what does the coastal morphology of Tohoku look like. Some significant morphological variations can be noted along the coastline of Tohoku that are responsible for variations in the local tsunami behaviour. The stricken coastal zone can be classified in two categories: 1) the rias coast in the northern half of Tohoku, and 2) the coastal plain in the southern half (figure 3.2). These two coastal types are described below in more detail.

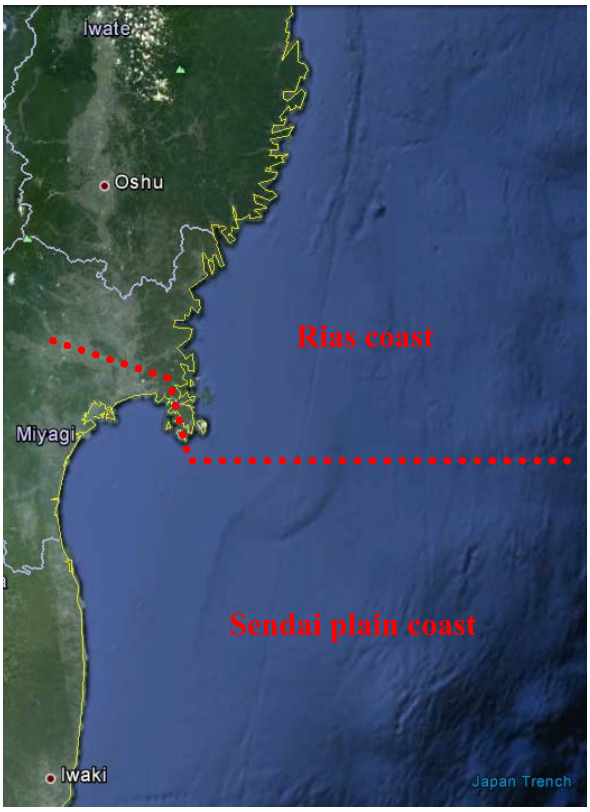

Figure 3.2: Coast types in Tohoku

3.2.1 Rias coast

The rias coast extends along Iwate prefecture and the northern half of Miyagi prefecture. Rias are fyord-like shaped coastal inlets formed by the submergence of former river valleys.

The rias coasts are therefore extremely irregular and indented in places, forming narrow and steep bays. At this type of coast, due to bathymetry focusing effects, the tsunami height increases. The narrow bays are surrounded by high grounds that face the ocean with steep cliffs, and relatively deep sea in the front. The basin created by the high grounds obstructs the intrusion of seawater far inland, which, combined with the increased tsunami height, resulted in large inundation and run-up heights (figure 3.3).

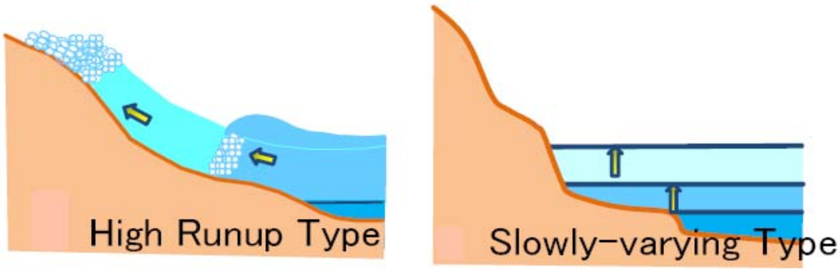

Figure 3.3: Typical cross sections of tsunami intrusion at rias coast (Source: Takahashi et al. 2011; Courtesy of Port and Airport Research Institute, all rights reserved)

Most urban and industrial areas in the rias are built in the basins that surround the narrow bays; hence the majority of coastal defences in this part are concentrated in the bays. The inundation pattern in Minamisanriku, a typical town in the rias, is shown below.

Figure 3.4: Inundation pattern in the rias. The white line is the boarder of the flooded area.

3.2.2 Coastal plain

Large low-lying areas fronted by mild-sloped sandy beaches characterize the southern half of Tohoku, starting from the coast of Sendai city in Miyagi prefecture, extending to Fukushima and further to the south. Unlike the case of the rias, in these flat plains the tsunami intrusion is not obstructed by high grounds. The tsunami broke near the shore and propagated inland, inundating large areas of flat land, while much lower inundation heights were recorded. At this type of coast long lines of land-based coastal dikes protected the inner land, where agricultural, urban and industrial areas were located.

The tsunami intrusion at this type of coast is shown in the following graph. Because of the sea dykes and dunes, fewer breakwaters can be found on the coast of these flat plain areas. Nevertheless, a number of ports are located throughout this coastline, and these were indeed protected by a variety of breakwater types. The inundation pattern in the frontage of Sendai city is shown in figure 3.6.

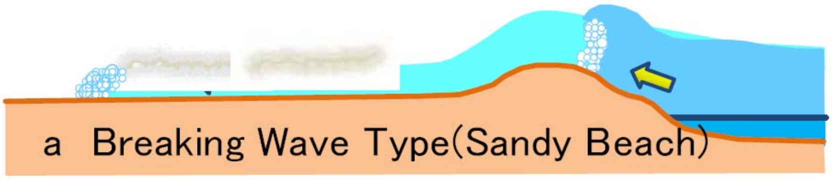

Figure 3.5: Typical cross section of tsunami intrusion at sandy beach flat land areas (Source: Takahashi et al. 2011; Courtesy of Port and Airport Research Institute)

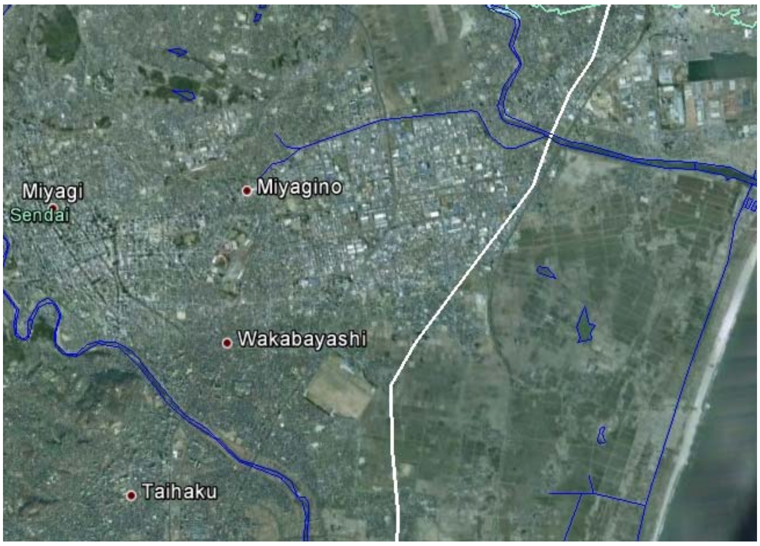

Figure 3.6: Inundation pattern in the coastal plain. The inundated part extends on the right side of the white line.

Fukushima Daiichi nuclear power station, where the major nuclear catastrophe took place due to the tsunami inundation, lies also in this part of the coast (figure 3.5). According to some information reported in the Wall Street Journal in July 2011 though, the original ground elevation at the site where the power station was placed was about 30 m, forming a natural sea defence. During the construction of the power station in 1967 the ground elevation was reduced to 10 m, so as to make it easier to pump seawater to the reactors. Apparently the expected tsunami inundation taken into account in the design of the station was much lower than the tsunami of March 2011.

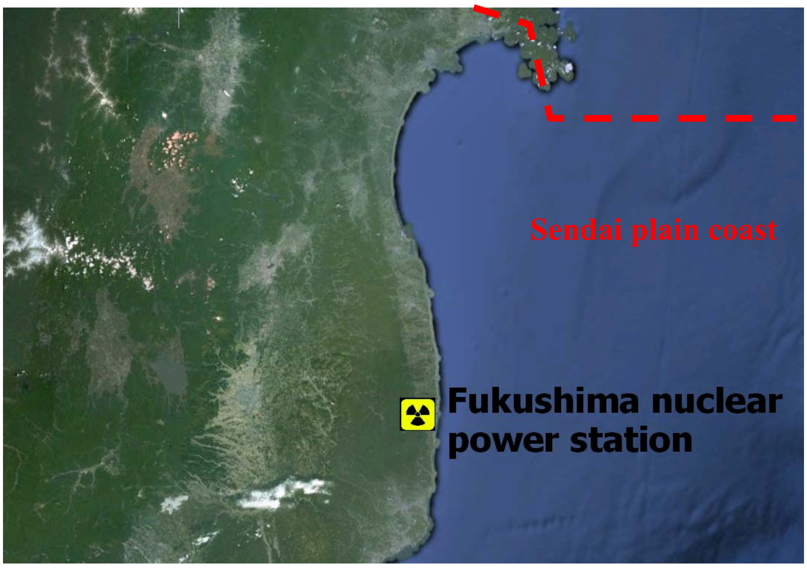

Figure 3.7: Position of Fukushima Daiichi nuclear power plant

3.3 Iwate prefecture

3.3.1 Ryori tsunami wall

Ryori is a village in a small bay in the rias, protected by a caisson breakwater. To the east of the town there is another small bay with a sandy beach and a harbour. At this small bay the rup-up height reached 40 m, which is the highest recorded run-up of this tsunami, but also the highest ever recorded tsunami run-up height in Japan (Mori et al. 2012). There was a tsunami protection wall in that small bay that was overtopped and seriously damaged, with a big section removed at its northern end.

Figure 3.8: Ryori bay after the tsunami. The severely damaged caisson breakwater (A) and the sandy beach with the tsunami wall (B) are designated (Google earth caption, 2011)

Figure 3.9: Zoom in the bay where the visited tsunami wall is located (region B). A large section of the tsunami protection dyke was broken at its north end, and severe damage of the caisson breakwater was also noted (Google Earth caption, 2011)

The tsunami gates that were originally attached on the wall were displaced towards the seaside. This shows that the cause of their failure was probably the run-down of the tsunami. As the land slope is quite steep in that area, a strong run-down must have been induced. On the backside of the wall there were large accumulations of debris and stones, which also provide evidence of a strong run-down. During the time of the survey work was been carried out to temporary strengthen the structure with placement of sandbags. The caisson breakwater located in the small harbour was also seriously damaged.

Figure 3.10: Temporary protection measures against storm surges.

3.3.1 Ofunato

Ofunato is a city located in the narrow bay of a ria in the Sanriku region, 8 km to the southwest of Ryori. The city has a low lying part, which was inundated, and a part lying on higher grounds, which was not affected. The maximum reported inundation height was 8.3 m. Most of the concrete buildings remained in place, but were seriously damaged. Windows and doors were missing from ground till the second or third floor, showing clear evidence of the tsunami depth. Wooden houses were completely destroyed. Port infrastructure seemed to have remained in place, although a uniform subsidence of more than 0.5 m was evident throughout the entire port area. By the time of the survey carried out by the lead author, most of the debris had been cleaned and accumulated in certain spots. The volumes of trash were impressively large, forming hills several meters in height.

The bay of Ofunato used to be protected by an offshore tsunami breakwater, which after the tsunami of March 11 had completely disappeared under the water. This breakwater was designed to withstand the attack of the Chilean tsunami of 1960, triggered by an earthquake of 9.5 magnitude on the Richter scale, that caused severe damages all around the Pacific Rim, including Sanriku region, where also a loss of over 100 lives was recorded. It is still not clear what was the mechanism that caused this catastrophic structural failure during the tsunami of March 2011.

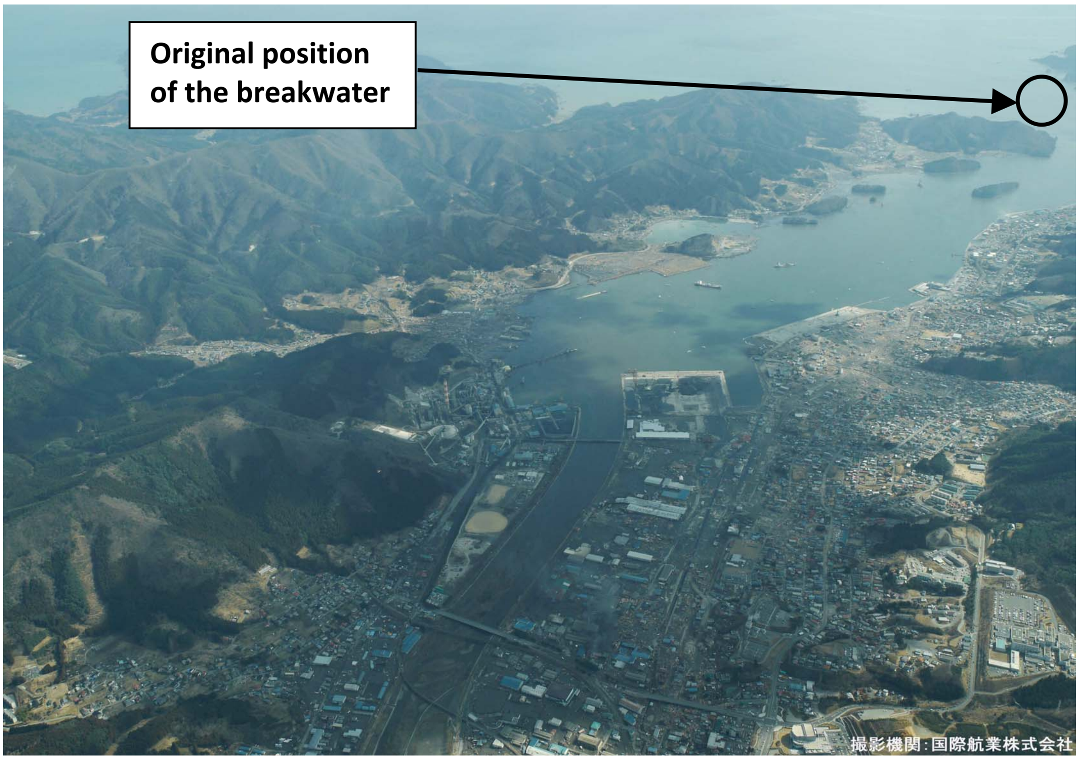

Figure 3.11: Ofunato bay on March 12, 2011. The position of the completely destroyed tsunami breakwater is designated on the upper right corner. (Source: www.kk-grp.jp; Courtesy of Kokusai Kogyo Holdings Co. Ltd, all rights reserved)

Apart from the breakwater, a concrete sea wall could be found along the southern waterfront, which also failed. More than 1 m deep scouring could be observed on the outer side of the wall, while many parts of it were overturned (figure 3.13).

Figure 3.12: Failed sea wall of Ofunato photographed in June 2012.

It should be noted that the damage in Ofunato bay was less than in other cities in the rias coastline, such as Rikuzentakata, which is located just 10 km to the southwest of Ofunato. The only difference is that Rikuzentakata was not protected by a tsunami breakwater, which could mean that the structure, although totally destroyed, contributed to the mitigation of damage in the bay. Some research on this topic could give interesting outcomes.

3.3.3 Rikuzentakata

Rikuzentakata was one of the most heavily damaged cities by the tsunami of March 11. It is located in a wide ria bay with a long natural sandy beach. On the top of the bay, in an area of about 1.5 km, the land slope is relatively mild. At this area, only concrete buildings of three floors or higher remained in place. In many of them, doors and windows of up to the fourth floor were missing, which shows that the water reached that height, and overtopped many of the buildings. The rest of the buildings were mainly wooden structures, which were washed away. As most of the debris has been cleaned and accumulated at certain spots, looking from above, the footprints of the foundations extending throughout several square kilometres could be seen, revealing the magnitude of the disaster.

On the waterfront, there used to be a coastal forest of more than 70,000 pine trees, which was devastated. At the time of the survey, only one tree had been left standing in that area. The removal of trees can be used as an indicator of the tsunami drag forces. All over that place there was evidence of subsidence, which reached 1 m near the waterfront. As the waterfront was so seriously damaged, the risk of further coastal erosion due to a storm or a typhoon increased. Hence some urgent measures were taken to prevent further erosion of the shoreline, with the use of sandbags or rock armouring. The inundation depth near the shoreline reached around 15 m. On the west side of the city there is a river reaching the coast, and the tsunami propagated along it several kilometres inland. Some of the river viaducts survived the tsunami, while others were seriously damaged and had their slabs removed.

Figure 3.13: Satellite image of Rikuzentakata before and after the tsunami (Source: www.kk-grp.jp; Courtesy of Kokusai Kogyo Holdings Co. Ltd, all rights reserved)

Figure 3.14: Concrete building that was overtopped

Figure 3.15: Empty space that used to be a railway reaching a station. Both the railway and the station were devastated.

3.4 Miyagi prefecture

3.4.1 Kesennuma

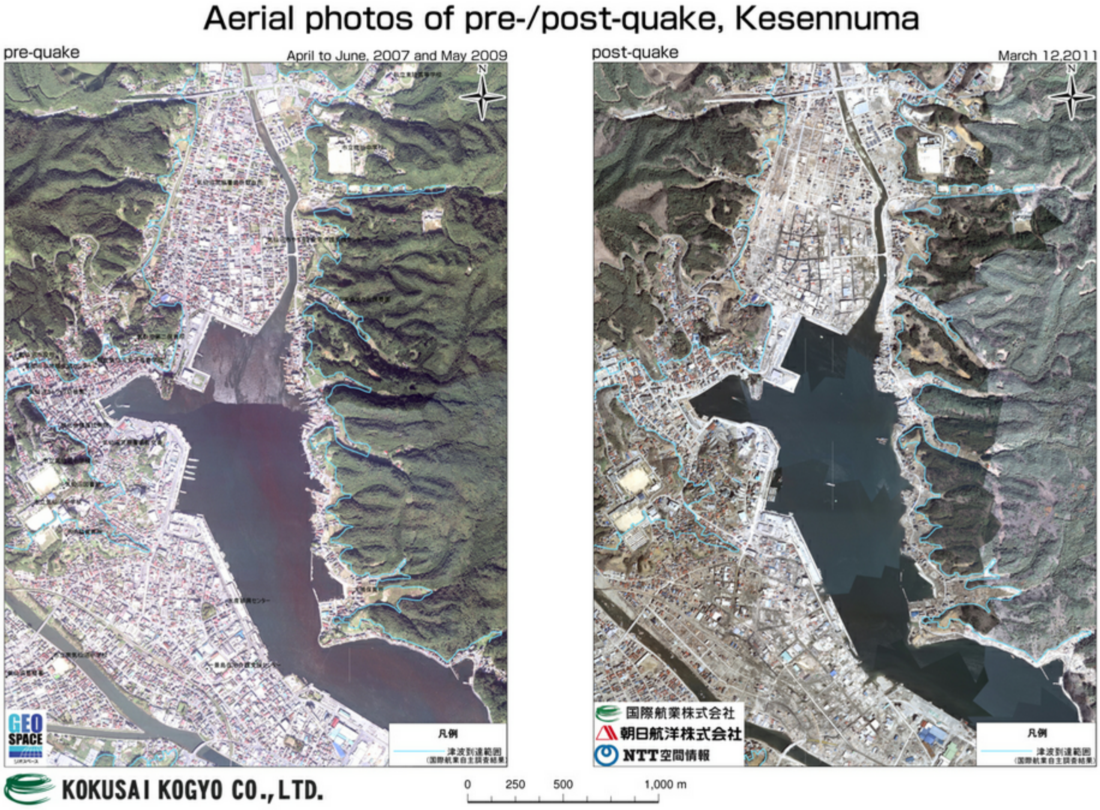

Figure 3.16: Kesennuma before and after the tsunami (Source: www.kk-grp.jp; Courtesy of Kokusai Kogyo Holdings Co. Ltd, all rights reserved)

Kesennuma lays 12 km to the south of Rikuzentakata, and was likewise severely damaged, with an inundation reaching 15 m in many spots on the frontage. Apart from the tsunami, Kesennuma also suffered some fire damages, as heavy oil was spilled and burnt during the tsunami attack. Important subsidence could be observed at the harbour, which moved the waterline inland, towards the first roads. Some parts of the quay walls were completely inundated, and temporary shore protection using sandbags was placed to prevent expansion of the erosion further inland. At the time of the survey, most of the rubble had already been cleaned up, yet much work was still needed.

Figure 3.17: Submerged quay wall

3.4.2 Minamisanriku

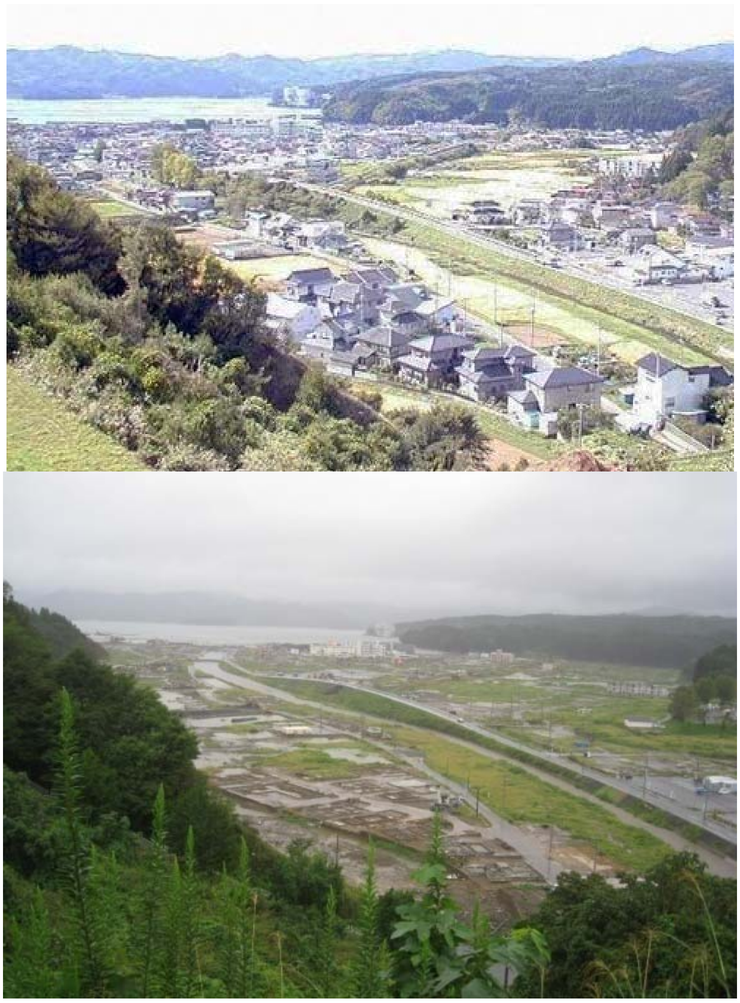

Figure 3.18: Minamisanriku before and after the tsunami (Source (top): Shizugawa Junior High School, rights unknown)

Minamisanriku is located in a quite narrow, fjord-like river valley. The town was devastated by the tsunami, with very little of it left. Like in Rikuzetakata, the tsunami ran-up along the river for a considerable distance. At this area the inundation line was clearly visible on the slopes of the mountains, where the inundated part of their forest was brown in colour, contrasting the green of the higher grounds. The inundation heights near the front of the town exceeded 15m, while the maximum run-up was in excess of 35 m.

Only a few high concrete buildings remained standing in the town, while the rest was washed away. Among the devastated buildings, it was also the Disaster Prevention Centre of Minamisanriku, which used to be the headquarters of emergency management of the town. Most of the people who were assisting evacuation by giving orders for evacuation to the citizens perished when the building was completely inundated. Only seven people survived, including the mayor of the town, by climbing on the antenna of building.

On the waterfront of Minamisanriku serious subsidence and erosion could be seen, as well as damage to coastal roads. The transportation in the area had not fully recovered at the time of the survey. The storm surge gates at the mouth of the river were also severely damaged, as well as parts of the river dikes. Some temporary protection measures have been attempted in the form of sandbags. On the northwest side of the town some temporary houses had been constructed in the sides of the hills, were the local population was being sheltered following the destruction of their houses.

Figure 3.19: Severely damaged storm-surge gates (Source: The 2011 Tohoku Earthquake Tsunami Joint Survey Group; www.coastal.jp/tsunami2011)

3.4.3 Onagawa

Onagawa is located further to the south of Miyagi prefecture, yet still in the rias coast, almost at the south end of it. This town received much media attention due to extensive damage that took place. The bay of Onagawa was protected only against storm waves by a caisson breakwater, which had not been designed to withstand tsunami waves, and which was completely destroyed.

Figure 3.20: View of Onagawa after the tsunami. The position of the failed breakwater is remarked. (Google Earth caption, 2011)

In the low-lying part of the city all wooden buildings were devastated, while it was interesting to see that many concrete buildings were overturned. The cause of this special type of failure must have been the fact that those buildings had pile foundations that due to the earthquake had failed in shear and were thus detached from the bottom of the building, and as a consequence the uplifting tsunami forces overturned the entire building. Liquefaction might have also played a role to this failure. Furthermore, some significant subsidence at the waterfront was evident, like in most areas in the rias. The inundation height near the shore was around 15 m.

Figure 3.21: Devastated waterfront of Onagawa

3.4.4 Arahama Wakabayashi-Ward of Sendai city

Figure 3.22: Arahama after the tsunami. The breakage on the sea dike is remarked with red, and the devastated forest zone is remarked with orange (Google earth caption, 2011)

Arahama is a settlement at the waterfront of Sendai city. The landscape is totally different than that a few kilometres to the north in the rias coastline. From this place and further to the south lies the flat plain coastal area. The coastline of Arahama is straight with a long sandy beach, with the inner land protected against storm surges by a dike.

Figure 3.23: Sandy beach and sea dike at Arahama Wakabayashi-Ward

The dike was overtopped by the tsunami of March 11 and propagated over to the flat land, inundating many square km of rice paddies, and devastating a coastal pine tree forest and the settlement of Arahama. The sea dike broke to the northeast of the settlement. The inundation depths in Arahama were relatively lower than the ones recorded in the coastal cities in the rias. The watermarks and damage to concrete buildings that survived the tsunami were up to the second floor. It is notable that some concrete buildings behind the dike that were founded on sandy subsoil did remain in place, yet significant scouring on their toe was observed, which exceeded 2.5 m in places. Scouring due to overtopping tsunami waves is considered to be the main cause of failure of the sea dikes in that area.

Figure 3.24: Scouring on the toe of concrete building (Source: The 2011 Tohoku Earthquake Tsunami Joint Survey Group; www.coastal.jp/tsunami2011)

The airport of Sendai is located a few kilometres to the south of Arahama, where also serious damage was recorded. Apart from the damage caused directly by the tsunami, this area suffered also the effects of the intrusion of salt water far inland, which is expected to affect agriculture in the coming two to three years.

3.4.5 Yamamoto elementary school

Yamamoto is a coastal town at the southern boarder of Miyagi prefecture, which was likewise heavily damaged by the tsunami. The team visited a still standing elementary school outside the town, and about 500 m from the waterfront. Apart from the school building, there was also a gymnasium that was partly sheltered by the school. The school building was well aligned to minimize tsunami forces, although it is not known if this was a design requirement or a random choice. The interior of the building was completely inundated, though the school was featured in the media for the successful vertical evacuation of all students on March 11, 2011. The recorded inundation height in that area was about 6m. From the first floor of the building the sea dike at the waterfront could be seen. The structure breached in several points and large armour units scattered on its inland side could be seen.

Figure 3.25: Designation of inundation height on the school building photographed in June 2012.

3.4.6 Watari coastal dike

The survey team visited a few more parts of the coastal dikes on the Sendai plain, such as those located in the waterfront of Watari, which is a town of 35,000 citizens. Many sections of the dike were destroyed in that area, mainly due to significant erosion in the inner slope and toe. The core of the structure consisted of sand and gravel and was protected by non-reinforced concrete on the seaside slope, and armour units at places. According to researchers of Waseda University that surveyed areas in the coastal plain region, the scouring on the toe of the dikes and eventually also their total damage was more severe in areas that there was no geotextile protection between the core of the dike and the encasing concrete layer. The absence of geotextile seems to have worsened the damage of those structures.

Figure 3.26: Breakage of coastal dike, where the original cross section is displaced several meters inland and its core is exposed due to the lack of a geotextile.

As the dike is meant to protect the land against high storm surges, which are quite common in the area, many temporary reconstruction works were taking place six months after the tsunami, which had an estimated lifetime of 5 to 6 years.

Figure 3.27: Plan for temporary retaining works, indicated in orange. The original cross section is indicated in grey.

The day of the visit was right after typhoon Roke hit the same coast on the 21st of September, inducing a high storm surge that overloaded the already damaged dike. The typhoon and caused some additional damage on the crest of the temporary structure, which was being urgently repaired the day of the visit. This clearly showed the necessity of temporary interventions in order to keep the inner land protected.

Figure 3.28: Crest of coastal dike one day after the pass of typhoon Roke, 22 September 2011 (Source: Disaster Prevention Research Institute, Kyoto University; Courtesy of Tomohiro Yasuda, all rights reserved)

3.5 Fukushima prefecture

3.5.1 Port of Soma

Figure 3.29: Port of Soma after the tsunami. The most severely damaged parts are indicated (Google Earth caption, 2011)

The port of Soma is an important commercial port on the coast of Fukushima, 32 km to the south of Sendai airport. As it is located on the straight coastline and not sheltered by natural barriers, it is protected against storm waves by a 2.6 km long offshore caisson breakwater, which was severely damaged by the tsunami of March 11. Only 3 out of the 546 caissons of the breakwater remained in place. The rest were displaced, and some could no longer been seen.

Figure 3.30: Damage of the caisson breakwater (Source: DPRI Kyoto University; Courtesy of Yusuke Tanaka)

The rest of port infrastructures were likewise severely damaged. Some significant subsidence of the quay walls, exceeding 1 metre in places, was evident, and scouring at their foundation had taken place. It was notable that some concrete elements of the quay wall, with approximate dimensions 6x10x3 m^3 were overturned and were left standing with their foundation upwards, which shows the enormous uplifting forces caused by the tsunami and that were intensified by the scouring. Furthermore some severe damage of warehouses and cranes could be observed. Inundation heights of up to 10 m were recorded in the port of Soma.

Figure 3.31: Damage of quay wall. After the tsunami sandbags were placed to protect further erosion, which were removed during a typhoon attack a few hours before photographed.

3.5.2 Soma

To the South of Soma port the city of Soma can be found, with a population of 38,000 inhabitants. Most of the city was located on higher grounds, and therefore it was not seriously affected by the tsunami. However an estuary with flat agricultural land in fronts it subsided and was inundated by the tsunami. The bad weather conditions during the visit, together with the high water levels that had intruded the subsided land, did not allow access to many parts of this area. This was in fact the case in more areas in the coastal plain, which shows how vulnerable this land is after the tsunami.

Figure 3.32: Inundated agricultural land on the waterfront of Soma

4 RESPONSE OF A MULTI-LAYER SAFETY SYSTEM

4.1 Introduction

The tsunami of March 11 2011, whose return period has been suggested to be 1000-1200 years (Fujita 2011), exceeded all pre-disaster assumptions used in the Japanese disaster management (CDMC 2011). Being designed to resist much smaller tsunamis, the primary defences, such as breakwaters, tsunami walls and coastal dikes were overtopped and suffered severe damage. As an overload of primary defences is not uncommon in tsunami-prone areas, a variety of measures for the mitigation of damage and casualties, such as placement of important community functions in higher grounds and emergency plans were combined with primary defences in Tohoku. This compound of measures that focus on both the reduction of risk probability and mitigation of damage in case that a disaster occurs, signifies a so-called multi-layer safety system.

Multi-layer safety is a concept in flood risk management that introduces the integration of flood risk probability-reducing measures and loss-mitigating measures in a flood protection system. Essentially the role of the former is to prevent inundation, while the latter are meant to function only in case that an extreme event exceeds the expectations of the prevention lines, and inundation occurs. This concept can be found in international literature with many different names, such as multi-level approach or multiple lines of defence. The term multi-layer safety has been mainly used in the Dutch flood risk management, and it also appears in the National Water Plan of the Netherlands as a national policy choice for safety against flooding. A graphical representation of multi-layer safety is shown in the figure below.

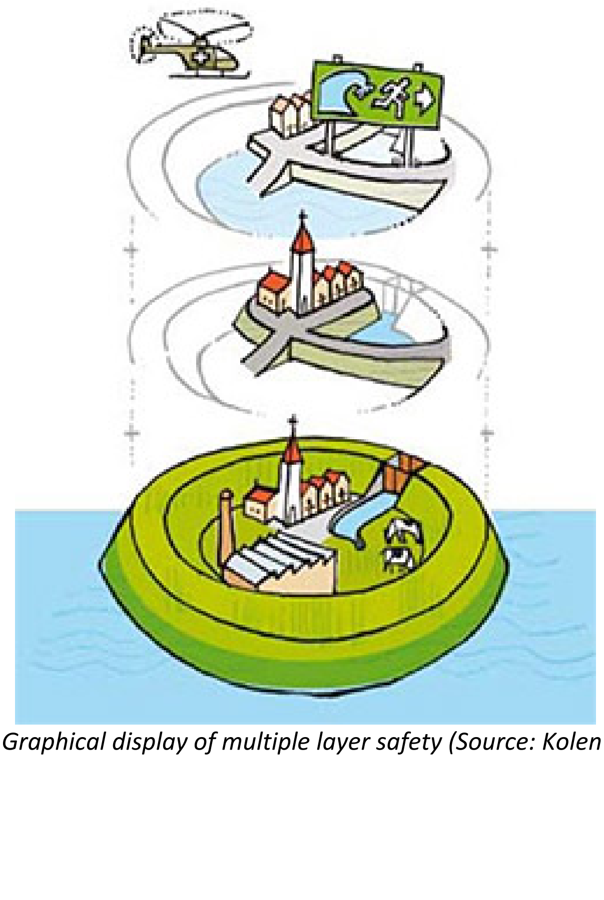

Figure 4.1: Graphical display of multiple layer safety (Source: Kolen et al. 2010)

The theoretical basis of multi-layer safety is the classification of measures into safety layers as follows (National Water Plan 2009):

- *Layer 1: Prevention*. Prevention is defined as preventing river and seawater from inundating areas that are usually dry, based on the definition of a flood given in the EU flood directive. This is done by building flood defences or preventing high river discharges.
- *Layer 2: Spatial Solutions*. Spatial solutions mean using spatial planning and adaptation of buildings to decrease the loss if a flood occurs.
- *Layer 3: Crisis Management*. This layer focuses on the organizational preparation for floods such as disaster plans, risk maps, early-warning systems, evacuation, temporary physical measures such as sandbags, and medical help.

This chapter presents a qualitative interpretation to the response of the multiple layers of safety in Tohoku during the tsunami attack, based on field observations and information provided by Japanese scientific institutes. The assessment presented is preliminary. Due to the variations of measures and safety levels along the coastline, a detailed assessment of multi-layered safety would require the performance of thorough site-specific analyses.

4.2 Tsunami countermeasures in Tohoku

A combination of structural and non-structural measures, representative of all the three layers of multi-layer safety can be found in Tohoku region. Their role is to prevent inundation or to mitigate its impact if prevention fails. Most structural measures belong to layers 1 and 2 of multi-layer safety. The types of structures and the degree of safety they provide are not uniform along the entire coastline, but they vary depending on the coastal morphology and the social and economic value of the protected land. Layer 3 consists mainly of non-structural measures, and also presents variations along the different types of coastal areas depending basically on the existence or not of higher grounds.

An overview of the tsunami countermeasures in the rias and in the coastal plain region is shown in the figures below. They are further described in the following paragraphs.

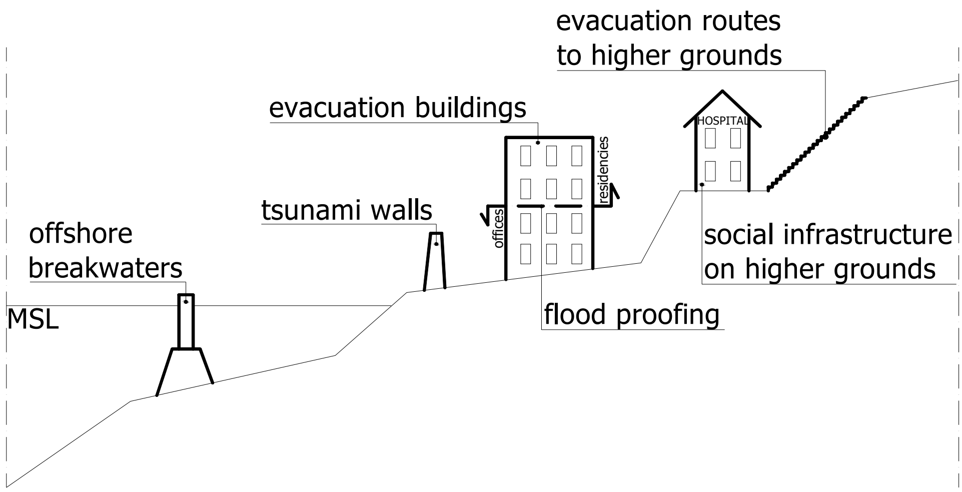

Figure 4.2: Tsunami countermeasures in the rias(MSL=mean sea level)

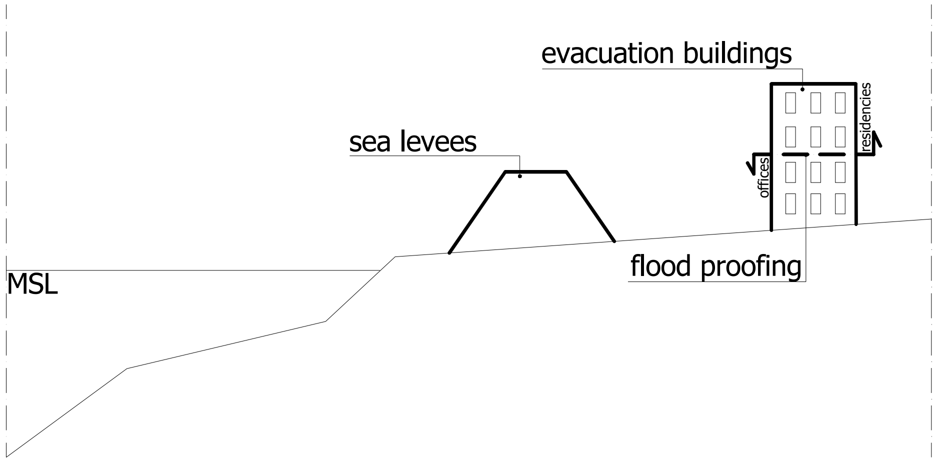

Figure 4.3: Flood risk countermeasures in flat plain region (MSL=mean sea level)

4.3 Layer 1: Prevention

The measures of layer 1 encountered in Tohoku were structures of different types along the rias of Sanriku region and along the flat plain coasts of Sendai region. The primary defences along the rias consisted mainly of offshore breakwaters and tsunami walls, while along the flat plains coastal dikes on the sandy frontage were the most common defence (figure 4.4)

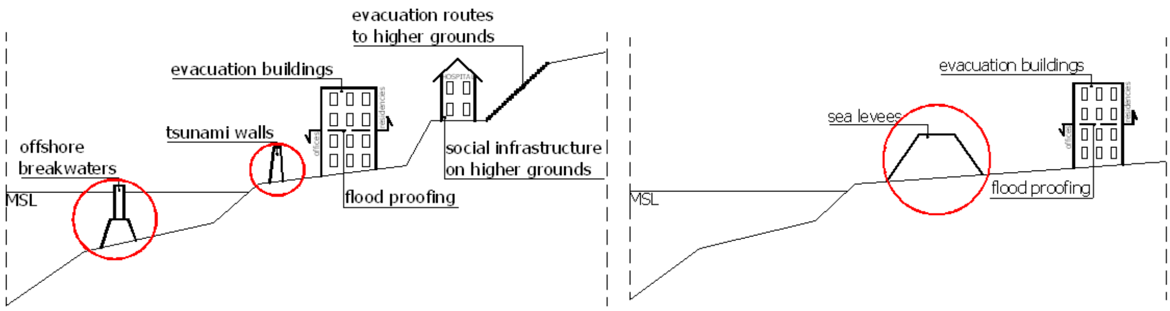

Figure 4.4: Layer 1 measures in the rias (left) and in the coastal plain (right)

These structures suffered severe damages with some of them failing catastrophically (ref. Chapter 3). Based on this fact, it becomes clear that their design specifications were exceeded by the tsunami of March 11, 2011. It is also notable that although all of them were located on a tsunami-prone coast, there was no consistency in their design specifications. Some of them were designed to withstand tsunamis, such as the offshore breakwater of Ofunato in the rias, while others were designed against storm waves, such as the breakwater of Onagawa in the rias and most of the coastal dikes in Sendai area. These variations could be justified by a general tendency in the Japanese flood risk management to design new defences based on previous experience with extreme events. In particular, the crest height of coastal defences in Japan is normally determined by the most severe condition between 1) previously experienced tsunamis, and 2) a 50-year-return wave on a storm surge. The difference between the time when each of the structures was constructed and the available amount of knowledge at the time in terms of recorded extreme storms and tsunamis can explain the inconsistency in design specifications. Some structures were much younger than others and probably designed to resist higher loads.

A remarkable case of tsunami protection that proved to be a “saviour” during the tsunami attack is the sea wall of Fudai, a village of 3088 inhabitants in Iwate prefecture (figure 4.5). This is a gigantic 15 m-high structure that did prevent inundation of the village. Nevertheless its construction lasted eleven years and the total investment cost was about 30 million US dollars, which seems to have been disproportionate to the size of the village. This is a unique case of coastal defence in Japan, and it is doubtful whether more of this type of structures will be built after the devastation of March 2011.

Figure 4.5: Tsunami wall in Fudai (Source: Tokyo University of Marine Science and Technology; courtesy of Akio Okayasu; all rights reserved)

It should be noted that although most of the coastal defences failed, they have played a role in the reduction of inundation heights in the protected land (Mori et al. 2011 & Takahashi et al. 2011). Takahashi et al. (2011) confirmed in their numerical simulations that the breakwater of Kamaishi was damaged but played a role to delay the time of the tsunami overtopping the sea walls and reduce the run-up height. Some further research on this topic might provide some useful insights. It is also interesting to note in this respect that the recorded inundation heights in Ofunato, protected by a tsunami breakwater, were much lower than other cities with similar morphologies and no tsunami breakwater.

4.4 Layer 2: Spatial solutions

Due to the fact that the tsunami exceeded the design specifications of prevention measures, urban areas were exposed to inundation. Hence layer 2 had to play a crucial role in the mitigation of losses. As spatial solutions are applied in a smaller geographical scale than measures of layer 1, a thorough assessment of the response of layer 2 measures to the tsunami in Tohoku would require a more detailed observation of the affected urban areas with separate visits and detailed data for every town and settlement. The following assessment is based on general characteristics of the urban areas in Tohoku that could be distinguished during the field observations, and on information provided in the post-event reports of Japanese institutions.

The spatial arrangements that seem to be part of layer 2 measures are the placement of important social infrastructure buildings to higher grounds, and the flood proofing of high buildings by accommodating the most important functions in higher floors (figure 4.6).

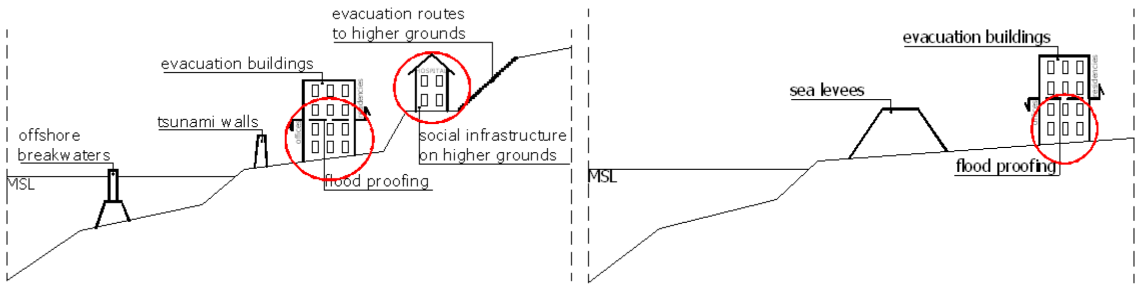

Figure 4.6: Layer 2 measures in the rias (left) and in the coastal plain (right)

Among the functions that need not to be completely destroyed during a tsunami are schools, as children are considered much more vulnerable than the rest of the population. A case of compartmentization was also noticed in the area of Sendai, where the existence of a highway, about 3 km behind the coastal dike, seemed to have limited inundation of Sendai plain.

Concerning the allocation of community functions to higher grounds, it should be noted that not all essential functions stayed unaffected. There were schools and hospitals located on grounds that were high enough to remain either completely or relatively less affected than the majority of buildings. Such is the case of the junior high school of Shizugawa on the northwest of Minamisanriku, situated 47 m above sea level. Another case is that of the hospital of Onagawa, on a ground elevation of 15 m, where only the ground floor was inundated. The location of those buildings may have been decided taking into account the risk of a tsunami.

Figure 4.7: Hospital of Onagawa

On the other hand, there were important administration buildings that were severely damaged and could not be used anymore, such as the city hall of Rikuzentakata and the Disaster Prevention Centre of Minamisanriku. The city hall of Rikuzentakata was located 7 m above sea level, which means that the building would have been exposed even if a much smaller tsunami had taken place. The Disaster Prevention Centre of Minamisanriku was placed very close to the waterfront, and it was devastated (figure 4.8). It is therefore not clear if the use of spatial planning for the enhancement of flood protection was part of a firm strategy.

Figure 4.8: Location of the Disaster Prevention Centre of Minamisanriku

As for the flood proofing of buildings, some occasional measures could be found, such as the case of an eight-floor building in Kamaishi city, where residencies were concentrated in the higher floors, while the lower floors were only used as offices (SA, OIC & KU 2011).

Another measure that could be classified as layer 2 is the construction of tsunami-resistant buildings. Although the design of tsunami-resistant buildings is not mandatory, there were a few buildings designed against tsunami loads, such as the evacuation building on the waterfront of Minamisanriku, which survived the March 2011 event. Nevertheless not only tsunami-resistant, but also many conventional concrete buildings withstood the tsunami forces, which could be possible due to their anti-seismic design. This is mainly the case for buildings constructed after 1981, when the building codes of Japan were renewed. Although a different type of loading is taken into account for earthquake proofing of buildings, it is possible that designing for a very strong earthquake makes the building resistant to the strong hydrodynamic tsunami forces, although buoyancy effects of hydrostatic pressure on buildings are not well considered for the most of existing anti-seismic designed buildings. Yet the majority of buildings in urban areas were made of wood and were swept away by the waves. Furthermore most concrete buildings were not higher than 4 floors, and therefore were completely inundated in the areas that inundation reached 15 m, with all their interiors being completely destroyed. This fact implies the need for a careful consideration of risk in the choice of evacuation building, which is addressed in the following section.

A general remark about layer 2 measures in Tohoku is that although they were distinct in urban areas, it is unknown in which extent they were a deliberate choice for the purpose of reducing flood risk.

4.5 Layer 3: Emergency management

As many devastating tsunamis have been recorded in the history of Tohoku, the local communities were considered to be well prepared for the case of a catastrophic event, with early-warning and evacuation schemes playing a central role in the prevention of casualties, which is the greatest concern for all communities. Apart from that, the authorities responded reasonably fast after the event organising search operations to recover the bodies of the victims, the establishment of massive rescue missions and the construction of shelters.

The early warning system worked effectively, as the tsunami alarm was issued only three minutes after the earthquake (SA, OIC & KU 2011). The expected tsunami height though, as first issued by the Japan Meteorological Agency, was exceeded. Although the wave height prediction was corrected within 30 min, many people trusting the height of the coastal defences that was higher than the predicted tsunami did not evacuate after the first announcement, which may have had a negative effect in the number of victims. It should be remarked that despite the effectiveness of early warning system, some people had less than 30 minutes available to evacuate, which is an extremely short time, comparing to the time available for evacuation during other extreme coastal events. The inhabitants of New Orleans had 48 hours available after a mandatory evacuation was issued for the landfall of hurricane Katrina (Wolshon 2006), while the same time is also the expected early warning time in the Netherlands (Kolen et al. 2012).

Due to the frequent tsunami attacks in Sanriku region, the local society was well prepared and willing to evacuate. Moreover the so-called “tendenco” local culture of mutual trust may have prevented many casualties. The literal meaning of it is that people trust that their families will also be properly sheltered, and as a consequence, during a tsunami alarm, they shelter themselves immediately without looking for their family members first, which could take some precious time (SA, OIC & KU 2011). This is not expected to be the case in the Netherlands and New Orleans, or even in other coastal areas in Japan.

Concerning evacuation, slightly different schemes were followed in the rias and in the plain region. In the rias, due to the existence of high mountains adjacent to the coast, evacuation to higher grounds was the main strategy, while there were also some evacuation buildings. In the plain region evacuation buildings could be found in urban areas, while evacuation to higher grounds was in most of the cases only possible by car.

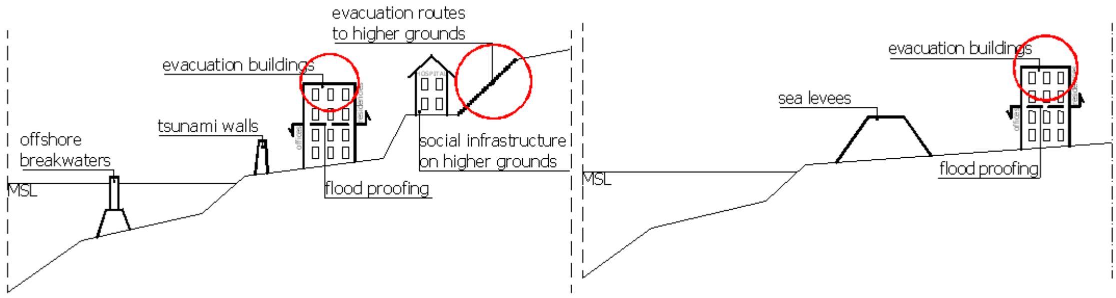

Figure 4.9: Evacuation measures in the rias (left) and in the plain region (right)

In the rias, due to the extreme inundation heights, that reached 20 m in some locations, the local evacuation plans were overwhelmed and many evacuation buildings were overtopped, exposing evacuees to further risk. A special case is an overtopped four-storey evacuation building on the waterfront of Minamisanriku, where luckily all evacuees survived, as the building was only just overtopped, according to information gathered during interviews of evacuees by the survey team of Waseda University (figure 4.10). It is notable that in that area the land subsided significantly due to the earthquake, which might have been crucial for the failure of the building as an evacuation centre. These sort events should be taken into account for the improvement of both evacuation schemes and the design regulations of evacuation buildings.

Figure 4.10: Evacuation building on the frontage that was just overtopped, people sheltered on the top of it survived (Source: The 2011 Tohoku Earthquake Tsunami Joint Survey Group; www.coastal.jp/tsunami2011)

In the low-lying areas of the Southern half of Tohoku, people could mostly evacuate to the top of high buildings, as higher grounds could not be reached in due time. Although inundation heights were lower in low-lying areas, and therefore the height of evacuation buildings sufficed for the protection of evacuees, in many areas it has been recorded that people did not succeed to evacuate in time, and the tsunami reached them on the way, as there were only a few evacuation centres covering too large areas. According to anecdotal information many people perished while stuck in a traffic jam. This implies that despite the formal instructions of most municipalities not to use a car for evacuation, many people believed that using their car would take them to a safe place faster.

Despite the degree of preparedness for evacuation among population, the death toll seems to be higher in the areas where inundation heights were very high. According to casualties' records available in November 2011, the fatalities over the total population in the plain region were 7 times higher than fatalities over total population in the rias. It should be noted though that the total population is larger than the exposed population, and an accurate conclusion about the number of fatalities, requires the computation of accurate mortality rates, which is the number of fatalities over the number of the exposed population.

The following graph, which is based on the same records, shows that fatalities in the rias outnumber fatalities in the plain region, while the rate of injuries over fatalities is lower.

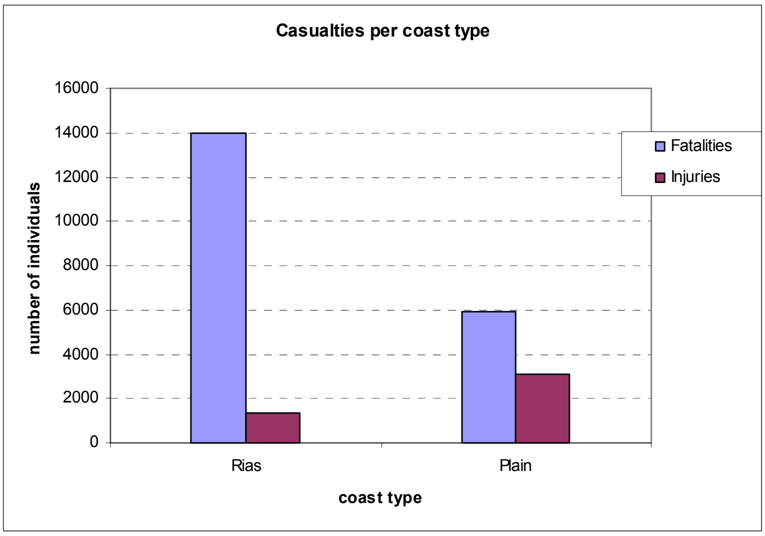

Figure 4.11: Recorded casualties in the rias and in the plain region (Data Source: Kyoto University, November 2011)

The inundation of evacuation centres can be one of the reasons for the much higher fatalities recorded in the rias. The higher rate of injuries over fatalities in the plain implies that most people exposed to the tsunami flow in the rias died, while in the plain many of them survived.

It is important to note that the efficiency of evacuation cannot be substantially assessed based on the overall statistics of Tohoku. Site-specific analyses of facts are necessary. Although one could claim that evacuation was relatively effective, considering the total number of casualties compared to the magnitude of inundation, not all inundated land was urban or needed to be evacuated, while the number of casualties varies along the affected coast. Site-specific analyses of facts concerning evacuation would also contribute in the identification of needs in local, regional and national level, and therefore in the formulation of effective strategies for the future. Some first site-specific studies have already been carried out, a summary of which is presented in chapter 5.

4.6 Overall discussion

Due to the frequent tsunami attacks in Tohoku, the idea of combining probability reducing with loss mitigating measures against tsunami had been implemented even before the event of March 11, 2011. Measures of all three layers were present in Tohoku, yet layers 1 and 3 were much more developed than layer 2. However the uncertainty inherent in the functionality of layer 3 during an emergency is much higher and difficult to define in tsunami-prone areas than that of layer 2, where the time available for evacuation is very short. The functionality of layer 3 depends greatly on human behaviour during the emergency, which can vary significantly between different moments of the day. In this respect, layer 2 solutions can be much more reliable in tsunami-prone areas for mitigation of losses. Some further research on this topic could give useful insights (Tsimopoulou et al. 2012).

Due to the catastrophic impact of the tsunami in large parts of the coastal urban areas, a good opportunity has been created for Japan to consider and develop layer 2 measures, which can make a significant contribution to the increase of safety against tsunami. Such measures could be the relocation of residencies and social infrastructure buildings to higher grounds or on mounds in the plain region, and the flood proofing of buildings in low-lying areas by locating the most important functions in higher floors that are less likely to be inundated.

The event of March 2011 overwhelmed the multi-layer safety system of Tohoku, causing severe damage and fatalities. It is not clear though whether we can talk about a failure of the multi-layer safety system. The Great Eastern Japan Earthquake and Tsunami is considered an extreme event, and one could claim that for such an event the protection of Tohoku performed reasonably well. However, looking at the system from a risk perspective, it is clear that an essential property for multi-layer safety systems was not ensured, which could be responsible for a failure in the system even if a less extreme event occurred; the synergy of the three safety layers with respect to safety. Synergy is ensured when the system remains functional even when some part of it fails. If for example layer 1 fails and a protected area is inundated, the probability that also layers 2 and 3 will not function as expected remains low.

In order to have this condition fulfilled, a common reference point for the evaluation and comparison of different measures and safety layers is necessary, which can only be the degree of safety that each measure adds to the system. This requires a risk-based approach to flood protection to be pursued (Tsimopoulou et al. 2012). In this case the target reliability of every measure under consideration should be the outcome of a cost optimization that takes into account risk in an explicit way. In particular the risk reduction offered in the system by the new measure is considered as economic benefit in this type of optimization, and the total cost function is presented in figure 4.12. As optimal investment the one that minimizes the cost function is considered.

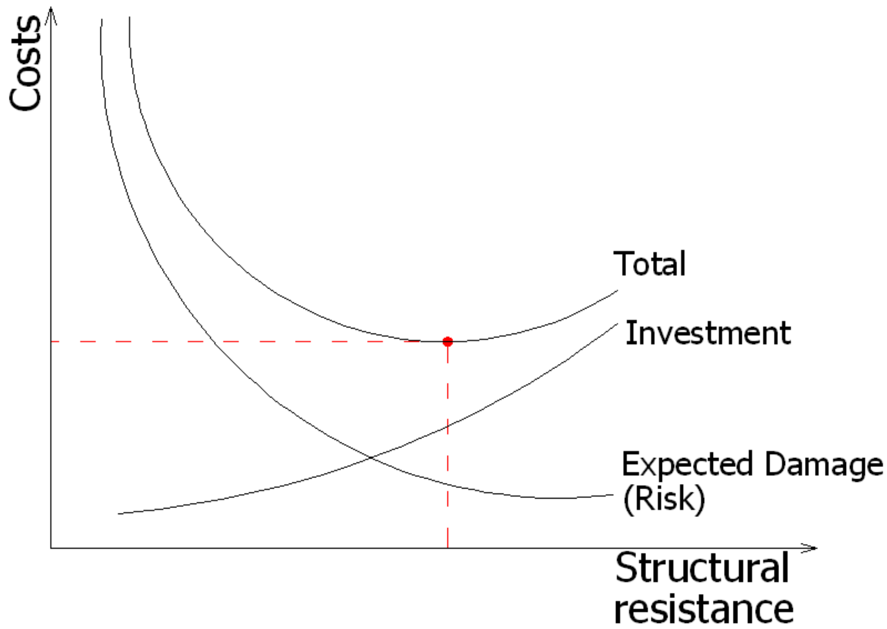

Figure 4.12: Total cost function for cost optimization of flood defences

5 REHABILITATION

5.1 Damage and casualties in numbers

The area afflicted by the disaster of March 11 2011 exceeded 560 km^2 of coastal zone, devastating among others urban areas, industry, agriculture and communication infrastructure, such as the high-speed Shinkansen railway lines. The total impact of the disaster, including economic losses in the private sector, social and cultural damage has not been accurately defined. Considering the fact that the long-term nuclear disaster effects cannot be easily foreseen and determined, it may take long until the full impact of this event is understood. In any case, this disaster was by far the costliest in 2011, with total economic loss estimates reaching 210 billion US dollars, with 36 billion in insurance losses, while the number of fatalities was more than 19,000 (The Economist, 2012). Based on estimates of the Japanese Government, the impact of the disaster on the national economy is in the same order of magnitude as the bankruptcy of Lehman Brothers in 2008.

The distribution of losses in stocks as estimated in February 2012 is shown in the figure below.

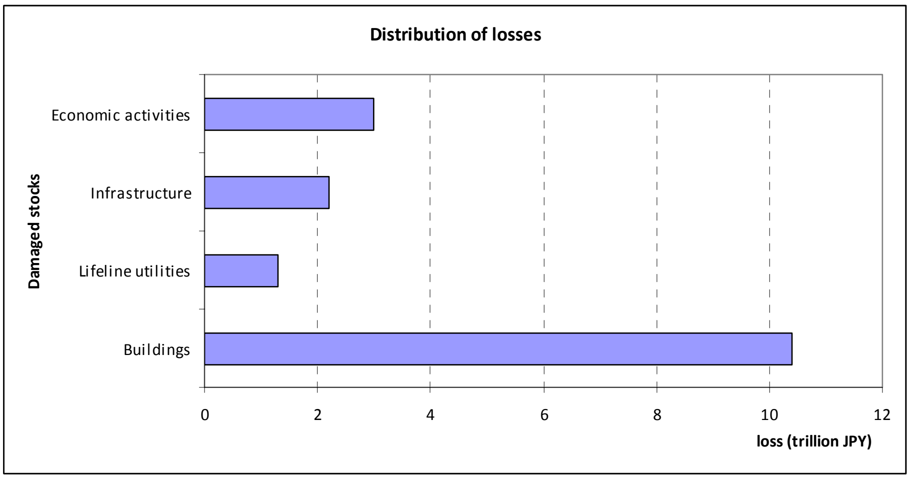

Figure 5.1: Distribution of losses over stocks (Government of Japan, 2012)

The above graph refers only to tangible stocks. Intangible losses such as fatalities, cultural and environmental degradation, and psychological effects on the victims cannot be easily expressed in monetary value. Yet mortality rates and the relative degree of damage over the exposed area or stocks can be computed, and are fairly good indicators not only of the total losses, but also of the performance of the tsunami protection systems in Tohoku. As mentioned in chapter 4, a complete assessment of the performance of the system of Tohoku requires the elaboration of site-specific analyses, including analysis of fatalities and the degree of damages, which can be later compared to the physical characteristics of the tsunami inundation. Hence many studies have been being carried out since completion of damage and casualties records, some indicative results of which are summarized in the figures below.

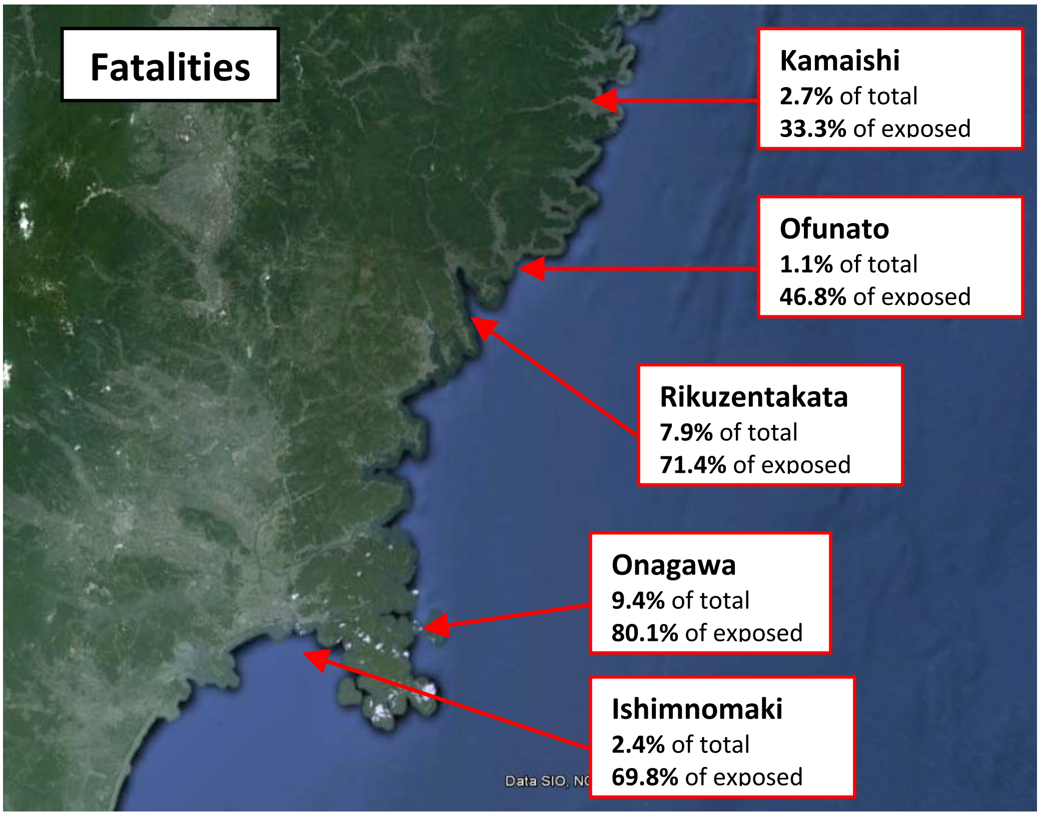

Figure 5.2: Percentage of fatalities over total and exposed population in five affected urban areas in the rias (Data source: Oyama 2012)

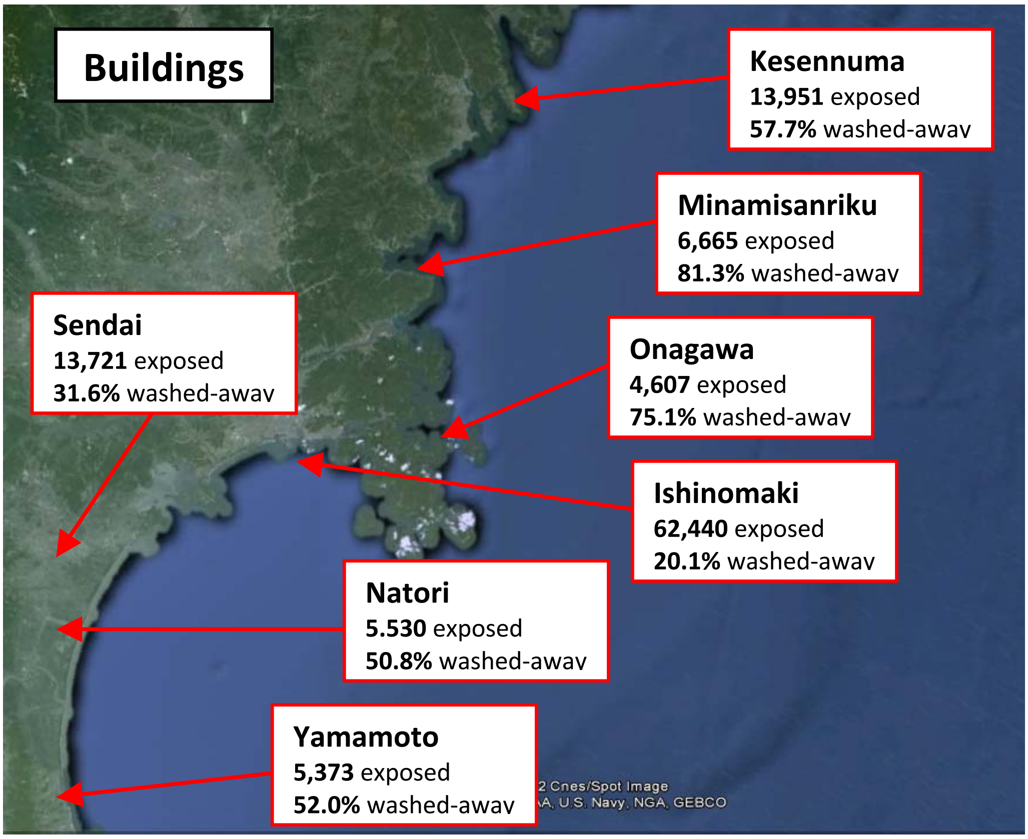

Figure 5.3: Percentage of washed-away buildings over exposed, and total number of exposed buildings in various urban areas (Data source: Gokon & Koshimura 2012)

5.2 The big challenges

The ultimate purpose of recording and analysing damage and casualties is to use this information in order to deal with rehabilitation effectively. In the aftermath of the disaster, Japan has been facing the great challenge of rehabilitating not only the affected coastal zone, but also the national economy, which was seriously afflicted. Concerning the coastal zone, large areas were entirely destroyed, and need to be rebuilt starting from “zero”. In this respect, decisions about land use planning and reconstruction of the area are going to be crucial for the future social-economic development of Tohoku. The greatest challenges inherent in this task are presented in the following paragraphs.

5.2.1 A long-lasting recovery

Rehabilitation cannot be a straightforward process. In order to rebuild Tohoku, high investments are necessary, which can only be supported by a strong economy. On the other hand the national economy can only return to its pre-disaster state with the recovery of production and industry. This requires the rehabilitation of the devastated areas. It is therefore necessary that a cyclic rehabilitation process be engaged, allowing for the gradual recovery of losses. Given the extent of the disaster, it should be realised that this process is likely to last long, making it necessary to direct short-term strategies for the temporary relief of the affected population.

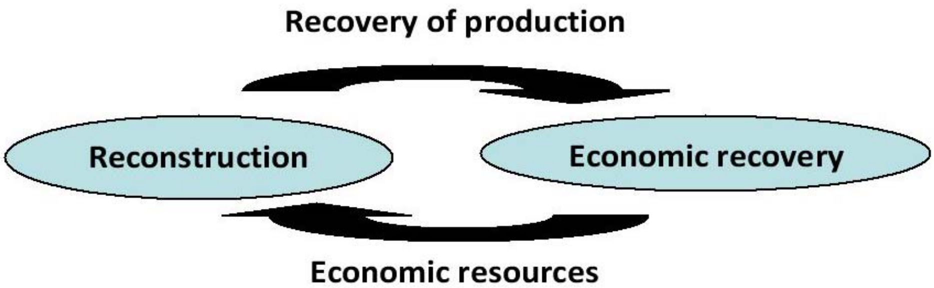

Figure 5.4: Recovery process

5.2.2 A deteriorating region

Before the events of March 2011, Tohoku used to be one of the least developing areas of Japan. Although having thrived on fishing ports and manufacture in the past, Tohoku suffered from changes in the industrial structure, followed by the migration of young adults to more developed parts of the country, and the aging of local population (Soda 2011). Investing in recovery is worthwhile only if the benefits of such an action outnumber its cost. Those benefits can be tangible, i.e. economic benefits, or intangible such as the sentimental value for local residents. For the case of a deteriorating region like Tohoku, the choice for restoration would be worthwhile only if a powerful economy were induced, capable of reversing the previous economic and social decline. It is therefore necessary that strategic planning is conducted, pointing out the long-term prospects of any decision made, and all appropriate measures taken to support the final decision.

5.2.3 Risk reduction

Due to the catastrophic impact of the tsunami, huge areas of the coastal zone of Tohoku need to be reconstructed. The fact that reconstruction is about to take place in entirely empty spaces represents a great opportunity for Japan to develop new land use plans at a relatively low cost. Those plans can include measures that can significantly contribute to the mitigation of tsunami risk, such as the relocation of residences and social infrastructure buildings to higher grounds or on mounds in the plain region, and the flood proofing of buildings in low-lying areas by locating most important functions in higher floors that are less likely to be inundated. Nevertheless such types of developments constitute layer 2 measures, as presented in chapter 4, and their role is to mitigate the degree of damage when a tsunami occurs, with no contribution to the reduction of the inundation probability. In developed countries, and regions where a prospect for the building of a powerful economy exists, which could be the case in Tohoku, prevention of disasters could prove to be much more cost-efficient than mitigation of losses. If this is case, layers 2 and 3 should be complimentary to layer 1 without replacing it. In order to achieve a balanced distribution of investments in the three safety layers, and to avoid situations that loss-mitigating measures are implemented in the expense of prevention measures, it is strongly recommended that the choice of measures are supported by cost-benefit analyses.

An interesting damage mitigating design has been suggested by Keiichiro Sako, a Japanese architect, the so-called sky villages. The design concerns the new spatial development of the devastated villages in the coastal plain of Sendai region on artificial high grounds.

Figure 5.5: Design for sky villages in Sendai coastal plain (Source: Designboom; http://www.designboom.com; all rights reserved)

Although promoting the coexistence of social-economic and natural environment, the cost efficiency of such sky villages should be thoughtfully considered. A sky village needs an expensive initial cost to construct the mounds, houses, and infrastructure, and a low coast to maintain the infrastructures that are concentrated in the village. The Japanese population has already reached its maximal and will decrease because of a small birth rate. Many infrastructures, which were constructed during the Japanese post-war economic miracle decades, late 1950s-fist 1970s, are now approaching the repair or reconstruction time. From these viewpoints, a highly dense compact village may be within a range of the discussion.

5.2.4 Management of economic resources

The great Eastern Japan earthquake and tsunami was one of the costliest natural disasters of modern times. Apart from the direct costs of the devastation of urban areas, industry and agriculture, the cost of their side effects like the disturbance of production lines worldwide, of logistics routes and electricity supply resulted in an important increase in the indirect losses associated with this event. The public bonds do not suffice for the recovery of Tohoku (Soda 2011). The utilization of private sector bonds and maybe also of financial assets of individuals may be necessary, which can be a time-consuming process. In order to utilize economic resources in a timely manner, major reviews of the corresponding legislation may be necessary. A key issue would be to make legislation more flexible for the convenience of the overall recovery project.

5.3 Towards reconstruction

In order for all appropriate actions towards reconstruction to be taken, one month after the disaster the Government of Japan ordered the constitution of the "Reconstruction Design Council in response to the Great Eastern Japan Earthquake". The council consisted of nineteen experts in post-earthquake reconstruction, and was convened by the Prime Minister at that time, Naoto Kan. The main purpose of this council was to create an advisory framework for the formulation of governmental guidelines for reconstruction in all regions affected by the earthquake, the tsunami and the nuclear accident. In June 2011 an advisory report by the council to the prime minister of Japan was published, suggesting a possible reconstruction framework. An outline of their recommendations is presented in the following paragraphs.

5.3.1 Reconstruction principles

The report of the reconstruction council begins with the statement of seven principles based on which the reconstruction framework should be developed. The principles are in fact a set of ideas that had been reached by consensus among the members of the council, and could be used for the elaboration of a detailed framework. The seven principles are stated in the report as follows:

Principle 1: *For us, the surviving, there is no other starting point for the path to recovery than to remember and honour the many lives that have been lost. Accordingly we shall record the disaster for eternity, including the creation of memorial forests and monuments, and we shall have the disaster scientifically analysed by a broad range of scholars to draw lessons that will be shared with the world, and passed down to posterity.*

Principle 2: *Given the vastness and diversity of the disaster region, we shall make community focused reconstruction the foundation of efforts towards recovery. The national government shall support the reconstruction through general guidelines and institutional design.*

Principle 3: *In order to revive disaster-afflicted Tohoku, we shall pursue forms of recovery and reconstruction that tap into the region's latent strengths and lead to technological innovation. We shall strive to develop this region's socioeconomic potential to lead Japan in the future.*

Principle 4: *While preserving the strong bonds of local residents, we shall construct disaster resilient safe and secure communities and natural energy-powered region.*

Principle 5: *Japan's economy cannot be restored unless the disaster areas are rebuilt. The disaster areas cannot be truly rebuilt unless Japan's economy is restored. Recognizing these facts we shall simultaneously pursue reconstruction of the afflicted areas and revitalization of the nation.*

Principle 6: *We shall seek an early resolution of the nuclear accidents, and shall devote closer attention to support and recovery efforts for the areas affected by the accidents.*

Principle 7: *All of us living now shall view the disaster as affecting our own lives and shall pursue reconstruction with a spirit of solidarity and mutual understanding that permeates the entire nation.*

As the impact of the disaster was not sufficiently concluded at that time, with the cleaning process and recovery of victims still in progress, the developed framework has an identifying character, pointing out issues of primary importance, and some preliminary ideas to base the development of strategies in the following months. It is characteristic that a year later, the Government of Japan has not announced any official decisions about reconstruction, which shows clearly the sensitivity and difficulty of the effort. The key issues included in the framework are summarized below.

5.3.2 Municipality-led reconstruction

Municipal authorities shall coordinate all reconstruction projects. This is supposed to enhance the linkage and communication between decision-making bodies and the local population, whose needs have to be carefully considered and fulfilled. The role of the central government shall be the coordination of all municipal projects, in order to avoid inconsistencies of decision-making between neighbouring municipalities. There should be no projects that obstruct developments in neighbouring areas. Involvement of the private sector in reconstruction is considered favourable and may also prove to be necessary; hence it should be addressed as soon as possible.

5.3.3 Disaster-reduction philosophy

All new developments in the devastated areas shall be based on a philosophy of disaster mitigation, i.e. measures will be taken to ensure that loss of life in future events is avoided, and material damage will remain low if a large-scale tsunami causing inundation occurs again. This can be achieved by combining the reconstruction of primary coastal defences with the improvement of evacuation plans and spatial planning. Concerning primary defences, new types of developments can be considered, such as the construction of sand dunes. Regarding spatial planning, the main suggestion for all areas is to relocate urban areas to higher grounds in the degree that this is possible, and to use strict building regulations for low-lying areas, where functions that cannot be moved far from the coast will be allocated, such as fisheries and industry. For the cities in the rias the greatest part of residencies could be moved to higher grounds, while in the coastal plain region they could be moved behind setback dikes, i.e. secondary dikes a few kilometres inland, which do not exist yet, hence have to be constructed. In all cases it is favourable to promote reconstruction in areas where disaster prevention and reduction can be more easily implemented.

5.3.4 Incorporating future vision

A long-term perspective shall be incorporated into all future plans. It is considered important that the economic potential of all areas that need to be reconstructed is investigated. This way developments can be promoted that will foster a leading role of the region in certain sectors. Looking at the long-term, special attention is supposed to be paid in aspects that can further stimulate social-economic development and create value in the region, such as the preservation of local ecosystems, utilization of local resources, development of efficient public transport infrastructure, promotion of renewable energy and cutting-edge technology etc.

5.3.5 Fostering resilience

Japan is a country frequently exposed to natural disasters. It is therefore necessary to increase resilience against disasters with the development of mechanisms for effective response, determining appropriate governmental actions, share of responsibilities and necessary provision of expertise in the aftermath of a disaster. An important aspect of a resilient society is the possibility of deregulation or flexibility in regulation in case of an emergency, so that swift actions can be taken. An important step should be the designation of special zones, where special regulatory measures can be applied during the recovery from a disaster.

5.3.6 Revision of land use

All previous land use regulations should be revised and appropriately modified to cover the needs induced by the disaster. In particular the existing legislation should become flexible enough not to obstruct swift implementation of reconstruction projects. Firm decisions are necessary in areas where large-scale changes in land use are made, such as the transformation of residential areas into agricultural and industrial zones. In those cases the development of appropriate mechanisms to facilitate these processes may be necessary. Another point of attention shall be the land registration issues induced by the dramatic transformation of the coastal zone after the disaster, which should be resolved so as not to obstruct rebuilding of those areas according to the new plans.

5.3.7 Revival of local economic activities

While reconstruction is taking place, it is considered absolutely necessary for local economic activities to start resuming their function. This is an essential step towards recovery of production and employment in the area. In this respect the first concern of the government should be to conclude measures that would encourage devastated industries to relocate domestically, and preferably within Tohoku, such as the provision of fund-raising assistance. Special measures shall be necessary for small and medium-scale enterprises that were built by taking loans, and whose previous debt may induce additional legal obstacles in the procurement of new funds. For the revival of economic activities in Tohoku, some effort should be taken for the promotion of technological innovation, which is expected to create new industries and employment, hence a core for growth in the future.

5.3.8 Securing financial resources

According to the report of the Reconstruction Council, securing financial resources for reconstruction is of great importance in order to maintain the confidence of international markets to the Japanese government bonds. After the great Hanshin-Awaji Earthquake of 1995, the fiscal situation of Japan declined dramatically, and an enormous debt caused by the increase of social security expenditures will be inherited by future generations. If the same policy were followed after the event of March 2011, combined with the expectance of a significant decline of the active population of Japan the coming ten years, the per capita burden of next generations would increase dramatically. It is therefore necessary that a new policy for fiscal consolidation, different than the one undertaken after previous disasters, is promoted. Therefore the existing expenditures should be revised and appropriate multidisciplinary studies should be implemented in order for the Government to determine a policy that can secure rehabilitation resources via the current generation, without shifting debt to next generations. A temporary increase in taxes combined with private sector investments and voluntary assistance funds during the period that reconstruction expenditures are necessary may be sufficient to serve this objective.

5.3.9 Response to the nuclear accident

The central government shall be assigned the response to the nuclear accident, as well as for the conduct of a thorough investigation of the cause of the accident, assessment of its impact and of the efficiency of all taken measures. This way international trust in the response of Japan can be gained. As main priorities of the government, the following four issues have been identified:

- Monitoring of radiation levels in an integrated and continuous manner, and transmission of accurate information about the measurements.
- Conduct of soil and waste decontamination work, using expertise assistance from related research institutes for the improvement of implemented methods.
- Support of health management efforts with measures for appropriate health maintenance, long-term surveys of the impact of radiation on human health, and promotion of research on this topic.
- Establishment of an organization to conduct all necessary activities for the financial compensation to people whose lives have been affected by the nuclear accident.

5.4 Tsunami risk management developments

Following the tsunami and its devastating impact in Tohoku, the Japanese scientific society intensified the effort to advance the tsunami and disaster management research. It has been realized that in order to protect the coastal zone against tsunami, it is absolutely necessary to combine effectively hard and soft countermeasures. The primary role of the former is to prevent the coastline being attacked by a tsunami, while the latter are meant to mitigate the damage and casualties in the coastal zone if the design specifications of the former are exceeded, as happened in March 2011.

5.4.1 Classification of tsunamis

In order to have the use of hard and soft measures organized in an effective way, a concept of tsunami classification is being adopted. Two tsunami levels are suggested as follows.

- *Level-1*. A level-1 tsunami is supposed to have a return period of about 100 years. The primary defences should be designed to resist the forces of a level-1 tsunami and prevent any loss of life or material damage in the coastal zone. A level-2 tsunami is a higher scale event, with a return period of 1000 or more years. The event of March 2011 is indicative of this level.
- *Level-2*. For level-2 events it is suggested to accept that the primary defences will fail and the tsunami waves will inundate the land, yet the degree of damage and casualties should be minimized. The primary defences should not fail catastrophically when a level-2 tsunami occurs, but they should prove to be sufficiently resilient, while the soft tsunami countermeasures of the coastal areas should prevent in the most efficient way any loss of life and should mitigate the material damage.

5.4.2 Classification of evacuation areas

Another interesting concept that has been suggested by researchers of Waseda University, is the classification of evacuation spots. Three categories are suggested (Shibayama et al. 2012):

- *Category A*. Category A includes higher terrains adjacent to the coast that are preferably part of higher mountains and have access to the hinterland and not isolated hills.
- *Category B*. Category B includes robust buildings of at least 6 floors that could shelter people even when a level-2 tsunami occurs.
- *Category C*. Category C includes robust buildings of 4 to 6 floors, which would be efficient in the case of a level-1 tsunami. The already existing evacuation buildings fall in this category. In case of a level-2 tsunami there would be the risk that these buildings are overtopped, as happened in some cases in March 2011. When a higher event is expected during a tsunami alert, people should be directed to points A and B if possible. It is also suggested that no new evacuation buildings of category C are built, while the ones existing should be only used while no better evacuation points of higher categories are available.

6 FROM RISK TO OPPORTUNITY

6.1 Introduction

Following the Great Eastern Japan Earthquake and Tsunami, the Japanese scientific society and authorities have been making an enormous effort to survey the event and to advance tsunami related research, which can be used for the formulation of effective strategies for the future. Comparing the Japanese case to the Netherlands it can be noticed that there are considerable differences in the type of flooding and its effects; however in both cases there is a common interest in that it is paramount for both countries to protect their societies against flooding and its devastating impact. In order to fulfil this need efficient flood risk management practice is necessary.

During a great disaster that causes multiple failures in the protection system, all weaknesses of the system can be easily identified due to the catastrophic consequences. This creates a unique chance to clearly identify and deal with them in an effective way in the future. The severe flooding of 1953 in the Netherlands, which cost the life to 1800 people and caused severe economic damage, was an event that initiated a major breakthrough in the Dutch flood risk management. Following the Dutch example, the devastating tsunami attack in Japan could be similarly used as an opportunity to greatly improve the Japanese flood risk management, while some important lessons for future practice in the Netherlands and worldwide can be derived. This chapter begins with the presentation of an overview the Dutch flood risk management approach, some attributes of which could be easily borrowed and implemented in Japan, contributing to the efficiency of flood risk management practice. Subsequently, based on the experience of this disaster, some important lessons for flood risk management in the Netherlands are derived. The chapter ends with some ideas for knowledge sharing between Japan and the Netherlands, pointing the benefits of potential collaborations.

6.2 The Dutch flood risk management

6.2.1 Breakthrough in the aftermath of a disaster

The fact that more than 60% of the Netherlands is flood-prone makes flood risk management a prerequisite for any type of land-based economic and social development. Before the Middle Ages the Dutch would reduce the risk of flooding by locating their essential activities on artificial hills. The first flood prevention measures were taken in the Middle Ages when the first river dikes were constructed. Together with the naturally formed dunes along the Dutch coast, the dikes reduced drastically the frequency of flooding. As the quality of the flood defences needed to be monitored and maintained, the first water boards were assembled in 1255, with the purpose to coordinate maintenance of the dikes at a local level. This system worked for several centuries, yet proved to be inefficient over time. The number of water boards kept growing, which made it necessary to have their activities coordinated by a central authority. All water management activities were centralized in the 19th century, and coordinated by Rijkswaterstaat, an agency that still exists and belongs to the Ministry of Infrastructure and Environment.

In February 1, 1953 one of the biggest floods ever recorded in the Netherlands occurred. The night of January 31 a severe storm in the North Sea induced very high water levels along the Dutch flood defences in the southwest of the country. The storm lasted several hours. The high water levels that were periodically intensified by the spring tide exceeded the capacity of the flood defences. As a consequence many dikes failed. In total 89 dike sections collapsed, and breakages and damages could be found over a length of 187 km. That night about 1800 people were drowned and thousands were evacuated. The economic damage was also serious.

Figure 6.1: Dike breakages in the Netherlands, 1953 (Source: www.deltawerken.com)

20 days after the disaster the Dutch Government founded the Delta Commission. This commission consisted of a group of specialists in water management issues, whose role was to come up with a national water management strategic plan that would ensure the achievement of two goals: to keep the country safe against flooding, and to ensure fresh water supply to all communities, while waterways of vital importance to the country's economy, like Western Schelde and Rotterdam, should remain operational. The Delta Commission designed the Delta Law of 1958 and the Delta Report of 1960. Their main recommendation was the shortening of the coastline by closing tidal estuaries, and the determination of design water levels for the strengthening of the existing dikes and for the design of hydraulic structures that would guarantee the safety of the areas along the sea, known as the Delta Works. They also remarked the need for further research on water safety. After that the commission was dissolved.

6.2.2 Safety standards

The key element of Delta Commission's recommendation that changed the entire approach to flood risk management was the determination of safety standards based on the prospects of economic development and population growth. Having the required safety within the dike rings determined implies an approach that acknowledges the fact that extreme weather conditions resulting in flooding can occur any time, and communities adjacent to water will have to deal with it. At the same time, it establishes safety against flooding as the main criterion based on which the choice of every investment in flood protection will be made. For every new measure under consideration, the degree of safety that it provides to the community needs to be determined, which has to be compared to the respective safety standard. Safety standards are based on risk, and concluded by means of cost-benefit analysis. They are expressed in exceedance frequencies of water levels, which are equivalent to probabilities. Every measure is in practice assessed according to how much it reduces the probability of flooding, or the probability of a certain degree of damage or casualties.

The recommendation of the Delta Commission started being implemented immediately with the construction of the Delta Works in the period 1958-1997. The safety standards were legally mandated within the Act of flood defences in 1996. The map indicating the safety standards of the Dutch dike rings can be seen below (figure 6.2). The safety of the dike rings as well as the safety standards are currently reassessed in a regular basis.

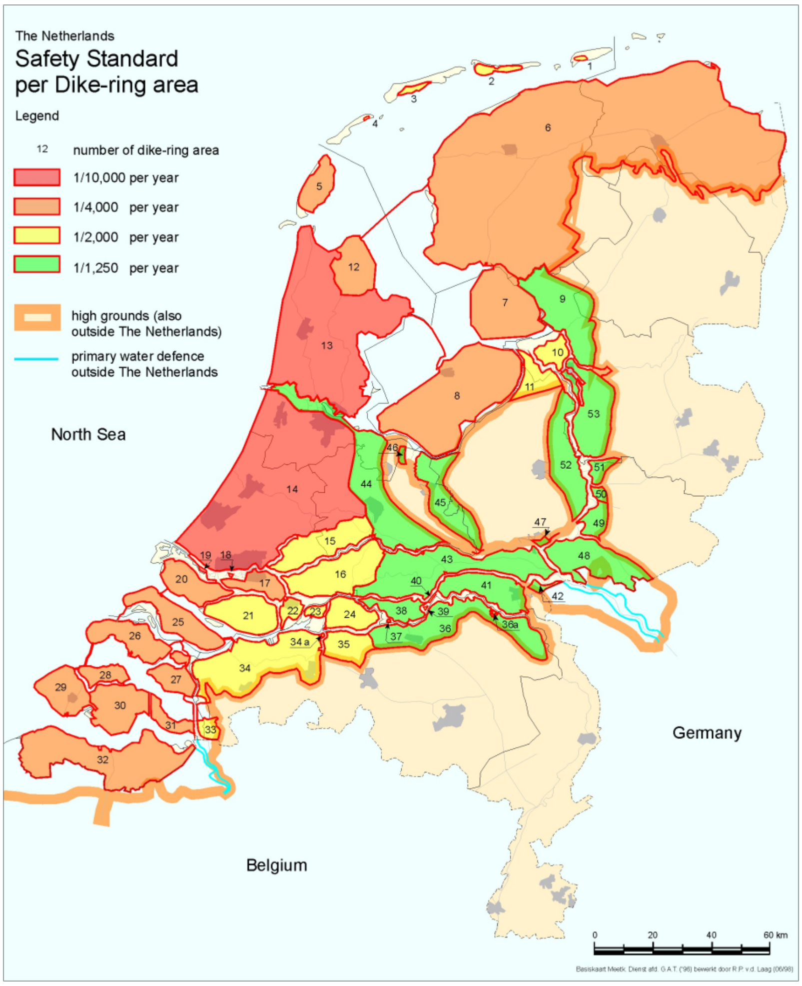

Figure 6.2: Safety standards in the Netherlands, 1996

In 2005 the Dutch Government established a second Delta Commission, the role of which was a water safety strategic planning for the Netherlands. Unlike the case in 1953, after the Delta Works and strengthening of the dikes, flooding was not considered an acute threat anymore. The main objective of the second Delta Commission was to investigate if and how safety could be maintained in the long-term, considering climate change and future social-economic developments. Their conclusion was that safety could be guaranteed for the coming centuries, yet further research on the topic was necessary. The Government approved this advice in 2008 and incorporated it into the National Water Plan.

6.2.3 A long-term perspective

text by Jos van Alphen

In order for the advice of the second Delta Commission to be implemented the Delta Program was initiated in 2010. This is a national project in which the national government, provinces, water boards and municipalities work together, with the active participation of the public, stakeholders and knowledge institutes with the scope of coming up with solutions that will ensure the long-term flood protection and fresh water supply in the Netherlands. Up to 2014, the Delta Program is aimed at the development of strategies and preparation of key decisions on these strategies. Later on, it will transform into the preparation, planning and execution of measures.

Within the Delta Program solutions are developed based on a water system-based approach, which takes into account the linkages between water management, economic development and nature preservation. Three qualities should be maintained with all solutions: 1) solidarity between regions and generations, 2) flexibility in view of uncertain future trends in climate, societal demands and political priorities, and 3) sustainability of population, environment and profit. These qualities serve as beacons for the many decisions to be made. Strategies and measures are evaluated in relation to the main objectives of the Delta Program i.e. flood protection and fresh water supply, the basic values, i.e. solidarity, flexibility and sustainability, costs and benefits, regional objectives, side effects on other interests like navigation, and their feasibility.

Like all deltas, the Dutch water system consists of an interconnected system of rivers, lakes, estuaries and coastal areas. Measures in one part of the delta may impact other water systems. In the Rotterdam/Rhine-Meuse estuary and Lake IJssel, the challenges relate to flood protection, fresh water supply and new urban developments are very big. Decisions taken here may affect surrounding regions or impose other boundary conditions on upstream regions. This interconnectedness requires consistency in the decisions to be made. Key decisions on flood protection standards, water supply and new urban developments, as well as the preferred strategies regarding the Rhine-Meuse estuary and Lake IJssel need to be prepared in close co-operation with regional and local stakeholders and administrations.

One of the biggest challenges of the Delta Program is dealing with future uncertainties in flood risk management. This is always a complicated task, as there is a wide range of aspects in the system and its surroundings that evolve over time, such as the climate, the available amount of knowledge, the risk perception in society, the structural components that deteriorate, economic and demographic growth, etc. These variations are hard to predict and difficult to incorporate in the decision-making process regarding the future of a flood-defence system. For policy or decision makers it is important not to make the wrong choices. They are interested in knowing what investment should be made in the flood-protection system, where and when, as well as when it would be more beneficial to postpone an investment.

Effective preparation for future conditions requires a robust long-term planning. This means that future uncertainties need to be analyzed and to become manageable by an adaptive way of planning. Adaptive planning in the Dutch flood risk management is an iterative feedback and learning-based process, whose main objective is to determine the type of investments that have to be made in the flood protection system and the most appropriate moments in time for these investments to take place, i.e. answering the questions, where to invest, how much and when.

One of the main objectives of adaptive planning is the determination of "tipping-points" in present infrastructure and policy. A tipping-point is reached when present infrastructure or policies are no longer sufficient to reach the present safety standards or objectives, becoming too expensive or unacceptable to society; therefore some decisions are necessary in order for the appropriate improvements to be implemented. Scenarios of plausible developments in climate change and society give an insight into the moments when tipping-points might occur, which is the first step towards the development of robust strategies. A robust strategy consists of measures that delay the reaching of the tipping-points and facilitate adaptation measures when a tipping-point is reached. Examples of this type of measures are the following:

- Investments on urban developments that can prevent or reduce the cost of damage, when flooding occurs. This type of developments fall into layer 2 measures of MLS, presented in chapter 4.
- Measures in the water sector whose implementation can be easily accelerated or decelerated if conditions other than those expected occur in the future. Such a measure can be, for example, beach nourishment for the combat of coastal erosion.
- Allocation of land for developments that are expected to be needed in the future, such as space for the development of a floodplain or the increase of a dike section.

6.3 Lessons learned for the Netherlands

text by Jos van Alphen

6.3.1 Probability of flooding

The Great Eastern Japan Earthquake was the most powerful earthquake recorded in Japan since records started. However it cannot be concluded that larger tsunamis never occurred. Tsunami protection walls were abundant along the coast, but they were designed to prevent much smaller tsunamis. This tsunami of March 11 dwarfed and overtopped all structures present.

An important lesson that can be learned from this event is that natural hazards should be seen from a geological perspective, i.e. on a timescale of millennia. A perspective on a time scale of human lifetime, or even of several centuries of records may not show the very rare but very extreme events that are always waiting to happen at the far end of the frequency-force distribution. This requires a probability-based approach to prevention instead of an approach based on prevention against a previously experienced disaster. Such an approach has already been adopted in the Netherlands, and the Japanese case confirms its value. According to it, a level of protection can be decided by politicians that society is willing to afford itself and of which it accepts the consequences when these design conditions are exceeded by nature. The higher the level of protection, the lower the probability of flooding, however the more extreme the design conditions, and the consequences of failure.

6.3.2 Consequences of flooding

Although an earthquake and related tsunami is an unlikely source of flooding in the Netherlands, the size and effects may have resemblance to large scale flooding as a result of a storm surge. The Worst Credible Floods (“ergst denkbare overstromingen” in Dutch), used for the purpose of disaster management exercise and contingency planning, assume a flooded area of 4000 km^2 due to a combination of several breaches along the Dutch North Sea coast and Lake Ijssel, which would have catastrophic consequences for the Netherlands, unless appropriate disaster countermeasures were taken.

In the Japanese tsunami case there was little time for evacuation, and the shelters were limited to high buildings, and to high grounds in the cities along the rias. For the case of a coastal flood in the Netherlands the situation would be similar, since under those conditions the crowded motorways will not allow many inhabitants to evacuate quickly out of the threatened area. Vertical evacuation saved thousands of lives in Japan and should also be the dominant approach in the Netherlands during a large-scale flooding. Along the ria-coast the vertical evacuation was rather effective, because of abundant nearby high grounds and inhabitants that are trained and familiar with the procedures. In the coastal plain region high concrete buildings were used as shelters, but their number was not sufficient and the distance to reach them was often too long. It is doubtful whether Dutch inhabitants will ever be trained and familiar with vertical evacuation procedures. However authorities should be prepared and have designated enough shelters.

One of the most remarkable effects of the tsunami was the flooding of Fukushima Daiichi nuclear power plant that induced the release of large amounts of radiation, and forced an important part of the country, including Tokyo, to a nuclear emergency. Since some of the Japanese industries produce essential goods for the international market, the effects of the tsunami were felt worldwide in all kinds of production chains. In this way the tsunami illustrated that a large scale flooding may have disruptive indirect effects outside the flooded area, even on a worldwide scale. The larger the flooded area and inundation height, the more likely it is that these outside indirect effects will occur. A flooding of the Dutch coastal area may show similar chain reactions on energy production and worldwide markets. This can be easily understood if one thinks of the role of Rotterdam in international transport and German industries. It is of major importance, not only for the Netherlands, to have a good overview of the vital infrastructure and how to guarantee its performance when a flood occurs.

A last lesson for the Netherlands could be derived by the compartmentization example in Sendai plain, where a heightened highway disturbed the expansion of flooding. It is expected that local infrastructure and old dikes may affect flooding of the Dutch coastal area as well.

6.3.3 Response to flooding

The tsunami caused severe destruction in many towns and villages, and at the same time it affected the capability of authorities to perform disaster management operations, like rescuing people in danger and emergency repair. The national authorities like teams from the Ministry of Land, Infrastructure, Transport and Tourism supplied assistance, but in many cases access required repair of demolished roads and bridges and debris removal. This took days (sometimes weeks) to accomplish. Although the clean up and temporary repair of infrastructure was almost completed within 6 months, the re-housing of people will take much longer. One year after the tsunami about 100,000 evacuees still live in temporary housing.

Should a major flood affect the Dutch coastal area the societal and administrative disruption might be even more serious, since large population centres like Amsterdam and Rotterdam might be affected. Especially flooding of The Hague might have a large effect on disaster management operations, since it accommodates several national and international organizations of high importance.

6.4 Some thoughts on Dutch-Japanese collaboration

text by Rob Stroeks

6.4.1 Challenges in Japanese water management

Urban development over the past half century in Japan has had a large impact on the water management system. Waterways had already lost much of their transport function since the introduction of railways at the end of the 19th century, and roads in the 20th century. But economic growth and strongly increasing land prices reduced space for waterways in urban areas to a minimum. In terms of water management this was not always an optimal situation, as most of these areas are situated along the coast and in between steep mountains and ocean areas characterised by their steep seabed.

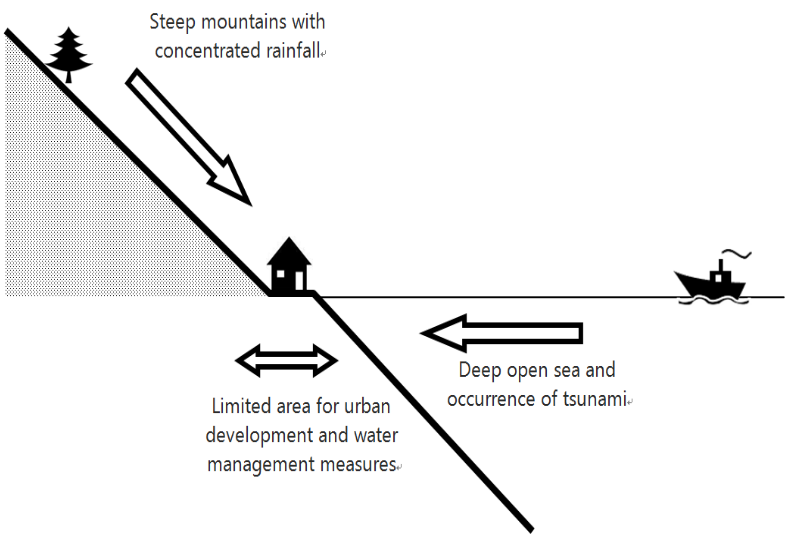

Figure 6.3: Characteristics of the Japanese coastal zone

Rivers upstream are mostly steep with large flow volumes in certain periods of the year. During those periods, the flow capacity of rivers in urban areas is challenged. To attempt to remedy these problems, upstream measures have been taken, like rerouting rivers around urban areas and building dams to control flows. Downstream, more innovative and sometimes expensive measures have been taken like underground water storage and bypass tunnels to manage the water level between rivers. In many cases, these measures are integrated with other facilities, like the Nissan Stadium in Yokohama of which the parking area can function as water storage. Also more soft measures have been designed. Examples are flood hazard maps, flood prediction systems based on satellite, IT systems including a glass fibre network along the Arakawa river to monitor water levels and communicate with citizens.

The sea around Japan is deep immediately from the coastline, and thus the possibility to construct measures to protect the land from a tsunami are limited to those constructed on the coast itself or directly adjacent to it. Any distance from the coast increases the depth and costs exponentially. In the city of Kamaishi for example, the world's deepest seawall with a depth of more than 60 meters was constructed to protect the bay area (figure 6.4).

Figure 6.4: World's deepest breakwater in Kamaishi, photographed in June 2012, during its reparation

6.4.2 Knowledge sharing

Both the Netherlands and Japan have large low-lying areas that are highly urbanized and economically active. Both countries have made large innovative and economic investments in the water management system in order to protect these areas. The investments differ due to differences in natural conditions and the potential water-related hazards in each area. The tsunami disaster of March 2011 has put an international spotlight on Japan. What is the impact of the disaster to Japanese water and coastal management? What is the impact of the disaster to setting new rules and customs in all parts of the world? And how should we anticipate to these changes? Finding new ways of knowledge sharing between Japan and the Netherlands on water management can contribute to better understanding about the functionality of measures under consideration or already taken. More insight in what these measures can and cannot contribute to a safe society is a basis to identify which risks are effectively dealt with and which not. This leads to optimized measures for current and future risks.

The awareness to share knowledge is strong and urgent immediately after unfortunate events, like dike breakages, a tsunami or subsidence due to earthquakes, damage due to extraordinary river discharges etc. In this context of urgency it is important to also share knowledge about gradual changes in, for example, climate, knowledge or society, budgets. There are many water management issues and activities for which knowledge sharing between Japan and the Netherlands can be beneficial. Some of them are in the domain of preventing events from happening and others in the domain of dealing with events after they occur. Some examples to show the variety:

- Strength and resilience of dikes and other facilities,
- Planning and execution of evacuation,
- Rescue teams and access to affected areas,
- Hazard maps,
- Analysis of short and long term effects of climate change,
- Citizen's own preparedness and emergency exercise,
- Sensing and monitoring,
- IT and communication towards citizens,
- Use of pumps for floods,
- Measures in relation to past disasters and expected future disasters,
- Water management measures in relation to spatial planning (urban and rural),
- Measures that combine natural assets and manmade facilities.

Together, the Netherlands and Japan have expertise and experience over the total range of these measures. Some of these issues have received attention in both countries in past years and the share of knowledge has taken place. Such is the case of the so-called delta dike, known in Japan as super levee. The delta dike or super levee a very wide and robust dike, which is meant to integrate urban functions on its width in densely populated areas at risk. This type of structure has been implemented in Tokyo in a small part of the dike along Arakawa River, but not yet in the Netherlands, where it just exists in conceptual level.

6.4.3 Visit to Iwate Prefecture

Iwate prefecture has set up a reconstruction council after the disaster, dealing with formulation of plans for reconstruction and recovery. In the first phase, the committee has been studying fundamental issues like how to deal with safety risks, which scenarios have to be studied or what are the long-term effects of measures. Prefectures in Japan are the intermediate level of government between the municipalities, of which the mayors are the ultimate decision makers for the city recovery, and the national government. The national government is in charge of national water management issues including coastal defence and large river management.

The tsunami hit the steel industry based city of Kamaishi just two years after the completion of world's deepest breakwater in front of the bay. The 1.5 billion dollar project was designed to prevent that the city is hit by tsunamis, which happened several times in the past. Although the barrier appears to have reduced the force of the tsunami (Mori et al. 2012), it could not prevent the city from being heavily damaged by the force of the waves that were higher and more powerful than the wall was designed for. The barrier itself has been heavily damaged, affecting the safety level for future disasters. It left specialists and decision-makers wonder about what measures to take to protect citizens from this type of natural disaster. The earthquake has also put out of operation a number of pumps that had to keep a lower part of the city centre dry. The area was inundated by the incoming water, a situation definitely in need for solutions but not acute as most buildings in the area had been wiped away by the tsunami. One of the solutions the city was considering was to heighten the area. In a separate bay in the northern part of the municipality a dike was constructed, including a sluice through which water from a pond behind the dike was naturally discharged to the sea. Outside the dike was a beach with a leisure function. The tsunami completely wiped out the dike, and the sand from the beach was carried by the water into the agricultural land further inland, with the natural pond having completely disappeared.

During a visit to the affected area in September 2011, the author of this section met the Reconstruction Council of Iwate prefecture and the mayor of Kamaishi. Discussions and a presentation on the Dutch water management generated interest in the Netherlands expertise and gave insight into some specific items of common interest. During the meetings, the following issues concerning water safety in the Netherlands were discussed:

- Design specifications and safety of dikes in the Netherlands,
- Conflicts between maintenance of flood defences and economic activities,
- Use of pumps for dewatering of flooded areas,
- Implementation of spatial solutions (layer 2 measures) for the increase of safety against flooding,
- Acceptance of the safety standards by the public,
- Use of floating houses
- Cooperation and support of the Netherlands to Indonesia after the 2004 tsunami disaster

6.4.4 Conclusion

The disaster of 11 March 2011 underlines the need to continue developments in water management systems. Finding new ways to share knowledge between Japan and the Netherlands on water and flood risk management can contribute to these developments. Issues raised during the meeting in Iwate prefecture hint to the areas for potential knowledge sharing. In some of these areas communication and knowledge sharing is ongoing. Existing contacts can also lead to new contacts in other areas, for the benefit of the Netherlands and Japan as leading countries in water management.

6.5 Collaboration initiatives

The need to deal with major coastal disasters on an international level has been apparent even before March 2011. The Great Eastern Japan Earthquake and Tsunami, and its devastating consequences have urged this need in Japan, but also in other countries where the threats of coastal hazards are prominent, like the Netherlands. In September 2011, a first collaboration effort between Japan and the Netherlands was initiated, which was successfully completed in June 2012, with the organization of joint seminar on coastal disasters risk management in Sendai, Japan.

The seminar was organized by the Disaster Prevention Research Institute of Kyoto University and Delft University, and was supported by JSPS (Japan Society for the Promotion of Science) and NWO (Netherlands Organization for Scientific Research). Its main objective was the exchange of information between Dutch and Japanese researchers in order to improve methods for assessing, managing and mitigating coastal risks. Among others, the following key issues were addressed:

- The causes and effects of the March 2011 tsunami,
- Performance of the coastal protection system, and lessons to be learned for design and coastal management,
- Strategies that can be used for the reduction and management of risks in coastal areas in Japan and in the Netherlands.

Apart from the focus on engineering measures for the prevention of coastal disasters by means of structural coastal defences, the discussions were also focused on land use planning and emergency management. The questions of how to incorporate future developments like climate change and future economic and population growth in the risk management of coastal areas were also addressed.

A number of interesting findings have been summarized in a concluding report. Besides the findings a number of joint follow-up activities were identified and discussed:

- Presentation of the seminar results at the Coastal Engineering conference (ICCE) in July 2012 in Santander, Spain.
- Application of Dutch concepts for design and risk evaluation in a case study in Japan as part of the PhD research of the lead author of this book, in cooperation with Japanese researchers.
- Information and case studies in Japan will be used for another ongoing Dutch research project on multi-functional flood defences.
- Preparations of a joint discussion paper on challenges in coastal disasters risk management.
- Cooperation in an existing research project on coastal and tsunami risk in Chile (SATREPS), and in an upcoming EU KP7 call in the field of coastal threats.

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APPENDIX

Overview of contributors

Vana Tsimopoulou is a researcher in the field of flood risk management. She holds a master's degree in hydraulic engineering from Delft University of Technology and a diploma in civil engineering from Aristotle University of Thessaloniki, Greece. Since January 2011 she has been employed as PhD student in Delft University, and as part-time consultant of risk and safety in HKV Consultants. Her research interests are the option valuation for investments in flood protection systems and the reliability of hydraulic structures. During her studies and career she has worked on projects in the Netherlands, Greece, Turkey, United States and recently in Japan.

Bas Jonkman is a researcher, advisor and expert in the field of hydraulic engineering flood risk management. He holds a PhD in civil engineering from Delft University and is currently working part-time as an associate professor for that university. Since 2007 he has also worked for Royal Haskoning on projects in the Netherlands and other regions (New Orleans, Vietnam, Cambodia, Romania and Qatar), and has been a visiting scholar at UC Berkeley. Together with colleagues from TU Delft and Kyoto University he has organized the seminar "Advances in Coastal Disasters Risk Management" (June 7 & 8, 2012, Sendai, Japan) to exchange lessons on the implications of the 2011 Tohoku tsunami for coastal management.

Bas Kolen works at HKV Consultants as a senior advisor of Disaster Management. His fields are water safety, disaster management, evacuation and self-reliance. He is among others involved in the innovation program Flood Control 2015. In the past he was involved in emergency planning, evacuation planning and the development of flood scenarios. He was also involved in activities around the Taskforce Management Flooding (National and regional planning, flooding and evacuation scenario's, Training activities) and in the preparation of the national exercise 'Waterproef' and the international Exercise Floodex. He also works at the Free University of Amsterdam on his PhD research with the subject: The feasibility of mass evacuation during floods.

Jos van Alphen is senior advisor on strategy and knowledge development of the Delta Program Commissioner. He graduated in Physical Geography. Since 1984 he was employed at different positions in the Ministry of Transport, Public Works and Water Management / Rijkswaterstaat, mainly in the field of water management and flood protection. He organized the 3rd International Symposium on Flood Defence (ISFD3, 25-27 May 2005, Nijmegen, The Netherlands) and was project-leader for the preparation of flood risk maps and management plans within the framework of the EU Floods Directive. In 2007 -

September 2008 he worked for the Committee on Sustainable Coastal Protection (2nd Delta Committee), advising on the long-term adaptation of the Netherlands to climate change (sea level rise, river floods, drought). Since 2010 he is employed at the Delta Program Commissioner's staff.

Rob Stroeks is senior advisor at the office for science and technology of the Netherlands Embassy in Tokyo, where he works since December 2003. Before that he worked for ten years at the technological development department of Chiyoda Engineering Consultants, based in Tokyo, where he advised governments on strategy, technology and development for traffic safety, environmental issues and disaster management. He was project manager at different infrastructural projects in Southeast Asia, including projects funded by ADB and JBIC. Combining Japanese and European technologies has been the central focus area in Rob's career over the past 19 years. Rob has an educational background in mathematics and Japanese.

Frans van de Ven is leader of the Urban Land & Water Management team at Deltares, the Dutch institute for delta technology, and he is associate professor of Urban Water Management at the Faculty of Civil Engineering and Geosciences at Delft University of Technology. He holds a PhD in Hydrology and is leading research worldwide on limiting the environmental footprint of cities and making them climate resilient and subsidence-free. This includes research on improved concepts for urban water management, urban flood & drought management and better methods for urban drainage design and water quality control.

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Hiroyasu Kawai is director of Marine Information Field at Port and Airport Research Institute in Japan. He graduated from the master course at Tokyo University of Science, Japan and started his coastal engineering research at Port and Harbour Research Institute in 1992. His major themes were reliability-based design of breakwater, stochastic typhoon and storm surge simulation, and wave and tide observation through NOWPHAS. He got a Dr. Eng. from Kyushu

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Nobuhito Mori is an associate professor at the Disaster Prevention Research Institute of Kyoto University. His research focuses on coastal processes, particularly nonlinear wave dynamics, extreme wave prediction and wave climate. He also has an interest in storm surge and tsunami modelling. He has an interest in applying fundamental physics to engineering application at air-sea interface.

Tomohiro Yasuda is an assistant professor of Kyoto University, Disaster Prevention Research Institute since 2004. Tomo has developed real time tsunami forecast system with inversion method, real time wave forecast system employing mesoscale climate model, and storm surge, wave and tide coupled model. He has joined post disaster survey team not only domestic such as 2011 Tohoku tsunami also abroad, such as Sri Lanka after Indian Ocean tsunami, Gulf shore after hurricane Katrina, and Bangladesh after cyclone Sidr. Tomo currently researches on climate change effect on coastal disaster. He has worked at National Oceanography Centre, Liverpool, UK, as a visiting fellow from March 2010 for a year supported by JSPS grant “Excellent Young Researcher Overseas Visit Program”.