

RECOVERY TWO YEARS AFTER THE 2011 TŌHOKU EARTHQUAKE AND TSUNAMI: A RETURN MISSION REPORT BY EEFIT



RECOVERY TWO YEARS AFTER THE 2011 TŌHOKU EARTHQUAKE AND TSUNAMI: A RETURN MISSION REPORT BY EEFIT

Mr. Antonios Pomonis, *Cambridge Architectural Research Ltd.* (Team Leader)

Mr. Joshua Macabuag, *University College London* (Editor)

Mr. Carlos Molina Hutt, *University College London* (Editor)

Prof. David Alexander, *University College London*

Mr. Anton Andonov, *Risk Engineering Ltd.*

Dr. Catherine Crawford, *University College London*

Dr. Stephen Platt, *Cambridge Architectural Research Ltd.*

Dr. Alison Raby, *University of Plymouth*

Dr. Emily Kwok Mei So, *University of Cambridge*

Dr. Ming Tan, *Mott MacDonald*

Dr. Joanna Faure Walker, *University College London*

Mr. Jack Yiu, *Arup*

Report prepared in association with:

Dr. Maki Koyama, *Kyoto University*

Professor Hitomi Murakami, *Yamaguchi University*

Dr. Anawat Suppasri, *Tōhoku University*

Report cover:

**Photos of the Crisis Management Department Building in Minamisanriku
taken during the 2011 (top) and 2013 (bottom) EEFIT missions.**

Executive Summary

The Great East Japan Earthquake on March 11, 2011 was the largest event that has been recorded in Japan since the beginning of instrumental seismology circa 1900, and is the most expensive natural disaster recorded in the world to date. EEFIT sent a team to the affected regions during the immediate aftermath of the event (May 29 – June 3, 2011) to learn lessons regarding the initial impacts of the disaster, and the findings are given in the 2011 EEFIT Japan Report (EEFIT 2011) available on the EEFIT website. Two years later EEFIT launched a return mission (May 28 – June 7, 2013) to examine the direction and progress of the recovery and reconstruction efforts in Japan. In addition we visited some critical facilities for which it had not been possible to investigate in 2011. This report outlines key long-term lessons for the engineering community worldwide as well as those involved in coastal protection structures, tsunami hazard and risk assessment, the nuclear industry, post-disaster housing, urban planning, disaster mitigation, response and recovery, the insurance industry and catastrophe modelling.

Japan's management of this disaster and the recovery process is very well documented providing the opportunity for a higher level of understanding of the technical aspects and the technologies used than could be afforded from previous disasters. This favourable setting and the generous contributions of Japanese colleagues enabled the EEFIT team to learn valuable lessons related to the engineering and social aspects of this complex event and its consequences. These lessons were not yet apparent in the immediate aftermath of the event and increasing post-disaster needs and the cascading effects in advanced and industrialized nations make the long-term study of major disasters and their recovery, of key importance.

During the original 2011 EEFIT mission ground shaking damage surveys were conducted in Sendai, Shirakawa, and Sukagawa, which identified the key factors for severe shaking damage considering both detailing and spectral content of the shaking (Goda et al., 2013). Similarly, tsunami damage surveys were carried out in Kamaishi City and Kesenuma City using a damage scale for reinforced concrete, timber and steel frame buildings adapted from an earlier EEFIT tsunami damage scale (Fraser et al., 2013). During the 2013 return mission, issues related to the effect of ground shaking on building structures and other infrastructure were not investigated due to the limited evidence of earthquake damage, as opposed to tsunami damage, two years after the event.

In Japan, two years after the event, the recovery process is still in its initial stages. Debris has been cleared, many sites have been repaired, and the country is now dealing with a difficult temporary housing situation and with long-term plans to secure the future and safety of several cities devastated by the tsunami. The recovery process is taking longer than originally envisaged, but the increased duration is also beneficial because it is allowing for better community consultation processes on long-term recovery and planning. These issues are discussed in the respective chapters of the report as follows:

Chapter 1 is a general introduction to the EEFIT team's composition, the main objectives and the itinerary of the mission during May 28 to June 7, 2013.

Chapter 2 considers building damage mechanisms, damage statistics, future damage predictions and proposed mitigation strategies, including proposed revisions to tsunami design guidance documents in Japan. Although ground-shaking damage was significant, this chapter focuses on the tsunami as this is the first event for which such an abundance of tsunami data has been present. This event therefore presents a unique opportunity to learn lessons relevant to tsunami design guidance, which is an under-developed field when compared to seismic engineering and one which has limited coverage in European guidance despite significant historical tsunamis in Europe.

Chapter 3 reviews some of the failure mechanisms of sea defence infrastructure, describes progress in reconstruction and provides an insight into new approaches to sea defence being adopted. Whilst there were some notable successes of sea defence structures providing protection against the tsunami, many structures did not prevent overtopping and suffered catastrophic collapse. Further investigations using physical and numerical model testing have led to recommendations, some of which have been incorporated into newly constructed defences.

Chapter 4 discusses the performance of several critical facilities as well as the implications of this event for the nuclear industry. The event damaged critical facilities (including the Fukushima Daiichi nuclear accident and the failure of the Fujinuma Dam) leading to additional human casualties, social disruption, devastation of natural eco-systems, and greatly increasing the economic losses. After the Fukushima Daiichi crisis, significant improvement and review of existing safety criteria has been undertaken in the nuclear industry in Japan, as well as around the world.

There are many lessons for the transitional shelter programmes around the world and Chapter 5 explains the context in which Japan learnt from previous disasters, prepared for and responded to the need for transitional shelter and settlement after the 2011 earthquake and tsunami. Various transitional shelter programmes were adopted in Japan, with prefabricated housing playing a critical role and with shelter policy playing out differently in rural and urbanized zones.

Chapter 6 presents the context of town planning in Japan, the effect that the 2011 earthquake and tsunami is having on current reforms to this process and the issues currently faced by the planners, communities and consultants involved with planning the reconstruction. Issues of safety and housing relocation are being faced in planning the reconstruction of the affected towns. Furthermore, population decline, ageing and economic shrinkage pose special planning challenges. Local governments have been tasked with recovery by the National Government who asked them to develop local plans based on consultation, but there is a disconnect in some local areas in terms of priorities and decision-making.

Chapter 7 develops a medium-term perspective on how disaster risk reduction measures have evolved in Japan after the earthquake and tsunami of 2011, including debris management and structural solutions to rebuild a safer environment. These solutions, which have a heavy emphasis on building sea walls and raising land for urban redevelopment, clash with environmental protection needs as well as the expectations of many of the beneficiaries because they create an unacceptable water-front to local residents' livelihood, business proprietors and visitors. Alternate solutions are presented, such as the use of natural landscaping and setbacks to partially replace sea walls. These solutions are discussed in a context of measures to revitalise city centres and stop the urban decline that had afflicted these areas before the tsunami.

Chapter 8 examines the economic and insured losses incurred following the Great East Japan Earthquake and places these in the context of how risk transfer is structured and implemented in Japan. The total loss from the 2011 earthquake and tsunami has been forecast between US\$479bn and US\$710bn, with both direct and indirect losses being felt worldwide. An earthquake of such high magnitude was not accounted for along this section on the Japan Trench within commercial catastrophe models, and so review and improvement of these models is underway.

The issues arising from the 2011 event are complex, challenging and relevant around the world where large subduction-tsunamigenic events are expected. A multi-hazard environment requires a holistic multi-disciplinary approach to preparedness, and examining the long-term effects and difficulties in recovery arising after 2011 provides crucial lessons to this end. The engineering and disaster mitigation communities have key roles to play in increasing resilience and ensuring that lessons learned are propagated so that losses of life, property and critical infrastructure are as far as possible prevented in the future. This report should be read by construction professionals and academics operating in short-, medium- and long- term reconstruction following disasters as well as policy makers and those in the catastrophe modelling and insurance industries. The findings presented are based on a review of the literature and key informant interviews during the EEFIT mission.

Contact

For any comments or queries about the report please contact EEFIT at mail@eefit.org.uk.

References

- EEFIT (2011), *The Mw9.0 Tōhoku Earthquake and Tsunami of 11th March 2011*, Institution of Structural Engineers (online), www.istructe.org/resources-centre/technical-topic-areas/eeffit/eeffit-reports, Dec 2011.
- Fraser, S., Raby, A., Pomonis, A., Goda, K., Chian, S. C., Macabuag, J., Sammonds, P., and others (2013). *Tsunami damage to coastal defences and buildings in the March 11th 2011 M w 9.0 Great East Japan earthquake and tsunami*. *Bulletin of Earthquake Engineering*, 11(1), 205–239. doi:10.1007/s10518-012-9348-9
- Goda, K., Pomonis, A., Chian, S. C., Offord, M., Saito, K., Sammonds, P., Macabuag, J., and others. (2013). *Ground motion characteristics and shaking damage of the 11th March 2011 M w9.0 Great East Japan earthquake*. *Bulletin of Earthquake Engineering*, 11(1). doi:10.1007/s10518-012-9371-x

Acknowledgements

The EEFIT Japan team would like to express our sincere thanks to the many following organisations and individuals for their support prior, during and following this mission, without whom we would not have been able to carry out the field trip and research so effectively.

Reviewers

- Dr. Sean Wilkinson, *Newcastle University*
- Dr. Ingrid Charvet, *University College London / Tōhoku University*
- Dr. Anawat Suppasri, *Tōhoku University*
- Mark Lenczner, *Marcai Design*
- Andrew Coatsworth, *Sellafield Ltd*

Institutions and Governmental Bodies

- Ms. Berenice Chan, *Institution of Structural Engineers*
- Keith Franklin, Sumie Ogiwara, Yuki Chamberlain and Seiichi Asano, *British Embassy in Tokyo*
- Yoshiyuki Akamatsu, Sanjaya Bhatia, Shingo Kouchi, Gerald Potutan and Gulzar Qayyum, *International Recovery Platform, UNISDR*
- Tomoya Otsuka, *Reconstruction Planning Office, Ishinomaki*
- Mitsuo Kikuchi, *Official of Rikuzentakata City*
- Tsuneaki Iguchi and Tetsuo Kikuchi, *Mayor and Vice-Mayor of Iwanuma City*
- Shuichi Sugai and Nobuaki Takahashi, *Officials of Iwanuma City*
- Hiroshi Sato and Yukiya Aizawa, *Officials of Natori City*
- Osamu Takahashi, *Executive Director of Department of Land Infrastructure, Iwate Prefecture*
- Hiroaki Yagi, *Division of Coastal Regional Development, Iwate Prefectural Government, Kamaishi*
- Yuki Kawaguchi and Atsushi Onodera, *Iwate Prefectural Government Office in Kamaishi*
- Takeshi Ogata, a member of the municipal assembly, *Kesennuma City*
- Norihisa Matsumoto, Hiroshi Itoh, *Japan Commission on Large Dams*
- Kazuro Ishigaki, *Ministry of Land Infrastructure Transport and Tourism*
- Dr Yasuo Okuda, Dr Toshikazu Kabeyasawa, Dr Hitomitsu Kikitsu, *National Institute for Land and Infrastructure Management*
- Yosuke Nakase, Akiko Nakagawa, Peter Kowalczyk, *Japan External Trade Organisation (JETRO)*
- Professor Shigeo Takahashi, Dr Taro Arikawa, Dr Kazuhiko Honda, Dr Yoshiaki Kuriyama, Dr Kenichiro Shimosako, *Port and Airport Research Institute*

Industrial Partners

- Tsuyoshi Futami, *Willis*
- Kazuya Fujimura, *AIR Worldwide*
- Toshihiro Yamada, *Risk Management Solutions*
- Akihiko Sugawara, *President of Otokoyama Sake, Kesennuma*
- Mr. Takashi Inoue, *Kajima Corporation*
- Dr Tomohiko Hatada, *Kajima Technical Research Institute*
- Yoshie Muramatsu and Masaki Tokubuchi, *Arup Tokyo*
- Yuko Ishihara, *Mott MacDonald*
- Isao Kato, Tomoji Fukushi, Nobuo Soekawa, Satoru Yasuda, Kazuo Hirata, Yoshihiro Ogata, *Onagawa Nuclear Power Station, Tohoku Electric Power Company Inc*
- Seiichi Hamada, Noritaka Sakakibara, Mari Yanase, *Chubu Electric Power Co. Inc*
- Tomohiro Kariya, *Machizukuri Manitou Co Ltd, Ishinomaki*

Academic Partners

- Professor Fumihiko Imamura, Professor Masato Motosaka, Professor Makoto Okumura, Professor Yuichi Ono, Professor Akira Mano, Associate Professor Jeremy Bricker, Associate Professor Kanako Iuchi, Associate Professor Anawat Suppasri, Research Fellow Dr Abdul Muhari, Research Associate Mr Yo Fukutani, *International Research Institute of Disaster Science (IRIDeS), Tōhoku University*
- Professor Atsushi Tanaka, *Tokyo University*
- Professor Naoshi Hirata, Professor Hiroshi Sato, Professor Kazuki Koketsu, Professor Toshimi Kabeyasawa, Assistant Professor Seizo Tanaka and Assistant Professor Hiroe Miyake, *Earthquake Research Institute, University of Tokyo*
- Professor Naomichi Kurata, Chair of the *Department of Urban Design and Planning, Kogakuin University, Tokyo*
- Ms Yoshie Isoda, Researcher, *Department of Urban Design and Planning, Kogakuin University, Tokyo*
- Professor Tomoya Shibayama, Visiting Senior Researcher Toshihiko Abe, *Waseda Institute of Urban and Regional Studies, Waseda University*
- Professor Junji Kiyono and Associate Professor Aiko Furukawa, *Graduate School of Global Environmental Studies, Kyoto University*
- Dr Charles Scawthorn, *SPA Risk LLC*
- Professor Akira Igarashi, *Research Center for Fluvial and Coastal Disasters, Disaster Prevention Research Institute, Kyoto University*
- Professor Robert Olshansky, *Department of Urban and Regional Planning, University of Illinois*

NGOs and Community Members

- Junichi Kano, *Architect at NPO Support Centre, Kamaishi*
- Masaki Takahashi, *Citizen's Restoration Committee, Kesennuma City*
- Tomoyuki Miura, *Shanti Volunteer Association, Kesennuma*
- Okamoto Shoma, Keiko Shoma, *Save Takata, Rikuzentakata*
- Hashizume Takumi, *Sakura Line, Rikuzentakata*
- Osamu Ogasawara, *Temporary Shopping Place, Hope, Rikuzentakata*
- Suzuki Shintaro and Shuichi Sugai, *fishermen of Shititachi Village, Kesennuma*
- Tomohiro Kariya, *Town Management Organization Manbou Inc., Ishinomaki*

Thanks are also due to the following organisations for funding the participation of team members:

- EPSRC for funding Dr. Alison Raby, Joshua Macabuag, Professor David Alexander, Dr. Catherine Crawford and Carlos Molina Hutt, Dr Joanna Faure-Walker
- Risk Engineering Ltd. for funding Anton Andonov
- Mott MacDonald for funding Ming Tan
- Arup for funding Jack Yiu

EEFIT would like to acknowledge the on-going support of corporate sponsors AIR Worldwide, Aon Benfield, Arup, British Geological Survey, CREA Consultants and Sellafeld Ltd.

Contents

Executive Summary	2
Contact.....	3
References.....	4
Acknowledgements	5
Reviewers	5
Institutions and Governmental Bodies.....	5
Industrial Partners	5
Academic Partners.....	6
NGOs and Community Members	6
Contents.....	7
List of figures.....	11
List of tables.....	15
1. Introduction	1
1.1. Preamble	1
1.1.1. Earthquake & tsunami	1
1.2. The 2013 EEFIT Tōhoku return mission	2
1.3. Objectives	3
1.4. Japanese collaboration	5
1.5. References	7
2. Tsunami damage to structures and new tsunami design measures for buildings	8
2.1. Tsunami data and modelling	8
2.1.1. Tsunami data – Offshore and onshore	8
2.1.2. Tsunami source modelling around Japan.....	9
2.1.3. Tsunami inundation modelling in Japan	9
2.2. New tsunami classifications	11
2.3. Tsunami damage to buildings	12
2.3.1. Tsunami damage mechanisms.....	12
2.3.2. Damage statistics	20
2.3.3. Case study: Kamaishi central business district	25
2.4. Tsunami fragility functions	27
2.4.1. Tsunami fragility functions developed from the 2011 building damage data	27
2.4.2. Tsunami vulnerability functions developed from the 2011 building damage data.....	29
2.5. Tsunami design of on-shore structures.....	30
2.5.1. Current design guidance in Japan.....	30
2.5.2. Proposed amendments to tsunami design guidance in Japan	32
2.6. Conclusions	33
2.6.1. Conclusions regarding damage data.....	33
2.6.2. Conclusions regarding tsunami fragility functions.....	34
2.6.3. Conclusions regarding tsunami-resistant design of structures	34
2.7. References	35
3. Tsunami defence structures.....	41
3.1. Classifications and typical failure mechanisms	41
3.1.1. Concrete revetments	41
3.1.2. Seawalls.....	42
3.1.3. Breakwaters	43
3.1.4. Quays.....	43
3.2. Field trip observations of reconstruction	43
3.2.1. New concrete revetments.....	43

3.2.2.	Quay walls rebuilding in Ishinomaki	47
3.2.3.	Nuclear power station seawalls	51
3.2.4.	Sea defences in Minamisanriku	54
3.3.	New approaches to coastal structure design	55
3.4.	Significant rebuilt defences	57
3.5.	Conclusions	57
3.6.	References	58
4.	Nuclear industry and critical facilities	60
4.1.	Background.....	60
4.2.	Fukushima Daiichi NPP	60
4.2.1.	What happened to the Fukushima Daiichi NPP?	60
4.2.2.	Decommissioning strategy for Fukushima Daiichi NPP.....	61
4.3.	Implication to Nuclear Industry.....	62
4.3.1.	Japan	62
4.3.2.	International	67
4.3.3.	United Kingdom.....	68
4.4.	Reports on visit to NPPs.....	69
4.4.1.	Onagawa NPP.....	69
4.4.2.	Hamaoka NPP.....	73
4.5.	Critical facilities	78
4.5.1.	General	78
4.5.2.	Visit to Nishigo Dam	80
4.5.3.	Visit to Fujinuma Dam	82
4.6.	Concluding Remarks and discussions on readiness of another event.....	84
4.7.	References	85
5.	Temporary housing	87
5.1.	Shelter after disasters.....	87
5.2.	Transitional shelter and settlement in Japan: terminology, strategy and regulation.....	88
5.2.1.	Terminology	88
5.2.2.	Strategy.....	88
5.2.3.	Regulation	88
5.3.	Key facts and figures on transitional shelter after the Great East Japan Earthquake and Tsunami.....	89
5.3.1.	Strategic options and individual choice	89
5.3.2.	Location, livelihood and care.....	90
5.3.3.	Covered living space and land	92
5.3.4.	Scale and speed.....	92
5.3.5.	Construction cost and quality control.....	93
5.4.	Transitional shelter response and recovery in the context of prevailing trends.....	95
5.4.1.	Temporary housing after previous disasters	95
5.4.2.	Settlement planning and covered living space	96
5.4.3.	Construction	102
5.4.4.	Case studies: alternatives to pre-fabricated housing from large suppliers	104
Multi-storey containers (ARUP, 2013; Shigeru Ban Architects, 2012).....	104	
Early repair supported by a non-governmental organisation (Ashmore et al., 2012).....	105	
5.5.	Concluding remarks: learning from Japan	109
5.5.1.	Strategic options and individual choice	109
5.5.2.	Location, livelihood and care.....	109
5.5.3.	Covered living space and land	109
5.5.4.	Scale and speed, cost and quality control	109
5.5.5.	Looking ahead.....	110
5.6.	References	110
6.	Urban planning and recovery.....	114

6.1.	Post disaster urban planning in Japan.....	114
6.1.1.	Planning process: coordination, regional strategy, city plans	115
6.1.2.	Land use and transport	116
6.1.3.	Use of information and science	118
6.2.	Bay of Sendai	119
6.2.1.	Yuriage Village, Natori City	120
6.2.2.	Iwanuma.....	120
6.2.3.	Ishinomaki.....	121
6.3.	Towns of the Rias Coastline	125
6.3.1.	Kesennuma.....	126
6.3.2.	Kamaishi	127
6.4.	Conclusions	128
6.4.1.	Demographic and economic issues.....	129
6.4.2.	Citizen involvement in decision making.....	130
6.5.	References	131
7.	Emergency management, disaster response and recovery.....	134
7.1.	Evolution of emergency management and response in Japan 2011-2013	134
7.1.1.	Emergency management and response at the time of the tsunami	134
7.1.2.	Developments in emergency management and response after the tsunami.....	135
7.2.	Measures against tsunamis within the 'all-hazards' perspective.....	136
7.2.1.	Interaction between measures for tsunamis and for other hazards	136
7.2.2.	Environmental protection and disaster reduction	137
7.3.	Balance between structural and non-structural measures	138
7.4.	Involvement of civil society and NGOs in disaster response and recovery.....	141
7.4.1.	Non-governmental organisations for disaster risk reduction and response	141
7.4.2.	Local leaders and other elements of civil society	141
7.5.	Balance between national, regional and local involvement in disaster response and recovery	142
7.6.	Disaster culture.....	142
7.7.	Conclusions	145
7.8.	References	147
8.	Financial management and Japan earthquake insurance.....	149
8.1.	Economic losses.....	149
8.1.1.	The Great East Japan Earthquake within the earthquake models	149
8.2.	Insured losses.....	150
8.3.	The Japanese insurance industry	151
8.3.1.	Primary insurance	151
8.3.2.	Reinsurance	152
8.3.3.	Capital markets	153
8.4.	Insurance policy structures	153
8.4.1.	Residential	153
8.4.2.	Non residential	154
8.4.3.	Life, health and accident	154
8.5.	Claims management.....	154
8.6.	Catastrophe models.....	155
8.6.1.	The Great East Japan Earthquake within the earthquake models	155
8.6.2.	Early loss estimates	156
8.7.	Financing of post disaster recovery	156
8.7.1.	Where the recovery costs are coming from.....	156
8.7.2.	Financial services and economic stability.....	158
8.7.3.	Compensation	158
8.7.4.	Examples of private-government partnerships for commerce	158
8.7.5.	NGO example from Rikuzentakata.....	159

8.8. Conclusions	160
8.9. References	160

List of figures

Figure 1.1 (left) USGS Shake map in Google Earth showing the epicentre, fault plane and the Modified Mercalli Intensity (MMI) distribution.	1
Figure 1.2 (right) Tsunami inundation extent mapped by Asia Air Survey KK (Asia Air Survey, 2011), overlaid on map of Tōhoku region, Japan, in Google Earth. An approximately 500 km long coastline (in red) has been affected.	1
Figure 1.3 The three prefectures most affected by the 2011 tsunami: Iwate, Miyagi, Fukushima (Ministry of Foreign Affairs, 2013). These Prefectures form part of the Tōhoku region, which refers to the Northeastern portion of Honshu Island comprising of six Prefectures: Akita, Aomori, Fukushima, Iwate, Miyagi and Yamagata.	4
Figure 1.4 Locations visited by the EEFIT team during the mission, spread over three prefectures (350 km stretch) of the Tōhoku region. Note that several meetings in the Tokyo and Kanagawa area are not shown on the map (e.g. British Embassy, PARI, Waseda University and others), as well as a visit to Hamaoka Nuclear Power Plant, Shizuoka Prefecture. See Table 1.2 for a full list of visited destinations.	4
Figure 1.5 EEFIT team and collaborators - standing (from left): AR, MT, JY, Dr Maki Koyama, DA, SP, ES, FW, Dr Anawat Suppasri; Crouching (from left): CC, CMH, Miss Farnaz Mahdavian, Miss Saki Yotsui, Mr. Ryo Yuasa. See Table 1.1 for EEFIT team initials.	6
Figure 1.6 EEFIT team and collaborators: (from left) CMH, CC, Professor Hitomi Murakami, DA, AA, AR, JM, Mr Ryo Yuasa, AP, Mayor Tsuneaki Iguchi, JY, SP, Dr Maki Koyama, ES, Miss Farnaz Mahdavian.	6
Figure 2.1 NOWPHAS equipment for tsunami detection (Kawai, Satoh, Kawaguchi, & Seki, 2011).	8
Figure 2.2 Offshore tsunami time-histories. The black records show the recorded waveforms, the red show recreated waveforms in a study by Gusman et al. (2012), one of several studies proposing source models based on Japan data.	9
Figure 2.3 Illustration of Level 1 and Level 2 tsunami with respect to a coastal defence structure.	11
Figure 2.4 Out-of-plane failure of walls due to lateral fluid load (hydrostatic and hydrodynamic).	13
Figure 2.5 Global lateral deflection/failure due to lateral fluid load (hydrostatic and hydrodynamic).	14
Figure 2.6 Damage due to debris impact and damming.	15
Figure 2.7 Soft-storey and disproportionate collapse.	16
Figure 2.8 Non-structural damage.	17
Figure 2.9 Scour undermining foundations building corners.	18
Figure 2.10 Overturning of structures due to a combination of tsunami effects (lateral fluid forces, buoyancy, debris impact and foundation failure).	19
Figure 2.11 Additional seismic damage indicated by conjugate shear cracking of facade in Kamaishi.	20
Figure 2.12 FDMA Damage Survey Form (FDMA, 2001).	22
Figure 2.13 Damage scale specified by the Japan Cabinet Office (2011) with translations by EEFIT.	23
Figure 2.14 Tsunami damage states used in the MLIT surveys (bottom-right image corresponds to level 1 in Figure 2.15, and top-left to level 6) (MLIT 2011).	24
Figure 2.15: MLIT damage states description (Suppasri et al., 2013).	24
Figure 2.16 8-storey mixed-use RC vertical evacuation structure in 2011 (left) and 2013 (right).	25
Figure 2.17 Retained building where inundation did not reach the 2nd floor, in 2011 (left) and 2013 (right). Note the adjacent building (which experienced the same inundation) has been demolished.	26
Figure 2.18 Retained steel framed building which suffered inundation up to the 2nd floor, in 2011 (left) and 2013 (right). Despite complete damage to non-structural finishes, the structural elements remain without significant damage.	26
Figure 2.19 Retained building with 2m inundation, in 2011 (left) and 2013 (right). Damaged non-structural finishes have been replaced and the building is now in use.	26
Figure 2.20 Comparison of wooden building damage criteria related to inundation depth since 2004 (Suppasri et al., 2013).	27
Figure 2.21 Fragility functions (mixed building types) for Ishinomaki comparing the coastal plains (left) and mountainous coastline (right) (Suppasri et al., 2013).	29
Figure 2.22 Damage scale and associated mean damage ratios used in the study by Masuda et al. (2012). Note that the order of damage states is opposite to that shown in Figure 2.15. (DS_DR) refers to the	

damage ratios (cost or repair as a percentage of property replacement value) associated with each damage state.....	29
Figure 2.23 Vulnerability curve for single-storey wooden structures (Masuda et al., 2012). Sigma+ and Sigma- represent the upper and lower confidence intervals, represented by the error bars shown. Inundation depth is in metres (m).....	30
Figure 2.24 Tsunami wave-loading for structural design recommended by Japanese guidance based on Nistor, Palermo, Nouri, & Murty (2004).....	30
Figure 2.25 Proposed amendments to the tsunami loading coefficient (after Nishiyama et al. (2012) and Fukuyama et al. (2012)).....	32
Figure 2.26 Japanese proposed design methodology for tsunami evacuation buildings (Fukuyama et al., 2012).....	33
Figure 3.1 (left) EEFIT team members reading a plaque indicating recent completion of section.....	44
Figure 3.2 (right) Abrupt end to recently completed revetment at Arahama.....	44
Figure 3.3 (top left) Seaward slope of newly built concrete revetment at Arahama.....	45
Figure 3.4 (top right) Steps on landward slope of concrete revetment at Arahama.....	45
Figure 3.5 (bottom left) Armour units on landward side of Arahama revetment, showing grout-filled lifting holes.....	45
Figure 3.6 (bottom right) Visible infill between armour units at Arahama revetment.....	45
Figure 3.7 (left) Construction of revetments at Arahama.....	46
Figure 3.8 (right) Seaward slope of Arahama revetments under construction.....	46
Figure 3.9 (left) Crest and seaward slope of Yuriage concrete revetment.....	46
Figure 3.10 (right) Crest of Yuriage concrete revetment.....	46
Figure 3.11 (left) Armour units on seaward slope of Yuriage concrete revetment with unfilled circular holes.....	47
Figure 3.12 (right) Sand-covered steps on seaward side of Yuriage concrete revetment.....	47
Figure 3.13 (left) Old and new ground levels at Ishinomaki fishing port.....	47
Figure 3.14 (right) Sloping ground into warehouse following recent elevation of ground levels in Ishinomaki fishing port.....	47
Figure 3.15 Elevated ground level at Ishinomaki fishing port.....	48
Figure 3.16 (left) Sheet piling for quay construction at Ishinomaki fishing port.....	48
Figure 3.17 (right) Sheet piling and formwork at Ishinomaki.....	48
Figure 3.18 (left) Formwork at Ishinomaki.....	49
Figure 3.19 (right) Newly-cast concrete sections of quay wall at Ishinomaki.....	49
Figure 3.20 (left) Renovated quay wall at Ishinomaki fishing port.....	49
Figure 3.21 (right) Close-up view of renovated quay wall showing original metal mooring bollard.....	49
Figure 3.22 Pair of photographs taken in the 2011 (left) and 2013 (right) EEFIT missions, towards the northern end of Onagawa port.....	50
Figure 3.23 Pair of photographs taken in the 2011 (left) and 2013 (right) EEFIT missions, towards the southern end of Onagawa port.....	50
Figure 3.24 Bridge piers for new quay in Onagawa.....	50
Figure 3.25 Locations of Onagawa and Hamaoka nuclear power stations (image source: Google Maps).....	51
Figure 3.26 (left) Scale model of Hamaoka NPS lines of defences in visitor centre.....	52
Figure 3.27 (right) Close-up of landward side of seawall in Hamaoka NPS visitor centre.....	52
Figure 3.28 Construction of tsunami wall at Hamaoka NPS (reproduced by kind permission of Seiichi Yamada, Hamaoka, NPS).....	53
Figure 3.29 Additional buttresses on Hamaoka NPS tsunami wall (reproduced by kind permission of Seiichi Yamada, Hamaoka, NPS).....	53
Figure 3.30 Pair of photographs taken in the 2011 (left) and 2013 (right) EEFIT missions across the port of Minamisanriku.....	54
Figure 3.31 (left) New port structure in Minamisanriku.....	55
Figure 3.32 (right) Close-up of Minamisanriku port structure with jetties and characteristic wooded island beyond.....	55
Figure 3.33 (left) Information board for the Millennium Hope Hills project in Iwanuma.....	56
Figure 3.34 (right) Steps up the first Millennium Hope Hill to be completed.....	56
Figure 4.1 Accident Progression for the Fukushima Daiichi Incident.....	61

Figure 4.2 Roadmap to restoration of Fukushima Daiichi site (extracted from [TEPCO, 2013]).	62
Figure 4.3 New regulatory policies and major requirements (source: Enforcement of the New Regulatory Requirements for Commercial Nuclear Power Reactors, NRA, July 8, 2013).	66
Figure 4.4 Comparison between the previous and the new regulatory requirements (source: Enforcement of the New Regulatory Requirements for Commercial Nuclear Power Reactors, NRA, July 8, 2013).	67
Figure 4.5 Timeline of Shutdown at Onagawa and Fukushima Daiichi (extracted from (Kato, 2013)).	70
Figure 4.6 Internal Flooding on the Heat Exchanger of Unit 2 (extracted from (Kato, 2013)).	71
Figure 4.7 Proposed “Super-Seawall” of Onagawa NPP (extracted from (Soekawa, 2013)).	72
Figure 4.8 Aerial Schematic of Hamaoka NPP (reproduced from Hamaoka NPP, 2013).	73
Figure 4.9 Earthquake Source Areas near Hamaoka Nuclear Power Plant (reproduced from Hamaoka NPP, 2013).	74
Figure 4.10 Seismic strengthening work undertaken in Hamaoka NPP (reproduced from Hamaoka NPP, 2013).	75
Figure 4.11 Conceptual design of Hamaoka NPP after Tsunami Countermeasures Implementation (reproduced from Hamaoka, 2013).	76
Figure 4.12 Tsunami protection wall currently under construction at Hamaoka NPP (reproduced from Hamaoka, 2013).	76
Figure 4.13 External and internal reinforced doors for reactor buildings at Hamaoka NPP (reproduced from Hamaoka, 2013).	77
Figure 4.14 Schematic diagram of the tsunami protection wall currently under construction (reproduced from Hamaoka, 2013).	78
Figure 4.15 Location and type of dams in the Tōhoku region (Matsumoto, 2011).	79
Figure 4.16 Location of the dams in Fukushima Prefecture, Nishigo and Fujinuma dams were inspected (Matsumoto, 2011).	80
Figure 4.17 Cracks in the crest of Nishigo Dam observed immediately after the earthquake on March 11, 2011 (Matsumoto, 2011).	81
Figure 4.18 Covering the cracks on the crest of Nishigo Dam to prevent water intrusion (Matsumoto, 2013).	81
Figure 4.19 Repair works on the upstream surface of the Nishigo Dam (Matsumoto, 2013).	82
Figure 4.20 Integrated map of slides of Fujinuma main dam (Sakamoto, 2012).	83
Figure 4.21 Fujinuma main dam after the earthquake (Matsumoto, 2011).	84
Figure 5.1 Parking area for Oya District transitional settlement.	91
Figure 5.2 Site plan of transitional settlement showing parking areas in Amagasawa area, Kesenuma city.	91
Figure 5.3 Number of transitional shelter packages delivered after GEJE (ADRC & IRP, 2011b; BRI & NILIM, 2011; IRP, 2012; MHLW, 2011).	93
Figure 5.4 Number of transitional shelter packages delivered after the Haiti earthquake (EPYPSA, 2011; UCLBP & IASC CCCM Cluster, 2013; UN-HABITAT, 2012).	93
Figure 5.5 International comparison of shelter projects (Ashmore et al., 2010, 2011; Ashmore, Urquia, & D’Urzo, 2012; IRP, 2012).	94
Figure 5.6 Household support packages in Japan (Ashmore et al., 2012; Brasor & Tsubuku, 2011; Federation of Housing and Community Centers, 2011; IRP, 2012; Japan Statistics Bureau, 2008; Japanese Red Cross Society, 2011).	94
Figure 5.7 Predominant transitional shelter option in each affected prefecture (IRP, 2012).	100
Figure 5.8 Annual rates of house completions in Japan.	103
Figure 5.9 Evolution of prefabricated housing (Daiwa House).	103
Figure 5.10 Temporary housing after the 2011 GEJE and tsunami taken from (ADRC & IRP, 2011a).	104
Figure 6.1 Recovery Governance Structure post GEJE (Iuchi, Johnson and Olshansky, 2013).	115
Figure 6.2 Reconstruction Agency Local offices (Reconstruction Agency, 2013) [red circles Prefecture Bureaus; blue dots Branch Offices].	116
Figure 6.3 Special measure for land readjustment (Reconstruction Agency, 2013).	117
Figure 6.4 (Left) The Millennium Hills master plan, Iwanuma.	121
Figure 6.5 (Right) Pilot demonstration hill built to aid fund raising.	121
Figure 6.6 Tsunami inundation area in Ishinomaki (Toyoshima et al, 2012).	122
Figure 6.7 Plans for housing relocation in Ishinomaki (Toyoshima et al, 2012).	123

Figure 6.8 Zoning Plan for Ishinomaki (Toyoshima et al, 2012).....	123
Figure 6.9 Organisation of Stakeholder Committee to redevelop the Ishinomaki CBD (Toyoshima et al, 2012).	124
Figure 6.10 (Left) Ogata House before the tsumani.....	127
Figure 6.11 (Right) Ogata House after the tsunami.....	127
Figure 7.1 Elevated plinth for housing under construction at Iwanuma.	137
Figure 7.2 Culture in relation to coastal hazards in Japan.	143
Figure 7.3 Partially rebuilt cemetery within the unrebuilt devastated area, Ishnomaki.	144
Figure 7.4 Children's satchels, unclaimed in a former gymnasium, Arahama school.....	144
Figure 7.5 Ship stranded by the tsunami in Kesenuma City.....	145
Figure 7.6. A classification of organisational learning (after Lam 2000).	146
Figure 8.1 How insured losses are ceded for different levels of insured event loss. All values are in Japanese Yen (exchange rate at time of 2011 Great East Japan Earthquake approximately ¥80 per US\$). Note for insured losses above the capacity of the programme (¥5.5bn at time of Great East Japan Earthquake, ¥6.2bn since 6 th April 2012) claims will be paid in proportion to the capacity of the programme divided by the total claims payment limit (GIROJ, 2011). Figure uses data from JER (2011) and JER (2012).	152

List of tables

Table 1.1 EEFIT Tōhoku team members (in alphabetical order).....	2
Table 1.2 Locations visited by EEFIT.....	5
Table 2.1 Tsunami level descriptors (Shibayama et al., 2013).....	11
Table 2.2 Comparison of national damage statistics (Fire and Disaster Management Agency, 2013; National Police Agency, 2013).....	21
Table 2.3 Damage statistics considering only buildings within the tsunami inundation zone, released by MLIT 26 th December 2011 (Ministry of Land Infrastructure Tourism and Transport, 2011).	21
Table 2.4 Fragility functions developed from 2011 damage data.	28
Table 2.5 Legislation and guidance documents relevant to tsunami design and planning in Japan.	31
Table 2.6 Proposed amendments to the tsunami loading coefficient (Fukuyama et al., 2012).	33
Table 3.1 Terminology used to describe seminal coastal defence structures.	41
Table 4.1 Fuel and Fuel Debris Removal Timeline (extract from [METI, 2013]), FY stands for Financial Year.....	62
Table 4.2 Data concerning Units 1, 2 & 3 at Onagawa NPP, Source: (Onagawa NPP, 2011).	70
Table 4.3 Damages to the units at Onagawa NPP (extracted from [Kato, 2013]).	71
Table 4.4 Predicted Tsunami height and site grade evaluation at Onagawa NPP (extracted from (Kato, 2013)).	72
Table 4.5 Reactors at Hamaoka NPP.	73
Table 4.6 Historical Tōkai earthquake (extracted from Wikipedia, 2013 ¹).	74
Table 4.7 Inspected dams after the earthquake (Matsumoto, 2011).	79
Table 4.8 Specification of Fujinuma dam.	82
Table 5.1 Transitional Shelter Options and Choices (compiled from various sources).	90
Table 5.2 Pre-disaster options and choice.	98
Table 5.3 Pre-disaster living space and land.	99
Table 5.4 Pre-disaster location, livelihood and care.....	100
Table 5.5 Summary of characteristics by prefecture.	101
Table 5.6 History of pre-fabricated housing in Japan summarised from (J Barlow & Ozaki, 2005; Iwashita, 2001)	104
Table 5.7 Average floor areas by tenure type, Japan (Japan Statistics Bureau, 2008).....	106
Table 5.8 Average floor areas by prefecture (Japan Statistics Bureau, 2008).	106
Table 5.9 Post-disaster floor areas by country (Ashmore et al., 2010, 2011; Federation of Housing and Community Centers, 2011).....	107
Table 5.10 Minimum standards and targets for floor areas (Fukushige & Ishikawa, 2013; Sphere project, 2011)	108
Table 6.6.1 Principle land use changes envisaged.	117
Table 6.6.2 Places visited classified by relative strength of economy and size.....	130
Table 8.1 Special Account for Reconstruction, Main Expenses related to the Great East Japan Earthquake (Adapted from MOF, 2011c and MOF, 2013).	157

1. Introduction

1.1. Preamble

1.1.1. Earthquake & tsunami

On March 11, 2011, a M_w 9.0 earthquake occurred in the Japan Trench off the coast of Tōhoku in north-east Japan (Figure 1.1). Ground shaking was felt as far as western Japan and lasted for almost four minutes (220 seconds), generating tsunami waves that seriously affected approximately 650 km of the Pacific Ocean shores of Northern Honshu Island (Figure 1.2). The large, unprecedented tsunami toppled sea defences, inundated more than 500 km² of land and destroyed entire settlements and towns along this coastline causing the loss of 18,500 lives including nearly 2,700 missing persons. This M_w 9.0 earthquake was the largest event that has been recorded in Japan since the beginning of instrumental seismology circa 1900 and contributed 5 percent of the global cumulative seismic energy released since 1900 (Witze, 2011).

This earthquake that in Japan came to be called the Great East Japan Earthquake and Tsunami (GEJE) destroyed nearly 400,000 dwellings of which nearly 318,000 in the tsunami affected Municipalities and partially damaged another 773,000 of which over 440,000 were in the tsunami affected Municipalities (FDMA, 2013). In addition it severely damaged critical infrastructure and buildings (such as vertical evacuation structures, schools, Municipal administration buildings and hospitals) and caused the second most serious nuclear crisis in the history of the World due to the damage and ensuing explosions that took place at the Fukushima Daiichi Nuclear Power plant.

Two years after the event, the recovery process is still in its initial stages. Debris has been cleared, reconstruction work has started on 31 percent of destroyed embankments, and Japan is dealing with a difficult temporary housing situation. Construction of new-permanent housing has taken longer than originally planned, but has been quite beneficial as it allowed for longer consultation process.

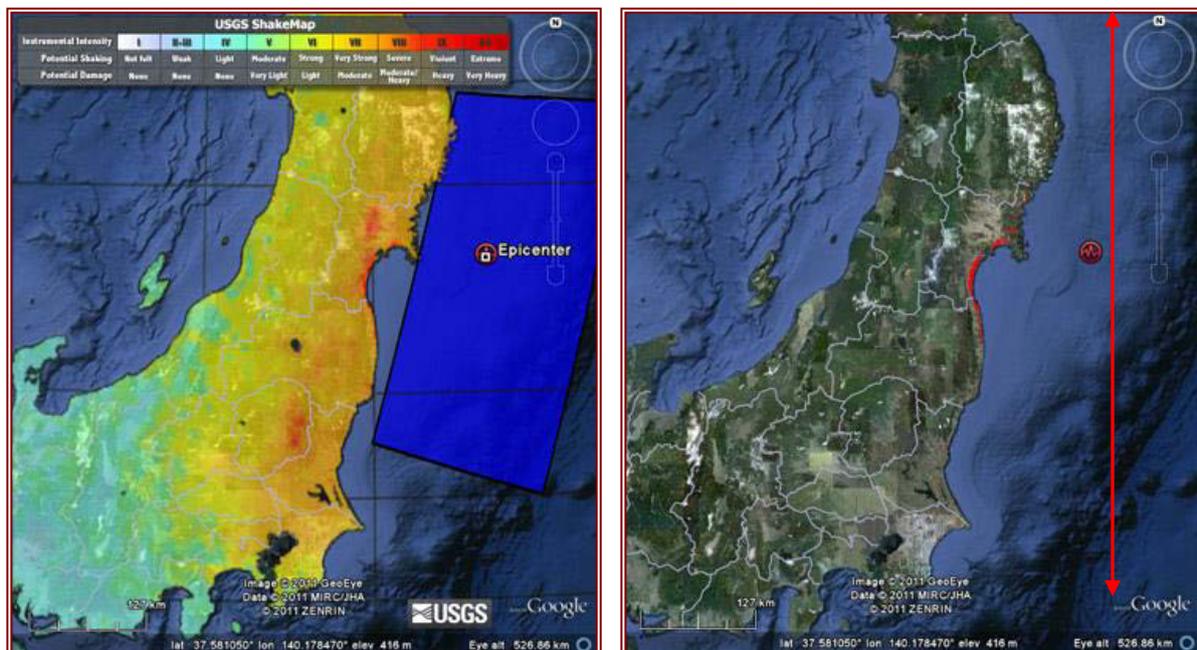


Figure 1.1 (left) USGS Shake map in Google Earth showing the epicentre, fault plane and the Modified Mercalli Intensity (MMI) distribution.

Figure 1.2 (right) Tsunami inundation extent mapped by Asia Air Survey KK (Asia Air Survey, 2011), overlaid on map of Tōhoku region, Japan, in Google Earth. An approximately 500 km long coastline (in red) has been affected.

1.2. The 2013 EEFIT Tōhoku return mission

Considering the historic significance of the event, the long-term effect it has had on Japan's society and its implications for various built environment professions around the World, EEFIT deployed a return field mission to the Tōhoku region to collect data on reconstruction efforts, perform key informant interviews and learn lessons relevant to construction professionals operating in short-, medium- and long- term reconstruction following disasters as well as policy makers and those in the catastrophe modelling and insurance industries. The team consisted of 12 members with wide-ranging backgrounds and research interests reflecting the complex nature of the March 11, 2011 event (see Table 1.1).

Table 1.1 EEFIT Tōhoku team members (in alphabetical order).

Name	Initials	Affiliations	Area of Interest
Prof. David ALEXANDER	DA	University College London	Emergency planning and management: disaster recovery & reconstruction
Mr. Anton ANDONOV	AA	Risk Engineering Ltd. (Bulgaria)	Structural design of seismic/tsunami resistant systems & infrastructure; Seismic strengthening of industrial & energy facilities; Urban planning for disaster resilience
Dr. Catherine CRAWFORD	CC	University College London	Post-disaster humanitarian shelter programmes; Sustainable urban infrastructure
Mr. Joshua MACABUAG	JM	University College London	Tsunami Vulnerability of Buildings
Mr. Carlos MOLINA HUTT	CMH	University College London	High rise design, structural and earthquake Engineering
Dr. Stephen PLATT	SP	Chairman, Cambridge Architectural Research, Ltd.	Disaster recovery
Mr. Antonios POMONIS (<i>Team Leader</i>)	AP	Director, Cambridge Architectural Research, Ltd.	Earthquake risk assessment & mitigation; Tsunami resilience
Dr. Alison RABY	AR	University of Plymouth	Coastal Engineering: Extreme wave impacts and overtopping
Dr. Emily Kwok Mei SO	ES	University of Cambridge	Earthquake casualties, damage assessment and recovery
Dr. Ming TAN	MT	Mott MacDonald	Seismic analysis & assessment of existing nuclear facilities
Mr. Jack YIU	JY	Arup	Planning & redevelopment after disaster

1.3. Objectives

The 2013 mission was different to the usual post-disaster reconnaissance missions successfully mounted by EEFIT in the past. This was a mission with a much broader scope in direct relation to the overwhelming effects of the March 11, 2011 earthquake, which caused widespread tsunami disaster to 600 km of coastline, widespread (though mostly moderate in nature) damage to buildings due to ground shaking, a lethal landslide and dam failure (in Fukushima prefecture) and widespread liquefaction in the northern shores of Tokyo Bay. Finally, this tremendous earthquake was followed by an extremely serious nuclear accident at the Fukushima Daiichi Nuclear Power Plant and therefore two of the team members had a direct interest in meeting with nuclear industry officials and learn more about the preparedness in other nuclear power plants.

The 2013 return mission to Japan therefore had many objectives in line with the interests of its members. These are listed below:

- Visit towns devastated by the tsunami and hold interviews with local authorities, people directly involved in reconstruction and recovery projects to learn about the challenges faced, the level of recovery, the new city master plans and local people's participation in the future of their cities;
- Visit the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) Tōhoku Regional Bureau in Sendai to learn about the overall recovery planning and progress so far;
- Visit areas designated for temporary housing to discuss with local associations issues related to recovery, financial uncertainties and future plans;
- Identify whether there have been revisions in design guidance (increased protection, design wave) of the sea defences destroyed or damaged during 2011; identify to what extent the affected defences are being replaced; investigate the process by which tsunami defence structures are agreed for a location;
- Visit to Hamaoka Nuclear Power Plant in Shizuoka Prefecture which has a new 18m tall tsunami wall and is implementing new disaster countermeasures and is under threat from the expected nearby Tokai earthquake;
- Visit to Onagawa Nuclear Power Plant in Miyagi Prefecture, with objectives such as discussion with the plant management about their experiences during 2011 and how these have changed the mode of operation since then, learn about any improvements to the tsunami protection of the plant, discuss their new disaster management plans in the advent of the 2011 earthquake, discuss the nuclear emergency management in the Onagawa region, discuss more detailed engineering issues (design standards) and how the plant performed during the strong ground shaking of March 11, 2011;
- Visit three dams in the affected area, from different types and constructed at different periods, including the collapsed Fujinuma dam, to assess the damages and the recovery process. Meeting with Japanese experts and the exploitation staff to discuss the seismic safety measures undertaken before and after the Tōhoku earthquake as regulations, seismic codes, emergency procedures, etc.

During the 2013 return mission, issues related to the effect of ground shaking on building structures and other infrastructure were not investigated due to the limited evidence of earthquake damage, as opposed to tsunami damage, two years after the event. For a review of these effects, the reader is encouraged to refer to the relevant sections in the 2011 EEFIT Mission to Japan Field Report as well as other reconnaissance trips that took place in the aftermath of the event when the impact of ground shaking on building structures and other infrastructures was most apparent and accessible to reconnaissance teams (EEFIT, 2011a; Fraser et al., 2013; Goda et al., 2013).

The multi-faceted effects have been far reaching and long-lasting, and some of the long-term impacts are only now starting to become apparent. The effects of this disaster have inter-linked implications or many industries including structural and coastal engineering, nuclear energy, catastrophe modelling, insurance and financial sectors, town planning, emergency relief and post-disaster shelter. This report attempts to highlight the key implications for each of these sectors that are emerging two years after the event.

The mission was carried out between 28 May and 7 June 2011. The team separated into different groups each day in order to conduct various key informant interviews in a number of locations. The team hired two cars and separated into two to three teams, depending on the itinerary for the day. The team returned to Sendai every day, apart from 5-6 June when some members stayed in the north to conduct visits to Kamaishi, Kesennuma and Rikuzentakata. The mission's itinerary is shown in Table 1.2 and the main locations visited are marked in Figure 1.4.



Figure 1.3 The three prefectures most affected by the 2011 tsunami: Iwate, Miyagi, Fukushima (Ministry of Foreign Affairs, 2013). These Prefectures form part of the Tōhoku region, which refers to the Northeastern portion of Honshu Island comprising of six Prefectures: Akita, Aomori, Fukushima, Iwate, Miyagi and Yamagata.

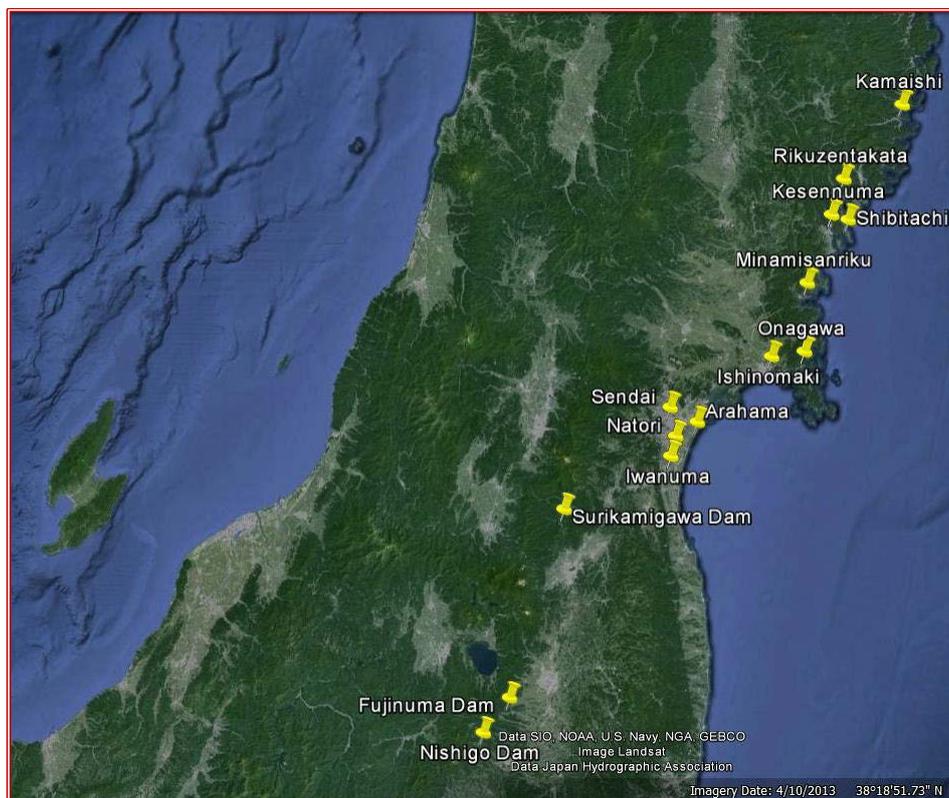


Figure 1.4 Locations visited by the EEFIT team during the mission, spread over three prefectures (350 km stretch) of the Tōhoku region. Note that several meetings in the Tokyo and Kanagawa area are not shown on the map (e.g. British Embassy, PARI, Waseda University and others), as well as a visit to Hamaoka Nuclear Power Plant, Shizuoka Prefecture. See Table 1.2 for a full list of visited destinations.

Table 1.2 Locations visited by EEFIT.

Date	Activity	Participants
28-May	Meeting: Willis	JM
29-May	Meetings: Tokyo University, AIR Worldwide	JM
30-May	Meetings: RMS, IStructE Japan	JM
31-May	Meeting @ Kajima Corporation (Nuclear)	CMH
31-May	Meeting @ PARI	JM/AR
01-Jun	Orientation field trip: Arahama, Yuriage, Iwanuma, Sendai Airport	DA/AA/CC/CMH/JM/SP/AP/AR/MT/JY
02-Jun	Orientation field trip: Minamisanriku, Ishinomaki, Onagawa, Matsushima	DA/AA/CC/CMH/ES/SP/AP/AR/MT/JY
03-Jun	Meeting: TRB Sendai	CC/CMH/JM/AR
03-Jun	Ishinomaki field trip	AP/DA/ES/SP/JFW
03-Jun	Meeting: Prof. Mano, Tōhoku University	AR/JM
03-Jun	JCOLD (Dams) field trip	AA/JY/MT
04-Jun	Kamaishi field trip	JM/JY/SP/ES/CC
04-Jun	Rikuzentakata field trip	AP/DA/JFW
04-Jun	Onagawa NPP visit	AA/MT/CMH
04-Jun	Waseda U visit	AR
05-Jun	Meeting: JETRO	CMH, JW, JY
05-Jun	Kesennuma field trip Group A: Oya coastal zone, Saichikawara, Koesuma	DA/CC/JM
05-Jun	Kesennuma Group B: Oya coastal zone, Shibilitachi village, Kesennuma port	AP/SP/ES
05-Jun	Hamaoka NPP	MT/AA/AR
05-Jun	ERI Tokyo	CMH/JY
05-Jun	Kajima Technical Research Institute	CMH/JY
05-Jun	Tōhoku University	JFW
06-Jun	Meetings: Iwanuma, Natori, IRIDeS	AP/CC/SP/ES/DA/AA/CMH/AR/JM/JY
07-Jun	Meeting: Arup	CMH/JY/AA/JM/CC
07-Jun	Embassy meeting	DA/CC/JM/AA/JY/CMH

1.4. Japanese collaboration

Whilst in Tōhoku, the EEFIT team received assistance from numerous Japanese organisations and individuals and would like to express particular thanks to: Professor Hitomi Murakami (Yamaguchi University); Dr Maki Koyama (Kyoto University); the International Research Institute of Disaster Science (IRIDeS), in particular Dr Anawat Suppasri (Associate Professor, IRIDeS, Tōhoku University).

A full acknowledgements list is presented at the beginning of this report.



Figure 1.5 EEFIT team and collaborators - standing (from left): AR, MT, JY, Dr Maki Koyama, DA, SP, ES, FW, Dr Anawat Suppasri; Crouching (from left): CC, CMH, Miss Farnaz Mahdavian, Miss Saki Yotsui, Mr. Ryo Yuasa. See Table 1.1 for EEFIT team initials.



Figure 1.6 EEFIT team and collaborators: (from left) CMH, CC, Professor Hitomi Murakami, DA, AA, AR, JM, Mr Ryo Yuasa, AP, Mayor Tsuneaki Iguchi, JY, SP, Dr Maki Koyama, ES, Miss Farnaz Mahdavian.

1.5. References

- EEFIT (2011), *The Mw9.0 Tōhoku Earthquake and Tsunami of 11th March 2011*, Institution of Structural Engineers (online), www.istructe.org/resources-centre/technical-topic-areas/eeffit/eeffit-reports, Dec. 2011.
- Fraser, S., Raby, A., Pomonis, A., Goda, K., Chian, S. C., Macabuag, J., Offord, M., Saito, K. and Sammonds, P.. (2013). *Tsunami damage to coastal defences and buildings in the March 11th 2011 M w 9.0 Great East Japan earthquake and tsunami*. *Bulletin of Earthquake Engineering*, 11(1), 205–239. doi:10.1007/s10518-012-9348-9
- FDMA (2013). Fire and Disaster Management Agency of Japan, *Report 148 on the effects of the March 11, 2011 Great Tōhoku earthquake*, September 9, 2013. <http://www.fdma.go.jp/bn/2013/detail/691.html> (accessed on October 18, 2013).
- Goda, K., Pomonis, A., Chian, S. C., Offord, M., Saito, K., Sammonds, P., Fraser, S., Raby, A. and Macabuag, J. (2013). *Ground motion characteristics and shaking damage of the 11th March 2011 M w9.0 Great East Japan earthquake*. *Bulletin of Earthquake Engineering*, 11(1). doi:10.1007/s10518-012-9371-x
- Witze, A. (2011). *Seismologists rumble over quake clusters*. *Science News* 179(10) 7 May 2011.

2. Tsunami damage to structures and new tsunami design measures for buildings

Various updates are now being proposed to tsunami building design guidance in Japan and the USA, based on extensive damage surveys carried out in the aftermath of the 2011 Great East Japan Earthquake and tsunami. This is a subject which has limited coverage in European guidance despite significant historical tsunamis in Europe (National Oceanic and Atmospheric Administration (NOAA), n.d.). Although ground-shaking damage was very significant, this chapter will focus on the tsunami as this event provides an unprecedented quantity and quality of tsunami data for tsunamis, providing a unique opportunity to learn lessons in an under-developed field when compared to seismic engineering.

This chapter considers tsunami inundation, building damage mechanisms, damage statistics, future damage predictions and proposed mitigation strategies including proposed revisions to tsunami design guidance documents.

2.1. Tsunami data and modelling

Tsunami hazard modelling is undertaken for the design of key structures (see Section 2.5 and Chapter 3), but also for town and evacuation planning and for the quantification of risk. The numerical modelling process can typically be broken down into the following steps, from wave generation to coastal inundation:

- Tsunami generation (modelling the wave induced by seafloor displacements);
- Wave propagation (from the source to nearshore);
- Interaction with the shoreline (e.g shoaling and reflections);
- Inundation over the land.

2.1.1. *Tsunami data – Offshore and onshore*

Real tsunami data allows for the validation and improvement of tsunami models, and this event has provided an unprecedented amount of such data. Offshore tsunami time-histories are available from Japan's Nationwide Ocean Wave Information network for Ports and Harbours (NOWPHAS) as shown in Figure 2.2, measured by equipment represented in Figure 2.1.

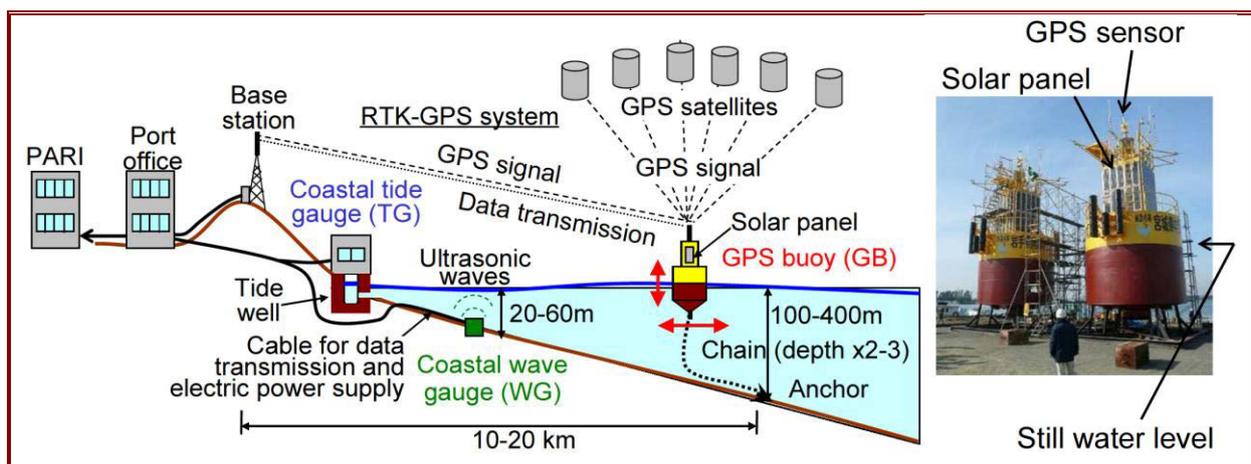


Figure 2.1 NOWPHAS equipment for tsunami detection (Kawai, Satoh, Kawaguchi, & Seki, 2011).

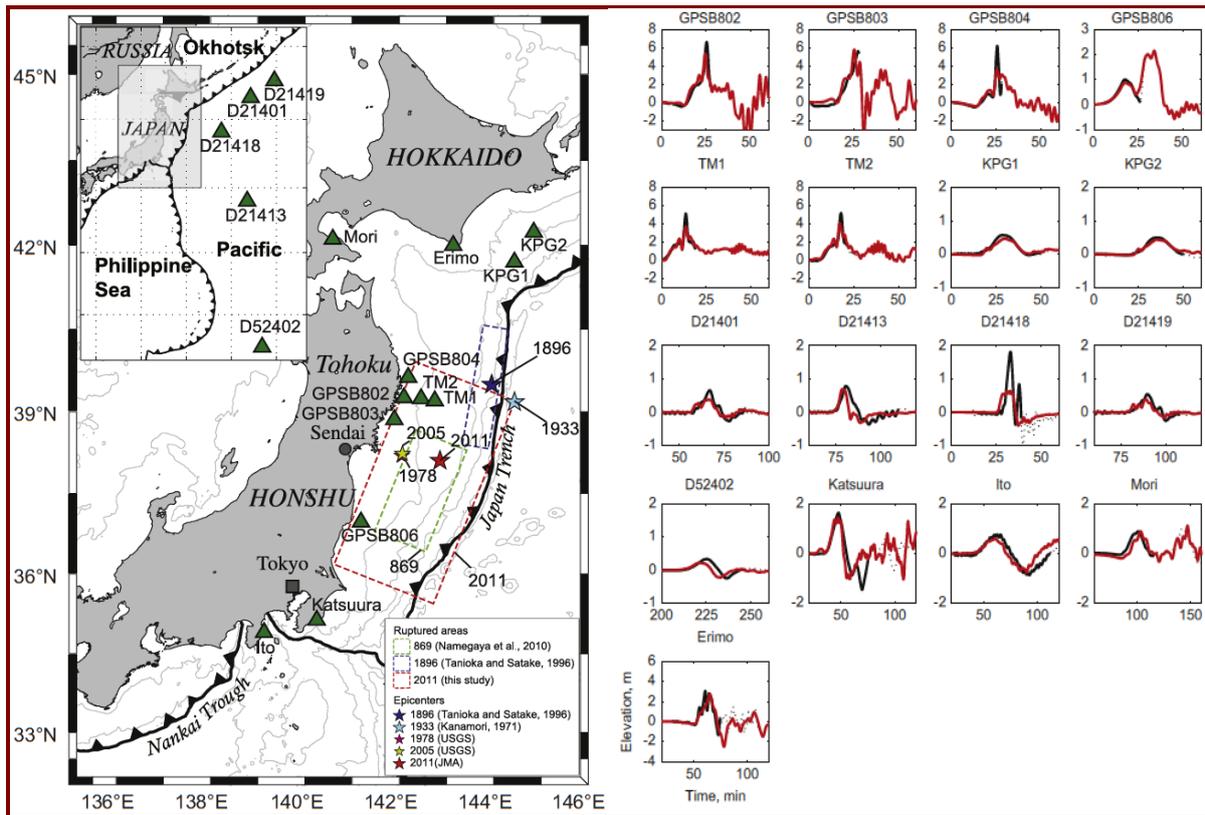


Figure 2.2 Offshore tsunami time-histories. The black records show the recorded waveforms, the red show recreated waveforms in a study by Gusman et al. (2012), one of several studies proposing source models based on Japan data.

2.1.2. Tsunami source modelling around Japan

The Japan National Seismic Hazard Maps produced by the Headquarters for Earthquake Research Promotion (HERP) were previously used as the principal hazard indicator within catastrophe models. The HERP source models are updated about once a year, but following the Great East Japan Earthquake significant updates were called for. Of particular note is that prior to this earthquake, the HERP source model indicated that earthquakes along this section of the trench could have a maximum magnitude of 7.5 (AIR Worldwide, 2012), a threshold significantly below the 9.0 magnitude of this event. However, following the Great East Japan Earthquake, the HERP source model has been updated with an event equivalent to the Great East Japan Earthquake having an average return period of 600 years (AIR Worldwide, 2012). The updates to the HERP model will also include changes in the seismic segment boundaries because this earthquake had a rupture length that crossed several of the previously assigned segment boundaries. (Note elsewhere in the world, there have been examples where large magnitude earthquakes along subduction zones have disputed segment boundary theories by rupturing across them, such as the Sumatra 2004 Boxing Day Earthquake). Current research is also focussing on the effect of the Great East Japan Earthquake on the surrounding faults and whether this event has increased or decreased the probability for other large magnitude events. Note also that time dependent models will show an increased hazard due to the expected aftershocks associated with the Great East Japan Earthquake.

2.1.3. Tsunami inundation modelling in Japan

Numerical modelling of waves is based on the classic mass and momentum conservation laws, and computationally implemented using stepwise solving algorithms. Computational fluid dynamics applied to wide domains is particularly complex and computationally expensive, as the fluid surface

changes simultaneously with the domain, which is bounded by a time varying shoreline. A full representation of the fluid dynamics, including the Navier-Stokes equations, would be computationally prohibitive for anything other than a small region of interest. Therefore, they are typically simplified for the modelling of entire regions. A key assumption that is used for this simplification arises from the fact that the wavelength to water depth ratio of a tsunami is so large that it can be considered to be a shallow water wave. This provides a simplification where vertical components of velocity or acceleration can be omitted, and pressure is regarded as hydrostatic. These assumptions are the ones used in Shallow Water models, which have been extensively used over the past decades for tsunami modelling. Different techniques have been developed for solving the resulting equations depending on the computational time, complexity of technique, accuracy and availability of the final results having an influence on the choice of technique and model. Many of the existing models have been tested on benchmark tsunami problems, as summarised by Liu et al. (2008). The two most significant Shallow Water inundation models used in Japan are described below.

TUNAMI (Tōhoku University Numerical Analysis Modelling for Inundation):

This software model was developed by Professor Fumihiko Imamura of the International Research Institute of Disaster Science at Tōhoku University (IRIDeS). The original model arose from the Tsunami Inundation Modelling Exchange (TIME) program that was supported by the International Union of Geodesy and Geophysics and UNESCO's Intergovernmental Oceanographic Commission. The project sought to provide numerical simulation techniques to regions that were prone to tsunami occurrence, with freely available source code and manuals leading to the use of this model beyond Japan. There are several TUNAMI programs, covering both constant and fixed grids, with standard Cartesian and spherical co-ordinates (for ocean propagation), but all using a finite difference technique to solve the shallow water equations. The software is currently being used to model tsunami propagation and runup at a variety of locations, with results being used to generate inundation maps.

STOC (Storm surge and Tsunami simulator in Oceans and Coastal areas):

STOC has been developed by the Port and Airport Research Institute (PARI) and is a more complex model based upon the Navier-Stokes equations, the general governing equations of fluid dynamics. It balances the requirement for accurate representation with reasonable computational time by using two nested sub-models: STOC-IC which models fine detail with a domain area of around tens of square kilometres using the Reynolds turbulence model with no assumptions of hydrostatic pressure and STOC-ML which does assume hydrostatic pressure and as a result is computationally faster and can be used for ocean tsunami propagation (Honda & Takashi, 2008). The inclusion of turbulence modelling in STOC-IC means that accurate wave-structure interactions are possible. At a presentation given to EEFIT during our visit to PARI on 31st May 2013, Kazuhiko Honda showed how the drifted multi-body model, STOC-DM, has been used in conjunction with STOC-IC and STOC-ML to model drifted vessels and containers in ports following tsunami inundation.

Several other inundation models are used internationally, including:

- MOST (Method of Splitting Tsunami) developed by Titov & Synolakis (1998) is used by the US National Ocean and Atmospheric Administration (NOAA). It is a nested model based on the shallow water equations using either spherical or Cartesian coordinates and it forms the basis of tsunami forecasting models in the U.S.;
- COMCOT (Cornell Multigrid Coupled Tsunami Model) developed by Liu et al. (1998) is another shallow water wave model that can use multigrids and either spherical or Cartesian coordinate systems;
- DELFT3D a general coastal hydrodynamics suite of software has recently been used for tsunami generation;

2.2. New tsunami classifications

Following the 2011 event, Japan has been working towards a tsunami level classification system to inform hazard planning. The process has involved debate between disaster management experts and the government. A consensus on tsunami classification has been achieved and is now implemented in Japan, though it has only recently been conveyed to an international audience (Shibayama et al., 2013).

The definition of tsunami levels is dependent on the frequency of the events: Level 1 corresponds to fairly frequent tsunami occurrence of a relatively modest inundation and Level 2 corresponds to more rare events with extensive inundation. These are described in Table 2.1.

Table 2.1 Tsunami level descriptors (Shibayama et al., 2013).

Level	Tsunami return period	Inundation depth
1	Several decades to around a hundred or so years	7 – 10 m
2	Few hundred to thousands of years	More than 10 m

However, Shibayama et al. 2013 explain that the level events are specific to particular locations as the same tsunami source will have different effects depending on proximity to the tsunami source and effect of local bathymetry. Also, what might be a rare level of inundation in one location might be more frequent in another.

Therefore at a particular location it is necessary to investigate historic tsunamis from field data and documentary records and combine these with numerical simulations of past and predicted future tsunamis using seismic data. Using tsunami heights as a function of date, the levels corresponding to return periods of approximately a hundred and up to a thousand years can be obtained, determining the Level 1 and Level 2 values.

Once a defined level has been set the tsunami defences can be designed. The defences should be built to withstand a Level 1 event, to protect property and help in the protection of life (Shibayama et al., 2013) but the worst-case scenario Level 2 event must also be anticipated. The actual height of the defence to protect against a Level 1 event may be informed by local community considerations, the local topography, bathymetry and further numerical simulations (see for example discussions on the Hamaoka Nuclear Power Plant in Chapter 4). The defence should be able to withstand a Level 2 tsunami but it would not be feasible or desirable to build structures that would not be overtopped at this level, so for these events there must be soft or non-structural measures in place e.g. evacuation areas. Figure 2.3 illustrates the design levels.

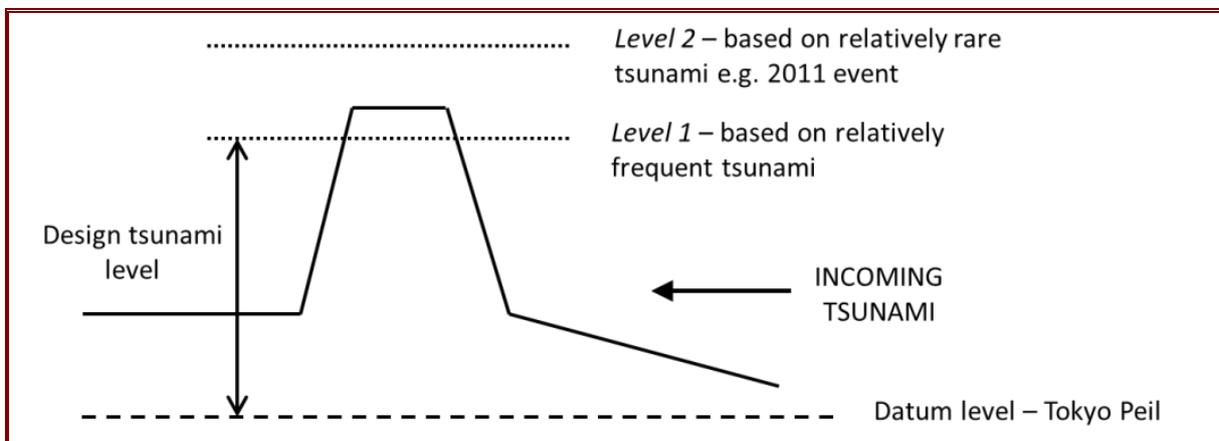


Figure 2.3 Illustration of Level 1 and Level 2 tsunami with respect to a coastal defence structure.

2.3. Tsunami damage to buildings

Ground shaking damage was a significant contributor to building damage across Japan. However, the impact of the tsunami on structures was a unique aspect of this disaster, for which there is now data of unprecedented quantity and quality. This section therefore outlines the key findings of the EEFIT return mission regarding building damage due to the tsunami and proposed design measures.

2.3.1. *Tsunami damage mechanisms*

This event exhibited tsunami-induced building damage due to the following effects:

- Hydrostatic forces (of the form $\sim k\rho gh$):
 - Lateral fluid pressure;
 - Vertical buoyancy effects;
- Hydrodynamic forces (of the form $\sim k\rho hu^2$):
 - Drag;
 - Bore impact (i.e. the impulse applied by the leading edge of the water);
- Debris (a function of $m, \sqrt{u}, \Delta t$):
 - Impact from large water-borne objects (e.g. cars, ships, shipping containers, trees, building fragments etc.);
 - Increase in flow viscosity/density due to collected smaller debris/sediment;
 - Damming (filling of openings with debris, increasing the effective area experiencing lateral load);
- Foundation Effects:
 - Scour;
 - Uplift;
 - Sliding;

Where k = constant (indicating proportionality), ρ = density, g = acceleration due to gravity,

h = inundation depth, u = flow velocity, m = mass of debris, Δt = debris impact duration.

It is difficult to isolate failure mechanisms associated with each of these effects individually as they often occur in combination. The main observed failure and damage mechanisms for consideration in analysis and design are summarized in Figure 2.4 to Figure 2.10.



Figure 2.4 Out-of-plane failure of walls due to lateral fluid load (hydrostatic and hydrodynamic).

The top images (left and right) of Figure 2.4 show deformed Reinforced Concrete (RC) shear-walls in Minami Gamou Wastewater Treatment Plant. The bottom images show failed RC walls in Onagawa. Note that analysis of the bottom left structure can be found in Chock et al. (2013), which describes the failed wall as 120 mm thick with a single central layer of 8 mm smooth reinforcement bars at 200 mm centres horizontally and vertically.



Figure 2.5 Global lateral deflection/failure due to lateral fluid load (hydrostatic and hydrodynamic).

The top left image of Figure 2.5 shows failed columns of a two-storey RC moment-resisting frame (Fukuyama, Kato, & Ishihara, 2013). The top-right image shows residual deformation of a moment-resisting (in the direction of failure) RC frame in Rikuzentakata (Tokyo Institute of Industrial Science, 2011). The bottom image shows residual deformation of a moment-resisting steel frame building in Onagawa.



Figure 2.6 Damage due to debris impact and damming.

The top images of Figure 2.6 show evidence of a large debris impact on the top floor of this overturned RC-framed building in Onagawa. The bottom left image demonstrates log impacts (Fukuyama et al., 2013). The bottom right image (from Shichigahama) demonstrates how debris can dam openings increasing the lateral fluid forces (hydrostatic and hydrodynamic) on the structure.



Figure 2.7 Soft-storey and disproportionate collapse.

The bottom-left image of Figure 2.7 shows the collapse of a steel moment-resisting frame building due to buckling of a ground floor column leading to overturning of the structure and pull-out of the remaining ground floor columns (due to lateral fluid forces) (Fukuyama et al., 2013). All other images of Figure 2.7 show soft-storey failures of timber framed buildings in Kamaishi. Note that all of these failures may have been caused by a combination of several tsunami effects (lateral fluid forces, buoyancy, debris impact and foundation effects) and ground shaking.

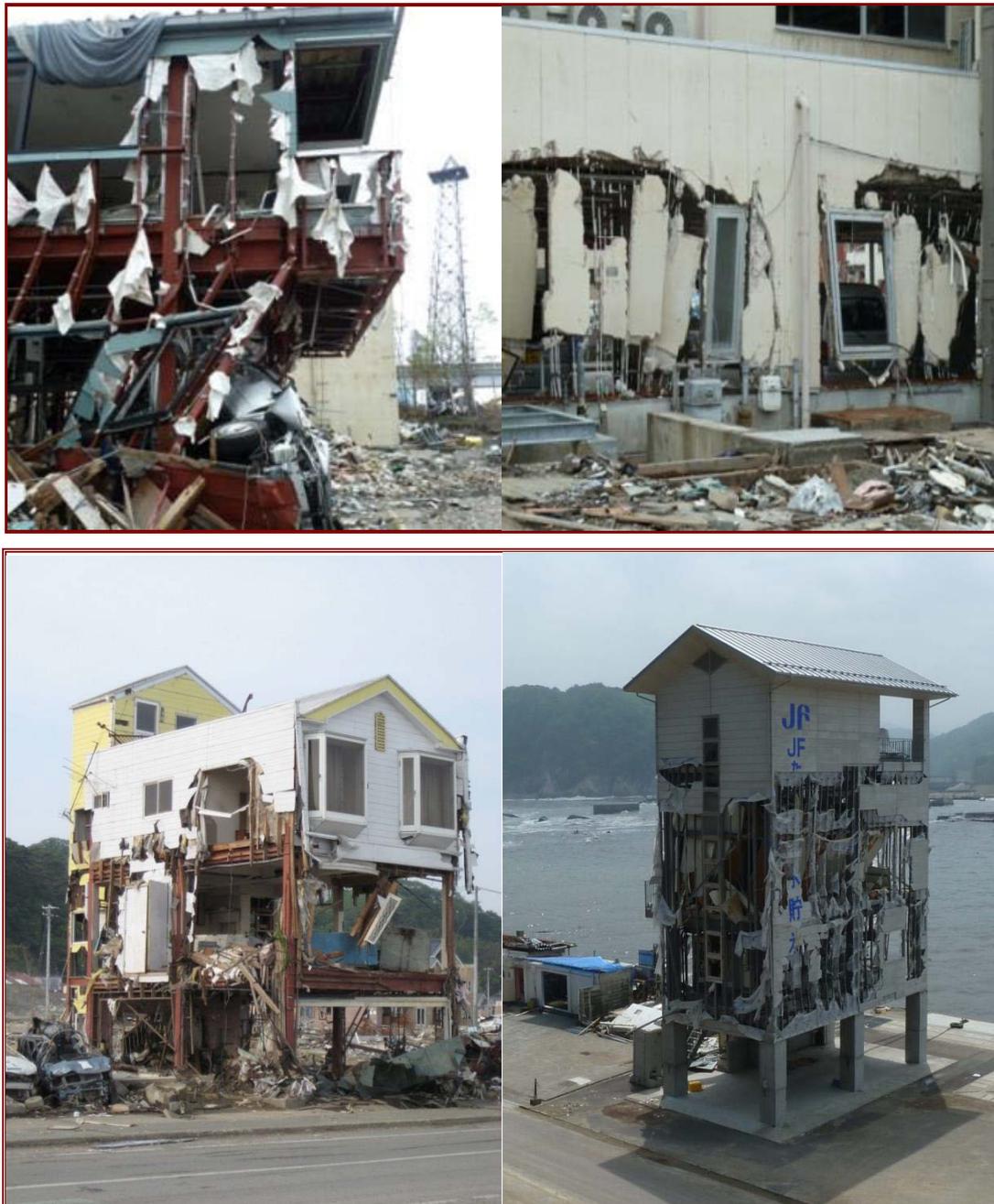


Figure 2.8 Non-structural damage.

The top-left image of Figure 2.8 shows deformed steel studwork on the external face of a steel frame structure in Kamaishi, due to a combination of fluid flow forces and debris impact (note the car pressed against the structural columns). The top-right image shows cladding panels on the ground floor (otherwise an open-plan car park) of an RC frame and shear wall evacuation structure in Kamaishi. The structure in the bottom-left image (in Ishinomaki) shows complete damage of non-structural elements up to the level of maximum inundation depth, whilst the structural steel frame remains relatively intact. Similarly the RC frame of the bottom-right image remains relatively intact despite extensive non-structural damage up to the inundation depth. Although structural damage may be limited, non-structural damage can render the building unsuitable for occupancy or use and may lead to the building being demolished rather than repaired (see also Chapter 8).



Figure 2.9 Scour undermining foundations building corners.

The bottom-right image of Figure 2.9 was taken in Onagawa, the other images are of single-storey structures in Arahama, Wakabayashi-ku, Sendai, whose structural stability has been compromised due to scour undermining the foundations.



Figure 2.10 Overturning of structures due to a combination of tsunami effects (lateral fluid forces, buoyancy, debris impact and foundation failure).

The top-left image of Figure 2.10 illustrates an overturned and displaced timber-framed building in Ofunato (this type of failure for timber structures was ubiquitous in this disaster). The top-right image shows an overturned and displaced two-storey RC shear wall Police Box with raft foundation in Onagawa. The central two images are of overturned multi-storey RC (left) and steel (right) piled structures in Onagawa (analysis of the steel building can be found in Chock et al. (2013)). The bottom two images are from Fukuyama et al. (2013) and show an overturned steel framed structure (left) due to failure of the column base connection (right).

An alternative categorization of failure and damage mechanisms by construction material (e.g. steel, RC or wood) is given in a report by NILIM (National Institute for Land and Infrastructure Management) (Fukuyama et al., 2013). An important factor in determining a structure's resistance to loading from near-field tsunami is the level of damage sustained from the preceding ground shaking (Figure 2.11).



Figure 2.11 Additional seismic damage indicated by conjugate shear cracking of facade in Kamaishi.

2.3.2. *Damage statistics*

Comprehensive damage surveys have been conducted by several organisations including:

- National Institute for Land and Infrastructure Management (NILIM);
- Japanese Building Research Institute (BRI);
- Ministry of Land, Infrastructure, Tourism, and Transport (MLIT);
- National Police Agency (NPA);
- Fire and Disaster Management Agency (FDMA);

Table 2.2 shows the latest available (as of September 2013) national damage datasets which include both tsunami and ground shaking-induced damage. For derivation of tsunami fragility functions it is necessary to consider only tsunami-induced damage, as shown in Table 2.3.

Discrepancies between publically available damage data from different sources (Table 2.2) for some damage states shows that it is important to reference several sources and examine the underlying methods and assumptions used for deriving each dataset.

Damage assessment forms have been used in Japan for many years. Figure 2.12 shows part of a damage assessment form taken from a 2001 amendment of an FDMA report originally published in 1970. Following the tsunami (31st March, amended on 12th April, 2011) the Japan Cabinet Office released damage scale guidance (Figure 2.13) and MLIT developed their own scale for use in their damage survey (Figure 2.14, Figure 2.15).

Table 2.2 Comparison of national damage statistics (Fire and Disaster Management Agency, 2013; National Police Agency, 2013).

Damage State	FDMA report 147 26th March 2013 (No. of Bldgs)	NPA Report 10th July 2013) (No. of Bldgs)
Total Collapse of Residential. Buildings	128,801	126,467
Half Collapse of Residential. Buildings	269,675	272,244
Partially Damaged Residential. Buildings	756,814	742,068
Inundated above floor level (ground storey)	3,352	3,352
Inundated below floor level (ground storey)	17,454	10,218
Damaged Public Buildings	21,257	59,176
Other damaged Non-Residential. Buildings	75,272	
Burnt Buildings (Residential & Non-Residential)	330	297
TOTAL	1,252,149	1,213,822

Table 2.3 Damage statistics considering only buildings within the tsunami inundation zone, released by MLIT 26th December 2011 (Ministry of Land Infrastructure Tourism and Transport, 2011).

MLIT Damage State	No. of Bldgs
Washed Away	92,420
Collapsed	33,864
Complete Damage (flooded above ground floor ceiling)	9,438
Major Damage	38,695
Moderate Damage (inundated above floor level at ground floor)	42,999
Minor Damage (inundated below floor level at ground floor)	21,302
TOTAL	238,718

Neither FDMA nor NPA conducted their own surveys to compile their damage data as the scale of the disaster was enormous. They instead both used data from the respective Municipality damage surveys, which may explain the similarities between their respective damage datasets (Table 2.2). However, whilst FDMA and NPA require data on structural damage for use in future disaster planning, the Municipal officers conducting the surveys were looking to gather information for the issue of damage certificates, used to define the level of compensation received by victims of the tsunami (guidance by Japan Cabinet Office (2013)). Furthermore, the Municipality surveys are not necessarily gathered by trained structural engineers (due to the scale and time-constraints of the task), and there were likely discrepancies between the experience and methodologies of the surveyors in different Municipalities.

都道府県		区		分		被		害		
災害名	確定年月日	月	日	時	確定	田	流失・埋没	ha		
							冠水	ha		
報告者名						畑	流失・埋没	ha		
							冠水	ha		
報告者名						そ の 他	文教施設	箇所		
区		分		被			病院	箇所		
人的被害	死者	人					道路	箇所		
	行方不明者	人					橋りょう	箇所		
被害	負傷者	重傷	人				河川	箇所		
		軽傷	人				港湾	箇所		
住家被害	全壊	棟					砂防	箇所		
		世帯					清掃施設	箇所		
		人					崖くずれ	箇所		
住家被害	半壊	棟					鉄道不通	箇所		
		世帯					被害船舶	隻		
		人					水道	戸		
住家被害	一部破損	棟					電話	回線		
		世帯					電気	戸		
		人					ガス	戸		
住家被害	床上浸水	棟					ブロック塀等	箇所		
		世帯								
		人								
住家被害	床下浸水	棟			り		災世帯数	世帯		
		世帯			り		災者数	人		
		人								
非住家	公共建物	棟					火災発生	建物	件	
		その他	棟					危険物	件	
		その他	棟					その他	件	

Figure 2.12 FDMA Damage Survey Form (FDMA, 2001).

The EEFIT team were informed that Municipality officers used the FDMA form for their assessment, but that there were discrepancies in how this form was used (for example, one Municipality officer reported that they did not input any data regarding building inundation (“inundation above/below ground floor” in Figure 2.12), others added this information but also included those buildings again in the minor/partial/total damage categories. This can be seen when examining the FDMA dataset (Fire and Disaster Management Agency, 2013), which shows that the building inundation data has only been entered for some of the tsunami affected Municipalities. Attempted correction for this may account for differences between the FDMA and NPA data for certain damage states (Table 2.2).

MLIT conducted their own surveys in tsunami affected regions only (using the damage criteria in Figure 2.13, Figure 2.14 and Figure 2.15) and released their data online in three stages on 4th August, 4th October and 26th December 2011 (Ministry of Land Infrastructure Tourism and Transport, 2011).

	Description	Damage State		Description	Damage State
	住家流失	全壊	<input checked="" type="checkbox"/>	Washed Away	Total Collapse
	概ね1階天井まで浸水	全壊	<input checked="" type="checkbox"/>	Inundated to approximately ground floor ceiling or above	Total Collapse
	床上浸水概ね1m	大規模半壊	<input checked="" type="checkbox"/>	Inundated approximately 1m or more above floor level at ground floor	Large Scale Half Collapse
	床上浸水	半壊	<input checked="" type="checkbox"/>	Inundated above floor level at ground floor	Half Collapse
	床下浸水	一部損壊	<input checked="" type="checkbox"/>	Inundated below floor level at ground floor	Partial Damage

Figure 2.13 Damage scale specified by the Japan Cabinet Office (2011) with translations by EEFIT.

区分	全壊 (流失)	全壊	全壊 (1階天井以上浸水)
主な建物 状況	基礎だけ残して、建物が完全に流されている	主要構造が損壊しており補修により元通りに再使用することが困難	1階天井以上浸水しており、大規模修繕等による再使用も可能
サンプル 写真			
区分	大規模半壊	半壊 (床上浸水)	一部損壊 (床下浸水)
主な建物 状況	床からおおむね1m以上(天井未満)浸水している	床から概ね1m未満の床上浸水(一部補修により再利用可能)	床下の泥を取り除けば再利用可能
サンプル 写真			

Figure 2.14 Tsunami damage states used in the MLIT surveys (bottom-right image corresponds to level 1 in Figure 2.15 , and top-left to level 6) (MLIT 2011).

Damage level	Classification	Description	Condition
1	Minor damage	There is no significant structural or non-structural damage, possibly only minor flooding	Possible to be use immediately after minor floor and wall clean up
2	Moderate damage	Slight damages to non-structural components	Possible to be use after moderate repair
3	Major damage	Heavy damages to some walls but no damages in columns	Possible to be use after major repairs
4	Complete damage	Heavy damages to several walls and some columns	Possible to be use after a complete repair and retrofitting
5	Collapsed	Destructive damage to walls (more than half of wall density) and several columns (bend or destroyed)	Loss of functionality (system collapse). Non-repairable or great cost for retrofitting
6	Washed away	Washed away, only foundation remained, total overturned	Non-repairable, requires total reconstruction

Figure 2.15: MLIT damage states description (Suppasri et al., 2013).

2.3.3. Case study: Kamaishi central business district

Kamaishi Town is situated in an east-facing bay, with urban development concentrated along a river valley 1.1 km wide at the port, bounded by steep hills to the north and south. The casualties in Kamaishi as of 9th September 2013 stood at 986 dead and 152 missing (FDMA, 2011). This is 2.9 percent of the city's population and 8.9 percent of the population estimated by the Geospatial Information Authority of Japan (GSI) to be living in the inundated zone.

EEFIT carried out a damage survey on 31st May 2011 along 1 km of a road comprising 2- to 3-storey mixed-use commercial and residential buildings and a few commercial buildings of over 5-storeys (EEFIT, 2011a). The same location was surveyed on 4th June 2013 and comparisons for some of the surviving buildings are shown in Figure 2.16 to Figure 2.19 below (2011 images are on the left, 2013 on the right).



Figure 2.16 8-storey mixed-use RC vertical evacuation structure in 2011 (left) and 2013 (right).

Inundation in the location shown in Figure 2.16 was up to the 3rd floor (EEFIT, 2011a). Note that the adjacent low-rise RC building (fully inundated) and steel frame vertical car park (tall, white structure to the front of the top-left image) have been removed, along with the damaged lower-floor cladding elements. Note also that the vertical car park structure on the seaward side of the evacuation building appears to act as a debris buffer, and the light reinforcing of the cladding panels allowed for their blow-out so relieving lateral fluid pressures experienced by the structure. It is unclear whether these design measures were deliberate.



Figure 2.17 Retained building where inundation did not reach the 2nd floor, in 2011 (left) and 2013 (right). Note the adjacent building (which experienced the same inundation) has been demolished.

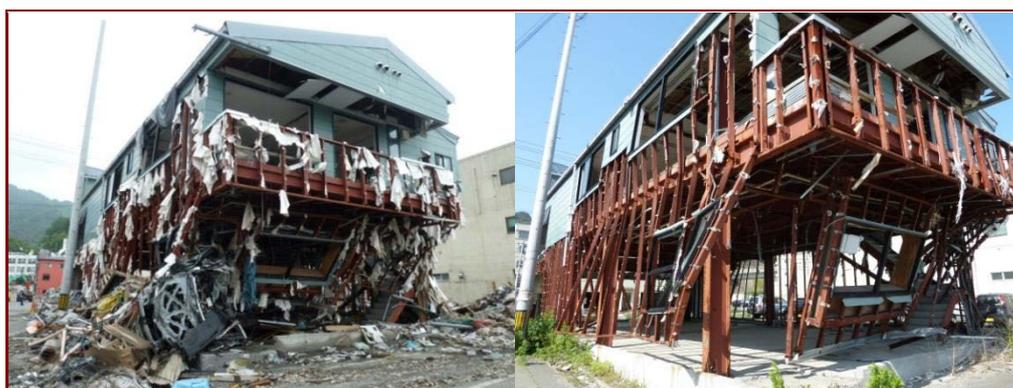


Figure 2.18 Retained steel framed building which suffered inundation up to the 2nd floor, in 2011 (left) and 2013 (right). Despite complete damage to non-structural finishes, the structural elements remain without significant damage.



Figure 2.19 Retained building with 2m inundation, in 2011 (left) and 2013 (right). Damaged non-structural finishes have been replaced and the building is now in use.

2.4. Tsunami fragility functions

Information regarding predicted future tsunami is used to estimate losses via damage, fragility and vulnerability functions. Fragility functions provide a probabilistic link between a tsunami Intensity Measure (IM) and the damage, expressed in damage states of increasing severity. They allow for quantification of risk and so are vital to both building loss estimation and Performance Based Tsunami Engineering (PBTE). Vulnerability curves are cumulative distribution functions that relate human or financial losses to the IM. Both fragility and vulnerability curves are specific to a given building type in a particular location.

2.4.1. Tsunami fragility functions developed from the 2011 building damage data

Empirical tsunami fragility functions are developed using building damage data observed after tsunamis. Studies which derive fragility and vulnerability functions from the 2011 data are shown in Table 2.4. Figure 2.21 shows an example of two fragility functions developed by Tōhoku University from the 2011 building damage data. The results are plotted against the surveyed tsunami inundation depths. Note that empirical fragility functions are very specific to the locations from where damage data was taken, as similar construction types from different countries (Figure 2.20) or regions (Figure 2.21) can perform very differently under the same tsunami conditions.

Tsunami event	Location	Damage description as a function of inundation depth
2004 Indian Ocean 2006 Java 2009 American Samoa 2010 Chile	Various	1.0 m: no damage to moderate damage 1.5 m: minor damage to collapse 2.0 m: moderate damage to collapse 2.5 m: major damage to wash away 3.0 m: collapsed or washed away
2011 East Japan tsunami	Plain coast in Sendai and Ishinomaki	2.5 m: minor damage 3.0 m: moderate damage 4.0 m: major damage 4.5 m: complete damage
2011 East Japan tsunami	All Tohoku region	0.5 m: minor or moderate damage 1.0 m: major damage 2.0 m: complete damage or collapse 3.0 m: washed away

Figure 2.20 Comparison of wooden building damage criteria related to inundation depth since 2004 (Suppasri et al., 2013).

Table 2.4 Fragility functions developed from 2011 damage data.

Reference	Source of Damage Data	Building Classes	Number of Buildings	Number of Damage States	y variable	x variable	Source of x-variable values
Suppasri, Mas, Koshimura, et al. (2012)	Survey (Miyagi, Japan – by research team)	2 types: Wood, Mixed type (RC & steel)	189	5	Damage probability	Inundation Depth	Field Survey
Suppasri, Mas, Charvet, et al. (2012)	Survey (Tōhoku, Japan by MLIT)	RC, Steel, Wood, Masonry (separated for 1, 2 & 3 storeys)	251,301	7	Damage probability	Inundation Depth	Field Survey
Masuda et al. (2012)	Survey (Tōhoku, Japan by MLIT)	Reinforced Concrete, Steel, Wood, Masonry	237,372	8	Mean Damage Ratio	Inundation Depth	Field Survey
Yanagisawa & Yanagisawa (2012)	Survey (Sendai – by research team)	Wooden Houses	202	4	Damage probability	Damage probability	Inundation Modelling
Koshimura & Gokon, (2012)	Satellite image and field survey	Combines All Types Into One Class	157,640	2	Damage probability	Inundation Depth	Inundation Modelling
Maruyama, Kitamura, & Yamazaki, (2011)	Survey (Asahi City, Chiba Prefecture)	Combines All Types Into One Class	335	5	Damage probability	Inundation Depth, Flow Velocity, Hydrodynamic Force	Inundation Modelling
Nihei, Maekawa, Ohshima, & Yanagisawa, (2012)	Satellite image and field survey (Natori)	RC, Steel, Wood	5,000	2	Building Survival Probability	Distance From Shore	Field Survey
Suppasri, Charvet, Kentaro, & Imamura (2014)	Survey (Ishinomaki Japan by MLIT)	RC, Steel, Wood, Masonry (separated for 1, 2 & 3 storeys)	63,605	7	Damage probability	Inundation Depth	Field Survey

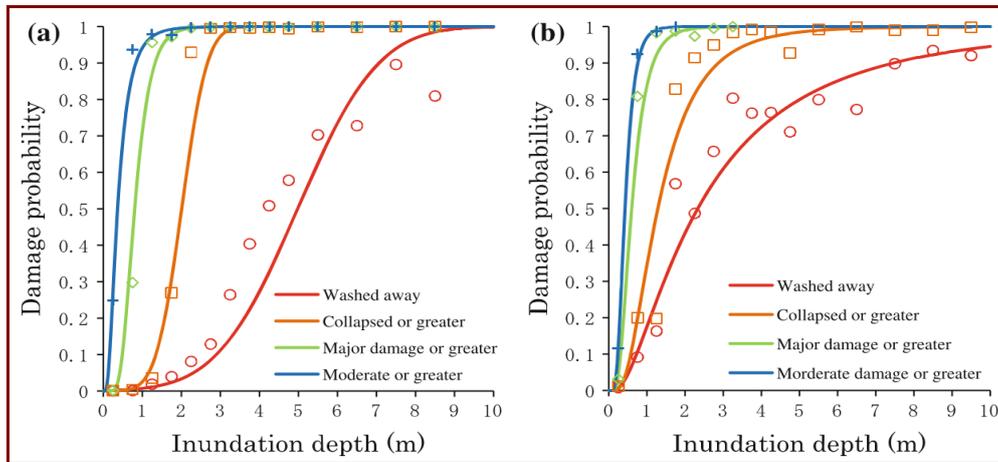


Figure 2.21 Fragility functions (mixed building types) for Ishinomaki comparing the coastal plains (left) and mountainous coastline (right) (Suppasri et al., 2013).

During interviews with Municipality officers it was stated that based on the damage surveys conducted, it is now assumed that an inundation greater than 2m leads to loss of a residential structure, and so dwellings are only to be constructed in locations where the inundation for an L2 tsunami (see Section 2.2) is simulated to be less than 2m. The implications of this for town planning are discussed in Chapter 6.

2.4.2. Tsunami vulnerability functions developed from the 2011 building damage data

Data from the 2011 tsunami is being used to update catastrophe models and financial loss estimations, which requires both vulnerability functions (e.g. relating financial loss to water depth) and construction costs. In a study by Masuda et al. (2012) fragility functions were converted to vulnerability curves using the damage ratios (DS_DR) shown in Figure 2.22, although it is not stated how these damage ratios were derived for each damage state. Losses were then estimated by multiplying the resultant Mean Damage Ratios (Figure 2.23) by construction costs estimated from the Japanese “Construction Year Book” (which gives newly-constructed floor areas and total project costs).

Code	Damage State	Description (MLIT)	DS_DR
D1	Total Collapse (Wiped)	Buildings completely washed away	100%
D2	Total Collapse	Only building structures left. It is not financially reasonable to rebuild.	100%
D3	Total Collapse (Inundated 1 st floor ceiling level)	Water reached above 1 st floor ceiling level. It required major effort to reconstruct buildings in this category.	90%-100%
D4	Major Half Collapse	Water level exceeded 1m above 1 st floor level but lower than 1 st floor ceiling level.	60%-90%
D5	Half Collapse (Inundated above 1 st floor level)	Water level was between 1m above 1 st floor level and 1F level. (Minor repair costs expected)	40%-60%
D6	Partial Damage (Inundated below 1 st floor)	Water level did not reach 1 st floor level. (Only debris removal is required to be operational)	10%-40%
D7	No Damage	No damage	0%-10%
D0	Unknown	Unknown	Unknown

Figure 2.22 Damage scale and associated mean damage ratios used in the study by Masuda et al. (2012). Note that the order of damage states is opposite to that shown in Figure 2.15. (DS_DR) refers to the damage ratios (cost or repair as a percentage of property replacement value) associated with each damage state.

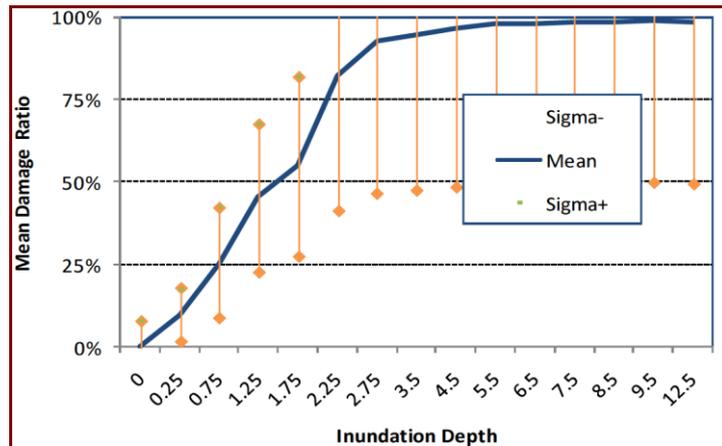


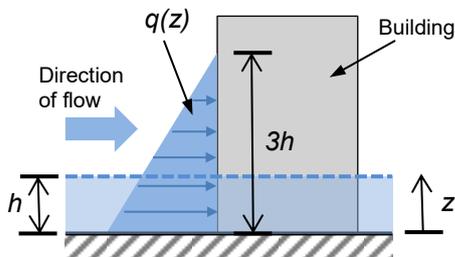
Figure 2.23 Vulnerability curve for single-storey wooden structures (Masuda et al., 2012). Sigma+ and Sigma- represent the upper and lower confidence intervals, represented by the error bars shown. Inundation depth is in metres (m).

Financial losses and loss estimation are discussed further in Chapter 8.

2.5. Tsunami design of on-shore structures

2.5.1. *Current design guidance in Japan*

Japanese guidelines prior to 2011 were based on a study by Asakura et al. (2000) which recommends using a simple hydrostatic pressure distribution applied over a height which is three times the height of the design inundation depth (Figure 2.24, Equation 2.1). Design inundation depth is based on Tsunami Hazard Maps provided by local governments (see Chapter 6).



$$q(z) = \rho g(3h - z) \quad \text{Equation 2.1}$$

Figure 2.24 Tsunami wave-loading for structural design recommended by Japanese guidance based on Nistor, Palermo, Nouri, & Murty (2004).

In equation 2.1, q_z is the design tsunami wave pressure.

For structures taller than three times the height of the design inundation depth ($3h$) Equation 2.1 gives a total force equal to nine times the hydrostatic force for an equivalent flow depth¹. A study by Yeh, Robertson, & Preuss (2005) suggested that this approach gives excessive loading estimates, and the current US guidance (FEMA 646) instead applies a surge force which is 1.5 times the hydrodynamic component based on empirical results.

¹ $\rho g \int_0^{3h_{max}} (3h_{max} - z) dz = 4.5\rho gh^2 \quad \rightarrow \quad \frac{4.5\rho gh^2}{1/2\rho gh^2} = 9$

Table 2.5 Legislation and guidance documents relevant to tsunami design and planning in Japan.

Year	Summary of regulations
1959	<p><i>Concerning the Prevention of Disasters to Buildings from Storm and Flood Damage (Housing Bureau Notification No. 42)</i></p> <p>Sets out the matters for the designation of disaster risk zones and states that schools, government offices, public halls and other community buildings accommodating large numbers of persons and housing should be sturdy and evacuation areas should be located higher than the predicted inundation depth. In addition, it is stated that the construction of buildings for dwelling purposes in particularly at-risk zones should be prohibited (MLIT, 2011a).</p>
1960	<p><i>Building Standard Law of Japan (BSLJ) - Article 39</i></p> <p>The 1960 update covers matters including the establishment of tsunami evacuation frameworks and the designation of high-risk areas possibly subjected to tsunami, storm surge, flood, etc. Although BSLJ allows local governments to designate tsunami-prone areas as High Disaster-Risk Area, there were few designated areas prior to 2011. Note that verification of structural safety against tsunami load is not mandatory in the Building Standard Law of Japan (BSLJ) (Hitomitsu, 2011).</p> <p>Note also that this clause is a general one covering floods and other hazards. There are no specific provisions for tsunami loadings (IStructE, 2013).</p>
2004	<p><i>Structural Design Method of Buildings for Tsunami Resistance (Okada et al., 2004)</i></p> <p>This document (SDBMTR) provides guidance on tsunami forces to be applied to buildings. The prescribed lateral tsunami force is described in Figure 2.24 and the document also provides guidance on the effect of buoyancy, as well as load combinations. The document is in two parts: preliminary discussion and proposed design method (Fukuyama et al., 2012; Shibayama et al., 2013).</p>
2005	<p><i>Japan Cabinet Office Tsunami Evacuation Building Guidelines (Japan Cabinet Office, 2005)</i></p> <p>Gives guidelines aimed at Municipality officers regarding the designation, location and usage of tsunami evacuation buildings. Appendix II (“Basic View on Structural Requirements”) provides official design guidelines with reference to SDBMTR (see above) (Fukuyama et al., 2012; MLIT, 2011a).</p>
Nov 2011	<p><i>The Design Method of Safe Buildings that are Structurally Resistant to Tsunamis, etc. (MLIT Technical Advice No.2570) (MLIT, 2011a)</i></p> <p>Provides provisional amendments to the Japan Cabinet Office Tsunami Evacuation Building Guidelines based on information gathered after the 2011 tsunami.</p>
Dec 2011	<p><i>Concerning Setting the Safe Structure Method for Tsunamis which are Presumed when Tsunami Inundation Occurs (MLIT Notification No.1318) (MLIT, 2011b)</i></p> <p>Makes several recommendations for design and construction of buildings which are resistant to tsunami loading (Kabeyasawa, 2013).</p>

2.5.2. Proposed amendments to tsunami design guidance in Japan

Following the 2011 tsunami an investigative study titled “A study of Improvement of Building Standards etc. in the tsunami critical areas” was carried out by the University of Tokyo Institute of Industrial Science and the Building Research Institute (BRI) under the building standards maintenance promotion program (Tokyo University & BRI, 2011). This review showed that the design wave pressure in Japanese guidance (Equation 2.1) overestimated the tsunami loading on buildings. The 2011 MLIT technical advice document adopts these findings to provide provisional amendments to the 2005 Japan Cabinet Office Tsunami Evacuation Building Guidelines. These proposed amendments were compiled in collaboration with the Housing Bureau and National Institute for Land and Infrastructure Management (NILIM). NILIM and the BRI have continued to develop more detailed guidance recommendations for design of tsunami evacuation structures, as detailed in Fukuyama et al. (2012).

Recommended changes to design guidance include reduction of the tsunami inundation depth coefficient from 3 (Figure 2.24) to the values given in Figure 2.25 and Table 2.6 based on distance from the shore and presence of seaward sheltering structures. It is also proposed that wave loading be reduced (by no more than 30 percent) in proportion to openings (e.g. doors and windows) on the pressure-exposed face (note that this appears to ignore the effect of debris damming of openings, Figure 2.6). Further guidance is also given on the calculation of buoyancy for foundation and superstructure design. Debris and scour are also to be considered, as shown in Figure 2.26, though quantification of these effects is still subject to investigation. For debris it is recommended that progressive collapse following the loss of individual load-bearing elements (e.g. the overturned steel structure in Figure 2.7) be designed against. Scour is to be combatted primarily by the use of piles.

Note that verification of structural safety against tsunami loading is not mandatory (or even prescribed (IStructE, 2013)) in the Building Standard Law of Japan (BSLJ) (Hitomitsu, 2011) except for buildings within local government-designated “high-risk areas” under BSLJ Article 39 (see Table 2.5). However, such a designation has large implications regarding certain prohibitions on construction, and currently no areas have been designated in Japan (NILIM, 2013).

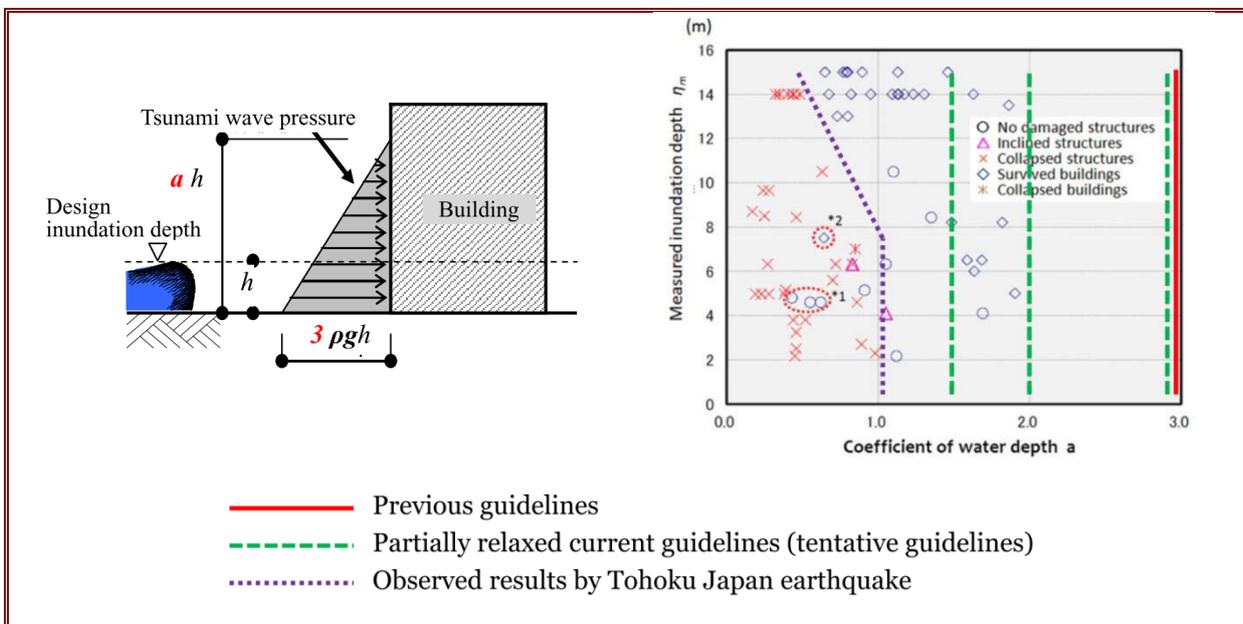


Figure 2.25 Proposed amendments to the tsunami loading coefficient (after Nishiyama et al. (2012) and Fukuyama et al. (2012)).

Table 2.6 Proposed amendments to the tsunami loading coefficient (Fukuyama et al., 2012).

	With shelter	Without shelter	No shelter
Distance from seashore or rivers	> 500m	< 500m	-
Water depth coefficient a (see Figure 2.25)	1.5	2	3

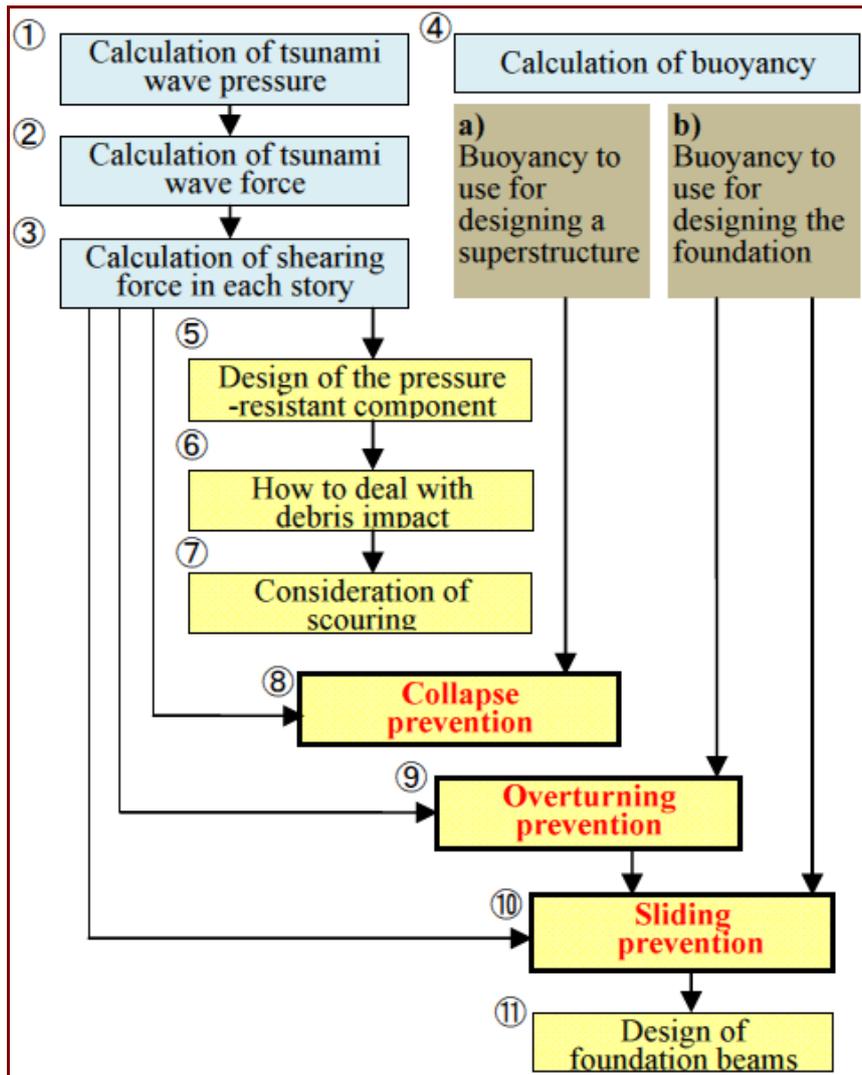


Figure 2.26 Japanese proposed design methodology for tsunami evacuation buildings (Fukuyama et al., 2012).

2.6. Conclusions

2.6.1. Conclusions regarding damage data

The NPA and FDMA datasets (Table 2.2) originate from the same source (Municipality surveys) and so may be compared. However they should not be compared with the MLIT dataset (Table 2.3), which used a different damage scale and covered only areas affected by the tsunami.

As the MLIT survey was a dedicated building damage survey due to the tsunami, the MLIT dataset is more likely to be appropriate for use in defining structural damage than the FDMA and NPA datasets, which were taken from Municipality surveys conducted for the purpose of awarding damage certificates to victims. In addition, as the MLIT surveys were conducted by MLIT staff using a damage scale developed in-house their results are likely to be more consistent than those of FDMA and NPA, which are derived from Municipality surveys where the surveyors' experience and methodologies have differed between Municipalities. Furthermore, as the MLIT surveys have only been carried out in locations within the tsunami inundation area their dataset is more appropriate for considering tsunami damage to buildings than the FDMA and NPA data, which also includes areas affected by the earthquake but outside of the tsunami inundation zone.

2.6.2. Conclusions regarding tsunami fragility functions

Fragility functions are being derived from Japan's tsunami and damage data and the quality of the predictions is dependent on the quality of the data. Where this data is collected empirically (post-tsunami survey) measures must be taken to limit uncertainties due to combining data from surveyors of differing experience, errors in survey forms, or the combination of data from different surveys. Consistent and adequate training for surveyors is also required but may be difficult to achieve for large-scale disasters where a large number of surveyors from different professional backgrounds will be deployed rapidly in the immediate aftermath of the disaster.

So as not to introduce biases in the data it is also important to include all buildings in a survey, and not segregate data collected to damaged buildings only. Aggregation of data (by location) must also be limited where possible, so as to reduce uncertainty when pairing damage and inundation data.

In order to compare and combine fragility functions, a taxonomy of building classifications for tsunami fragility analysis is needed. An example is the seismic building classifications recommended by the Global Earthquake Model (Brzev, Charleson, & Jaiswal, 2013) although this would need to be updated for features which affect building fragility to tsunamis (e.g. the number of openings). A standardization of damage scales and their relation to financial loss would also be necessary for successful comparison of results from different studies.

2.6.3. Conclusions regarding tsunami-resistant design of structures

Central to tsunami risk mitigation is the protection of critical infrastructure and buildings (such as vertical evacuation structures, schools, Municipal administration buildings and hospitals). Key buildings must be designed to be both tall enough that people can evacuate to a level above the design inundation depth (for an L2 tsunami, see Section 2.2), and strong enough that they do not collapse or are washed-away under the forces induced by the tsunami.

Currently there are no mandatory tsunami building design codes anywhere in the world (Shibayama et al., 2013), and the guidance that does exist is not consistent. Some guidance documents rely on tsunami force estimations which are derived from river flood or storm surge relationships, but structural failures in recent events have shown this approach to be inadequate. Tsunami loading is unique due considerations of bore flow velocities, large debris impacts, scour and other tsunami-specific effects, which are still the subject of current research.

Proposed updates to Japanese guidance on tsunami design provisions have been outlined in this chapter. Alternative design methodologies are concurrently being proposed in the USA (Chock, Robertson, & Riggs, 2013). However, this is a subject which has very limited coverage in European guidance (and other risk areas), despite significant historical tsunamis in Europe (National Oceanic and Atmospheric Administration (NOAA), n.d.). Therefore the lessons outlined in this chapter are very poignant for tsunami risk mitigation strategies in Europe and other risk areas around the world.

2.7. References

- AIR Worldwide (2012). Understanding Earthquake Risk in Japan Following the Tōhoku-Oki Earthquake of March 11, 2011. [Online] 2012. Available from: <http://www.air-worldwide.com/Publications/White-Papers/Understanding-Earthquake-Risk-in-Japan-Following-the-Tōhoku-Oki-Earthquake-of-March-11-2011/>. [Accessed: 1st July, 2013].
- ADRC & IRP (2011a, June). *Great East Japan Earthquake (GLIDE: EQ-2011-000028-JPN) Update on damage and recovery (2nd report) April 6, 2011*.
- ADRC, & IRP (2011b, June). Great East Japan Earthquake (GLIDE: EQ - 2011 - 000028 - JPN) Update on damage and recovery (2 nd report). Asian Disaster Reduction Centre & International Recovery Platform.
- Alexander, D. (2002). *Principles of Emergency Planning and Management*. Edinburgh: Terra Publishing.
- Asakura, R., Iwase, K., Ikeya, T., Takao, M., Kaneto, T., Fujii, N. and Omori, M. (2000). Experimental research on wave power of tsunami surged over the land beyond the upright seawalls (in Japanese). *Coastal Engineering Journal*, , *Japan Society of Civil Engineering*, No.47, 911–915.
- Ashmore, J., Fowler, J., Kennedy, J., Davis, I., Hirano, S. and D'Urzo, S. (2010). Shelter Projects 2009. (J. Ashmore, Ed.). UN-HABITAT and IFRC.
- Ashmore, J., Fowler, J., Kennedy, J., Davis, I., Hirano, S. and D'Urzo, S. (2011). Shelter Projects 2010. (J. Ashmore, Ed.). UN-HABITAT and IFRC.
- Ashmore, J., Urquia, M., & D'Urzo, S. (Eds.). (2012). Shelter Projects 2011-2012. UN-HABITAT, UNHCR and IFRC.
- Asia and Japan Watch (2013, February). Quake victims allowed to stay in temporary housing another year - AJW by The Asahi Shimbun. *AJW by The Asahi Shimbun*.
- Baird, A., O'Keefe, P., Westgate, K. and Wisner, B. (1975). Towards and Explanation and Reduction of Disaster Proneness: Occasional Paper No. 11. Disaster Research Unit, University of Bradford.
- Barlow, J, & Ozaki, R. (2005). Building mass customised housing through innovation in the production system: lessons from Japan. *Environment and Planning A*, 37(1), 9–20.
- Barlow, J., Childerhouse, P., Gann, D., Hong-Minh, S., Naim, M. and Ozaki, R. (2003). Choice and delivery in housebuilding: lessons from Japan for UK housebuilders. *Building Research & Information*, 31(2), 134–145. doi:10.1080/09613210302003.
- BBC (2012, March). Japan quake: Loss and recovery in numbers. *BBC*.
- Bendimerad, F. (2004). The 21 May 2003 Boumerdes Earthquake Lessons Learned and Recommendations: 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, 2004 Paper for Special Session on Seismic Risk Reduction and Disaster Preparedness for Major Urban Centers.
- Brasor, P. and Tsubuku, M. (2011, October). Disaster housing proves cash cow for general contractors. *The Japan Times: Yen for Living*.
- BRI & NILIM (2011, August). Technical Note of National Institute for Land and Infrastructure Management: Summary of the Field Survey and Research on “The 2011 off the Pacific coast of Tohoku Earthquake” (the Great East Japan Earthquake). Building Research Institute and ISSN 1346-7328 Technical Note of NILIM No.647 ISSN 0453-4972 BRI Research Paper No.150 Technical Note of National Institute for Land and Infrastructure Management No. 647 September 2011 BRI Research Paper No. 150 September.
- Brzev, S., Charleson, A. W. and Jaiswal, K. (2013). *GEM Basic Building Taxonomy Report produced in the context of the GEM Ontology and Taxonomy Global Component project*. Retrieved from <http://www.nexus.globalquakemodel.org/gem-building-taxonomy/posts/updated-gem-basic-building-taxonomy-v1.0>.
- Burnell, J. and Sanderson, D. (2011). Whose reality counts?: Shelter after disaster. *Environmental Hazards*, 10(3-4), 189–192. doi:10.1080/17477891.2011.595581.

- Chock, G., Carden, L., Robertson, I., Olsen, M. and Yu, G. (2013). Tohoku Tsunami-Induced Building Failure Analysis with Implications for U.S. Tsunami and Seismic Design Codes. *Earthquake Spectra*, 29(S1), S99–S126. doi:10.1193/1.4000113.
- Chock, G. Y. K., Robertson, I. and Riggs, H. R. (2013). TSUNAMI STRUCTURAL DESIGN PROVISIONS FOR A NEW UPDATE OF BUILDING CODES AND PERFORMANCE-BASED ENGINEERING. In *ASCE 2011 Solutions to Coastal Disasters 2011 SOLUTIONS TO COASTAL DISASTERS 2011* (pp. 423–435). doi:10.1061/41185(417)38.
- Clermont, C., Sanderson, D., Sharmu, A. and Spraos, H. (2011). Urban disasters – lessons from Haiti: Study of member agencies' responses to the earthquake in Port au Prince, Haiti, January 2010, Report for the Disasters Emergency Committee (DEC). DEC.
- Crawford, C. A. (2011). Can humanitarian responses in urban areas reinforce underlying causes of vulnerability? Tweaking a livelihoods analysis of inequality and infrastructure in splintering cities. *Environmental Hazards*, 10(3-4), 327–345. doi:10.1080/17477891.2011.597497.
- Davis, I. (2011). What have we learned from 40 years' experience of Disaster Shelter? *Environmental Hazards*, 10(3-4), 193–212. doi:10.1080/17477891.2011.597499.
- Edgington, D. W. (2010). *Reconstructing Kobe: The Geography of Crisis and Opportunity*. British Columbia, Canada: University of British Columbia Press.
- EEFIT. (2011a). Field Report: Earthquake and Tsunami of 11th March 2011, (March).
- EEFIT. (2011b). The Mw9.0 Tōhoku Earthquake and Tsunami of 11th March 2011: A Field Report by EEFIT.
- EPYPSA (2011, December). An Evaluation of the Haiti Earthquake 2010 Meeting Shelter Needs: Issues, Achievements and Constraints. International Federation of Red Cross and Red Crescent Societies.
- FDMA (2001). *Interim Note from the Secretary of FDMA: Disaster Damage Reports* (災害による被害報告について).
- Federation of Housing and Community Centers. (2011, April). Guideline on Acceptance and Listing of Proposals for Emergency Temporary Housing Using Imported Materials. MLIT.
- Fire and Disaster Management Agency (2013). *FDMA Report 147 - 2011 Japan Tsunami Damage Data*.
- Fraser, S., Raby, A., Pomonis, A., Goda, K., Chian, S. C., Macabuag, J., Offord, M., Saito, K. and Sammonds, P. (2013). Tsunami damage to coastal defences and buildings in the March 11th 2011 M w 9.0 Great East Japan earthquake and tsunami. *Bulletin of Earthquake Engineering*, 11(1), 205–239. doi:10.1007/s10518-012-9348-9
- Fukushige, M. and Ishikawa, N. (2013). Target Standards for Floor Space in a Government Housing Plan: an empirical investigation of the Kanto Area in Japan. *International Real Estate Review*, 16(2), 208–229.
- Fukuyama, H., Kato, H. and Ishihara, T. (2013). Categorization of Damage to Buildings Caused by the 3.11 Tsunami. In *14th U.S.-Japan Workshop on the Improvement of Structural Design and Construction Practices* (pp. 1–8). Retrieved from https://www.atcouncil.org/files/ATC-15-13/Papers/03_FUKUYAMApaper.pdf.
- Fukuyama, H., Kato, H., Ishihara, T., Tajiri, S., Tani, M., Okuda, Y., Kabeyasawa, T. and Nakano, Y. (2012). Structural Design Requirement on the Tsunami Evacuation Buildings. In *14th U.S.-Japan Workshop on the Improvement of Structural Design and Construction Practices*. Retrieved from http://www.nehrp.gov/pdf/UJNR_2013_Tsunami_Manuscript.pdf.
- Goda, K., Pomonis, A., Chian, S. C., Offord, M., Saito, K., Sammonds, P. Fraser, S. Raby, A. and Macabuag, J. (2013). Ground motion characteristics and shaking damage of the 11th March 2011 M w9.0 Great East Japan earthquake. *Bulletin of Earthquake Engineering*, 11(1). doi:10.1007/s10518-012-9371-x.
- Government of Japan (2011, August). Basic Guideline to Recovery from the Great East Japan Earthquake.

- Gusman, A. R., Tanioka, Y., Sakai, S. and Tsushima, H. (2012). Source model of the great 2011 Tohoku earthquake estimated from tsunami waveforms and crustal deformation data. *Earth and Planetary Science Letters*, 341-344, 234–242. doi:10.1016/j.epsl.2012.06.006.
- Habitat International Coalition (1996, January). Still Waiting: housing rights violations in a land of plenty: The Koke Earthquake and beyond. HIC.
- HERR (Ed.) (2011, March). Humanitarian Emergency Response Review. Independent Review Panel Chaired by Lord (Paddy) Ashdown.
- Hirayama, Y. (2000). Collapse and Reconstruction: Housing Recovery Policy in Kobe after the Hanshin Great Earthquake. *Housing Studies*, 15(1), 111–128. doi:10.1080/02673030082504.
- Hitomitsu, K. (2011). Tsunami-induced Damage to Buildings and Related Activities by NILIM , BRI and MLIT: IRCC Workshop, Gold Coast, Australia. In *IRCC Workshop, Gold Coast, Australia*. Retrieved from http://www.irccbuildingregulations.org/pdf/07kikitsu_japan.pdf.
- Honda, K. and Takashi, T. (2008). TSUNAMI INUNDATION SIMULATION BY THREE-DIMENSIONAL MODEL, 1–14.
- Horita, Y. (2006). Local Authority Housing Policy in Japan: Is It Secure To Function As Safety Net? *Housing Finance International*, 20(4), 34–42.
- IFRC (2013a). About disaster management.
- IFRC (2013b). Coordinating shelter activities.
- IFRC (2013c). How we do shelter. *IFRC Shelter and Settlement*.
- IRIN (2012, September). DISASTERS: Learning from Japan's tsunami. *IRIN*. Bangkok.
- IRP (2012). Transitional Shelter: Knowledge Notes, Cluster 4: Recovery Planning Note 4-3. Government of Japan, GFDRR, The World Bank.
- IStructE (2013). EEFIT Interview with Mark Lenczner of IStructE Japan on 30th May 2013.
- Iwashita, S. (2001). Custom made housing in Japan and the growth of the super subcontractor. *Construction Management and Economics*, 19(3), 295–300. doi:10.1080/01446190010020417.
- Iwate Prefecture (2011, August). Iwate Prefecture Great East Japan Earthquake and Tsunami Reconstruction Plan Basic Reconstruction Plan. Iwate Prefecture, Bureau of Reconstruction.
- Japan Cabinet Office (2005). *Tsunami Evacuation Building Guidelines (津波避難ビル等に係るガイドライン)*. Retrieved from <http://www.bousai.go.jp/kohou/oshirase/h17/pdf/guideline.pdf>.
- Japan Cabinet Office (2011). *Research methods of dwelling house damage certification for the Tohoku-Pacific Ocean Earthquake*. Retrieved from <http://www.bousai.go.jp/taisaku/pdf/h23jshin.pdf>.
- Japan Cabinet Office (2013). *Residential Disaster Damage Accreditation Criteria Operational Guideline.pdf*. Retrieved from <http://www.bousai.go.jp/taisaku/unyou.html>.
- Japan Statistics Bureau (2008). Housing and Land Survey. Ministry of Internal Affairs and Communications.
- Japanese Red Cross Society (2011, December). Japan: Earthquake and Tsunami Operations Update n° 1 Glide no. EQ-2011-000028-JPN April 13,2011. JRCS.
- Johnson, W. (2007). Lessons from Japan: A comparative study of the market drivers for prefabrication in Japanese and UK private housing development, report submitted as part of the MSc European Property Development and Planning at University College London. University College London Faculty Of The Built Environment Bartlett School of Planning.
- Kabeyasawa, T. (2013). New Design Method of Tsunami Shelters (NILIM presentation to EEFIT Sep 2013).

- Kako, M. and Ikeda, S. (2009). Volunteer experiences in community housing during the Great Hanshin-Awaji Earthquake, Japan. *Nursing and Health Sciences*, 11(4), 357–359.
- Kawai, H., Satoh, M., Kawaguchi, K. and Seki, K. (2012). *Recent Tsunamis Observed by GPS Buoys off the Pacific Coast of Japan*. *Coastal Engineering*, 2012.
- Kitamura, M. (2011, March). Japan's Post-Earthquake Rebuilding Begins With Prefab Housing for Evacuees. *Bloomberg*.
- Koshimura, S. and Gokon, H. (2012). Structural vulnerability and tsunami fragility curves from the 2011 Tohoku earthquake tsunami disaster. *Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering)*, 68(2), I_336–I_340. doi:10.2208/kaigan.68.I_336.
- Langenbach, R. (2009). *Don't Tear It Down! Preserving the Earthquake Resistant Vernacular Architecture of Kashmir*. Oinfoin Media.
- Langenbach, R., Mosalam, K. M., Akarusu, S. and Dusi, A. (2006). ARMATURE CROSSWALLS: A PROPOSED METHODOLOGY TO IMPROVE THE SEISMIC PERFORMANCE OF NON-DUCTILE REINFORCED CONCRETE INFILL FRAME STRUCTURES. Proceedings of the 8th U.S. National Conference on Earthquake Engineering April 18-22, 2006, San Francisco, California, USA.
- Liu, P.L.-F., Woo, S.-B. and Cho, Y. S. (1998). *Computer Program for Tsunami Propagation and Inundation*.
- Liu, P.L.-F., Yeh, H. and Synolakis, C. E. (2008). *Advanced Numerical Models for Simulating Tsunami Waves and Runup*. World Scientific Publishing Co. Pte. Ltd. Retrieved from http://cascadiageo.org/documentation/books/liu_et_al_2008_advanced_numerical_modeling_tsunami_waves.pdf.
- Lyons, M., Schilderman, T. and Sanderson, D. (2011). Harnessing time: Reflections on constraints to development. *Environmental Hazards*, 10(3-4), 213–217. doi:10.1080/17477891.2011.597498.
- Maly, E., and Shiozaki, Y. (2012). Towards a Policy that Supports People-Centre Housing Recovery-Learning from Housing Reconstruction after the Hanshin-Awaji Earthquake in Kobe, Japan. *International Journal of Disaster Risk Science*, 3(1), 56–65.
- Maruyama, Y., Kitamura, K. and Yamazaki, F. (2011). Tsunami damage assessment of buildings in Chiba Prefecture, Japan using fragility function developed after the 2011 Tohoku-Oki Earthquake, (1993). Retrieved from http://ares.tu.chiba-u.jp/~papers/paper/2013/2013ICOSSAR_Maruyama.pdf.
- Masuda, M., Williams, C., Shahkarami, A., Rafique, F. and Bryngelson, J. (2012). Tsunami Vulnerability Function Development Based on the 2011 Tohoku Earthquake in Japan. In *15 World Conference on Earthquake Engineering*.
- MHLW (2011, March). The Damage Situation of and Measures Taken Against the Great East Japan Earthquake —116th Announcement. Ministry of Health, Labour and Welfare.
- Ministry of Foreign Affairs (2013). Regions & Cities. Retrieved December 20, 2013, from <http://web-japan.org/region/tohoku.html>.
- Ministry of Land Infrastructure Tourism and Transport (2011). MLITT 2011 Tsunami Damage Statistics (by Prefecture). Retrieved August 15, 2013, from <http://www.mlitt.go.jp/toshi/toshi-hukkou-arkaibu.html>.
- MLIT (2011a). *Further Information Concerning the Design Method of Safe Buildings that are Structurally Resistant to Tsunamis - Technical Advice No. 2570.pdf*.
- MLIT (2011b). *Concerning Setting the Safe Structure Method for Tsunamis which are Presumed when Tsunami Inundation Occurs - Note 1318*.
- MLITT (2011). *Results of the Tohoku Disaster Damage Survey - Press Release*.
- Mori, H. (1998). Land Conversion at the Urban Fringe: A Comparative Study of Japan, Britain and the Netherlands. *Urban Studies*, 35(9), 1541–1558. doi:10.1080/0042098984277

- National Oceanic and Atmospheric Administration (NOAA) (n.d.). NOAA/WDS Global Historical Tsunami Database at NGDC. Retrieved August 28, 2013, from http://www.ngdc.noaa.gov/hazard/tsu_db.shtml.
- National Police Agency (2013). *NPA Damage Report 9June2013.pdf*. Retrieved from http://www.npa.go.jp/archive/keibi/biki/higaijokyo_e.pdf.
- Nihei, Y., Maekawa, T., Ohshima, R. and Yanagisawa, M. (2012). Evaluation of Fragility Functions for Tsunami Damage in Coastal District in Natori City , Miyagi Prefecture and Mitigation Effects of Coastal Dune. *Journal of Japan Society of Civil Engineers*, 68(2), 1_276 – 1_280. Retrieved from https://www.jstage.jst.go.jp/article/kaigan/68/2/68_1_276/_pdf.
- NILIM (2013). EEFIT interview with NILIM on 30th September 2013.
- Nishiyama, I., Okawa, I., Fukuyama, H. and Okuda, Y. (2012). Presentation: Brief review of building damage by the 2011 Tohoku Japan earthquake and following coping activities. In *14th U.S.-Japan Workshop on the Improvement of Structural Design and Construction Practices*. Applied Technology Council (ATC) and Japan Structural Consultants Association (JSCA). Retrieved from <https://www.atcouncil.org/Projects/atc-15-13.html>.
- Nistor, I., Palermo, D., Nouri, Y. and Murty, T. (2004). Tsunami-Induced Forces on Structures. In Y. C. Kim (Ed.), *Handbook of Coastal and Ocean Engineering* (pp. 261 – 286). World Scientific Publishing Co. Pte. Ltd. Retrieved from <http://www.scribd.com/doc/77272681/3/Tsunami-Induced-Forces-on-Structures>.
- Office of the Prime Minister of Japan (n.d.). Frequently Asked Qs: 3.11 Tsunami Debris.
- Okada, T., Sugano, T., Ishikawa, T., Ohgi, T., Takai, S. and Hamabe, C. (2004). *Structural Design Method of Buildings for Tsunami Resistance*. Retrieved from http://www.bcj.or.jp/src/c06_course/bltr/2004/bltr465.pdf.
- OXFAM (2005). *Transitional Settlement: Displaced Populations*. Oxfam.
- Sato, K. (2011). Microsimulation of the Temporary Housing Situation Following an Urban Disaster: Case Study of an Anticipated Tokyo Metropolitan Earthquake. *Social Science Computer Review*, 29(1), 103–126. doi:10.1177/0894439310370111.
- Schilderman, T. and Lyons, M. (2011). Resilient dwellings or resilient people? Towards people-centred reconstruction. *Environmental Hazards*, 10(3-4), 218–231. doi:10.1080/17477891.2011.598497.
- Shelter Centre (2010). ALNAP Innovations Case Study No. 5: Transitional shelter: understanding shelter from the emergency through reconstruction and beyond. ALNAP.
- Shelter Centre, UN and DfID. (2010). *Shelter after disaster: strategies for transitional settlement and reconstruction*. Shelter Centre.
- Shibayama, T., Esteban, M., Nistor, I., Takagi, H., Thao, N. D., Matsumaru, R., Mikami, T., Aranguiz, R., Jayaratne, R. and Ohira, K. (2013). Classification of Tsunami and Evacuation Areas. *Natural Hazards*, 67(2), 365–386. doi:10.1007/s11069-013-0567-4.
- Sorensen, A. (2000). Conflict, consensus or consent: implications of Japanese land readjustment practice for developing countries. *Habitat International*, 24(1), 51–73. doi:10.1016/S0197-3975(99)00029-6.
- Sphere project (2011). *The Sphere Handbook, Humanitarian Charter and Minimum Standards in Humanitarian Response*. (2011th ed.). The Sphere Project.
- Suppasri, A., Charvet, I., Kentaro, I. and Imamura, F. (2014). Fragility curves based on data from the 2011 Great East Japan tsunami in Ishinomaki city with discussion of parameters influencing building damage. *Earthquake Spectra*, (awaiting publication).
- Suppasri, A., Mas, E., Charvet, I., Gunasekera, R., Imai, K., Fukutani, Y., Abe, Y. and Imamura, F. (2013). Building damage characteristics based on surveyed data and fragility curves of the 2011 Great East Japan tsunami. *Natural Hazards*, 66(2), 319–341. doi:10.1007/s11069-012-0487-8.
- Suppasri, A., Mas, E., Koshimura, S., Imai, K., Harada, K. and Imamura, F. (2012). Developing Tsunami Fragility Curves From the Surveyed Data of the 2011 Great East Japan Tsunami in Sendai and Ishinomaki Plains. *Coastal Engineering Journal*, 54(01), 1250008–1. doi:10.1142/S0578563412500088.

- Titov, B. V. V. and Synolakis, C. E. (1998). NUMERICAL MODELING OF TIDAL WAVE RUNUP. *Journal of Waterway, Port, Coastal and Ocean Engineering*, 1(August), 157–171.
- Tokyo Institute of Industrial Science (2011). *Investigation Contributing to Preparation of Structural Codes in Tsunami Danger Areas - Structural Code Preparation Promotion Project - Interim Report*. Retrieved from <http://www.mlit.go.jp/common/000172791.pdf>.
- Tokyo University & BRI (2011). *Interim report of the Building Standards Improvement promotion project No.40, A study of Improvement of Building Standards etc in the tsunami critical areas*. Retrieved from <http://www.mlit.go.jp/common>.
- UCLBP & IASC CCCM Cluster (2013). Fact Sheet - UCLBP & Shelter and CCCM Cluster Haiti January 2013. IOM.
- UN (2008). Transitional settlement and reconstruction after natural disasters. United Nations.
- UNDP & UNDRO (1991). UNDP/UNDR Disaster Management Manual. UNDP/UNDRO.
- UNEP (2012). Managing post-disaster debris: the Japan experience: report of the international expert mission to Japan. United Nations Environment Programme.
- UN-HABITAT (2012). Support for post-earthquake housing rehabilitation and reconstruction: progress and issues HAITI. UN-HABITAT.
- USAID (2012). USAID Fact Sheet #1 FY 2012 Disaster Risk Reduction - Latin America and the Caribbean. USAID.
- Washington Times (2011, April). Japan slow to build housing for tsunami survivors. *The Washington Times*.
- World Bank (2008). *The Growth Report: Strategies for Sustained Growth and Inclusive Development*. World Bank.
- Yanagisawa, H. and Yanagisawa, H. (2012). Fragility Function of House Damage by the 2011 off the Pacific Coast of Tohoku Earthquake Tsunami. *Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering)*, 68(2), I_1401–I_1405. doi:10.2208/kaigan.68.I_1401.
- Yeh, H., Robertson, I. and Preuss, J. (2005). *Development of design guidelines for structures that serve as tsunami vertical evacuation sites*. Retrieved from http://nctr.pmel.noaa.gov/tsu400/documents/Course_3_Day_3/Session_8/ofr05-4.pdf.
- Zetter, J. (1986). Challenges for Japanese Urban Policy: Some Findings from the OECD Review. *The Town Planning Review*, 57(2), 135–140. doi:10.2307/40112284.

3. Tsunami defence structures

Whilst there were some notable successes in the ability of the defence structures to provide protection against the 2011 tsunami, the majority of structures performed inadequately; they did not prevent overtopping and many of them suffered catastrophic collapse. Whilst it is likely that the structures reduced the physical damage of the tsunami by reducing some of the energy of the waves, some structures might have led to a false sense of security leading to higher casualty rates.

This chapter reviews some of the failure mechanisms, describes progress of the defence reconstruction and provides an insight into new approaches being adopted.

3.1. Classifications and typical failure mechanisms

First it is necessary to be clear about the terminology used for defence structures. Table 3.1 provides some simple classifications of the seminal coastal structures found in Japan. These classifications vary depending from one country to another. Therefore, alongside the diagrams are the main definitions used, followed by source a reference. The terms used in this EEFIT report are underlined in Table 3.1 following the UK conventions. The terms are usually prefixed with construction material or method, e.g. concrete-armoured revetment, mass concrete seawall, caisson breakwater.

Table 3.1 Terminology used to describe seminal coastal defence structures.

Terminology	Schematic diagram of structure section
Reveted embankment (Reeve et al., 2004) / <u>Revetment</u> (Reeve et al., 2004) / Levee (MLIT, n.d. a) / Sea dike (Burcharth and Hughes, 2003)	
<u>Seawall</u> (PIANC, 2013) / Breast wall (MLIT, n.d. a) / Upright levee (Mano et al., 2013)	
<u>Breakwater</u> (generic)	

3.1.1. *Concrete revetments*

Concrete revetments, frequently referred to as levees in Japan, previously extended for 62 percent or 290 km of the Tōhoku coastline (PIANC, 2013). During the 2011 tsunami 190 km of the revetments in the three worst-affected prefectures (Iwate, Miyagi and Fukushima) were overtopped and

subsequently destroyed (Kato et al., 2012). At a presentation by Mr Shinichi Endo, the Director of Earthquake Disasters at the Ministry of Land Infrastructure, Transport and Tourism's (MLIT) Tōhoku headquarters on 3rd June EEFIT was informed that the reconstruction of these coastal revetments was due to take place within 5 years.

Mano et al. (2012, 2013) suggest a number of failure mechanisms depending on specific sites. These include breaking of the slabs and/or concrete lattices, scatter of the covering blocks and soil erosion at the lee side. Furthermore from field and video data it can be observed that the return flow concentrated around the locations of old channels and swamps (and breaches caused from the incoming wave) and caused further damage on the return flow.

Suwa et al. (2012a) confirm the site specific nature of the failures identifying locations where 100 percent destruction of the revetments had occurred with only a 3m wave but other locations where there was no destruction with a 10m wave. They also discovered that for overflow depths of less than 6 m there was less damage to the revetments when the landward toe was covered, though oddly no difference was found in performance between covered and uncovered landward toes when the overflow was deeper. If failure was due to scour this apparent anomaly may be explained by the fact that overflow depth seems to be inversely related to velocity (e.g. Titov & Synolakis, 1997).

Kato et al. (2012) provide a comprehensive range of failure mechanisms with examples, including failure of the crown armour, confirmed in hydraulic model tests. They also cite damage at the seaward toe in addition to other causes previously mentioned.

Jayarathne et al. (2013) also confirm the contributory effect of damage to the landward slope or toe of the structure from field observations and provide as yet unvalidated numerical model results using Large Eddy Simulation, showing the high velocities on the landward slope and high vorticity at the landward toe.

A further observation, made by Shibayama et al. (2013), is that most of the cores they had surveyed did not show the presence of geotextiles, which protect leaching of the sand core of the revetment. They observed that revetments on the Natori River suffered less damage where they had geotextiles incorporated.

The ASCE-COPRI-PARI team report (ASCE, 2013) comments that failure of the concrete revetments (sea dikes) are likely to be due to a combination of mechanisms, including the wave overtopping process and associated uplift forces which may have removed concrete panels from the landward side leading to loss of material due to the lack of geotextile membrane and hence reduced lateral support for the seaward side of the structure. Catastrophic collapse would then be caused by impact loads exceeding the lateral strength.

3.1.2. Seawalls

According to a survey by Kumagai (2011) reported in PIANC (2013), the majority of seawall failures in the Miyagi and Iwate prefectures were due to sliding failure of the foundations caused by scour or 'drawing out' as a result of the action of repeated incoming and outgoing waves. Additionally damage was due to drifting objects and breakage along the seawall joints. Kato et al. (2012) report on the seawall at Ryoishi where the inundation height was 21 m and the height of the seawall was 9.2 m. Here the overturning moment due to the wave force on either runup or drawdown could have been larger than the resistive moment of the gravity wall structure, leading to toppling.

Suppasri et al. (2013) investigated the infamous Taro seawall (EEFIT, 2011) and list several reasons for its failure: the X-shaped layout of the old and new seawalls caused the waves to funnel and increase in magnitude, foundations of the eastern wall may have been weakened by its proximity to the riverbed, poor maintenance was in evidence, the initial build had no strong connections and scouring was observed at the foundations. Ishikawa et al. (2012) provide more details of potential failure mechanisms. From field observations they describe the state of the concrete covers (armour blocks) that comprised both the offshore and inland slopes of the seawall and which had elastomeric connections at the joints between blocks. Many of the armour blocks were removed, some by overflow and some by drawdown flow as indicated by the position of the displaced blocks. There was evidence of shear failure at the joints between blocks. Also, there was evidence of concrete foot

protection being destroyed by overflow leading to removal of the concrete blocks on the rear slope. Further, Ishikawa et al. (2012) combine the field observations with numerical and 1:5 scale laboratory modelling to suggest further failure mechanisms which include collapse due to impulsive force and removal of blocks due to negative pressure under the overflowing wave.

3.1.3. Breakwaters

The most famous example of a breakwater collapse was that of the world record Kamaishi tsunami breakwater previously reported in EEFIT (2011). It stood in water 63 m deep and was designed to reduce tsunami inundation to just 0.5 m within Kamaishi, though this was based on the 1896 tsunami. Large sections of the breakwater failed in 2011 though there is evidence from numerical modelling using STOC-ML (see Section 2.4) that suggest the inundation heights were reduced by 40 percent with a corresponding delay in the tsunami arrival of 6 minutes. Arikawa et al. (2012) suggest that the principle failure mechanisms are sliding due to difference in hydrostatic head during overflow and loss of stability due to scouring of the mound at the base of the caissons. There was also evidence of mound failure at the site.

Many other general breakwaters totalling around 8,500 m (PIANC, 2011) were also destroyed by similar mechanisms (PIANC, 2013).

3.1.4. Quays

Considerable damage to quay walls was experienced (PIANC, 2011) from settlement of up to 1 m of the quay level, to failure of the quay pavement, exposing underlying material, to swelling of sheet pile walls and in some locations mass concrete quay walls were tilted towards the harbour. Additionally some quays were damaged by debris including boats (PIANC, 2013).

3.2. Field trip observations of reconstruction

3.2.1. *New concrete revetments*

At two different locations along the Sanriku coastline the EEFIT team witnessed recently completed concrete revetments (alternatively called sea dikes or coastal levees). Figure 3.1 shows a plaque at the Arahama revetment (the Arahama area is in Wakabayashi-ku, Sendai City) indicating that work had just finished. Photographs of completed sections at Arahama are shown in Figure 3.2, Figure 3.3, Figure 3.4, Figure 3.5 and Figure 3.6. Prefabricated armour units were placed over rock fill. Revetments along this coast are assumed to be the standard 7.2 m above Tokyo Peil (T.P.) where T.P. is the fundamental metric datum of Japan. This crest level is intended to give protection against Level 1 events, experienced every few decades (see Section 2.3).



Figure 3.1 (left) EEFIT team members reading a plaque indicating recent completion of section.

Figure 3.2 (right) Abrupt end to recently completed revetment at Arahama.



Figure 3.3 (top left) Seaward slope of newly built concrete revetment at Arahama.

Figure 3.4 (top right) Steps on landward slope of concrete revetment at Arahama.

Figure 3.5 (bottom left) Armour units on landward side of Arahama revetment, showing grout-filled lifting holes.

Figure 3.6 (bottom right) Visible infill between armour units at Arahama revetment.

Ongoing construction work was also in evidence at Arahama as shown in Figure 3.7 and Figure 3.8.



Figure 3.7 (left) Construction of revetments at Arahama.

Figure 3.8 (right) Seaward slope of Arahama revetments under construction.

Defending the international airport at Sendai are the new revetments south of Yuriage village, Natori City, shown in Figure 3.9, Figure 3.10, Figure 3.11 and Figure 3.12. They are of similar design to those at Arahama though the armour units had different details. We were told by Mr Shinichi Endo at a meeting with MLIT that different civil engineering contractors met the required specification using slightly different designs. The lifting holes on these units remained unfilled.

It was not clear from either of the constructions the extent of landward toe protection.

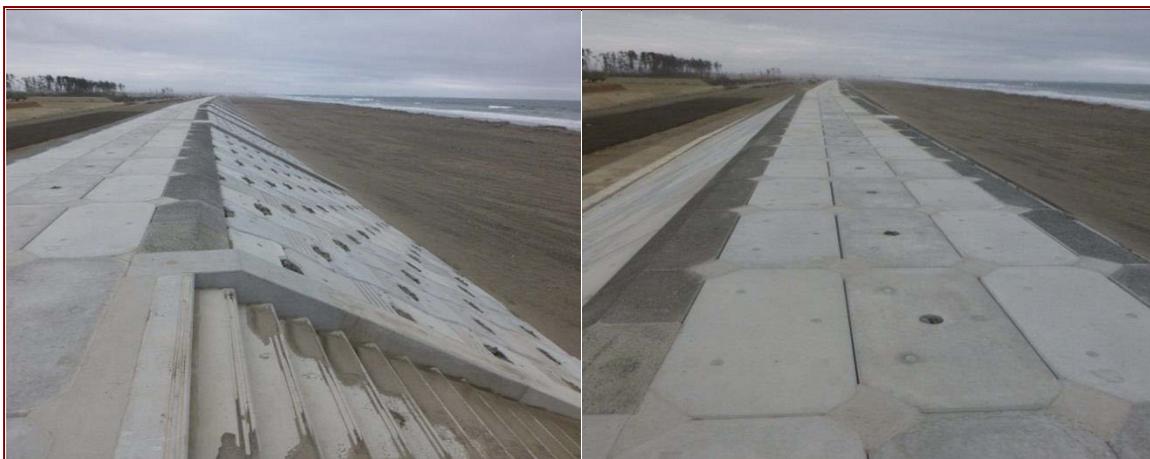


Figure 3.9 (left) Crest and seaward slope of Yuriage concrete revetment.

Figure 3.10 (right) Crest of Yuriage concrete revetment.



Figure 3.11 (left) Armour units on seaward slope of Yuriage concrete revetment with unfilled circular holes.

Figure 3.12 (right) Sand-covered steps on seaward side of Yuriage concrete revetment.

3.2.2. Quay walls rebuilding in Ishinomaki

Following the earthquake in 2011 coastal areas of Ishinomaki City subsided by up to 1.2 m (EEFIT, 2011; ASCE, 2013). The team re-visited one such place: Ishinomaki fishing port. The roads around the factories had all been elevated by around half a metre and where some buildings had survived the tsunami inundation, they were now at a lower level than the newly-elevated road, as illustrated in Figure 3.13 and Figure 3.14. Where buildings had been lost or removed large swathes of ground were being raised up with fill as shown in Figure 3.15.



Figure 3.13 (left) Old and new ground levels at Ishinomaki fishing port.

Figure 3.14 (right) Sloping ground into warehouse following recent elevation of ground levels in Ishinomaki fishing port.



Figure 3.15 Elevated ground level at Ishinomaki fishing port.

New quay walls were also being constructed in Ishinomaki. Whether these were replacing damaged walls or were just part of a general renovation was not clear from the 2011 mission. Figure 3.16, Figure 3.17, Figure 3.18 and Figure 3.19 show the sheet piling, formwork and newly cast concrete sections of the quay wall. Presence of formwork suggests that the quay wall sections may be cast in-situ though details of the rounded crest of the new quay suggested prefabricated construction.



Figure 3.16 (left) Sheet piling for quay construction at Ishinomaki fishing port.

Figure 3.17 (right) Sheet piling and formwork at Ishinomaki.



Figure 3.18 (left) Formwork at Ishinomaki.

Figure 3.19 (right) Newly-cast concrete sections of quay wall at Ishinomaki.

Figure 3.20 and Figure 3.21 show a quay wall that had survived but has had the level subsequently elevated, exposing only the metal mooring bollards and the very edge of the old quay.



Figure 3.20 (left) Renovated quay wall at Ishinomaki fishing port.

Figure 3.21 (right) Close-up view of renovated quay wall showing original metal mooring bollard.

The situation in Onagawa was a little clearer as the quay damage had been captured during the 2011 mission. Figure 3.22 and Figure 3.23 show pairs of photographs taken in the 2011 and 2013 EEFIT missions. The 2011 photographs clearly show the inundation of the sea due to the low freeboard of the quay and damage. The 2013 photographs show the numbered rubble-filled bags that were providing a retaining wall structure against which to build up the ground and provide a barrier to the sea. Figure 3.24 shows the new concrete piers in place ready for the quay deck to be placed.



Figure 3.22 Pair of photographs taken in the 2011 (left) and 2013 (right) EEFIT missions, towards the northern end of Onagawa port.



Figure 3.23 Pair of photographs taken in the 2011 (left) and 2013 (right) EEFIT missions, towards the southern end of Onagawa port.

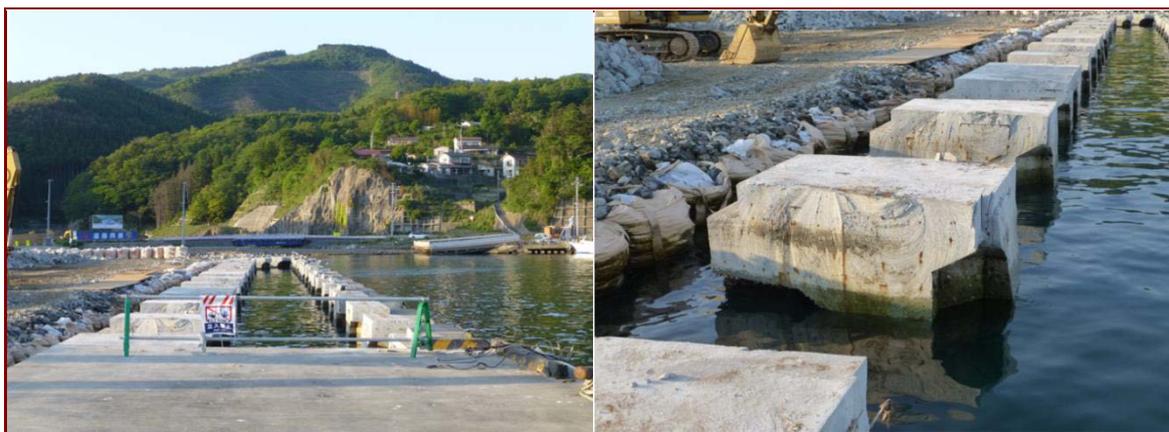


Figure 3.24 Bridge piers for new quay in Onagawa.

3.2.3. Nuclear power station seawalls

The disastrous consequences of the tsunami overtopping the Fukushima Daiichi Nuclear Power Station (NPS) caused other NPSs to reassess their seawalls. The EEFIT Team visited Onagawa NPS within the Tōhoku region and Hamaoka NPS in the Chubu region, some 200 km south-west of Tokyo.

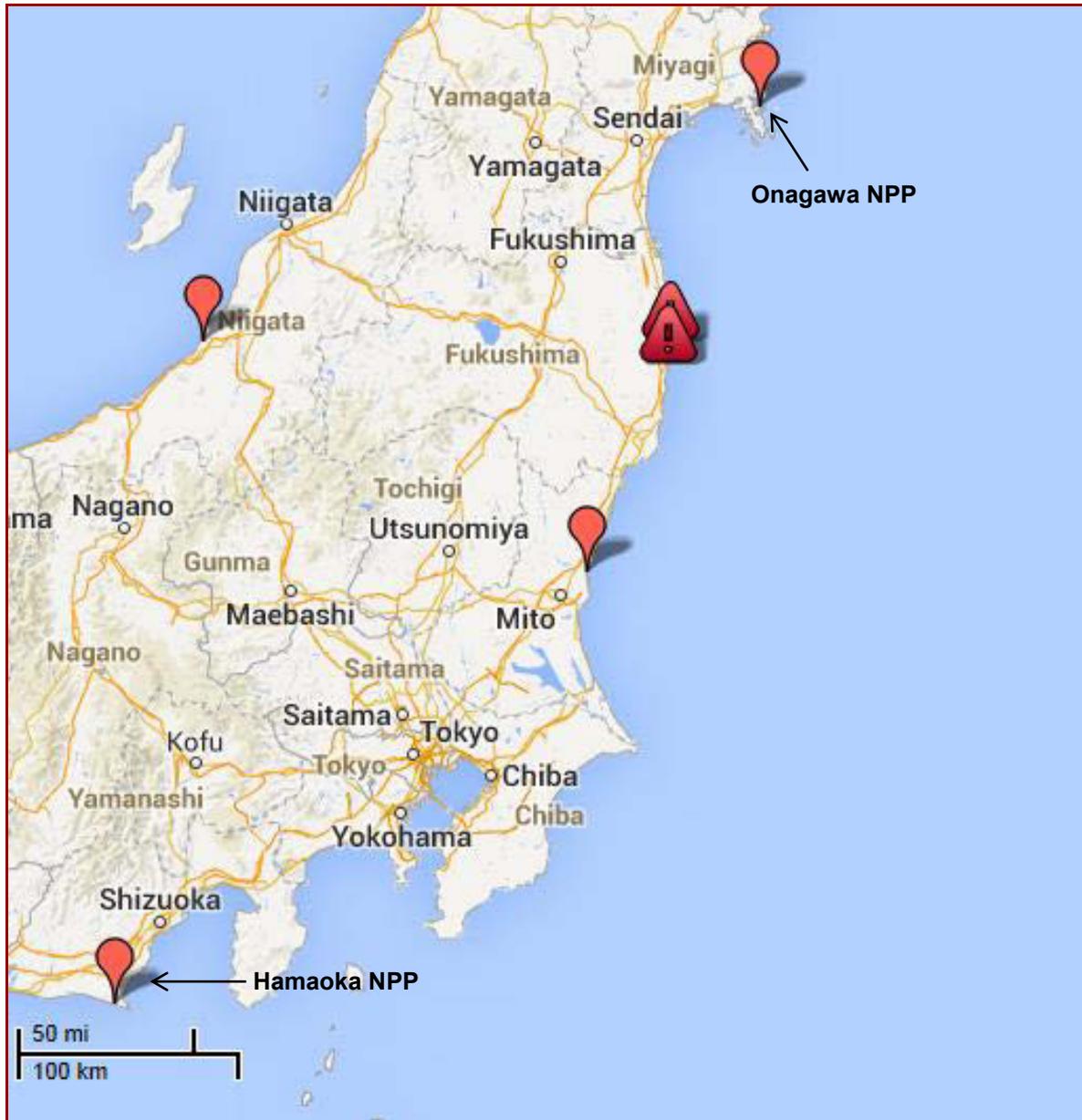


Figure 3.25 Locations of Onagawa and Hamaoka nuclear power stations (image source: Google Maps).

For security reasons photography was not permitted except in the visitor centre and whilst official photographs are available to view on the websites permission has not been granted to use the images in this report.

The Hamaoka NPS is the only plant in Japan which is not built within a port due to its shallow water depth and as such has different defences i.e. no harbour walls. The site faces SSW and has no offshore defences, e.g. detached breakwaters. An indication of the line of protective defences is shown in Figure 3.26 (left).

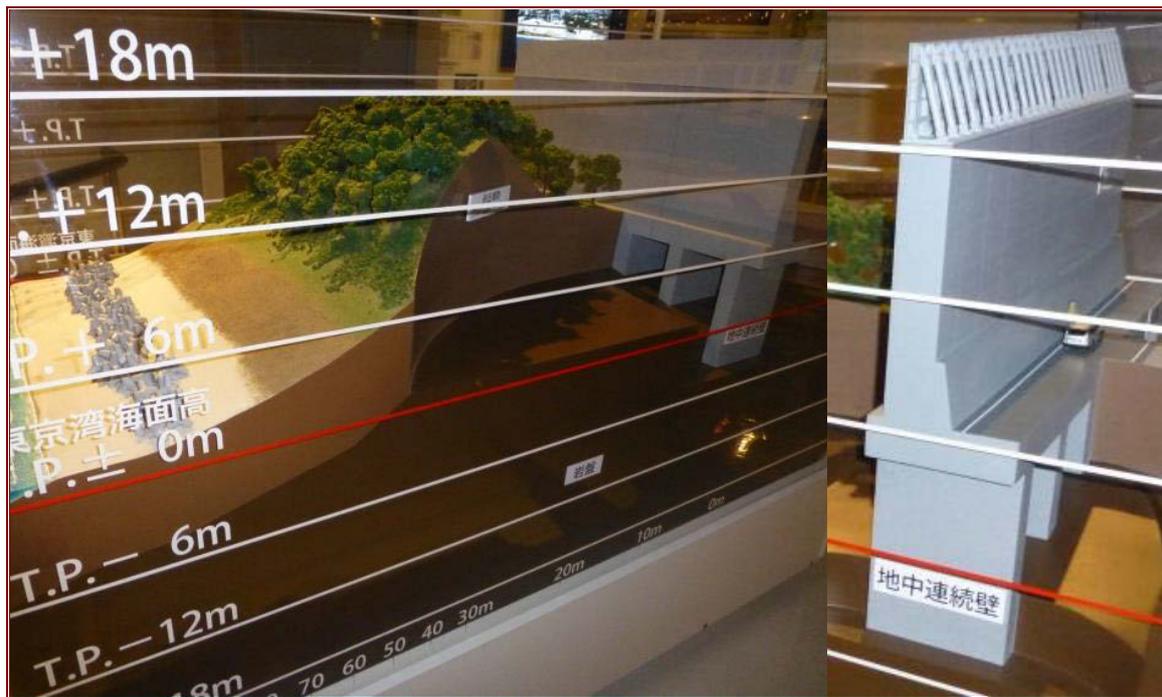


Figure 3.26 (left) Scale model of Hamaoka NPS lines of defences in visitor centre.

Figure 3.27 (right) Close-up of landward side of seawall in Hamaoka NPS visitor centre.

Vertical elevations with respect to Tokyo Piel (T.P.) are indicated alongside the model. Designs are based upon events corresponding to a combined Tokai/Tonankai/Nankai trough earthquake. The lines of defence begin with a line of tetrapod concrete armour units close to the shore, designed to reduce wave energy but not to act as a rigid boundary to the flow. Then there are sand dunes of 12 m to 15 m elevation above T.P. Finally there is a new tsunami wall, 22 m in elevation with respect to T.P.; simulations undertaken for the worst-case tsunami scenario suggest that the wave will have an inundation height of 21.4 m. The depth of the wall foundations vary from 10 m to 30 m, down to bedrock with a floor slab 7 m wide. The main body of the wall starts at an elevation of 6 m T.P. It is constructed from steel, for speed, in 109 individual sections, each with 14,000 bolts. Construction is shown in Figure 3.28. The steel frame is filled with concrete: the bottom third with a standard mix and the remainder with light concrete. The height of this part of the wall is 12 m. Finally, as shown in Figure 3.29, a 4 m steel buttressed extension to the crest of the wall brings the structure to 22 m T.P. At the time of writing further buttressing is being constructed to the lee side of the main wall. The entire structure will be covered in around 70 mm of concrete to stop corrosion.



Figure 3.28 Construction of tsunami wall at Hamaoka NPS (reproduced by kind permission of Seiichi Yamada, Hamaoka, NPS).

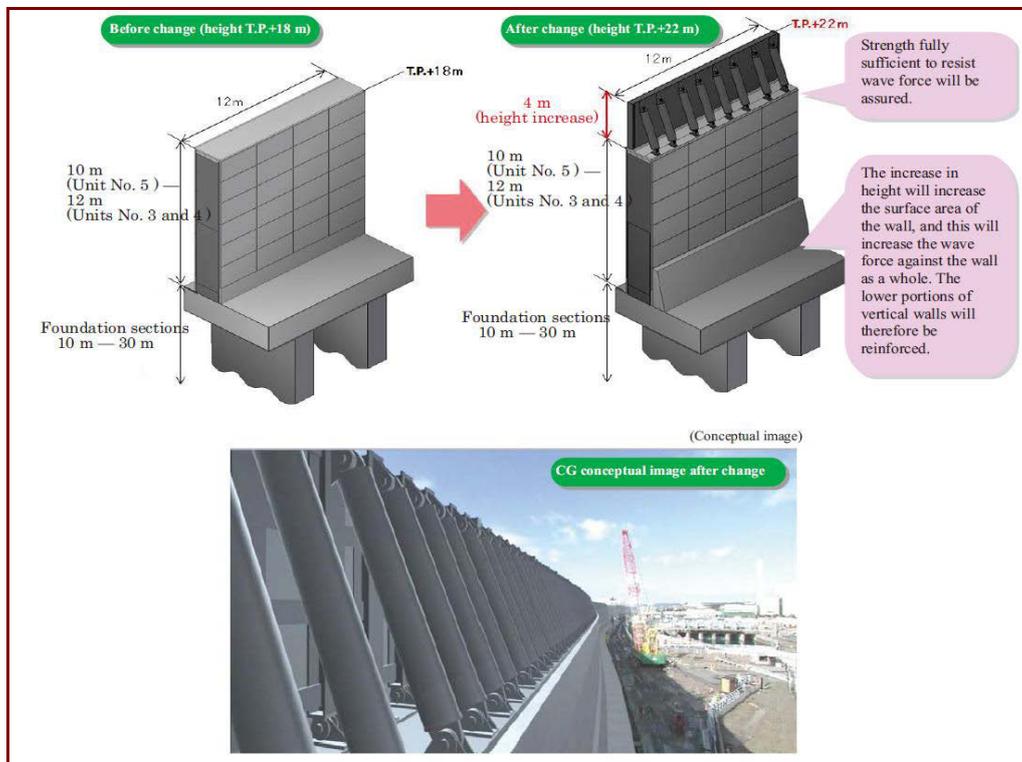


Figure 3.29 Additional buttresses on Hamaoka NPS tsunami wall (reproduced by kind permission of Seiichi Yamada, Hamaoka, NPS).

At either end of the 1.3 km long protection wall the works terminate with end sections that are built into 22 m to 24 m embankments which comprise soil mixed with cement. At the western boundary of the site is the river Niino, therefore the embankment is longer than at the eastern end. Construction of the wall was undertaken with a 24 hour shift pattern and took 14 months to complete; this extent of work would normally be scheduled for a 3 year period.

The Onagawa NPS is situated closer to the epicentre of the 2011 earthquake than Fukushima Daiichi. The inundation height was 13 m whilst the elevation of the defences was 14.8 m (minus subsidence). The defences were built to withstand a 9.1 m wave but they withstood the tsunami. Following the event the defence levels were raised to 17 m and there are plans for a super-seawall with a crest level of 29 m, to withstand a 23 m tsunami. The wall, built immediately landward of the existing harbour protection. To the east of that wall will be a concrete reinforced embankment of 120 m length. It is due for completion by March 2016.

3.2.4. Sea defences in Minamisanriku

The town of Minamisanriku has suffered extensive devastation as reported in EEFIT (2011). Signs of rebuilding were apparent further inland but along the coast activity had focused on removing further buildings and the construction of new facilities for fishing. Gravity wall structures and tsunami river gates which had been affected were left as they were, as is evident from Figure 3.30 that shows the situation in 2011 and 2013. There was no evidence of any rebuilding of domestic structures, just the removal of further buildings that had survived collapse in the earthquake/tsunami.



Figure 3.30 Pair of photographs taken in the 2011 (left) and 2013 (right) EEFIT missions across the port of Minamisanriku.

However, a replacement port structure was seen, as shown in Figure 3.31 and Figure 3.32, indicating return of commercial fishing activity. Commercial fishing boats were seen in both Ishinomaki and Minamisanriku.



Figure 3.31 (left) New port structure in Minamisanriku.

Figure 3.32 (right) Close-up of Minamisanriku port structure with jetties and characteristic wooded island beyond.

3.3. New approaches to coastal structure design

An evolution in engineering design philosophy has taken place over the past 50 years: moving from the use of design equations for optimising safety versus cost to performance-based design, which systematically and explicitly describes performance requirements. Coastal engineers in Japan have been fully engaged in this process: Shigeo Takahashi of the Port and Airport Research Institute presented performance design of armour stones and blocks of breakwaters (Takahashi et al., 2003) and presented a performance design framework for coastal structures subject to storm surge (Takahashi et al., 2004). Subsequently, in 2007 design standards for port facilities in Japan underwent major revision and are now performance-based (PIANC, 2013). Following the 2011 tsunami Takahashi commented on the need for the integration of coastal defence design approaches to take into account huge tsunamis (PARI, 2012).

In terms of revisions to design elements in the light of failures, Shibayama et al. (2013) argue for the need for geotextiles to be incorporated into concrete revetment designs to provide a barrier to infill leaching at the leeside, not just the seaward side as it is already common practice. This is based on observations of revetment failures along the Natori River. Kato (2012) suggest that new revetment design includes a concrete foundation for the landward toe and the use of notched (interlocking) slope armour. This design has been adopted in the southern part of the Sendai plain. In a physical modelling study of breakwater failure Arikawa and Shimosako (2012) investigated the effect of widening the breakwater. This was achieved by raising the foundation mound behind the breakwater with riprap (loose rocks) and covering with armour blocks and scour protection mats. The effect of this was to delay the effect of scouring making the structure more resilient to tsunamis. The paper stops short of recommending it for new design or renovation though the work is reported in the PIANC Working Group No. 53 Appendix on Mitigation of Tsunami Disasters in Ports (PIANC, 2013).

Whilst not strictly coastal structures, The Ministry of Land, Infrastructure, Transport and Tourism (MLIT, n.d. b) is recommending tsunami adaptation structures to be used away from the shoreline to stop inundation further inland. They use similar types of structure as those along the shoreline: lock gates, seawalls and embankments. In certain locations the raised road in the Sendai plain areas was seen to provide a physical barrier to tsunami flow and this has presumably provided some of the inspiration for the idea.

Previous tsunami modelling used for hazard planning had been based on 2003 estimates of seismic activity. These estimates had not been informed by studies of sediment layers from past tsunamis; neither had they included information on large slip areas which may have been responsible for unexpectedly high waves in some areas following the 2011 earthquake. Revised modelling was undertaken, focusing on the Nankai trough, and results were alarming as the predicted tsunami levels

were much larger than had been previously forecast (Nature, 2012a). This type of event would correspond to a Level 2 tsunami i.e. rare and extremely large. Coastal structures would not be expected to stop inundation of a Level 2 tsunami but they would be expected to survive intact while dissipating a large amount of the tsunami energy.

Guidance on the use of simulations is provided by the National Institute for Land and Infrastructure Management, the technical/research department that supports MLIT (Suwa et al., 2012b). According to Nature (2012b) Professor Fumihiko Imamura of Tōhoku University ran 200 simulations where defence structure parameters were varied leading to Sendai city's zoning plans. These zones are colour-coded according to inundation depth and activities are limited within certain zones (see Chapter 6).

During the EEFIT return mission the EEFIT team visited officials in Iwanuma City, Miyagi prefecture. This region covers an area of about 60 km² which prior to the 2011 tsunami had a population of 44,000. Iwanuma City is formed from the merger of many old villages including old Iwanuma town. Within its boundary lies Sendai airport, the gateway to regional and international travel. Following the tsunami 48% of Iwanuma City was inundated, 186 people were killed and much of the coastal pine tree forest was heavily damaged. The redesign of the city features three lines of defence:

- 1) New coastal revetments with a crest height 7.2 m above Tokyo Peil (T.P.). This revetment runs for 9.9 km;
- 2) Inland of the revetment is a canal that has an elevation of 3.7 m above T.P. This runs 13.5 km along the coast;
- 3) Further inland is a new planned raised roadway at an elevation of between 4 m and 5 m above T.P. that will run for a length of 7.3 km.

Between the revetments and the canal will lay the newly planned Millennium Hope Hills: 15 individual hillocks of elevation 8 m to 10 m, some of which are joined by elevated walkways. Figure 3.33 shows an information board for visitors to the area with artist's impressions of the final scheme and details of the construction. Up to 20 percent of the composition of the hills is debris: soil, concrete and wood chopped into 1m lengths. These are intended primarily as refuge points for those that may be caught in the low-lying areas during a tsunami but the area is also designed as a park which could attract further government funding. One such hill had just been completed (Figure 3.34) and was just about to be planted with young trees and shrubs in a community activity. The trees will provide a level of frictional resistance to the tsunami flow.



Figure 3.33 (left) Information board for the Millennium Hope Hills project in Iwanuma.

Figure 3.34 (right) Steps up the first Millennium Hope Hill to be completed.

3.4. Significant rebuilt defences

Replacement structures were reported earlier in Section 3.2. This sub-section describes two further particular coastal structures whose failures were described in the original mission report (EEFIT, 2011).

During the 2011 EEFIT mission two of the team visited the town of Taro towards the north of the worst-affected region (see Section 3.1.2 in this report). Taro was famous for the size and extent of its seawalls but the most recently built sections had collapsed, with devastating consequences for the town. The design of the new seawalls as reported in the Japanese press (Japan Today, 2013) seems to follow an identical layout to those previously destroyed. An X-shaped layout is shown, which according to Suppasri et al. (2013) may have led to intensification of the wave. The article suggests that the shape will be beneficial in case the first wall is breached. A significant improvement of the design however is the use of steel reinforcement rods (Japan Today, 2013), absent from the wall that was destroyed. The first stage of the restoration works is to restore the height of the seawall that survived the tsunami, as it settled by 0.7m during the earthquake. The second stage will be to reconstruct the destroyed section but the height of sea wall is still under discussion (Arikawa, 2013).

The Kamaishi breakwater, the world record breaking structure that failed in the 2011 tsunami (EEFIT, 2011) is a continuing source of controversy in terms of its use of public funds, its effectiveness and its effect on neighbouring settlements. It is currently being repaired at an estimated cost of £350 million (compared with the initial build cost of £770 million) (Nature 2012b). In a region that was already suffering from depopulation some have questioned the sense of further investment. However, Akihiro Murakami of MLIT is reported as saying that the rate of depopulation would only increase without the repairs being undertaken (New York Times, 2011). Regarding its effectiveness, since the Port and Airport Research Institute's (PARI) original simulations, criticisms have been that the modelling was inaccurate since it was assumed that the breakwater remained intact (New York Times, 2011). But recent simulations by PARI (Tomita et al., 2013) show that even if the breakwater had failed before the arrival of the main tsunami it would have reduced the tsunami inundation height in the port by 40 percent. Whether or not the population was complacent due to the breakwater, leading to ineffective evacuation of the population is another matter; the mayor of Kamaishi, Takenori Noda, is of this opinion (New York Times, 2011). Finally the effect of the breakwater on neighbouring bays was understood to be an issue from physical modelling studies in the 1970s (New York Times, 2011). It was discovered that a new breakwater at Kamaishi would amplify the size of waves in neighbouring bays including Ryoishi, to the extent that a breakwater at Ryoishi was a prerequisite for the construction of one at Kamaishi. In fact Ryoishi was virtually destroyed by the 2011 tsunami with wave heights more than double those at Kamaishi; a photograph of the seawall structure was included in the 2011 EEFIT report (Figure 6.12 in EEFIT, 2011). Despite these issues the reconstruction is underway; photographs of the new concrete caissons being floated out appear in The Japan Times (2013).

3.5. Conclusions

Prior to the Great East Japan earthquake and tsunami, 40 percent of the country's coastline was protected by hard-engineered structures. In the affected regions many of these structures failed, or suffered damage. Initial surveys suggested apparent failure mechanisms, reported here. Further investigations using physical and numerical model testing have shed new light on the processes leading to recommendations. These include the inclusion of geotextile membranes in concrete revetments to stop leaching of infill material, reinforcement of the landward toe of the revetments, widening of breakwater mounds and reinforcement/improved tying together of block structures. Japan continues to innovate and one idea to provide protection to seawalls in a Level 2 tsunami scenario is to build space type grids (Ishikawa et al., 2012) which are essentially the bones of a seawall without solid faces. These will permit water but not debris (including cars) to pass through and importantly they will reduce the impulsive force on structures further inland.

In several places visited e.g. the nuclear power stations and Iwanuma city in Miyagi prefecture there was evidence of the drive to protect sites using multiple lines of defence, accepting that one single defence will not be adequate. These plans for multiple lines of defence are included in reconstruction plans (see for example Miyagi Prefecture, 2013).

Some of the recommendations have been incorporated into newly constructed defences but some issues are proving more difficult. According to Arikawa (2013) there is a disaster law in Japan that says it is a principle to return the damaged structure to its former state. In cases like the Taro seawall and the Kamaishi breakwater where the effect of the structures was not totally benign or there are controversies that are still to be resolved, this may not be the wisest route.

However, the government is clearly committed to repopulate areas by providing hard engineered structures and there is no doubt about the tremendous effort and competency with which the task is being undertaken. By and large, the coastal defence observations made during the EEFIT return mission to Japan provided much encouragement and inspiration as the country seeks to provide protection from the sea into the future.

3.6. References

- Arikawa, T.M. (2013). Rebuilding of Taro seawall. [email] (Personal communication, 4 September 2013).
- Arikawa, T., Sato, M., Shimosako, K., Hasegawa, I., Yeom, G.S., and Tomita, T. (2012). Failure mechanism of Kamaishi Breakwater due to the Great East Japan Earthquake Tsunami, Proc. of the 33rd International Conference on Coastal Engineering, Santander.
- Arikawa, T. and Shimosako K. (2012). Failure mechanisms of breakwaters due to tsunami; a consideration to the resiliency, Proc. 6th Civil Engineering Conference in the Asia Region, August 2013, Jakarta.
- ASCE (2013). Tōhoku, Japan, Earthquake and Tsunami of 2011 Survey of Coastal Structures, Eds. L. Ewing, S. Takahashi and C. Petroff. Virginia: American Society of Civil Engineers.
- Burcharth, H. F. and Hughes, S. A. (2002). "Types & functions of coastal structures," S. Hughes, ed., in Coastal Engineering Manual, Part VI-2, Design of Coastal Elements, Engineering Manual EM 1110-2-1100, U.S. Army Corps of Engineers, Washington, DC.
- EEFIT (2011). The Mw9.0 Tōhoku Earthquake and Tsunami of 11th March 2011: A Field Report by EEFIT [online]. Available at: <<http://www.istructe.org/webtest/files/1d/1d158684-b77b-4856-99f8-2522fa25533b.pdf>> [Accessed 02 September 2013].
- Ishikawa, N., Arikawa, T., Beppu, M. and Tatesawa, H. (2012). Collapse mechanism of seawall protective structure by huge tsunami. In: Hao, H. and Li, Z.-X. *Advances in Protective Structures Research*. London: Taylor & Francis Group. Ch. 9.
- Japan Today (2013). 2.4-km-long X-shaped seawall being built in Iwate [online]. Available at: <<http://www.japantoday.com/category/national/view/2-4-km-long-x-shaped-seawall-being-built-in-iwate>> [Accessed 02 July 2013].
- Japan Times (2013) Laying a foundation [online]. Available at: <<http://www.japantimes.co.jp/news/2013/06/06/national/state-lowballed-nankai-tsunami-impact-osaka/>> [Accessed 04 September 2013].
- Jayarathne, R., Mikami, T., Esteban, M. and Shibayama T. (2013). Investigation of Coastal Structure Failure due to the 2011 Great Eastern Japan Earthquake Tsunami, Proc. Coasts, Marine Structures and Breakwaters Conference, ICE, Edinburgh.
- Kato, F., Suwa, Y., Watanabe, K. and Hatogai, S. (2012). Mechanisms of Coastal Dike Failure Induced by the Great East Japan Earthquake Tsunami, Proc. of the 33rd International Conference on Coastal Engineering, Santander.
- Kumagai, K., Watanabe, Y., Nagao, N. and Ayugai, M. (2011). Field Survey of the 2011 off the Pacific coast of Tōhoku Earthquake and Tsunami on Shore Protection Facilities in Ports, Technical note of National Institute for Land Infrastructure Management, No. 658 (in Japanese).
- Miyagi Prefecture (2013). Reconstruction plans [online]. Available at: <<http://www.pref.miyagi.jp/seisaku/sinsaihukkou/keikaku/index.htm>> [Accessed 04 November 2013].
- MLIT (n.d. a). Coastal Management in Japan [online]. Available at: <http://www.mlit.go.jp/river/trash_box/paper/pdf_english/e_137.pdf> [Accessed 02 September 2013].
- MLIT (n.d. b). Recent policy changes regarding tsunami disaster countermeasures [online]. Available at: <http://www.mlit.go.jp/river/basic_info/english/pdf/conf_10-3.pdf> [Accessed 03 September 2013].

- MLIT (2013). Response of Tōhoku Regional Bureau, MLIT, to the Great East Japan Earthquake, PowerPoint presentation, MLIT, Sendai, Japan.
- Mano, A., Tanaka, H. and Udo, K. (2012). Destruction Mechanism of Coastal Levees on the Sendai Bay coast hit by the 2011 Tsunami Proc. of the 33rd International Conference on Coastal Engineering, Santander.
- Mano, A., Iida, T., Udo, K. and Tanaka, H. (2013). Breaking process and mechanism of coastal levees on Sendai Bay Coast hit by the 2011 mega tsunami, *J. Coastal Res. Special Issue* No. 65.
- Nature (2012a). Tsunami simulations scare Japan, 17 April 2012 [online]. Available at: <<http://www.nature.com/news/tsunami-simulations-scare-japan-1.10460>> [Accessed 02 September 2013].
- Nature (2012b). Rebuilding Japan: After the deluge, 07 March 2012 [online]. Available at: <<http://www.nature.com/news/rebuilding-japan-after-the-deluge-1.10172>> [Accessed 02 September 2013].
- New York Times (2011). Japan Revives a Sea Barrier That Failed to Hold, 02 November 2011 [online]. Available at: http://www.nytimes.com/2011/11/03/world/asia/japan-revives-a-sea-barrier-that-failed-to-hold.html?pagewanted=all&_r=0 [Accessed 02 September 2013].
- PARI (2012). Port and Airport Research Institute: 50 Years 1962 to 2012, Vol. 7, April 2012.
- PIANC (2013). Tsunami Disasters in Ports due to the Great East Japan Earthquake (Appendix to Report No. 112-2010 Mitigation of Tsunami Disasters in Ports), PIANC Working Group 53.
- Reeve, D., Chadwick, A. and Fleming, C. (2004). *Coastal Engineering Processes, Theory and Design Practice*. London: Spon Press.
- Shibayama, T., Esteban, M., Nistor, I., Takagi, H., Thao, N., Matsumaru, R., Mikami, T., Aranguiz, R., Jayaratne, R. and Ohira, K. (2013). Classification of Tsunami and Evacuation Areas, *Nat Hazards* 67:365-386.
- Suppasri, A., Shuto, N., Imamura, F., Koshimura, S., Mas, E. and Yalciner, A.C. (2013). Lessons Learned from the 2011 Great East Japan Tsunami: Performance of Tsunami Countermeasures, Coastal Buildings, and Tsunami Evacuation in Japan, *Pure Appl. Geophys.* 170:993-1018.
- Suwa, Y., Kato, F. and Watanabe, K. (2012a). Analysis of damage to coastal dikes by tsunami, 2012 Annual Report of NILIM [online]. Available at: <<http://www.nilim.go.jp/english/annual/annual2012/3.pdf>> [Accessed on 02 September 2013].
- Suwa, Y., Kato, F. and Watanabe, K. (2012b). Guidelines of setting design tsunami water level and guidelines on tsunami inundation simulations, 2012 Annual Report of NILIM [online]. Available at: <<http://www.nilim.go.jp/english/annual/annual2012/11.pdf>> [Accessed on 03 September 2013].
- Takahashi, S., Kawai, H., Tomita, T. and Takayama, T. (2004). Performance design concept for storm surge defence, *Proc. of the 29th International Conference on Coastal Engineering*, Lisbon.
- Titov, V.V. and Synolakis, C.E. (1997). Extreme inundation flows during the Hokkaido-Nansei-Oki Tsunami, *Geophysical Research Letters* 24(11): 1315–1318.
- Tomita, T., Arikawa, T. and Takahashi, S. (2013). Tsunami Resilient Ports on the Basis of Lessons from the 2011 Great East Japan Earthquake and Tsunami [online]. Available at: <http://www.nehrp.gov/pdf/UJNR_2013_Tomita.pdf> [Accessed on 02 September 2013].

4. Nuclear industry and critical facilities

4.1. Background

The 2011 March 11 Tōhoku Earthquake and its subsequent tsunami were amongst the strongest extreme natural events in the last 100 years. This event devastated a significant area on the north-east coast of Japan, and triggered several “man-made” disasters by damaging critical facilities with high secondary risk for the society. This led to additional human casualties, devastation of natural eco-systems and economic losses. Some of the most significant incidents to the critical facilities were the Fukushima Daiichi nuclear accident (covered in Section 4.2) and the failure of the Fujinuma Dam (covered in Section 4.5.3).

One of the primary focuses of the 2013 EEFIT return mission to Japan was to visit some of the critical facilities and investigate the preparedness of these facilities for future events. With assistance from the British Embassy in Japan and the Japan Commissions of Large Dams, the EEFIT mission team managed to visit a number of critical facilities, including

- Onagawa Nuclear Power Plant (NPP) on the 3rd June 2013 (see Section 4.4.1),
- Hamaoka NPP on the 5th June 2013 (see Section 4.4.2),
- Surikamigawa Dam on the 4th June 2013,
- Nishigo Dam (see Section 4.5.2) on the 4th June 2013, and
- Fujinuma Dam (see Section 4.5.3) on the 4th June 2013.

Due to the 20km exclusion zone still in place, the mission team did not manage to arrange a visit to the Fukushima Daiichi NPP.

4.2. Fukushima Daiichi NPP

4.2.1. *What happened to the Fukushima Daiichi NPP?*

The Fukushima Daiichi NPP is owned and operated by Tokyo Electric Power Company (TEPCO). There were six reactors on site and at the time when the 2011 Tōhoku Earthquake struck, three (Unit 1, 2 and 3) were operating. The reactors involved were all boiling water units of a 1960s design.

On March 11 2011, the Fukushima Daiichi NPP was first struck by a ground motion of 0.56g (measurement from Unit 2) (Kato, 2013) at 14:46 local time followed by a tsunami with inundation height of up to 15.5m at 15:35 local time. As is standard procedure, immediately after the earthquake, the operating reactors went into ‘scram’ (emergency shutdown) and emergency generators were initiated to provide power supply to the cooling water pumps, the motor operated valves and other vital systems. However, the tsunami that followed the earthquake quickly flooded the low-lying rooms in which the emergency generators were housed. The flooded generators failed, cutting power to the critical pumps that must continuously circulate coolant water. Without cooling water, the cores of units 1, 2 and 3 overheated and partially melted in the first three days. Hydrogen generated by this high-temperature process caused explosions in the upper service floors of reactor buildings at units 1 and 3. Unit 4, although it had not been operating, was affected by a hydrogen explosion possibly due to gas back-flow from unit 3. Two other reactors at the plant were not involved in the accident (WNA, 2013).

The major accident was rated at Level 7 on the International Nuclear Event Scale due to high radioactive releases to the air in the first few days. Access was gained to the three reactors buildings and TEPCO declared cold shutdown conditions in December 2011.

Special mention goes to the site operators who stayed at the Fukushima Daiichi immediately after the incident. They fought courageously to control the damaged reactors, at great personal risk. Their heroism and improvisation contributed greatly in containing the escalation of the nuclear accident.

An accident progression flow chat is shown in Figure 4.1 (WNA, 2013).

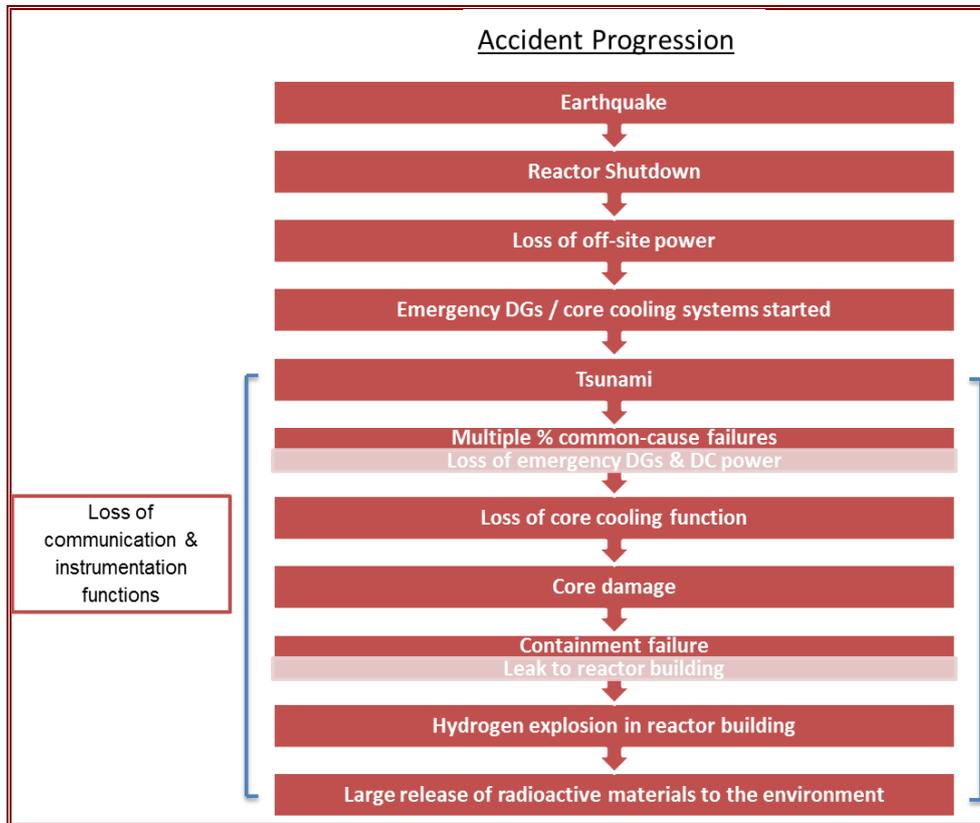


Figure 4.1 Accident Progression for the Fukushima Daiichi Incident.

4.2.2. Decommissioning strategy for Fukushima Daiichi NPP

Since the accident, TEPCO and the Japanese government have since prepared a “roadmap” (see Figure 4.2) towards the restoration of the site and pursued planned action on that basis towards an early resolution of the accident (TEPCO, 2011). The first objective of the above roadmap was the “steady downward trend in radiation levels” which was achieved in July 2011. The Step 2 objective was to keep the “release of radioactive materials under control and radiation doses are being significantly held down” and this has recently been achieved. Through these efforts, the reactors reached a state of cold shutdown in December 2011, and it is now possible to maintain an adequately low level of radioactive exposure at the site boundaries. The impact of radiation beyond the plant site has also been adequately reduced (METI, 2011).

After the end of Step 2, there will be a transition from efforts up to that point, aimed at plant stabilisation, to efforts to reliably maintain that stable state. Beyond Phase 1, this roadmap defines the period targeted to start ten years after the completion of Step 2 and continuing to the start of fuel debris removal, as Phase 2, and the subsequent period to the end of decommissioning as Phase 3.

In March 2013, the “roadmap” programme was further reduced in terms of timeframe and each individual unit has its own timeline (see Table 4.1). The reason cited for the squeezed programme is to ensure the fuel in the spent fuel pond and the fuel debris will be removed at the earliest possible time (METI, 2013).

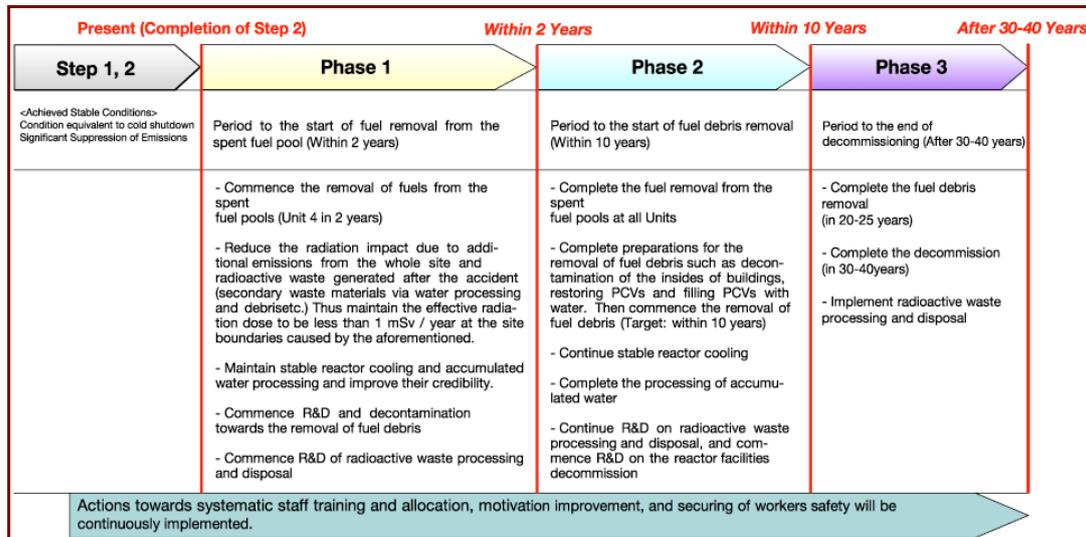


Figure 4.2 Roadmap to restoration of Fukushima Daiichi site (extracted from [TEPCO, 2013]).

Table 4.1 Fuel and Fuel Debris Removal Timeline (extract from [METI, 2013]), FY stands for Financial Year.

	Fuel Removal	Fuel Debris Removal
Initial Targets	December 2013 – earliest units	December 2021 – earliest
Unit 1	Second Half of FY2017	First Half of FY2020
Unit 2	Second Half of FY2017	First Half of FY2020
Unit 3	First Half of FY 2015	Second Half of FY2021
Unit 4	November 2013	-

4.3. Implication to Nuclear Industry

4.3.1. *Japan*

Immediately after the Fukushima Daiichi nuclear accident, two procedures were initiated in Japan: 1) a process of nuclear risk and safety reassessments of all existing power reactors [NISA, 2011]; and 2) an investigation of the main direct and indirect causes of this accident [NAIIC, 2012].

The first procedure is the so-called “stress tests” as performed in Europe. This procedure was initiated with a letter from the Nuclear Safety Commission (NSC) to the Ministry of Economy, Trade and Industry (METI) on 6 July 2011, stating that the Nuclear and Industrial Safety Agency (NISA) should undertake comprehensive safety reviews of NPPs, together with assessment methods and timetable. Responding to the request of NSC, NISA developed a document titled “Assessment Procedures and Implementation Plan Regarding the Comprehensive Assessments for the Safety of Existing Power Reactor Facilities Taking into Account the Accident at Fukushima Daiichi Nuclear Power Station, Tokyo Electric Power Co. Inc” (NISA, 2011) to set out the expectations for licensees when undertaking the Comprehensive Safety Assessment. The facilities subject to the assessment are existing power reactor facilities, including those under construction. However, Fukushima Daiichi and Fukushima Daini NPPs, as well as any facilities that are being decommissioned are not included. The

following events are subject to the assessments taking into account the accident at Fukushima Daiichi NPP:

- Natural phenomena: Earthquake and tsunami;
- Loss of safety functions: Loss of all Alternating Current (AC) power sources and loss of the ultimate heat sink (UHS).

The assessments were performed by the Operators following the methods described in the document (NISA, 2011) and were submitted to NISA. NISA evaluated the results and requested the NSC to confirm its evaluation. The assessments by each operator comprise a preliminary assessment and a secondary assessment, which according to (NISA, 2011) includes the following procedures:

- Preliminary assessments: Assessments will be implemented for the degree to which safety margins are secured for structures, systems and components (SSCs) with safety functions of especially high importance, against the events beyond the design basis. The assessment will be implemented from the perspective of the degree to which safety margins are secured against the allowable limit and other related values. The assessment will also indicate the effectiveness of measures taken to secure safety against the events beyond the design basis, from the defence in depth perspective. These processes will determine whether higher safety margins have been added to the required safety standards;
- Secondary assessments: The safety margin (the ultimate limitations of strength) will be assessed by evaluating the scale of events that a NPP can withstand without significant damage to the fuel, assuming the occurrence of events beyond the design basis. Additionally, in terms of measures to prevent significant damage to the fuel, their effectiveness will be indicated from the defence-in-depth perspective. At the same time, any cliff edge effect will be identified to uncover potential vulnerabilities. These processes will yield a comprehensive assessment of the robustness of existing NPPs against external events beyond the design basis.

Following the request of the Government of Japan, the International Atomic Energy Agency (IAEA) reviewed NISA's approach to the Comprehensive Assessment for the Safety of Existing Power Reactor Facilities and NISA's approach to the review of the results of the licensee's assessments. The IAEA safety review mission was conducted in the period of 23-31 January 2012 and all findings and conclusions are summarised in the report (IAEA, 2012).

The other very strong step taken by the Japanese authorities towards understanding the Fukushima Daiichi nuclear accident was the formation of the Fukushima Nuclear Accident Independent Investigation Commission (NAIIC), formed on October 30, 2011 by the NAIIC Act. The NAIIC was created with the authority to request the legislative branch to use its investigative powers to obtain any necessary documents or evidence required. This was the first independent commission created in the history of Japan's constitutional government. On December 8, 2011, the chairman and nine other members were appointed, and charged with the following mandate, in accordance with Article 10 of the NAIIC Act:

- 1) To investigate the direct and indirect causes of the Tokyo Electric Power Company Fukushima nuclear power plant accident that occurred on March 11, 2011 in conjunction with the Great East Japan Earthquake.
- 2) To investigate the direct and indirect causes of the damage sustained from the above accident.
- 3) To investigate and verify the emergency response to both the accident and the consequential damage; to verify the sequence of events and actions taken; to assess the effectiveness of the emergency response.
- 4) To investigate the history of decisions and approval processes regarding existing nuclear policies and other related matters.

- 5) To recommend measures to prevent nuclear accidents and any consequential damage based on the findings of the above investigations. The recommendations shall include assessments of essential nuclear policies and the structure of related administrative organizations.
- 6) To conduct the necessary administrative functions necessary for carrying out the above activities.

After six months, NAIIC issued a detailed report with the main findings, conclusions and recommendations, also available in English in the form of executive summary: "The National Diet of Japan. The Official Report of the Fukushima Nuclear Accident Independent Investigation Commission. Executive Summary" (NAIIC, 2012). One of the main conclusions of NAIIC was that the *"The TEPCO Fukushima Nuclear Power Plant accident was the result of collusion between the government, the regulators and TEPCO...Therefore, we conclude that the accident was clearly "manmade"..."*, (NAIIC, 2012). The NAIIC also concludes that *"In order to prevent future disasters, fundamental reforms must take place. These reforms must cover both the structure of the electric power industry and the structure of the related government and regulatory agencies as well as the operation processes. They must cover both normal and emergency situations..."* (NAIIC, 2012).

New Regulatory Requirements

Various investigation reports and studies on Fukushima Daiichi underlined vulnerabilities and failures in Japan's existing nuclear safety systems, procedures and standards, including a lack of the back-fit system that applies revised standards to existing nuclear reactors (NAIIC, 2012). The main findings can be summarised as follows:

- Regulatory requirements did not cover 'severe accidents' and there were few preventive activities in place. Therefore, countermeasures against severe accidents including external events were left purely to the discretion of operators (NAIIC);
- No legal framework to retroactively apply new regulatory requirements to existing nuclear power plants (so-called "back-fitting" system) (NAIIC);
- Japanese regulators made little effort to either introduce the latest foreign technology or improve safety procedures dealing with uncertain risks (NAIIC);
- Comprehensive risk assessment covering not only earthquakes and tsunamis but also fires, volcanic eruptions, and slope failures that may trigger accidents, had not been conducted. (Investigation Committee on the Accident at the Fukushima Nuclear Power Stations of Tokyo Electric Power Company);
- An integrated legal system is preferable to avoid confusion caused by multiple laws and the involvement of multiple government agencies (NAIIC).

To overcome the main problems in the Japanese nuclear regulatory domain, the national authorities introduced significant changes in their nuclear safety system. One of the centrepiece actions is the creation of a new nuclear regulatory body, the Nuclear Regulatory Agency (NRA). Following its inauguration on September 19, 2012, the NRA carried out a complete review of safety guidelines and regulatory requirements with the aim of formulating a set of new regulations to protect people and the environment. The new regulatory requirements for commercial power reactors came into force on July 8, 2013 (NRA, 2013⁴).

The new regulatory requirements were developed taking into account the lessons-learnt from the accident at Fukushima Daiichi NPP. These include those which were identified in the reports of the NAIIC, the Government's Nuclear Accident Investigation Committee and the Independent Investigation Commission on the Fukushima Daiichi nuclear accident. The new requirements specifically considered the harsh natural conditions unique to Japan, as well as to maintain consistency with the safety standards and guidelines of the International Atomic Energy Agency (IAEA) (NRA, 2013⁴).

The new regulations are also applicable to existing NPPs. However, a five-year deferment period from the time of enforcement of the new regulations to realisations of some of the safety measures is

given. These safety measures include filter vents for pressurized water reactors (PWR) and control rooms for the time of emergency.

Nuclear power reactors, that are generally limited to 40 years of operation life-time, will be given one-time legal permission to extend it by another 20 years. Under the revised Reactor Regulation Act, operators applying for such an extension are required to implement special inspections to assess whether their facilities meet the latest technical standards and properly maintain their operation from the viewpoints of any expected wear/tear and deterioration of facilities and equipment in the 20-year time period.

Based on lessons learned from Fukushima Daiichi, laws were amended in June 2012, adding the environment in addition to the general public as major safety targets. The new regulations expand also the coverage to severe accidents and introduce a provision that new requirements can be applied retroactively to existing nuclear facilities. Amendments shall be enforced within 10 months of the date on which the Nuclear Regulation Authority was established (by July 18, 2013). The key points on which the new safety criteria are based are (NRA, 2013⁴):

- To assume large-scale natural disasters, terrorist attacks and other criminal acts will occur in the future;
- To protect the lives, health, and property of the public, preserve the environment and contribute to national security;
- To include measures against severe accidents in safety operations and new regulations
- To require nuclear operators to conduct periodic and comprehensive safety assessments and file the results to the regulator and public to ensure continuous safety improvement;
- To introduce a “back-fitting” system authorising enforcement of the latest regulatory requirements on already licensed facilities;
- To integrate power plant safety regulations contained in the Electricity Business Act (periodic inspections) into the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors (the Reactor Regulation Act);
- To delete provisions on the planned use of nuclear energy from objectives and permission criteria in the Reactor Regulation Act and clarify that nuclear safety is paramount.

The above requirements for periodic and comprehensive safety assessments was introduced by the UK nuclear regulatory requirement in 1997, and has been adopted around the World. The last of these criteria separates promotion of the activity (nuclear power generation) from the regulation of its safety, and follows the recommendation of Lord Cullen on the public inquiry into the Piper Alpha disaster (Cullen, 1990).

The new requirements, the design basis for and, counter measures against, natural phenomena are significantly enhanced in order to prevent simultaneous loss of safety functions due to common causes. In addition, countermeasures against events other than natural phenomena such as fires, which may cause simultaneous loss of safety functions due to common causes, are also enhanced. Based on the concept of defence in depth, the new regulations focus on the following actions (NRA, 2013⁴):

- Emphasis on Defence-in-Depth: Prepare multi-layered protective measures to achieve specific objectives in each layer independent of other layers;
- Significantly enhance design basis and strengthen protective measures against natural phenomena which may lead to common cause failure: Strict evaluation of earthquakes, tsunamis, volcanic eruptions, tornadoes and forest fires; countermeasures against tsunami inundation and due consideration to ensure diversity and independence;
- Enhance countermeasures against events other than natural phenomena that may trigger common cause failures: Strict and thorough measures for fire protection, countermeasures against internal flooding, reinforcement of power supply systems to prevent power failure;

- Performance-based requirements in regulatory requirements: Operators select concrete measures to comply with requirements and the characteristics of their facilities.

The new regulations (NRA, 2013⁴) also introduce some new basic polices against severe accident and terrorism (NRA, 2013⁴):

- Prepare multi-layered protective measures, including prevention of core damage, maintenance of containment integrity, controlled release by venting, and suppression of radioactive material dispersion;
- Use mobile equipment as in the United States and enhance reliability by permanent equipment;
- Enhance protective measures in spent fuel pools;
- Improve command communication and instrumentation. Strengthen emergency response centre, communication system, and instrumentation, facility systems including spent fuel pools;
- Prepare procedure manuals, ensure the presence of essential personnel, and provide training to integrate equipment (hardware) and on-site work (software) functions;
- Disperse mobile equipment and their connection points to combat intentional aircraft crashes, and introduce “a specialized safety facility” as a backup to enhance reliability.

A summary of the main regulatory policies and requirements and the main changes compared to the old standards can be seen on the charts of Figure 4.3 and Figure 4.4 respectively.

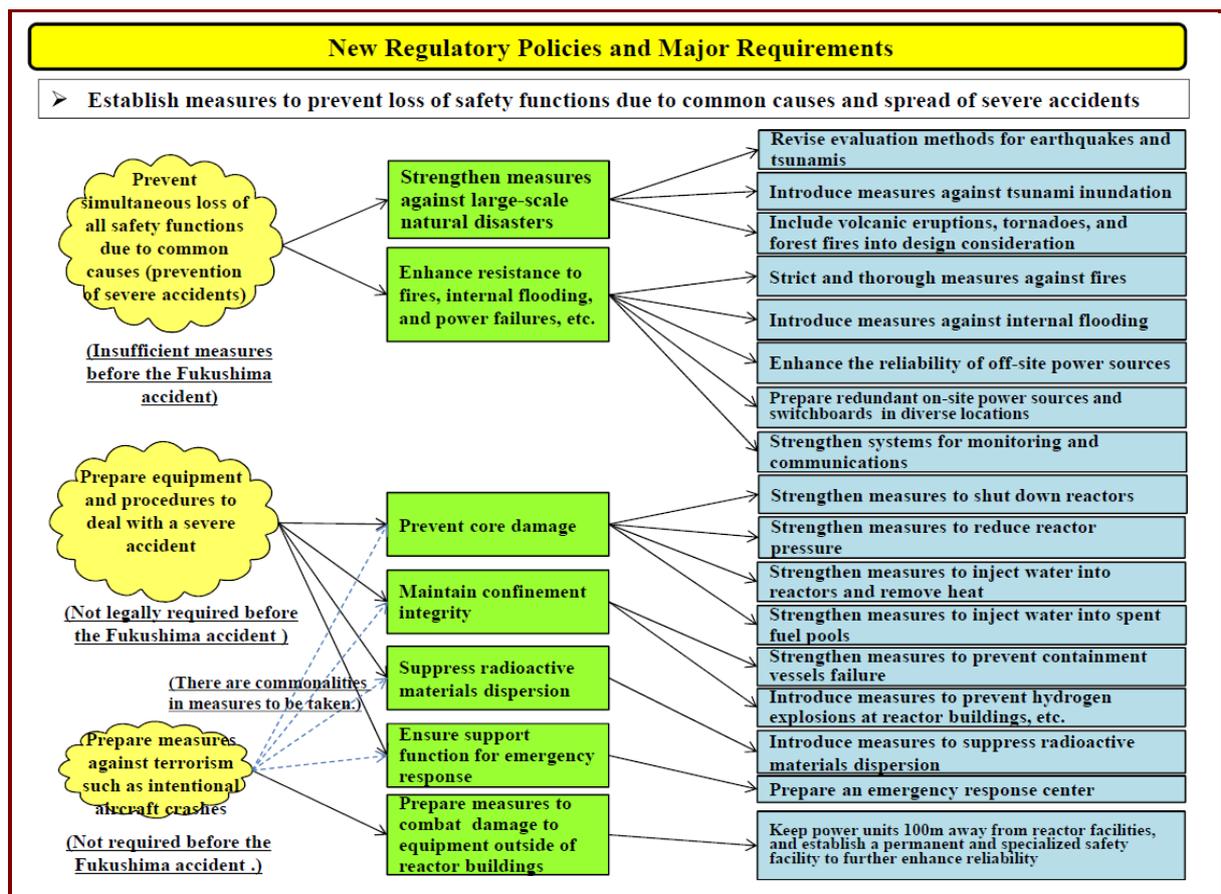


Figure 4.3 New regulatory policies and major requirements (source: Enforcement of the New Regulatory Requirements for Commercial Nuclear Power Reactors, NRA, July 8, 2013).

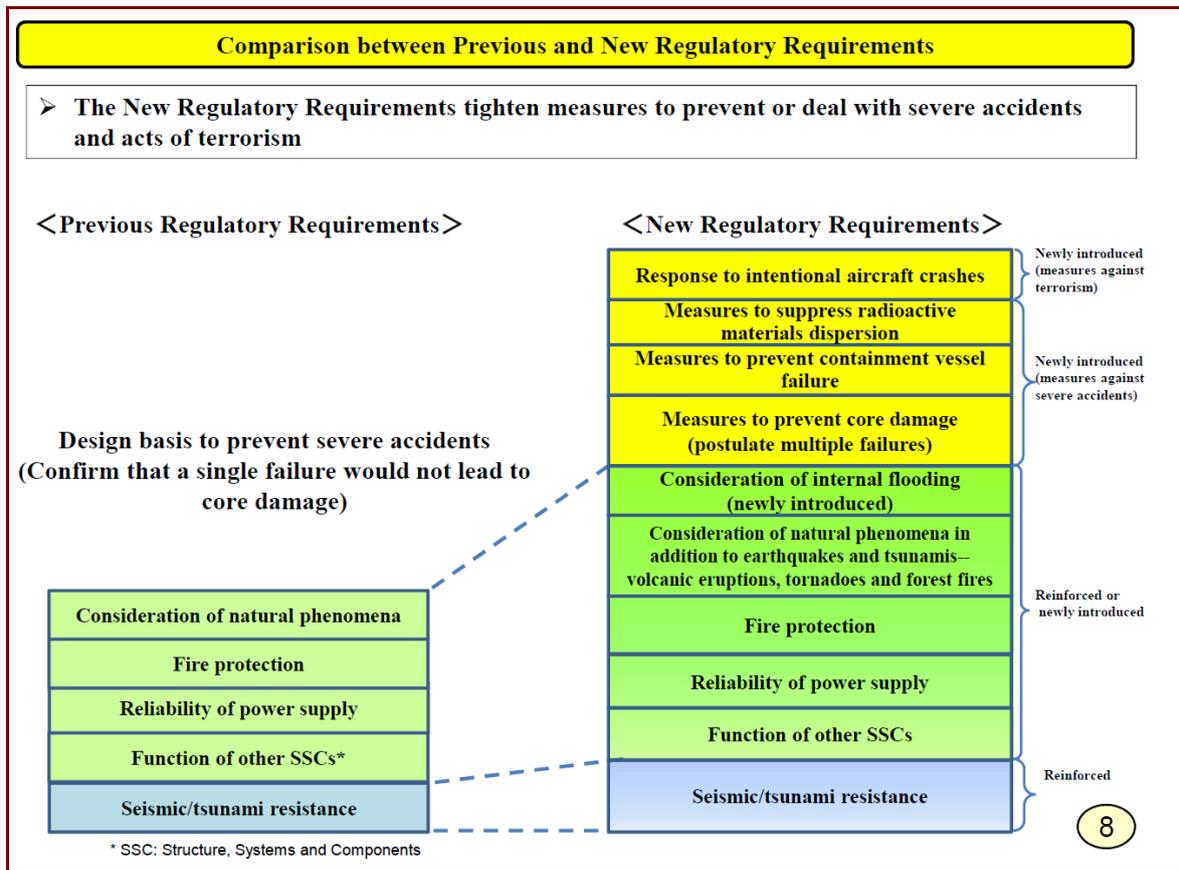


Figure 4.4 Comparison between the previous and the new regulatory requirements (source: Enforcement of the New Regulatory Requirements for Commercial Nuclear Power Reactors, NRA, July 8, 2013).

4.3.2. International

Shortly after the Fukushima Daiichi accident, on 25 March 2011, the European Council declared that safety of all EU nuclear plants should be reviewed on the basis of comprehensive and transparent risk assessment – “stress test”. On 13 May 2011 the Western European Nuclear Regulator Association (WENRA) agrees on the definition of “Stress test” and the approach to be used. Generally, the stress tests were based on the following three work streams:

1. Initiating events: earthquake, flooding and extreme weather.
2. Consequences of loss of safety functions from any initiating event conceivable at the plant site: loss of electrical power including station blackout, loss of ultimate heat sink, combination of both.
3. Severe accident management issues: core cooling, fuel storage pool, containment integrity.

According to the announced programme, each national regulator was expected to provide a national report, based on agreement with the licenses, covering all three work streams for all plants by the end of 2011. The national reports were subjected to peer-reviews by experts organised by the European Nuclear Safety Regulators Group (ENSREG) in the period of January to April 2012, with the final report issued in April 2012.

The results of the conducted stress tests and the detailed peer reviews highlighted several important issues regarding the safety of the EU nuclear industry.

The consequences of extreme natural hazards can include:

- Devastation and isolation of site;
- Long durations;
- Unavailability of numerous safety systems;
- Simultaneous accidents in several plants including spent fuel pools;
- Radioactive releases.

A number of measures to improve the plant reliability were identified following the conducted stress tests. These measures include:

- Bunkered lines of protection including instrumentation and communication systems ;
- Mobile equipment protected against extreme hazards;
- Emergency response centres protected against extreme natural hazards and radioactive releases;
- Rescue teams and equipment rapidly available to support local operators.

The conducted stress tests also yielded additional improvements on existing plants. These improvements include:

- Local flood protection to key plant items;
- Provision of emergency backup equipment that can be deployed quickly following an extreme event;
- Enhanced resilience of diesel generators and coolant supplies;
- Use of passive temperature and pressure devices;
- Introduction of satellite communication technology;
- Storage of on-site back up equipment in diverse locations;
- Improvements in disposition of off-site emergency equipment.

In the United States, a near-term task force was formed soon after the accident and was given 90 days to provide improvement recommendations. 12 recommendations were put forward (FAS, 2013) and they are briefly outlined as following: 1) hardening vents, 2) enhancing the NRC's framework for addressing beyond-basis-events, 3) updating seismic and flooding analysis to protect plants from those events, 4) evaluating the threat from seismically induced fires and floods, 5) strengthening the ability to protect against long duration station blackouts, 6) identifying insights about hydrogen control inside containments, 7) enhancing spent fuel pool instrumentation and makeup water capability, 8) strengthening and integrating on-site emergency response capabilities, 9) ordering licensees to modify emergency operating procedures, 10) requiring facility emergency plans address prolonged station blackout and multiunit events, 11) evaluating over the long-term additional emergency preparedness topics related to station blackout and multiunit events, and 12) strengthening regulatory oversight of licensee safety performance by focusing more on defence-in-depth requirements.

The majority of these recommendations may be seen as taking the opportunity afforded by the Fukushima Daiichi nuclear accident to propose measures to address long standing issues in a regulatory system that had developed in a somewhat ad-hoc manner over very many years.

4.3.3. *United Kingdom*

Following the Fukushima Daiichi incident, the UK government has commissioned the Office of Nuclear Regulations (ONR) to undertake a full review identifying the implications of the incident for the UK nuclear industry, covering both the nuclear power generating sector and other UK nuclear facilities (ONR, 2011).

In the UK, all but one working nuclear power plants use gas-cooled technology, i.e. the Magnox Reactor and the later Advanced Gas-cooled (AGR) Reactor. The operating Magnox stations and AGR differs significantly from that of light water reactors and is unique to the UK. They use carbon dioxide as the primary coolant and have pre-stressed concrete reactor pressure vessels. The AGR reactor core is assembled from high purity graphite bricks. These are keyed together in layers, and are arranged in a polygonal structure with an overall diameter of approximately ten metres and a height of about eight metres. Circular channels in the bricks allow passage of fuel elements, coolant and control rods. The graphite also acts as a moderator. The power density of the reactor core is lower and its thermal capacity is significantly larger, hence giving more time for operators to respond to loss of cooling accidents.

The only other power reactor in UK is a Pressurised Water Reactor (PWR) at Sizewell B, which is the most recent nuclear power plant to be built in the UK in 1995. It uses enriched uranium oxide fuel clad in zircaloy with pressurised water as the coolant and is one of the most advanced PWRs operating in the World. It has improved containment, control of nuclear reactions and hydrogen in fault conditions, and cooling systems, compared to many previous designs.

In summary, the report states that the incident has not highlighted any issues with current UK nuclear power plants, and there is no reason to curtail their operation. The licensing regime was found to be without significant weakness and no evidence was found to suggest Mixed Oxide (MOX) fuel significantly contributed to the health impact of the accident on or off the site in Japan.

However, the report concludes that further examination of some aspects of the industry may be necessary. The ONR recommends a review of the following areas: (ONR, 2011)

- Available techniques for estimating radioactive source terms and adequacy of arrangements for environmental dose measures;
- UK national nuclear emergency arrangements and extent of long-term service accidents including existing severe accident contingency arrangements;
- Plant and site layouts and ventilation routes;
- Need for provision of long-term independent electrical supplies on sites and ability to provide long-term coolant supplies;
- More detailed flooding studies and site contingency for pond water make up;
- On-site emergency control and off-site communications.

As well as further examination of these areas, the ONR also recommended the following tasks to be carried out immediately:

- Assurance of structure, systems and components for managing and controlling accident response;
- Assurance of adequate Level 2 Probabilistic Safety Analysis for all nuclear facilities;
- Examination of existing control systems for commercial and residential developments off the nuclear licensed site;
- Review of dependency of nuclear safety on off-site infrastructure;
- Improvement of national grid to ensure availability of off-site electrical supplies under severe hazard conditions.

4.4. Reports on visit to NPPs

4.4.1. *Onagawa NPP*

With the assistance of the British Embassy in Japan, Dr Ming Tan, Anton Andonov and Carlos Molina-Hutt from the EEFIT team visited the Onagawa Nuclear Power Plant on the 4th June 2013. The NPP is located in the Oshika District, Miyagi Prefecture, Japan and the site is managed by Tōhoku Electric

Power Company. There are 3 reactors on site and they all are boiling water reactors. At the time of the visit, all of the reactors were shut down as it was under periodic inspection (Onagawa, 2011).

Table 4.2 Data concerning Units 1, 2 & 3 at Onagawa NPP, Source: (Onagawa NPP, 2011).

Name	Unit 1	Unit 2	Unit 3
Reactor Type	BWR	BWR	BWR
Power Output	524MW	825MW	825MW
Start of Construction	July 1980	April 1991	Jan 1998
Commencement of Operation	June 1984	July 1995	Jan 2002
Current Status	Under Periodic Inspection (at the time of the visit)		

During the March 2011 earthquake, Onagawa NPP was the closest to the epicentre. The site experienced a peak ground acceleration of 0.58g and a maximum tsunami height of 13.0m, which are very similar to those at the Fukushima Daiichi. Despite this all three reactors successfully withstood the earthquake and tsunami, unlike the Fukushima Daiichi plant. This is partly because contrary to the Fukushima NPP, the Onagawa NPP has an alternative reactor cooling mechanism which does not rely on direct access to seawater. The following chart shows the timeline of the units at Onagawa in comparison to unit 1 at Fukushima Daiichi. At the time of the earthquake, Unit 2 had just completed a periodic inspection and reactor was only started 46minutes before the earthquake's occurrence. Hence, a cold shutdown on Unit 2 could be achieved within 3 minutes of the earthquake hit. For Units 1 and 3, cold shut down were achieved within 12 hours of scram.

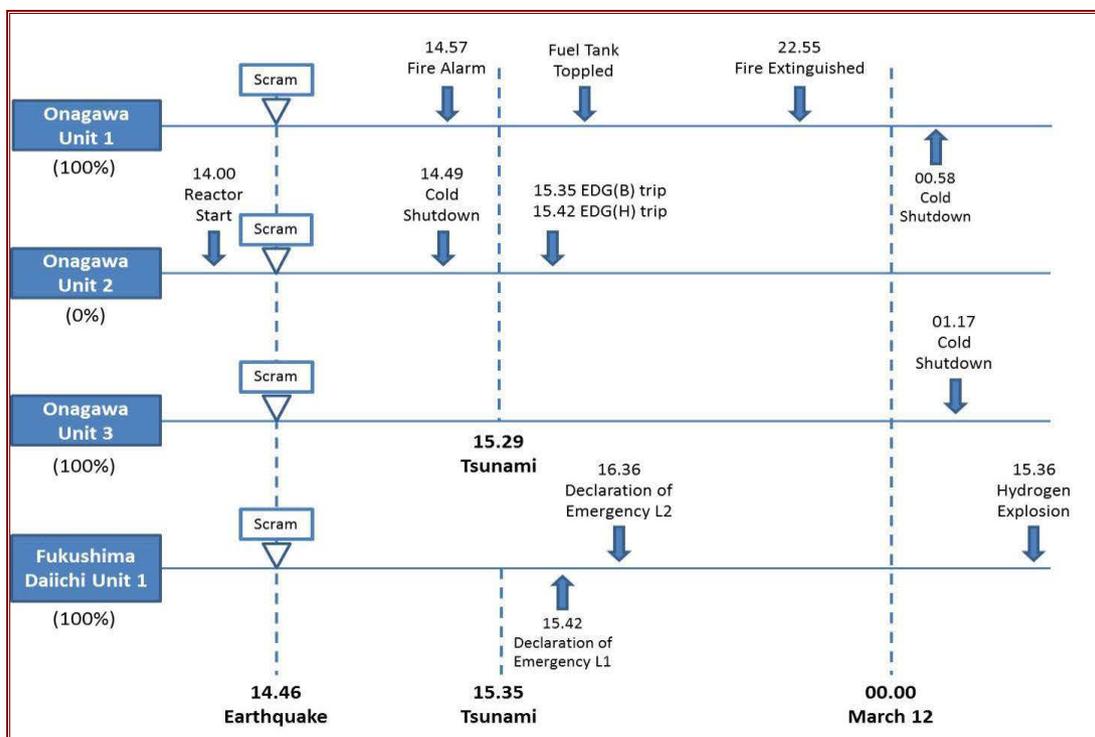


Figure 4.5 Timeline of Shutdown at Onagawa and Fukushima Daiichi (extracted from (Kato, 2013)).

Though the 3 reactors in Onagawa NPP achieved cold shutdown within a short period of time, the site did suffer minor damage which is summarised in the table 4.3. None of the damage was considered safety critical, including the tsunami-induced internal flooding at Unit 2 shown on Figure 4.6.

Table 4.3 Damages to the units at Onagawa NPP (extracted from [Kato, 2013]).

Unit	Damaged System	Condition	Cause
1	Non-Safety Switchgear	Short Circuit and Burnt	Earthquake
	Fuel Oil Tank	Toppled and Spilled	Tsunami
2	Emergency Diesel Generator Cooling Systems	Flooding resulted in the loss of EDG*(B)&(H)	Tsunami-Induced Internal Flooding



Figure 4.6 Internal Flooding on the Heat Exchanger of Unit 2 (extracted from (Kato, 2013)).

It is worth noting that the original design basis event for tsunami for Unit 1 in the 1970s was set as 3m. The engineers at the time made a judgement to increase the site grade to 14.8m above TP. The design basis event for tsunami was revised up several times since then with the latest predicted tsunami height to be 13.6m in 2002. The following table shows these predictions.

The Tsunami on March 11th was estimated at 13m, less than the Site Grade.

Since the incident, Tōhoku Electric has undertaken a series of immediate upgrades to the site including:

- Increased height of sea defence wall by 3m
- Constructed 3 air-cooled diesel generators at 52m above sea level
- Deployed 6 backup high-voltage electric supply trucks
- Constructed power supply centre at 60m above sea level
- Deployed mobile seawater circulation pump

Table 4.4 Predicted Tsunami height and site grade evaluation at Onagawa NPP (extracted from (Kato, 2013)).

		Tsunami Evaluation	Predicted Tsunami	Evaluation
1970	Unit 1 License Application	Old Literatures	3m	Site Grade 14.8m
1987	Unit 2 License Application	-Numerical Simulation -Jogan Tsunami Field Study	9.1m	Site Grade Reinforcement
1994	Unit 3 License Application	-Numerical Simulation -Jogan Tsunami Field Study	9.1m	Site Grade Reinforcement
2002	Trial Evaluation	JCSE "Tsunami Assessment Method for Nuclear Power Plants in Japan"	13.6m	Below Site Grade

In addition, Tōhoku Electric is planning to further increase the defence against tsunami by constructing a series of steel piles and plate along the existing embankment, essentially increasing the height of the sea wall to 29m above sea level (see Figure 4.7 below), dubbed "Super-Seawall". The wall will be 680m long with an additional 120m of cement reinforced embankment, achieving an overall length of 800m. The expected completion date for this is March 2016.

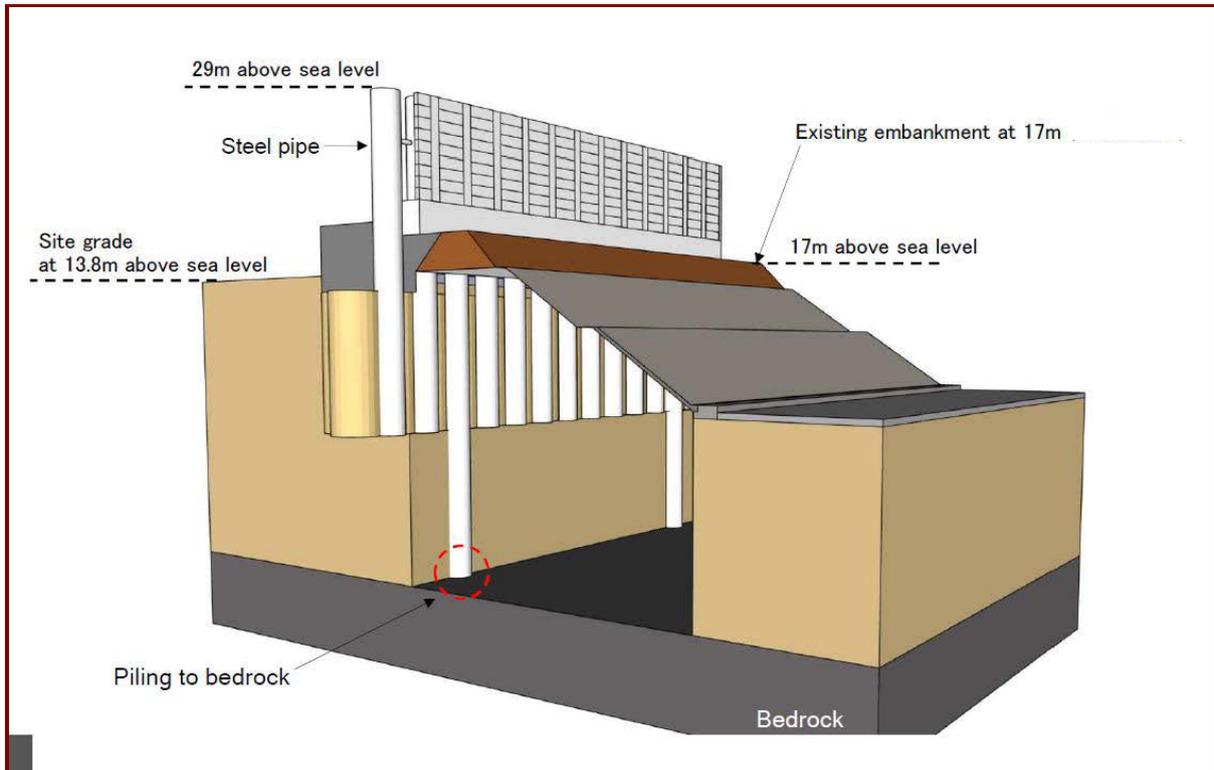


Figure 4.7 Proposed "Super-Seawall" of Onagawa NPP (extracted from (Soekawa, 2013)).

4.4.2. Hamaoka NPP

With the assistance of the British Embassy in Japan, Dr Ming Tan, Anton Andonov and Dr Alison Raby visited the Hamaoka Nuclear Power Plant on the 5th June 2013. The Hamaoka NPP, operated by Chubu Electric Power, is located in Sakura, Omaezaki City, Shizuoka Prefecture. It sits along the flat coast of the Enshu Sea, with its back to the Makinohara Plateau surrounded by tea plantations. There are five reactors in the NPP, of which Units 1 and 2 have ceased operation and are scheduled to be decommissioned (see Table 4.5). The layout of the plant is shown on Figure 4.8. At the time of the visit, Units 3, 4 and 5 were not in operation as they were under periodic inspection (Hamaoka, 2011).

Table 4.5 Reactors at Hamaoka NPP.

Name	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
Reactor Type	BWR		BWR		ABWR
Power Output	540MW	840MW	1100MW	1137MW	1380MW
Start of Construction	Mar 1971	Mar 1974	Nov 1982	Feb 1989	Mar 1999
Commencement of Operation		Nov 1978	Aug 1987	Sep 1993	Jan 2005
Current Status	Decommissioning under way (operation terminated 2009)		Under periodic inspection		



Figure 4.8 Aerial Schematic of Hamaoka NPP (reproduced from Hamaoka NPP, 2013).

The Hamaoka NPP site is located within the area where the combined Tokai/Tonankai/Nankai Earthquake is projected to occur. The Tokai earthquakes, which have epicentres in Ise Bay, and Nankai earthquakes, which have epicentres in Suruga Bay and off Shikoku and the Kii Peninsula, are one of the most feared and destructive quakes (Mogi, 2004 and Wikipedia, 2013¹). They occur every 100 to 150 years (see Table 4.6) in areas where a lot of people now live and often take place almost simultaneously or sequentially, potentially producing several quakes with moment magnitude of 8.0 or above. Tokai, Tonankai and Nankai earthquakes, which could occur in conjunction, could produce massive damage and a tsunami that could pose a serious threat to the Hamaoka NPP.

Table 4.6 Historical Tōkai earthquake (extracted from Wikipedia, 2013¹).

Earthquake	Date	Magnitude	Death toll
Hakuhō	November 26, 684	8.3	Unknown
Ninna	August 22, 887	8.5	Unknown
Kōwa	December 11, 1096	8.4	Unknown
Shohei	July 26, 1361	8.5	Unknown
Meiō	September 11, 1498	8.4	40,000
Keichō Nankaidō	February 3, 1605	7.9	2,300
Hoei	October 28, 1707	8.4	20,000
Ansei-Tōkai	December 23, 1854	8.4	3,000

Considering the risk of the Hamaoka NPP to potential future earthquake and tsunami, the remaining three reactors have been requested to temporarily shutdown until the Japanese regulators are satisfied that the risks have been mitigated. This clearly brings significant financial cost to the operator Chubu Electric Power with the operator currently actively implementing a series of countermeasures against future earthquakes and tsunamis.

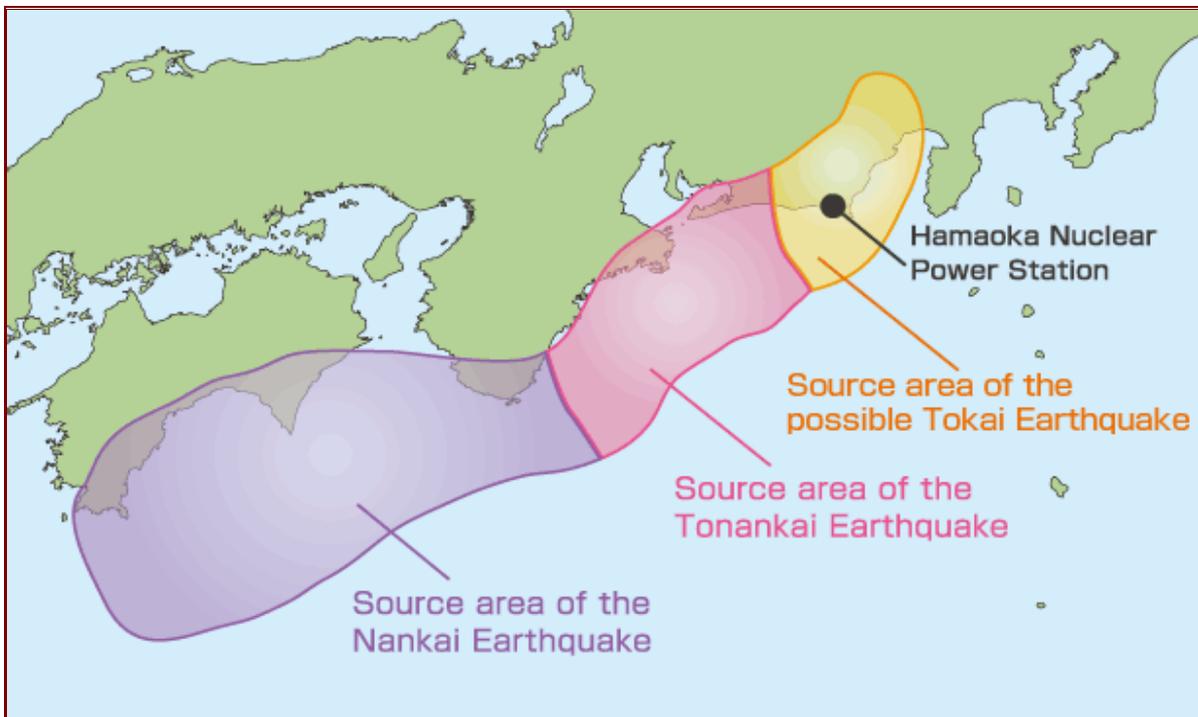


Figure 4.9 Earthquake Source Areas near Hamaoka Nuclear Power Plant (reproduced from Hamaoka NPP, 2013).

Earthquake countermeasures

The projected seismic motion for the combined Tokai/Tonankai/Nankai Earthquake (Figure 4.9) for the Hamaoka NPP is expected to have a horizontal peak ground acceleration of 0.82g and this has been specified by the Japanese regulator as the design basis event. To ensure compliance, Chubu Electric Power has voluntarily increased the target earthquake resistance level to 1.02g. Seismic strengthening work on Units 3-5 to achieve the target was completed in March 2008. These include installing additional supports at approximately 5,000 points (including pipes and conduits) inside reactor buildings, and constructing supporting towers for exhaust stacks (see Figure 4.10).

Carrying out similar work on Units 1 and 2 and then resuming operations was deemed economically impractical. Therefore, operation of these reactors was discontinued on January 30, 2009.



Figure 4.10 Seismic strengthening work undertaken in Hamaoka NPP (reproduced from Hamaoka NPP, 2013).

During the Suruga Bay earthquake in August 2009, it was found that Unit 5 is more susceptible to amplifications. Hence, Unit 5 was re-assessed and Chubu Electric Power has further increased the target earthquake resistance for Unit 5 to a horizontal peak ground acceleration of 1.94g. Further seismic strengthening work is expected to increase seismic resistance for Unit 5 and its surrounding facilities critical to safety.

Tsunami Countermeasures

For tsunami prevention, the Hamaoka NPP is taking a multi-layered approach, such that if one method of countermeasure is compromised, the next level of countermeasure will kick in, ensuring overall safety of the site remains intact (see Figure 4.11). The countermeasures are

- Flood prevention measure 1 – Prevention of flooding on the Station site;
- Flood prevention measure 2 – Prevention of flooding in buildings at the time of flooding on the Station site;
- Enhanced Emergency Measures – Ensuring cooling function if both flood prevention measures 1 and 2 fail.

Flood prevention measures 1 are designed to prevent a tsunami from reaching the reactor site and to mitigate the effect of overflow from the water intake system within the grounds while preserving the function of the outdoor seawater pumps. The measures include constructing a protection wall of 22m high with a total length of approximately 1.6 km (see Figure 4.12, Figure 4.13 and Figure 4.13). The lower portion of the protection wall consists of reinforced concrete up to 18m level above T.P and the remaining 4m will be constructed in steel plates. During the EEFIT visit, the reinforced concrete portions of the walls had been completed and the remaining steel construction was being installed.

To mitigate the effect of overflow from the water intake system, flood prevention measures 1 also include installing flood protection walls with a height of 1.5 m around outdoor seawater pumps.

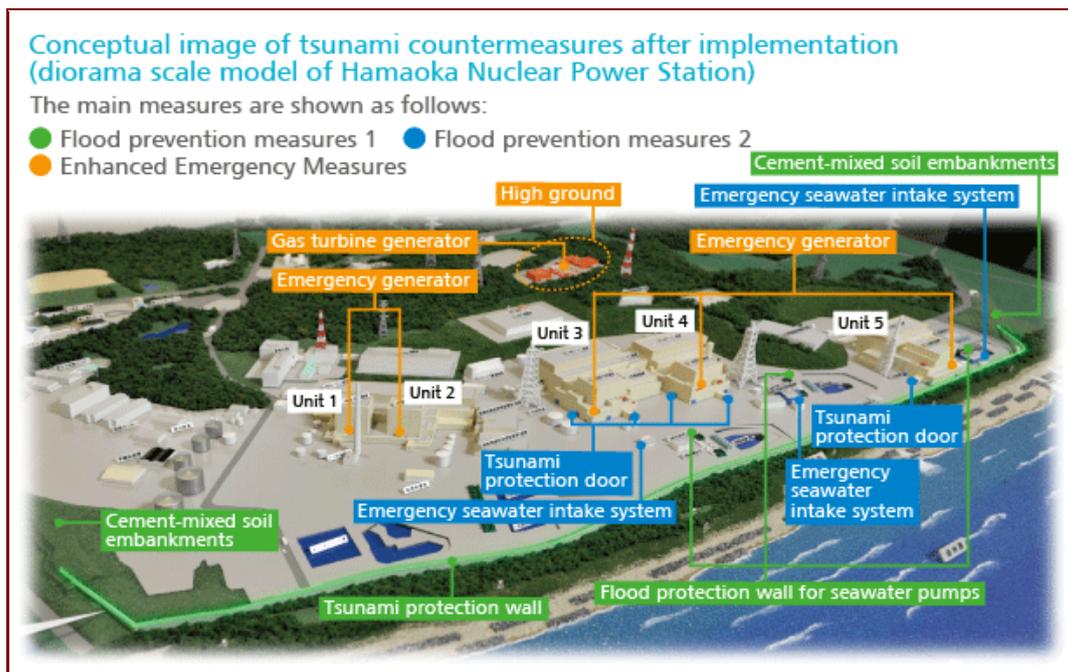


Figure 4.11 Conceptual design of Hamaoka NPP after Tsunami Countermeasures Implementation (reproduced from Hamaoka, 2013).

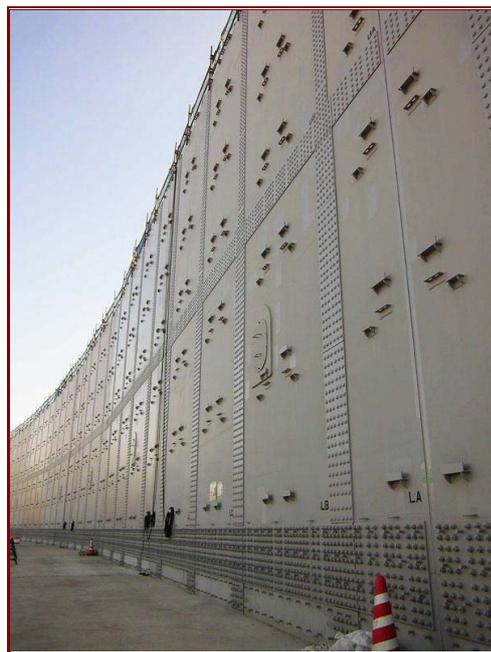


Figure 4.12 Tsunami protection wall currently under construction at Hamaoka NPP (reproduced from Hamaoka, 2013).

Flood prevention measures 2 are designed to counter the scenario where flood prevention measures 1 are compromised, i.e. a tsunami overflows the protection wall and reaches the site. If this is to occur, there are measures in place preventing flooding within buildings and protect the safety-critical equipment that is required for cooling functions.

To protect the reactor buildings from flooding, the operator of Hamaoka NPPs have undertaken significant strengthening measures including constructing an external reinforced door that weighs

over 40tonne, measuring 6.9m by 7.1m by 1m and an internal watertight door that weighs over 23tonne measuring 5.6m by 5.8m by 0.8m (see Figure 4.13).

In addition, Hamaoka NPPs are installing equipment that can take over the function of the outdoor seawater pumps. Alterations are also being made to the air intake and exhaust openings for the ventilation and air conditioning system and to the exhaust openings for the emergency diesel generators. Automatic closing gates have been installed in Unit 5.



Figure 4.13 External and internal reinforced doors for reactor buildings at Hamaoka NPP (reproduced from Hamaoka, 2013).

Finally, if measures 1 and 2 were both compromised and the seawater pumps, emergency diesel generator and other equipment became unusable, as was the case at Fukushima Daiichi, continued cooling function will be ensured by multiple alternative systems to perform water injection, heat removal and electric power supply. This is classed as Enhanced Emergency Measures.

To ensure alternative means of power supply

- Gas turbine generators are being installed on high ground;
- Emergency generators are being installed on the roofs of reactor buildings;
- Emergency batteries will be secured in seismically qualified battery racks;
- Power panels and switchboards will be installed on high ground.

To ensure continuous water supply to the reactor

- Air-cooled heat exchangers will be installed in preparation for possible cases in which motor powered pumps that send water to reactors at high pressure cannot be cooled with seawater;
- Portable power pumps that do not require an electric power source will be installed to ensure continued water injection in emergencies;
- Water supply can be supplied from the adjacent river via a special hose;
- Additional water tanks to ensure multiple water sources will be installed on high ground and in other locations.

To ensure residual heat is removed from the reactor

- Nitrogen cylinders will be installed to enable ventilation at the time of power loss;
- Remote operation will be introduced to enable direct ventilation from the central control room;
- Spare equipment necessary for cold shutdown will be secured.

In addition, heavy machinery will be deployed for removal of any debris carried by a tsunami and storehouses for spare items will be established on high ground. Mobile transformers will be stationed on high ground to increase external power supply if required.

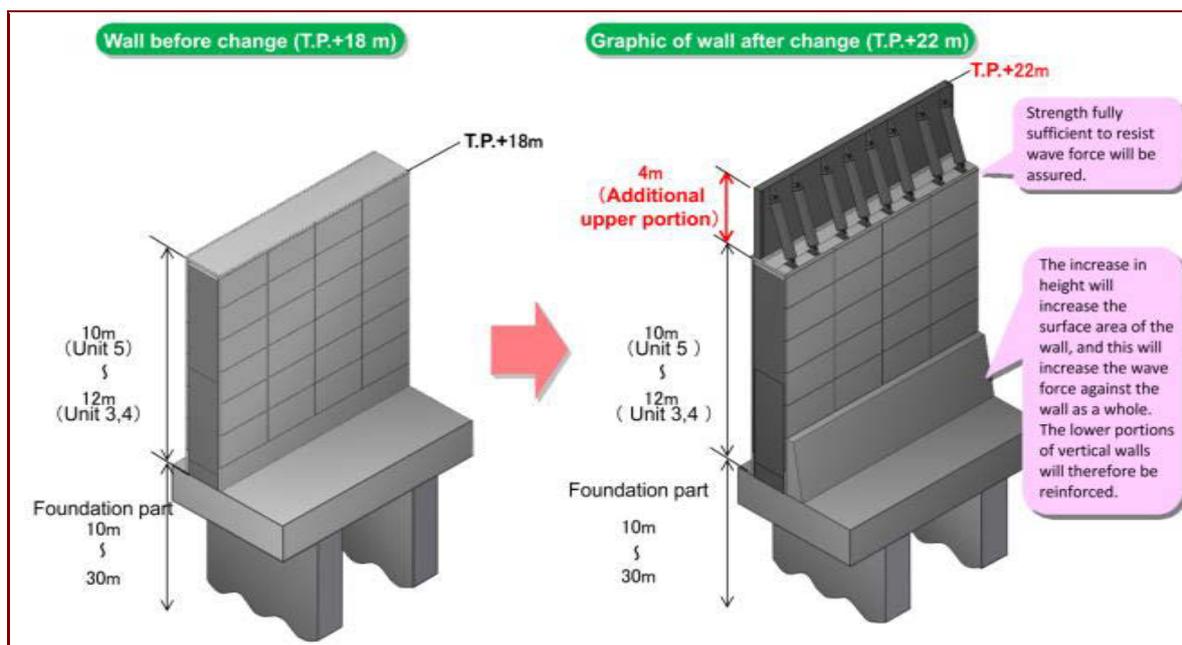


Figure 4.14 Schematic diagram of the tsunami protection wall currently under construction (reproduced from Hamaoka, 2013).

4.5. Critical facilities

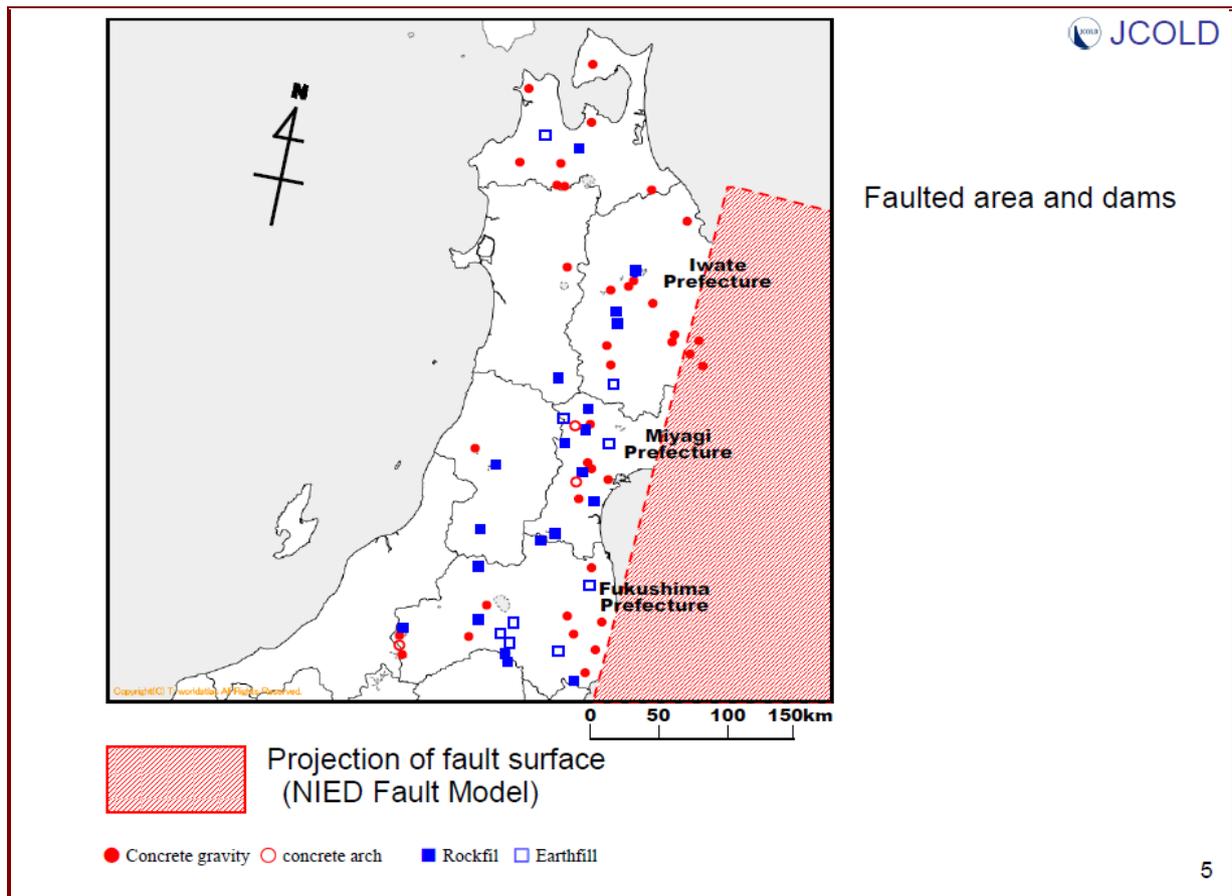
The 2011 Tōhoku earthquake caused significant damages to the infrastructure along the north-east coast of Japan, including significant damages to power generating and industrial facilities, road and rail network, lifelines, dams and other critical facilities that possess high secondary risk. Due to the limited time available to organise (especially to obtain access permissions) and conduct site visits to assess the seismic response and recovery of critical facilities after the March 11 event, the focus of the 2013 EEFIT mission was on dams.

4.5.1. *General*

A significant number of dams, of differing structural type and ages, are located in the mountains of the Tōhoku region and were subjected to strong ground motion during the earthquake on March 11th, 2011. Following the earthquake, various Japanese government and non-government agencies formed engineering teams to investigate the damage status of these dams and to evaluate their structural safety.

Generally, the dams performed well and withstood the severe ground motion with minor to moderate damage, see Figure 4.15 and Table 4.7. The only remarkable exception is the sudden failure of Fujinuma dam (Ch.4.5.3), an earthfill dam constructed in 1949, which led to uncontrolled release of a huge volume of water claiming seven lives with one still missing.

During the mission, with the assistance of the Japan Commissions of Large Dams, three of these dams, Surikamigawa Dam, Nishigo Dam and Fujinuma Dam (locations shown on Figure 4.16), were visited by Anton Andonov, Dr. Ming Tan and Jack Yiu together with Japanese experts and guided by the local operational staff.



5

Figure 4.15 Location and type of dams in the Tōhoku region (Matsumoto, 2011).

Table 4.7 Inspected dams after the earthquake (Matsumoto, 2011).

		Inspected	Suffered unusual behaviour* or damage (failure)
Ministry of Land, Infrastructure, Transport and Tourism (150)	Central Gov.	46	11
	Local Gov.	104	8
Ministry of Agriculture, Forestry and Fisheries (172)	Central Gov.	51	4
		121	23 (1**)
Electric Power Companies (69)	Hokkaido	8	0
	Tōhoku	24	0
	Tokyo	29	1
	J-Power	7	1
	Kansai	1	0
Total		391	48 (1)

* unusual behaviour: small increase of leakage & uplift, nominal settlement and others

** The failed dam was on a non-regulated river

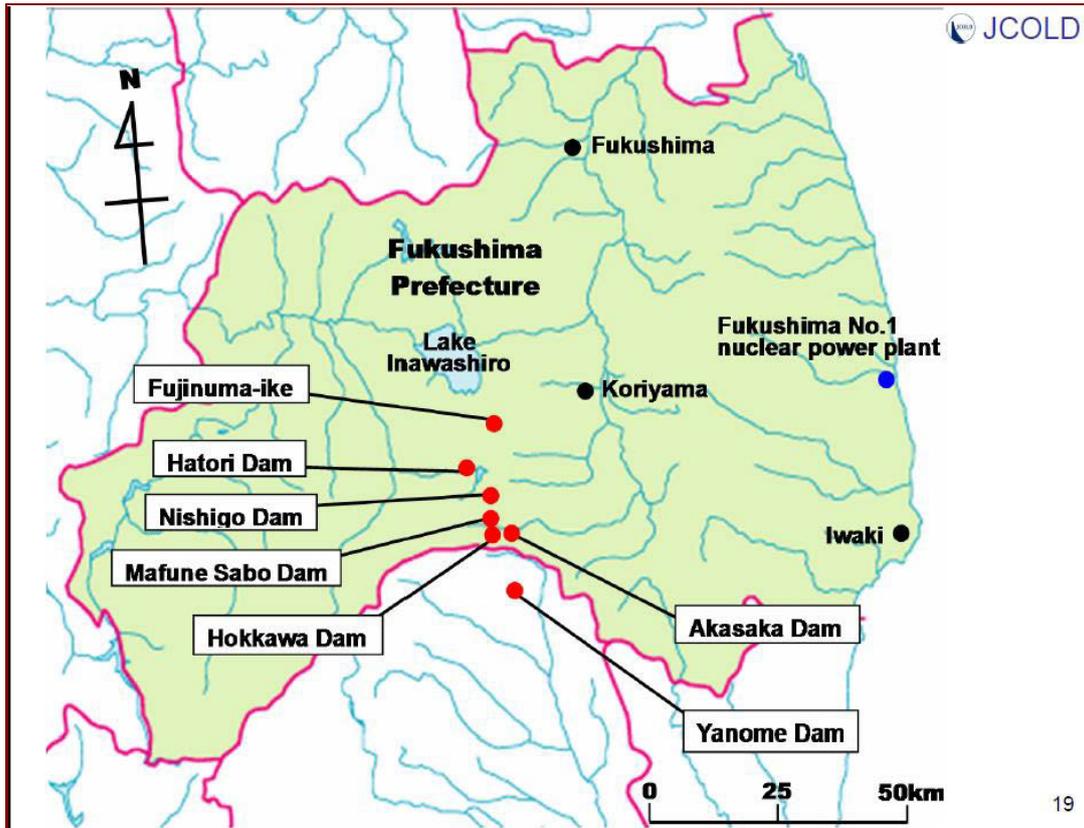


Figure 4.16 Location of the dams in Fukushima Prefecture, Nishigo and Fujinuma dams were inspected (Matsumoto, 2011).

4.5.2. Visit to Nishigo Dam

Nishigo Dam is a 32m high (earthfill dam with rock upstream face) completed in 1955. The dam was designed and constructed before the introduction of the modern seismic requirements. As the dam was not instrumented with accelerometers, there is no information about the characteristics of the ground motion. However, based on the overall instrumentation in the region, the intensity in JMA scale at the dam site was estimated to be between 5 (upper) and 6 (lower).

The dam was inspected immediately after the earthquake on the same day by the operational personnel. Moderate damage, in the form of longitudinal cracks (see Figure 4.17 and Figure 4.18) on the crest and sliding of the upstream rock face, were observed and reported. The main reason for the observed damage was reported to be the formation of a sliding plane on the upstream face, about 1.9m below the rubble layer on the surface. It was decided to lower the water level and to start rehabilitation of the dam. The repair works consisted of excavation and removal of the unstable rubble of the upstream face and replacement with gravel (Figure 4.19).



Figure 4.17 Cracks in the crest of Nishigo Dam observed immediately after the earthquake on March 11, 2011 (Matsumoto, 2011).



Figure 4.18 Covering the cracks on the crest of Nishigo Dam to prevent water intrusion (Matsumoto, 2013).



Figure 4.19 Repair works on the upstream surface of the Nishigo Dam (Matsumoto, 2013).

4.5.3. Visit to Fujinuma Dam

Fujinuma pond secures water storage by water conveyance from the adjoining indirect catchments, and is not regulated as part of a river management system by the Japanese River Law. According to the Japanese legislation of river law, the dam is defined as a water storage structure which is on a regulated river and having a height of 15 meters or greater. Fujinuma-ike is on a non-regulated river and is treated as an irrigation pond, although it defined as a dam by ICOLD (International Committee on Large Dams). The agricultural water taken from Fujinuma dam irrigates a land of 837 ha and the dam is managed and operated by Ebanagawa Irrigation District.

The construction started in 1937 and was completed in 1949. Subsequent modifications included improvement of the spillway and the breakwater protection work from 1977 to 1979 and seepage control work by grouting and improvement of intake facilities from 1984 to 1992. The specification of the dam is given in Table 4.8.

Table 4.8 Specification of Fujinuma dam.

Commissioning Entity	Fukushima Prefecture
Location	Sukagawa city, Fukushima Prefecture
Type	Main: Earth dam Auxiliary: Earth dam
Height	Main: 18,5m; Auxiliary: 10,5m
Crest length	Main: 133,2m; Auxiliary: 72,5m
Volume	Main: 99 000 m ³
Total Storage Capacity	1 500 000m ³
Effective Storage Capacity	1 480 000m ³
Completed	1949

Fujinuma Dam failed due to the 2011 Tōhoku Earthquake (Fig. 4.21) and large amounts of released water reached the downstream community causing a loss of seven lives with one still missing. In addition, some 750 other small embankment dams and irrigation ponds were damaged in the Fukushima Prefecture. Therefore, the prefectural government set up "the panel to evaluate the seismic stability of dams and small ponds for agricultural purpose" [Sakamoto, 2012] consisting of experts with relevant knowledge and experience on August 4, 2011. The panel also reviewed the cause of the failure of Fujinuma Dam which incurred especially severe damage. The first panel meeting was held on August 4 and 5, 2011 with the fifth and final meeting held on January 25, 2012.

The panel had worked continuously to investigate and establish the cause of the Fujinuma dam and auxiliary dam failure. Key issues studied were seismic stability of the dams before the earthquake and mechanism of the failure due to earthquake shaking.

Summarising the investigation results, the slides were classified in seven stages (Figure 4.20). Among these slides, the upstream slides triggered the subsequent overflow and erosion and resulted in a failure of the dam. The slide that occurred in the upper embankment was recognized from the remnant of the structural elements in the reservoir, while the sliding surface was lost by washout. However, the performed earthquake deformation analysis (by modified Newmark procedure) considering the strength reduction due to cyclic loading indicated the existence of this slide.

There may be some possible processes of breach (initiation of overflow) such as the case of the upstream slides combined with the secondary downstream slide and the case of the downstream slide caused by the reduction of water tightness in the upper embankment and others. Considering the loss of upper embankment in the large areas in a short period, it was possible that these processes were combined resulting in a cause of overflow, hence accelerating the velocity of erosion of the dam.

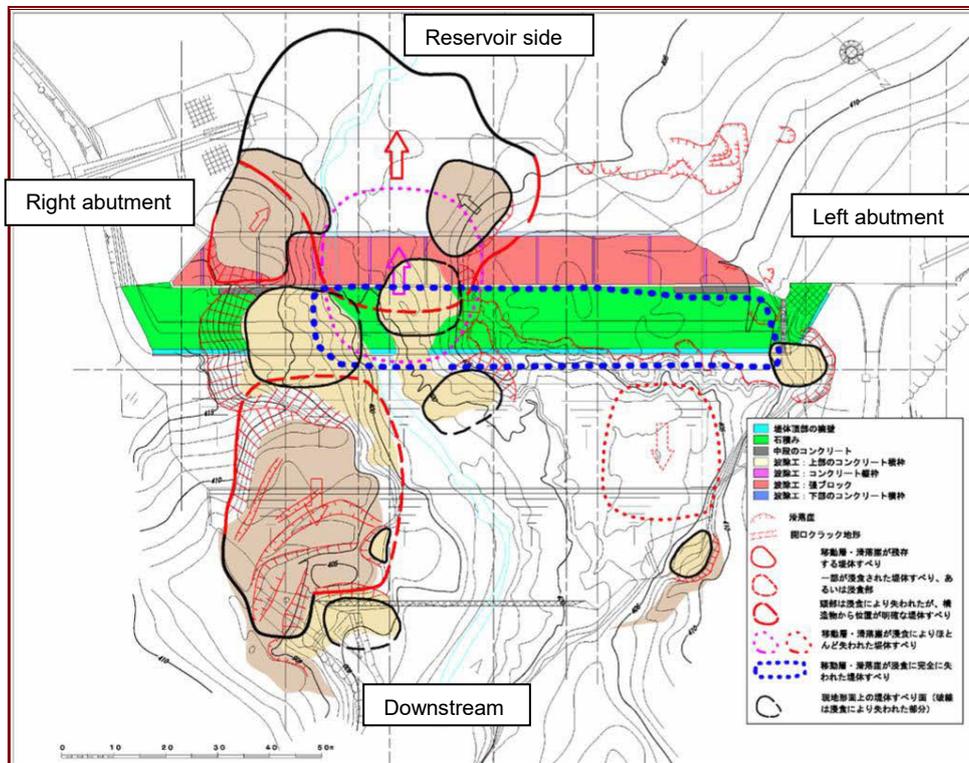


Figure 4.20 Integrated map of slides of Fujinuma main dam (Sakamoto, 2012).



Figure 4.21 Fujinuma main dam after the earthquake (Matsumoto, 2011).

The conclusions of the panel are that the primary cause of the failure of Fujinuma Dam was the nature of its upper embankment and middle embankment and the triggering cause was the strong earthquake motion and its long duration. In addition, the panel obtained the following findings from integrating the results of field investigations, laboratory tests and analytical procedures.

- 1) The earthquake response analysis suggests that the peak acceleration at the dam crest was 442 cm/s^2 and the duration of the motion exceeding 50 cm/s^2 continued for 100 seconds which was an earthquake motion never previously experienced.
- 2) The compaction of the embankment was low compared to the compaction achieved by the modern construction method. As a result, the strength of the embankment is small in the undrained condition during earthquakes. This is especially the case in the upper embankment area where it consists mainly of sand rich materials.
- 3) The slide occurred in the auxiliary embankment that consists of similar material to the upper embankment of the main dam. One of the causes of the failure was the nature of the soil in the embankment, which is of rich sandy materials.
- 4) In the slide occurring in the auxiliary dam, the sliding surface was restricted to the embankment boundary of the different construction periods. In the main dam, the occurrence of the sliding is possibly attributed to the differing degrees of compaction used during the different construction process.

4.6. Concluding Remarks and discussions on readiness of another event

After the Fukushima Daiichi incident, significant improvement and reviews of existing safety criteria have been undertaken in the nuclear industry in Japan as well as around the world. In Japan, a new nuclear regulatory body was formed and significant changes were introduced to the Japanese nuclear safety system. These changes in the regulatory requirements were developed taking into account the lessons-learnt from the accident at Fukushima Daiichi NPP. In addition, the design basis for and, counter measures against, natural phenomena are significantly enhanced in order to prevent simultaneous loss of safety functions due to common causes.

The Fukushima incident also provided the world a unique opportunity to learn from a serious nuclear accident. Many countries agreed on undertaking a series of “stress tests” to their existing NPPs to flush out potential weaknesses of their facilities to extreme natural events and man-made hazards. These tests were based on a common methodology and were conducted by independent national authorities and through peer review. Potential weaknesses identified can then be rectified or mitigated by putting countermeasures in place.

Some international regulatory bodies have also taken the opportunity to propose or make amendments to regulatory systems.

Considering the amount of effort that has been undertaken in the nuclear industry following the event, it could be concluded that if a similar event is to happen again, failings similar to the Fukushima Daiichi are highly unlikely to occur.

For dams, most of the dams in the affected region performed well, with only slight or no damage. Most of these dams were constructed in the last fifty years and have been, to some extent, designed specifically for seismic motion. Some questions remain for the older and smaller dams such as the ones at Fujinuma and Nishigo. This is because these dams were often constructed without any seismic requirements or with very limited or incorrect seismic assumptions. Many of these dams are owned and maintained by small communities or agricultural farms. The strict seismic regulations applicable to larger dams may have not always been applied or adhered to. In addition, the owners could have little understanding of the vulnerability of their small embankment dams under seismic motion and the potential risk they pose. This issue is not restricted to Japan and the same could be said for many other places. Additional efforts should be made worldwide to assess the seismic safety of such facilities.

4.7. References

Cullen, Hon. Lord W. Douglas (1990). The public inquiry into the Piper Alpha disaster. London: H.M. Stationery Office. ISBN 0101113102.

FAS (2013). Regulating Japanese Nuclear Power in the Wake of the Fukushima Daiichi Accident. Federation of American Scientists, http://blogs.fas.org/wp-content/uploads/2013/05/Regulating_Japanese_Nuclear_13May13.pdf (accessed 06/09/2013).

Hamaoka Nuclear Power Plant: Hamaoka NPP website, <http://hamaoka.chuden.jp/english/> (accessed August 27, 2013).

IAEA (2012). IAEA Mission to Review NISA’s Approach to the “Comprehensive Assessments for the Safety of Existing Power Reactors Facilities” conducted in Japan. IAEA mission report 23-31 JANUARY 2012, <http://www.iaea.org/newscenter/focus/actionplan/reports/nisa-mission-report0312.pdf> (accessed 06/09/2013).

Kato I. (2013). Presentation entitled “Tōhoku Electric Power Co: Onagawa Nuclear Power Station: Safe Shutdown”, (presentation date 04/06/2013).

Matsumoto, N., et al. (2011). The 2011 Tōhoku Earthquake and Dams. ICOLD 89th Annual Meeting in Lucerne.

Matsumoto, N. (2013). Personal correspondence: E-mail from 10/06/2013.

METI (2013). Japan Ministry of Economy Trade and Industry. Mid and Long-Term Roadmap for decommissioning Fukushima Daiichi nuclear power plant, http://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/111221_02.pdf.

METI (2013). Japan Ministry of Economy Trade and Industry. Summary of Mid and Long-Term Roadmap for decommissioning Fukushima Daiichi nuclear power plant, http://www.meti.go.jp/english/press/2013/pdf/0627_01.pdf (Published 27/06/2013).

Mogi, K. (2004). "Two grave issues concerning the expected Tokai Earthquake". Earth Planets Space 56 (8): li–lxvi.

NAIIC (2012). The National Diet of Japan. The official report of Fukushima Nuclear Accident Independent Investigation Commission. Executive summary, http://www.nirs.org/fukushima/naic_report.pdf (accessed 06/09/2013).

NISA (2011). Assessment Procedures and Implementation Plan Regarding the Comprehensive Assessment for the Safety of Existing Power Reactor Facilities Taking into Account the Accident at Fukushima Dai-ichi Nuclear Power Station, Tokyo Electric Power Co. Inc. Nuclear and Industrial Safety Agency, <http://www.meti.go.jp/english/earthquake/nuclear/iaea/pdf/20110911/annex6.pdf> (accessed 06/09/2013).

NRA (2013¹). Outline of the New Regulatory Requirements for Light Water Nuclear Power Plants (Earthquake and Tsunamis). Provisional translation, April 2013, Nuclear Regulatory Agency, http://www.nsr.go.jp/english/data/new_regulatory_requirements2.pdf (accessed 06/09/2013).

NRA (2013²). Outline of New Regulatory Requirements (Design Basis). Provisional translation, April 2013, Nuclear Regulatory Agency, http://www.nsr.go.jp/english/data/new_regulatory_requirements1.pdf (accessed 06/09/2013).

NRA (2013³). Overview. Draft New Safety Standards for Nuclear Power Stations. January 2013 Nuclear Regulatory Agency, http://www.nsr.go.jp/english/data/new_safety_standards.pdf (accessed 06/09/2013).

NRA (2013⁴). Enforcement of the New Regulatory Requirements for Commercial Nuclear Power Reactors. Nuclear Regulatory Agency. July 8, 2013, http://www.nsr.go.jp/english/e_news/data/13/0912.pdf (accessed 06/09/2013).

Onagawa Nuclear Power Plant: Onagawa NPP website, <http://www.tohoku-epco.co.jp/genshi/onagawa/index.html> (accessed August 27, 2013).

ONR (2011)..Japanese Earthquake Tsunami: Implications for the UK Nuclear Industry, Final Report, <http://www.hse.gov.uk/nuclear/fukushima/final-report.pdf> (published September 2011).

PWRI (2011). Damage to Dams. Results of Special Safety Inspection of Dams and Detailed Investigation at Several Damaged Dams. Public Works Research Institute.

Sakamoto, T. (2012). Review of the Case of Fujinuma-ike Failure. Summary report. Panel to evaluate the seismic stability of dams and small ponds for agricultural purpose of Fukushima Prefecture. Japan Committee of Large Dams.

Shepard, D. (2013). Seismic Reevaluation following Fukushima accident. Insights so far on safety arising from the European Stress Tests. Special session presentation. SMiRT 22, San Francisco.

Soekawa, N. (2013). Presentation titled "Tōhoku Electric Power Co: Onagawa Nuclear Power Station: Heightening of the Tsunami Wall, (presentation date 04/06/2013).

TEPCO (2011). Future Action Plans, http://www.tepco.co.jp/en/nu/fukushima-np/review/review3_1-e.html (Published 21/12/2011).

Tohoku Electric Power Co. (2013).. Onagawa Nuclear Power Station, <http://www.tohoku-epco.co.jp/index-e.html> (Updated 04/06/2013; Accessed 10/09/2013).

Wikipedia¹. Tokai Earthquake, http://en.wikipedia.org/wiki/T%C5%8Dkai_earthquakes (Accessed 27/08/2013).

Wikipedia². Hamaoka Nuclear Power Plant, http://en.wikipedia.org/wiki/Hamaoka_Nuclear_Power_Plant (Accessed 27/08/2013)

World Nuclear Organisation (n.d.). Fukushima Incident 2011, <http://www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Fukushima-Accident-2011/> (Updated 09/09/2013)

5. Temporary housing

The Great East Japan Earthquake and tsunami (GEJE) destroyed nearly 239,000 dwellings and 561 km² of land in the tsunami affected areas in the Pacific coastline of Northern Honshu Island stretching from Aomori to Chiba prefectures. In addition thousands of homes were destroyed by the earthquake's ground shaking across the entire Tōhoku region. The number of homeless was initially 450,000 including around 75,000 evacuated from the areas near the Fukushima Daiichi Nuclear Power Plant (BRI & NILIM, 2011; EEFIT, 2011b).

This section explains the context in which Japan learnt from previous disasters, prepared for and responded to the need for transitional shelter and settlement after the GEJE. It is based on a review of the literature (limited to resources available in English) and key informant interviews during the EEFIT mission.

5.1. Shelter after disasters

The debate about post-disaster shelter and housing sits in a broader framework of disaster management: conceived as cyclic processes of preparedness, disaster response and recovery (Alexander, 2002; Baird, O'Keefe, Westgate, & Wisner, 1975; UNDP & UNDRO, 1991) and as parallel processes of response, recovery and risk reduction (IFRC, 2013a).

In the international humanitarian sector, the International Federation of the Red Cross (IFRC) is co-chair of the Global Shelter Cluster and convener of the Emergency Shelter Cluster, the coordination entity for humanitarian shelter agencies that seeks "to improve the provision of adequate shelter to households that have been affected by natural disasters" (IFRC, 2013b). The IFRC promotes an idea, first proposed in the 1970s (Davis, 1978) and regularly reiterated (Davis, 2011), that post-disaster shelter is "a process – not just a product" and describes shelter needs after disasters as:

"A process of 'sheltering' done by affected households with different materials, technical, financial and social assistance... Sheltering goes beyond the immediate provision of basic shelter solutions and is closely associated with longer-term reconstruction as well as with assisting individuals, families and communities to re-establish themselves and enable a return of individual dignity" (IFRC, 2013c).

The handbook of common principles adopted by humanitarian agencies (Sphere project, 2011) offers a set of minimum standards that indicate the importance of existing, appropriate and acceptable shelter including but not limited to:

- Settlement Planning: identifying and using existing planning processes, housing and identifying land and property ownership and/or use rights, access to shelter and access to services (see Chapter 5);
- Covered Living Space: ensuring that covered living space is adequate, safe/private, allows for household and livelihoods activities, uses materials that are familiar to the disaster-affected population and, where possible, culturally and socially and climatically acceptable and environmentally sustainable;
- Construction: using appropriate safe building practices, materials and expertise which maximises local livelihood opportunities.

These indicators require standards to be set a) with the people affected by the disaster; and b) in light of their pre-disaster shelter and housing processes. The indicators encourage questions about why people build their homes in certain locations or in certain ways; who decides when, where, what and how to build housing; who pays; who owns and who rents and how these factors might affect different households and communities after a disaster. These questions are often complicated to answer before a disaster: housing and housing policies are political, controversial and sometimes intractable.

This has led to claims that: "[p]roviding adequate shelter is one of the most intractable problems in international humanitarian response..." and that "arguments between experts over design, quality and cost can slow the process, and weak coordination in the sector often leads to a wide variance in what is provided." (HERR, 2011). Furthermore the issues of early policy-making, design, quality and cost are addressed in Sections 5.3.4, 5.3.5 and 5.4.3.

5.2. Transitional shelter and settlement in Japan: terminology, strategy and regulation

5.2.1. *Terminology*

The knowledge-sharing project sponsored by the Government of Japan and the World Bank that was initiated after the GEJE and tsunami, *Learning from Megadisasters*, adopts the term "transitional shelter" (The World Bank Institute, 2012).

This terminology is also used in the humanitarian literature (OXFAM, 2005; Shelter Centre, UN, & DfID, 2010; UN, 2008) to capture the idea that people who lose their homes, flee a disaster or seek refuge in nearby evacuation centres, have to find alternative accommodation until they can return to rebuild or repair or until they decide to resettle elsewhere. The transitional shelter approach – though its meaning is confused and its application contested – was conceived to promote a “wider understanding of the settlement options selected by the entire affected population” and allow these options to be supported such that “additional opportunities emerge for coordinating the transition from shelter to housing” (Shelter Centre, 2010).

The three sources of confusion over the terminology are, firstly, that pre-packaged or pre-fabricated shelter kits are often called "transitional shelters" when, in fact, the shelters themselves are just one component of the post-disaster transitional shelter response. Secondly, this leads to the assumption that the thing in transition is the shelter (that the shelter kit will be incrementally upgraded and improved) rather than the people affected by the disaster who might want to move rather than transition a kit into a permanent home. Thirdly, that facilitating movement and relocation is achieved by making the shelter kit lightweight and mobile rather than taking a broader view of what would enable people to dwell elsewhere, perhaps in alternatives like rental accommodation. This chapter uses the term transitional shelter to describe the overall policy approach in Japan. The temporary, collective shelters where people initially sought refuge are called evacuation centres and pre-fabricated housing units are called temporary housing or temporary houses.

The main criticism of transitional shelter - which comes from the confusion over terminology but is of particular relevance to analysis of the Japanese response - has been levelled at the use of pre-fabricated shelters or kits. In the context of some developing countries, this is regarded as intrinsically limited: in scale (expensive and thus limited in number); in scope (large floor areas and single storeys only suitable in some locations and for some households); and in the possibilities it offers for building capacity (Lyons, Schilderman, & Sanderson, 2011; Schilderman & Lyons, 2011), addressing the reality of building practices (Bendimerad, 2004; Langenbach, Mosalam, Akarusu, & Dusi, 2006; Langenbach, 2009) and for local economic recovery (Burnell & Sanderson, 2011; Clermont, Sanderson, Sharmu, & Spraos, 2011; Crawford, 2011; UN-HABITAT, 2012). Section 5.4.3 looks at the specific, historical conditions which make this option viable in Japan.

5.2.2. *Strategy*

What the transitional shelter concept offers is a framework for rapid strategic analysis where decision-makers in government or international humanitarian organisations must identify the different transitional situations in which people find themselves; estimate the scale of the need in terms of the population groups in each situation; and identify priority or vulnerable groups and a menu of appropriate and acceptable assistance packages.

Decisions about assistance packages depend on fundamental assumptions about how long people might need or expect assistance to last, which, in turn, is based on estimating how long it will take to clear debris, plan for reconstruction and rebuild (see Section 5.3.4).

5.2.3. *Regulation*

In Japan, the regulatory framework anticipates these decisions in several fundamental ways (Edgington, 2010). Firstly, the national government has responsibility for recovery (*fukkyū*), which traditionally means clearing debris (including from private land) and restoring important public infrastructure rather than private property, economic or individual recovery but it also means that the

government is accountable for making reliable and public estimates for how long this might take and then for delivering against these targets, as exemplified by public statements on the amount and methods of estimating debris issued by the government (Office of the Prime Minister of Japan, n.d.). Secondly, norms are based on principles of self-reliance (Horita, 2006) such that taxpayer money cannot be used to rebuild private property or to subsidise the development of private property. The development of private property has been interpreted in the past to include the building of temporary housing on private land. Thirdly, and in line with these principles, the provision of temporary housing, made available free of charge, is preferred over distributing cash for rebuilding as this can be considered an "in kind" welfare benefit for those who have lost homes (interpretation of the Disaster Relief Law), priority is given to the vulnerable and the definition of temporary housing is that it is expected to last for two years (interpretation of Building Standards Law).

Previous analyses of transitional shelter after disasters in Japan suggest that equitable allocation and appropriateness has to be examined at a small spatial scale. Just as for housing policies generally, it is here that the trade-offs play out between finding safe sites for resettlement and isolating people socially or economically; between defining eligibility criteria to target the most vulnerable and stigmatising certain groups; and between the households, regardless of whether they qualify for immediate relief, that are able to access or capitalise on other sources of support or finance and those that cannot (Edgington, 2010; Hirayama, 2000; Horita, 2006; Maly & Shiozaki, 2012). Data exists at this level of granularity in Japan but were not accessed by the EEFIT team, either because they are not in the public domain, subject to data protection or not translated.

The following sub-sections follow the logic of the Sphere standards and the framework for decisions set out above: strategic options and individual choice; location, livelihood and care; covered living space and land; speed and scale; and construction quality and cost control.

5.3. Key facts and figures on transitional shelter after the Great East Japan Earthquake and Tsunami

An excellent summary of the approach to transitional shelter in Japan has been compiled by the Government of Japan and World Bank (IRP, 2012). This sub-section borrows from this summary and adds further disaggregation by prefecture, uses international comparisons and draws on data about the pre-existing housing stock.

5.3.1. *Strategic options and individual choice*

Transitional shelter options were based on three large scale programmes:

- Support for people to move into private rental housing: information on available units was provided by the Centre for Information on Public Houses for the Affected, set up by MLIT on 22nd March 2011; a rental subsidy was paid directly to the disaster-affected tenant household for up to 2 years - as defined in regulation explained in Section 5.2.3. This was extended by another 12 months in April 2012 (Asia and Japan Watch, 2013);
- Temporary housing units: procurement was financed by the national government, production and construction was sub-contracted to manufacturers by the prefectural governments (BRI & NILIM, 2011) and site selection and planning permission was by Municipal governments². Although prefectures had pre-agreements with housing manufacturers in place prior to the earthquake (IRP, 2012), the scale of the crisis meant that an international invitation to tender was launched on behalf of Iwate, Miyagi and Fukushima prefectures on 15th April 2011 (Federation of Housing and Community Centers, 2011);
- Making government-owned or public housing available as rental accommodation.

The number of people that chose each option is summarised in Table 5.1.

Allocation of temporary housing units was initially by lottery, with priority given to the elderly, families with young children and other vulnerable residents³, but people could choose to delay moving to

² Key informant interview, Arup 8th June, Tokyo

temporary housing on large sites in favour of waiting for smaller group or "networked relocations" and some chose to stay on in evacuation centres because the costs of food and utilities were covered (IRP, 2012). Immediately after the disaster, eligibility criteria for accessing rental housing were given as: "those who live in the areas designated under the Disaster Relief Act and who can no longer live in their houses because of the relevant disaster; evacuees associated with the Fukushima Nuclear Power Plant accident" (MHLW, 2011).

12 months after the earthquake 330,000 people were still in temporary accommodation and 500 remained in evacuation centres (BBC, 2012).

Table 5.1 Transitional Shelter Options and Choices (compiled from various sources).

	Number of houses allocated or chosen ⁴	Number of houses supplied	Number of houses allocated or chosen ⁴	Number of houses supplied
Temporary housing (mostly prefabricated)	-	37,962	52,182	52,620
Government-owned accommodations	-	-	9,832	38,464
Public housing	7,010	28,100	8,238	24,505
Private rental housing	42,300	-	65,692	-
Total	49,310	66,062	135,944	115,589
	Source: (BRI & NILIM, 2011)		Source: (IRP, 2012)	

5.3.2. Location, livelihood and care

Alongside temporary housing, as reported in EEFIT 2011, the government quickly announced a package of financial measures so that: "victims who have lost immediate family members will receive ¥350,000 (US\$4,200) per dead or missing member; households whose homes were destroyed (approximately 110,000), will receive ¥350,000 (US\$4,200) each; households whose homes were severely damaged, (approximately 127,000) will get ¥180,000 (US\$2,160) each. Other forms of support available to the victims include donations, tax exemptions, student tuition waivers, debris removal and various kinds of loans." (EEFIT, 2011b). The Japanese Red Cross Society also provided six home appliances: refrigerator, washing machine, rice cooker, microwave, hot water dispenser and television to 280,000 affected households (Japanese Red Cross Society, 2011).

To address transport and access to new temporary sites, measures included waiving parking charges (MHLW, 2011) and including a space allocation "transitional car parking"⁵, as shown in Figure 5.2 at temporary housing sites.

⁴ "Houses chosen" = transitional shelter option chosen by affected households.

⁵ Key informant interview, 6th June, community mobiliser Miura San, Oya District



Figure 5.1 Parking area for Oya District transitional settlement.

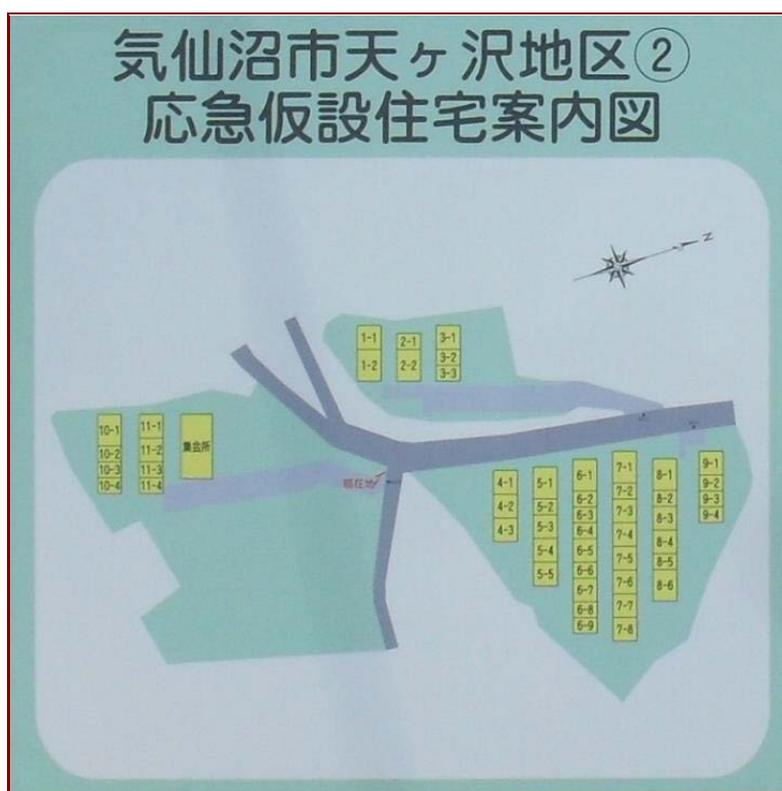


Figure 5.2 Site plan of transitional settlement showing parking areas in Amagasawa area, Kesennuma city.

Community mobilisers interviewed during the EEFIT visit reported organising social and cultural activities at temporary settlements⁶. Other reported initiatives include proposals to install alarm lights outside prefabricated houses so that elderly people living alone can alert people for help (IRIN, 2012).

⁶ Key informant interview, 6th June, community mobiliser Miura San, Oya District, Kesennuma.

As well as small-scale initiatives to promote handicraft production for people in temporary settlements (IRP, 2012), plans for commercial space similar to those for temporary housing were proposed including: designating temporary sites and spaces for recovering commerce and providing limited-term rental support for industrial machinery (Iwate Prefecture, 2011).

Evaluating the impact of systemic measures to stimulate the local (rather than prefectural or national) economies via the construction of temporary housing is beyond the scope of this report but it is notable that the tender invitation, released to make up a shortfall of about 7,000 units, set as a requirement a low threshold of production capacity – 100 units (see also Section 5.4.3) – but only included as a “consideration” the “utilization of local materials as well as the creation of job utilizing local construction workers”. The Japan Times reported Iwate, Miyagi and Fukushima only procured 18, 1 and 36 per cent respectively of their temporary housing locally (Brasor & Tsubuku, 2011).

5.3.3. Covered living space and land

The size of temporary housing units was standardised at 30m² while the floor areas of rental apartments obviously varied depending on what was typically available. Temporary housing units were largely single storey, serviced pre-fabricated units requiring utility connections and basic services on site (see 5.4.4 for an example of two storey units).

Areas where building was prohibited had been designated by April 2011 and were enforced by national law (ADRC & IRP, 2011a) (see Chapter 5). As explained in Section 5.2.3, strict interpretation of national law would mean not building temporary housing on private land. Although this was relaxed in some cases to allow fixed-term leases of privately owned land⁶, with construction immediately prohibited in the disaster-affected areas – legally and practically because of debris – sites for temporary housing were limited and sometimes at some distance from people’s communities of origin and this also caused delays in delivery of temporary units (IRP, 2012). Learning from previous disasters (Edgington, 2010; Habitat International Coalition, 1996), the GoJ adopted a principle of networked relocation, wherein people were encouraged to organise into groups of 5 households before being allocated temporary housing (IRP, 2012). The data suggest that the average number of units per site was 44 in Iwate, 56 in Miyagi and 89 in Fukushima (ADRC & IRP, 2011b). An example of a site layout at this scale - 51 temporary housing units - is shown in Figure 5.2. For comparison, after the Kobe earthquake 16 sites hosted 4,400 units each with two further sites hosting 1,000 units each (Edgington, 2010).

5.3.4. Scale and speed

The first rental housing units were identified as ready or available within 11 days (MHLW, 2011) and the first temporary housing units were nearing completion after four to eight weeks. Within eight months of the disaster, 75 percent of the 450,000 people who had sought refuge in evacuation centres had been able to move to alternative accommodation (IRP, 2012). Although the pace of delivery was criticised (Washington Times, 2011), Figure 5.3 shows the progress of delivery by shelter option following the earthquake and tsunami in Japan and Figure 5.4 shows the progress following the earthquake in Haiti in 2010. The pre- and post-disaster contexts in these disasters are obviously different but the transitional shelter and settlement strategies were similar.

The key point for comparison is not what was achieved in Japan but what was assumed to be possible in the first instance and the reliability of assumptions about the short delivery times for temporary housing and the time needed for debris clearance and planning for reconstruction. By May 2011, the Ministry of Environment had set a deadline of March 2014 for the debris clean up: this was to be a three year operation (UNEP, 2012). The life-time specified for temporary housing and the duration of rental subsidies set out in the initial plan (and in law, see Section 5.2.3) was two years but the extent of post-tsunami land use changes (see Chapter 5) and the sheer scale of debris meant that rental subsidies had to be extended (Asia and Japan Watch, 2013) and temporary housing had to be upgraded (IRP, 2012).

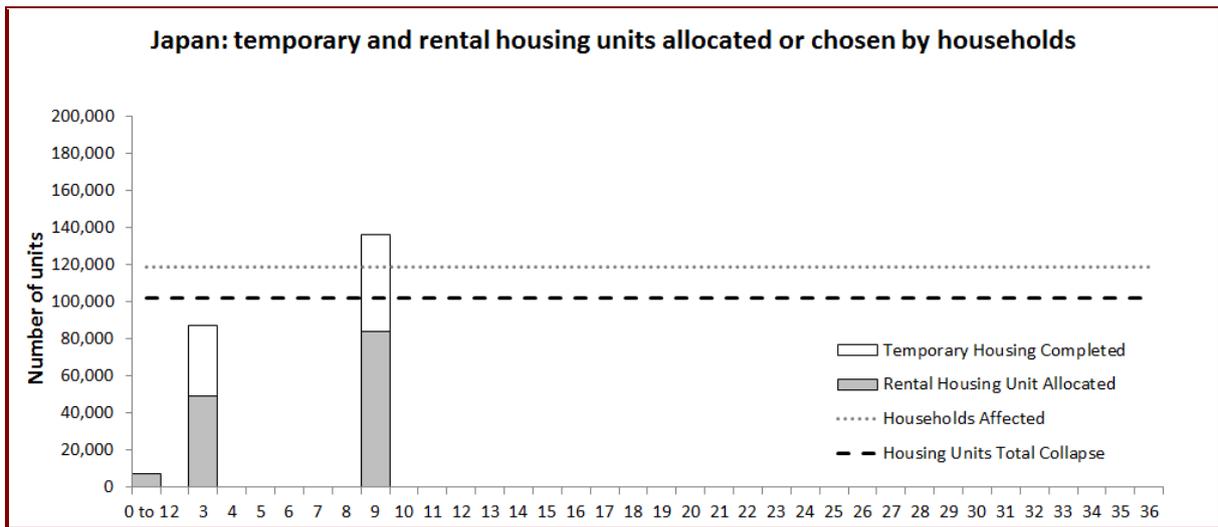


Figure 5.3 Number of transitional shelter packages delivered after GEJE (ADRC & IRP, 2011b; BRI & NILIM, 2011; IRP, 2012; MHLW, 2011).

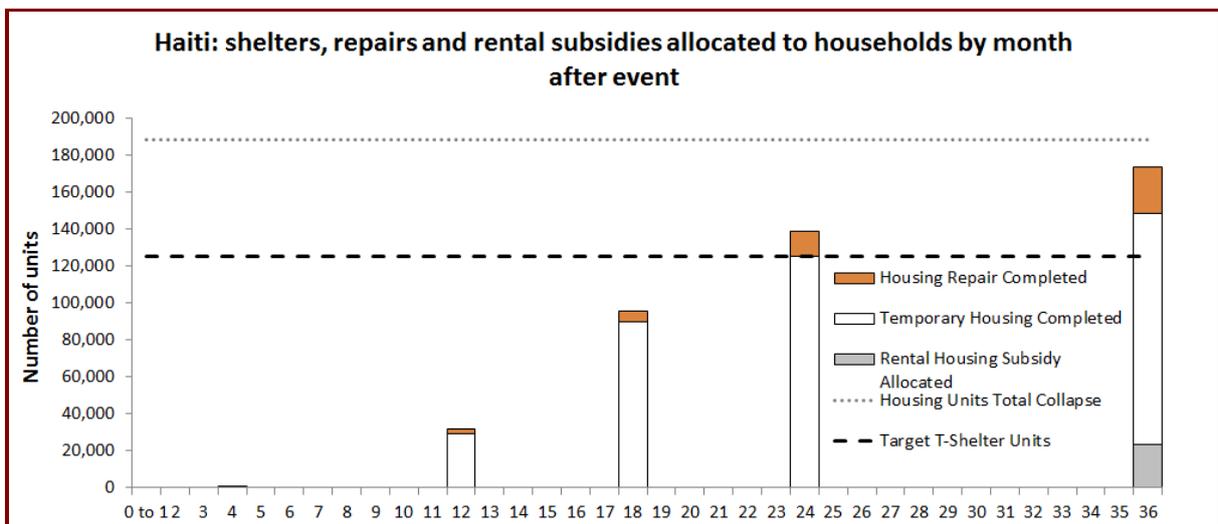


Figure 5.4 Number of transitional shelter packages delivered after the Haiti earthquake (EPYPSA, 2011; UCLBP & IASC CCCM Cluster, 2013; UN-HABITAT, 2012).

5.3.5. Construction cost and quality control

A number of different subsidies and compensation packages were released by the national government in accordance with the Disaster Relief Law and disbursed directly to people's bank accounts (see Section 5.3.2). The unit costs of temporary housing were controlled through prior arrangements with suppliers, open tenders (advertised internationally but required to be in consortium with a Japanese partner) and standardised, detailed specifications (Federation of Housing and Community Centers, 2011).

Figure 5.5 compares the shelter costs per unit area in recent disasters in other countries and Figure 5.6 shows a comparison of the different household support packages provided in Japan. Two points worth noting are that a) in line with regulation, none of the compensation packages are sufficient or intended for the reconstruction or repair of private housing (except for the Iwate repair project covered in 5.4.4) and b) even with the extension of rental subsidies by a further 12 months, the cost of this transitional shelter option is far less than the pre-fabricated temporary housing units.

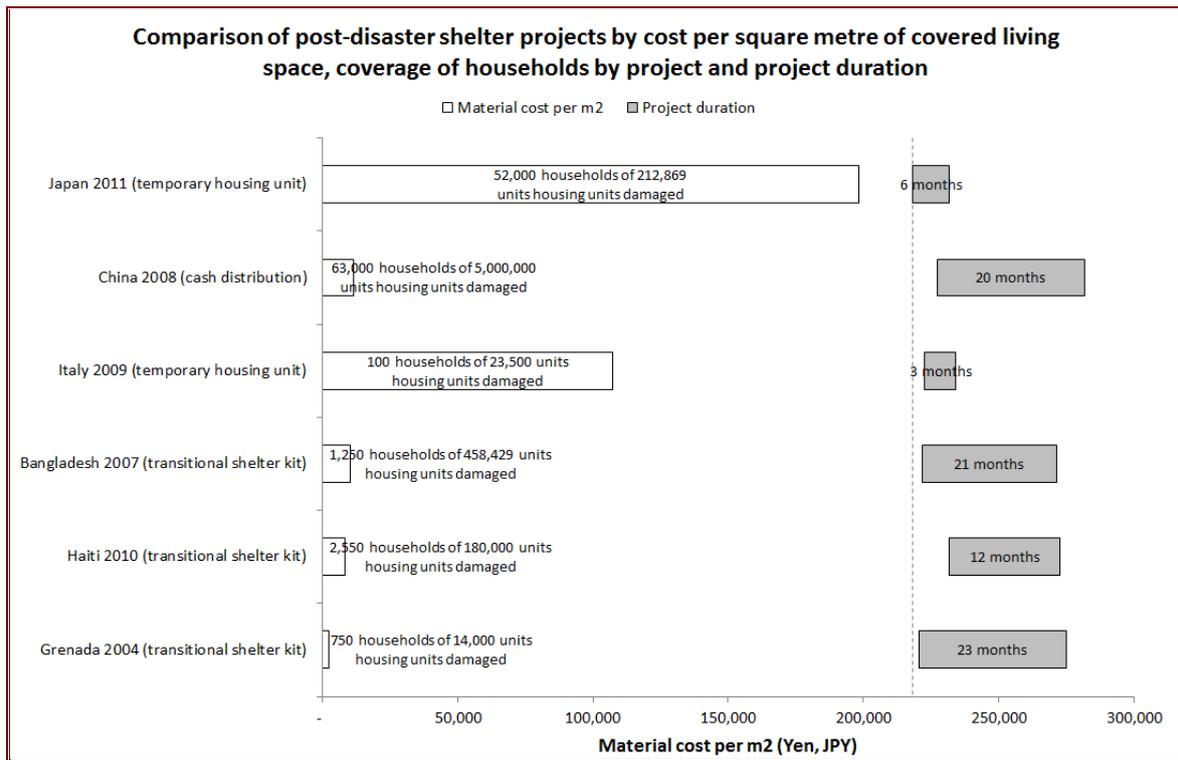


Figure 5.5 International comparison of shelter projects (Ashmore et al., 2010, 2011; Ashmore, Urquia, & D’Urzo, 2012; IRP, 2012).

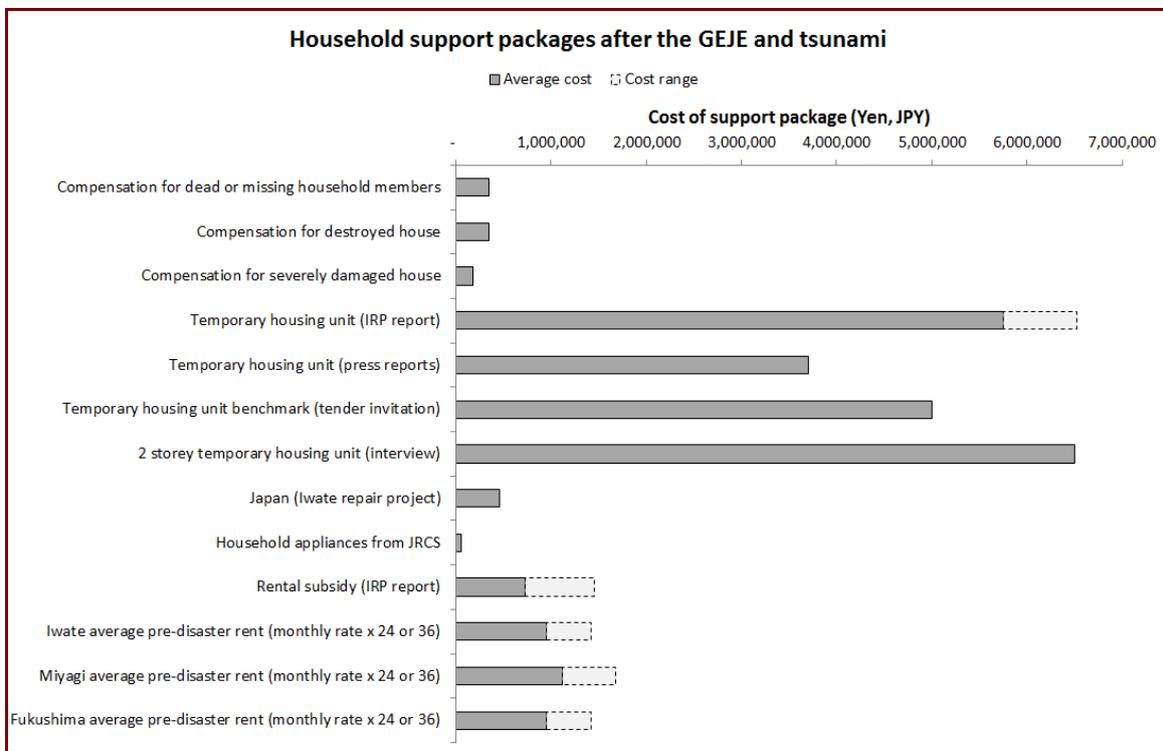


Figure 5.6 Household support packages in Japan (Ashmore et al., 2012; Brasor & Tsubuku, 2011; Federation of Housing and Community Centers, 2011; IRP, 2012; Japan Statistics Bureau, 2008; Japanese Red Cross Society, 2011).

Among the criteria applied in the invitation to tender were a minimum production capacity for suppliers of 100 units (see also Section 5.4.3 on supplier capacity) and lead time to completion of 2 months; a 2 year aftercare agreement; structural design for 1m snow loads and 30-34m/s wind speeds; and fire insurance premiums. The price per unit was not fixed but the tender invitation gave an indicative price based on previous emergencies of ¥5,000,000 (Federation of Housing and Community Centers, 2011).

5.4. Transitional shelter response and recovery in the context of prevailing trends

5.4.1. *Temporary housing after previous disasters*

The GoJ's *Basic Guideline to Recovery* after the GEJE and tsunami prioritised a regional approach to planning, setting a broad, high-level framework that allowed for different local options and where the housing objective was placed alongside the need to ensure employment (livelihoods), take particular account of the needs of the elderly and draw on (and control/subsidise the cost of renting) public housing (Government of Japan, 2011).

These key elements can be traced back at least to the Great Hanshin Earthquake that struck the city of Kobe, Japan in 1995. Spatial analysis following that disaster showed that the destruction of old, wooden, multi-family rental housing and wooden terraced housing affected low-income (often the renters) and elderly people (often the owners) disproportionately (Edgington, 2010; Hirayama, 2000). This lower quality housing suffered more damage but, precisely because it was of lower quality, had also been the bedrock of the lower cost private rental sector, characterised by much simpler administrative procedures for people wanting to move in and out and short, flexible leases (Hirayama, 2000). These pre-existing conditions, the pattern of the earthquake and the post-disaster housing policies interacted to compound the disproportionate impacts on the vulnerable because:

- Poor living conditions in temporary housing: the isolated, cold, noisy, small (20-26m²) pre-fabricated housing units that had no communal facilities and were installed on the outskirts of the city attracted national and international criticism and appeared to result in higher incidents of 'kodokushi' or "solitary and initially unnoticed deaths" (Habitat International Coalition, 1996; Kako & Ikeda, 2009);
- Proportionately more vulnerable people ended up in temporary housing: housing policy, as for more general public policy norms outlined in Section 5.2.3 in Japan and similar to the model historically operating in the UK and USA – is based on a) self-help and b) help for "households unable to help themselves" via targeted provision of welfare. This means publicly owned housing provided at subsidised rents to people whose eligibility is based on income and welfare criteria (elderly, disabled, single-parent families) (Horita, 2006). The problems associated with these housing policies in 'normal' times – geographic concentration of disadvantage and knock-on negative impacts on community support or communal activities including basic upkeep, high rents for low quality private rental housing and limited market interventions to stimulate the supply of low-cost private housing options (Horita, 2006) – carried over into the post-disaster housing logic where eligibility for temporary housing was based on still being in an evacuation centre and eligibility for permanent public housing was prioritised for people still in temporary housing. A year after the Kobe earthquake a disproportionate number of elderly and low-income people were still in temporary housing. This prompted a policy change designed to open up housing options – stimulating diversity in supply similar to French or German social housing models – not only by increasing the target number of new public housing units to be reconstructed but also by speeding up repair and rehabilitation, subsidizing private rental housing (government leases it and then lets units at subsidised rents) and through a further subsidy to reduce the rent of existing public housing;

- Proportionately more vulnerable people were unable to leave temporary housing: rates of reconstructing in the older parts of the city from which the vulnerable population had come were slower because:
 - Space: these densely packed areas did not meet new building standards for street dimensions and could not be rebuilt without being reconfigured for compliance
 - Land: options for group relocation to sites leased to the government or to tenant groups were rejected by the city authorities because of the lack of public land/ information about available land and the perceived “complexity of the process of negotiated land consolidation and redevelopment” (Habitat International Coalition, 1996; Sorensen, 2000). The land readjustment⁷ process for replanning the densely packed areas of the city with small plots and many owners, was protracted, deemed viable only if (unpopular) two storey housing units were replaced by high rise blocks (Edgington, 2010; Hirayama, 2000), required government intervention in the housing market to prevent rent inflation (Habitat International Coalition, 1996);
 - Livelihood: elderly people, who were also the landlords supplying the rental inventory and depending on rental income for their livelihoods, were not able to access the low interest loans made available after the disaster because they had lost their source of income and collateral, their housing asset, and faced age-discrimination from lenders.

This shows that it was not only the general vulnerabilities associated with being elderly or on a low-income but that housing-specific vulnerability, correlated with age and income, led to and then amplified the vulnerability of those who found themselves in temporary housing because the housing stock occupied by the old and the poor was particularly badly damaged and complicated to rebuild and the elderly owners depended on income from their low income tenants whose livelihoods, in turn, were located in the damaged areas.

Looking back at Table 5.1, the learning from the Kobe recovery is clear in the policy response to the GEJE and tsunami: supply of public housing was a key priority for the tsunami-affected areas, known to be home to an elderly, low-income population.

5.4.2. Settlement planning and covered living space

What is also clear from Table 5.1 is that the take up of the public housing option was far lower than anticipated and ultimately private rental apartments proved more “popular due to lower prices, higher comfort, and greater versatility” (IRP, 2012). To explore this and look at other ways in which the strategic high level post-tsunami policy has played out, this sub-section looks at geographic variations in temporary housing choices. This is examined at the level of each prefecture but in time, and for researchers and officials with access to higher resolution data, the consequences for longer term recovery for different households at a smaller spatial scale will also emerge. To underline the fact that lessons learned from an urban earthquake (Kobe) might not wholly apply to a coastal tsunami (GEJE) and should be interpreted for application to future disasters, the comparison case for the three prefectures affected by this disaster is Tokyo. A number of key indicators for the three worst-affected prefectures (Iwate, Miyagi and Fukushima) and Tokyo-shi are plotted in Table 5.2 to 5.4. The temporary housing plans and housing destruction in the three prefectures are summarized in Table 5.5.

Indicators of the options and choices available to people before the earthquake include:

- Strategic options and individual choice: Table 5.2 shows that people were already choosing to migrate away from the areas affected by the GEJE and tsunami. Time series data for net migration from 1993 to 2012 shows that the three worst-affected prefectures had been experiencing outward migration until 2008, particularly Fukushima, although in 2008 the rate of outward migration had fallen slightly, most steeply in Miyagi. The pattern of housing tenure

⁷ Land readjustment in urban planning is based on funding infrastructure and meeting the planning requirements for wider roads or public space like wider roads or public space, by getting each land owner to give up a portion of their plot and then selling off a proportion of this portion when land values rise thanks to the infrastructure investment. Land owners lose some of their land but what remains is worth more (Sorensen, 2000).

has also remained less “urbanised” (shortage of supply of land and housing pushes up prices and creates a rental market). This is not the case in Miyagi where the proportion of households privately renting is approaching the rate of owner-occupation and average rents are higher than in Iwate and Fukushima. The housing and land survey gives average monthly rents in Tokyo, Iwate, Miyagi and Fukushima as 77,000, 40,000, 47,000 and 40,000 Yen respectively (Japan Statistics Bureau, 2008). The proportion of households in public sector rental housing is small;

- Location, livelihood and care: The most obvious aspect of location is that the impact of the disaster on land and housing varied according to whether the coastal areas were flat or steep and inhabited or uninhabited (Ashmore et al., 2012; IRP, 2012). Within prefectures, there were significant variations between places in terms of the local population, economy and access to markets and services: remote, proudly self-reliant fishing villages shared the coastline with marinas and tourist resorts, ports, industrial food processing facilities, a steel plant and two nuclear facilities. In general, however, some key informant interviews suggested that there were declining opportunities for young people to find work locally⁸. These track long term national trends of an aging population, a declining agricultural sector and an urbanising population (World Bank, 2008; Zetter, 1986);
- Covered living space and land: In terms of housing types, construction materials and land ownership, again Miyagi is the exception in having more apartment dwellers (pressure on land encourages vertical construction and multiple occupancy), more reinforced concrete (RC) frame buildings and fewer households owning land. This has an impact on floor areas and, consequently, what might be considered an appropriate and adequate standard for floor space⁹ as well as, the amount of space available for transitional settlement. The housing and land survey gives average floor areas of dwellings in Tokyo, Iwate, Miyagi and Fukushima as 64m², 126m², 100m² and 117m² respectively. Table 5.7 to Table 5.10 illustrate and compare these differences. What distinguishes the approach in Japan is not the size of temporary housing – although as shown in Table 5.9 this is markedly higher than in other contexts – but that this standard had been pre-agreed in light of both national space standards (Fukushige & Ishikawa, 2013) and evidence on the ‘normal’ living conditions of different socio-economic groups (Housing Statistics 2008). This meant that a clear, evidence-informed policy – that would determine what people would be entitled to, how temporary units should be designed and how much they would cost - was in place before the disaster. As argued in Section 5.2.1, in other humanitarian settings, this standard-setting process often happens in real-time with limited information against which to benchmark and disagreement over standards (HERR, 2011).

⁸ Key informant interview, 6th June, community mobiliser Miura San, Oya District, Kesenuma

⁹ The international humanitarian standard for covered living space recommends that “people have sufficient covered space to provide dignified accommodation...” where “essential household activities can be satisfactorily undertaken, and livelihood support activities can be pursued as required.” but emphasises that this must be appropriate and adequate for the specific context.

Table 5.2 Pre-disaster options and choice.

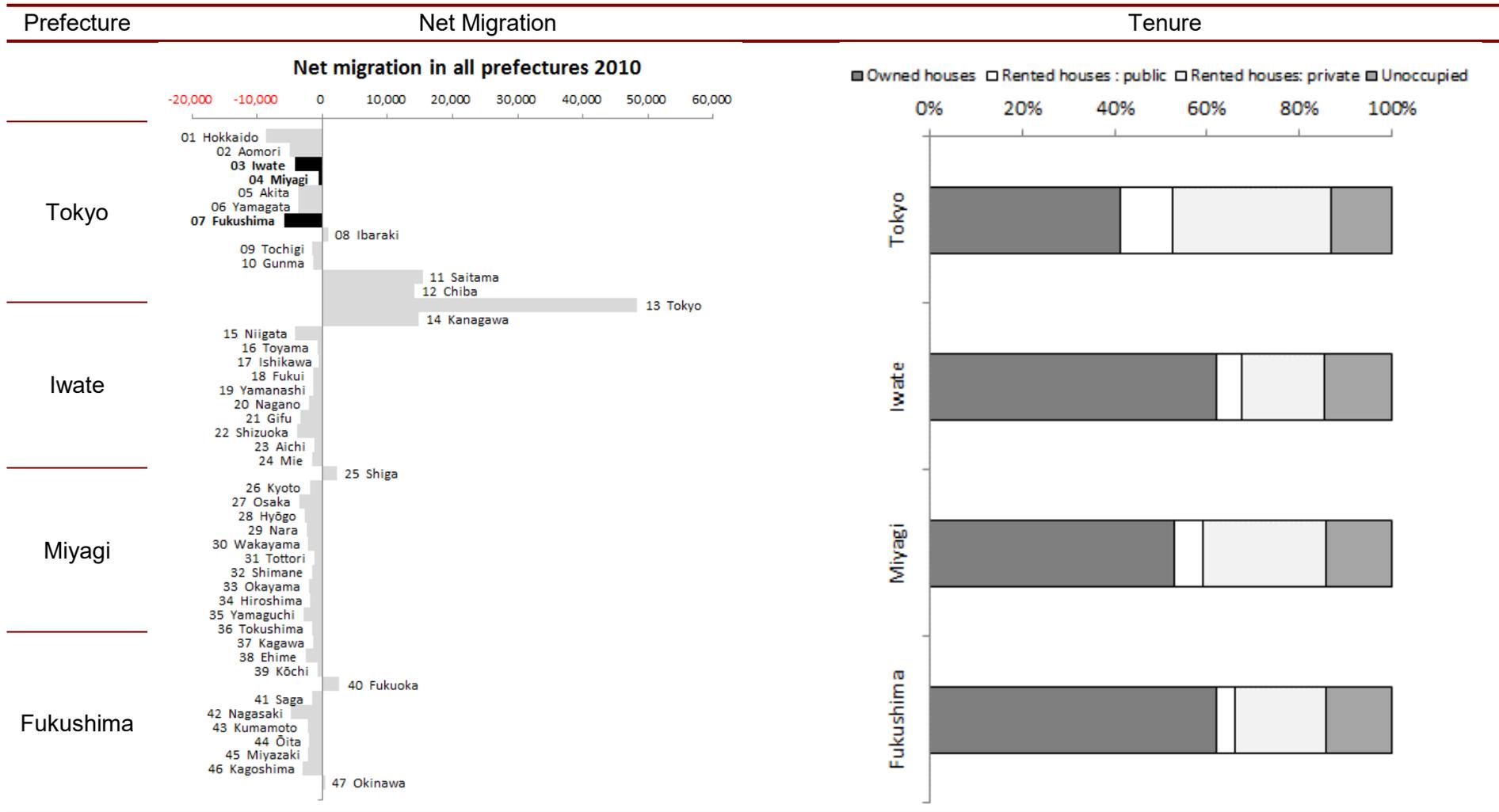


Table 5.3 Pre-disaster living space and land.

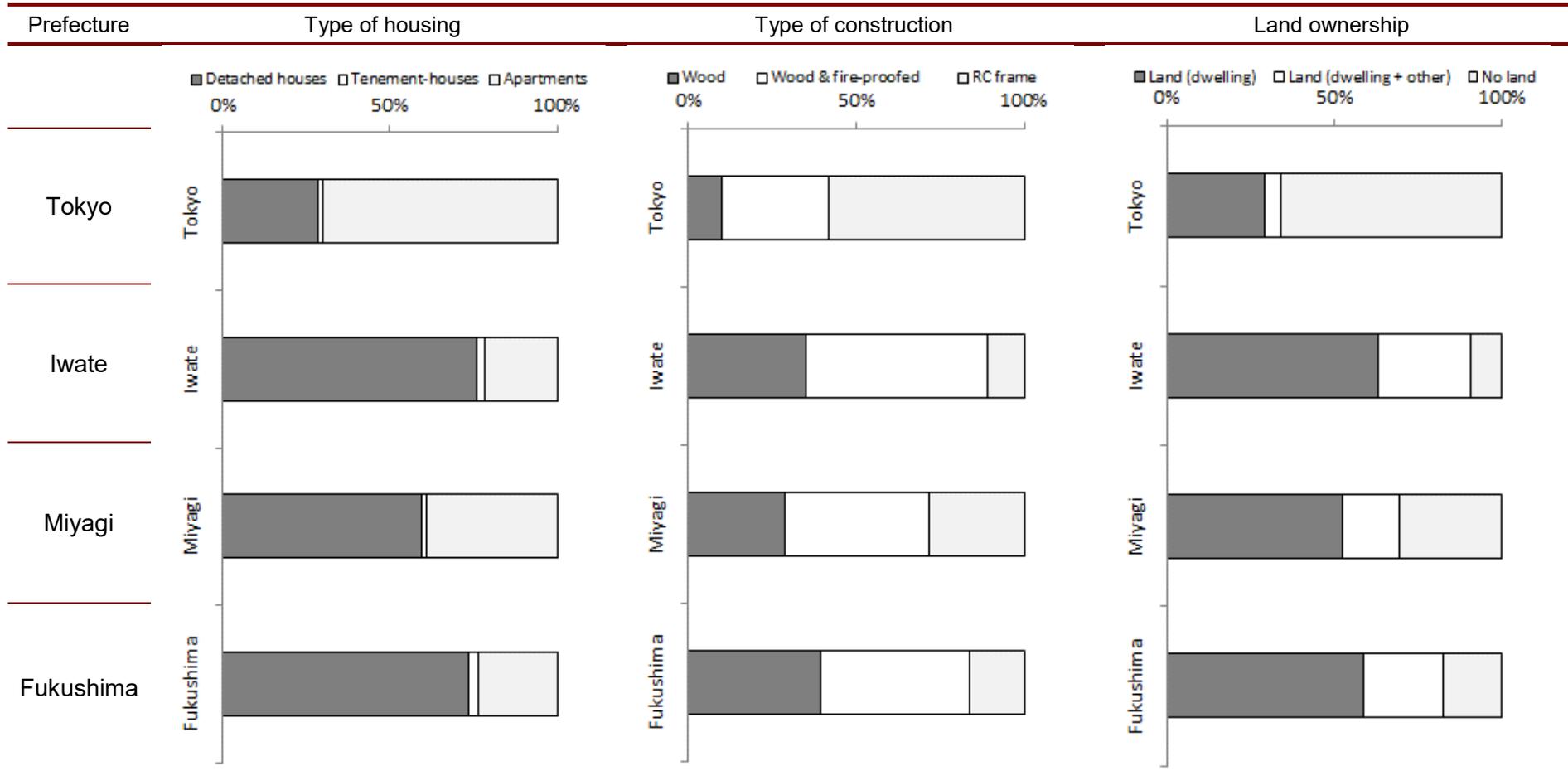


Table 5.4 Pre-disaster location, livelihood and care.

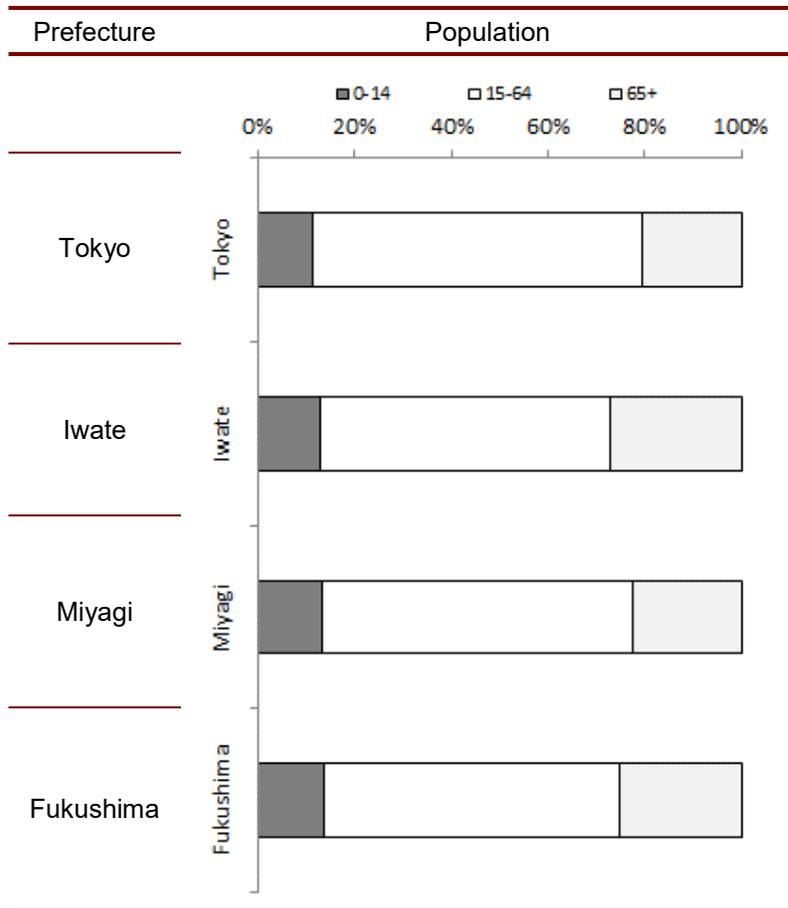


Figure 5.7 Predominant transitional shelter option in each affected prefecture (IRP, 2012).

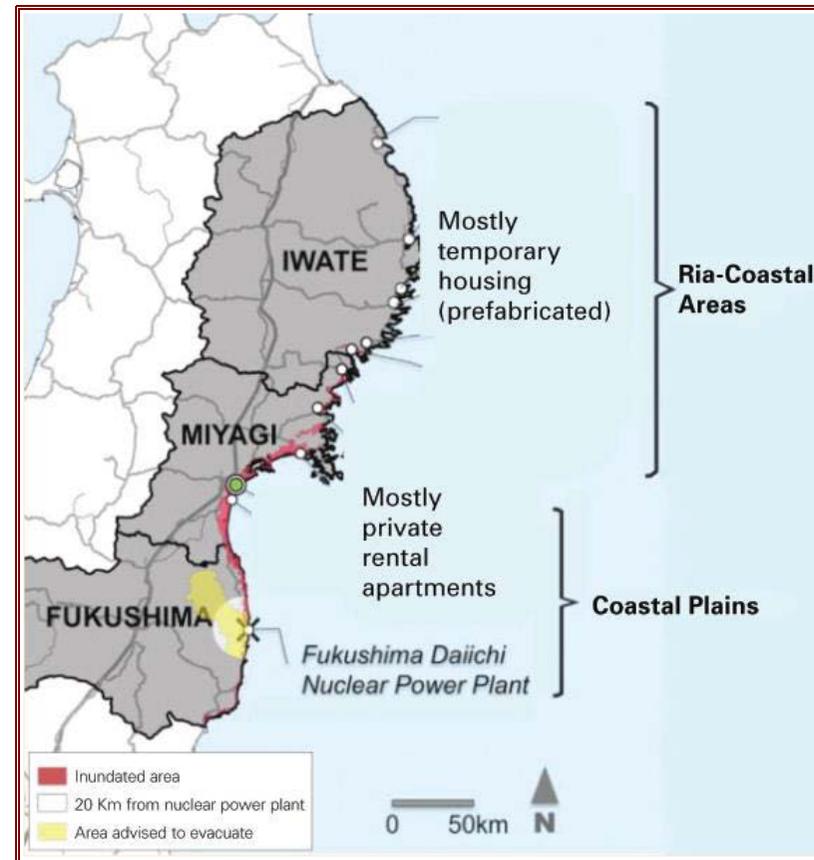


Table 5.5 Summary of characteristics by prefecture.

Prefecture	Geography	Housing totally collapsed	Land area affected by the tsunami	Number of temporary housing sites under construction by June 2011	Number of temporary housing sites still in planning by June 2011	Temporary housing planned	Temporary housing as a percentage of totally collapsed housing	Preferred option
Iwate	Ria-Coastal Areas	20,998	58	312	-	13,833	66%	Mostly temporary housing (prefabricated)
Miyagi	Coastal Plains	65,462	327	358	15	22,453	34%	Mostly private rental apartments
Fukushima	Coastal Plains	15,885	112	152	-	14,000	88%	Mostly private rental apartments

5.4.3. Construction

Given the controversy over pre-fabricated housing in other contexts (Section 5.2.1), it is useful to put the scale, speed, quality and costs of temporary housing after the disaster in the context of the 'normal' capacity of Japanese housing and pre-fabricated housing sectors. When prefectures began to procure temporary housing beyond their pre-arranged contracts with suppliers, the international business press reported that requests went out to the Japan Prefabricated Construction Suppliers and Manufacturers Association and named a few of its higher profile members including Daiwa House Industry Co., Sekisui House Ltd. and Misawa Homes Co. (Kitamura, 2011). Ten years ago, Sekisui and Misawa were already supplying 60,000 and 30,000 pre-fabricated units per year (James Barlow et al., 2003). Specialist pre-fabricated housing manufacturers supplied about 20 percent of the market for detached, family houses in Japan and about 14 percent of all housing completions or 160,000 housing units per year (Johnson, 2007) hence the potential interest of international investors.

The size and capacity of these firms and the choice and possibilities they have created for pre-fabricated housing are due to a number of interacting factors that are particular to Japan and undoubtedly contribute to the rapid delivery times shown in Figure 5.5.

- Housing supply and demand: Figure 5.8 shows annual house completions in Japan (for comparative reference rates at the turn of the century are roughly 6 times the rate of the UK but for only twice the population). The drivers for these high rates include the preference for new rather than second-hand house building (80 percent in Japan compared to 5 percent in the UK) and the short design life of wooden housing (20 - 30 years). On the supply side, light touch planning control makes it easy to get permission to build (Mori, 1998) and there has been a historical tendency to use housing policies to manage the national economy (i.e. low-cost housing finance to boost domestic demand and control inflation (James Barlow et al., 2003). In addition, a third of all completions (75 percent of houses) is owner-driven: commissioned by individual, owner-occupiers. This is critical because it means that "the majority of housebuilding is non-speculative" and "does not involve land development, as the plots are already in the ownership of the housebuilder's customer" (J Barlow & Ozaki, 2005) but it also means that land prices make up a significant proportion of housing costs for individuals (Zetter, 1986). Post-disaster capacity for reconstruction is also vast with figures of 4,000-6,000/month reported for Kobe (Hirayama, 2000);
- Cultural attitudes to transience and permanence: according to one source "buildings in Japan are perceived as transient rather than permanent" (Johnson, 2007) and this combined with the short life span of wooden houses means that traditionally the value of buildings has been disconnected from the value of land and the value of a house depreciating over time more like a consumer than an investment good (J Barlow & Ozaki, 2005); this is driven by family ownership of land and (at least until the 1990s) employment in a single location for life combined with a "strong cultural attachment to the land in Japan" and parcelisation and redistribution of small-scale tenant farmers after the Second World War (Zetter, 1986); cultural and religious preferences for modernity and renewal (Johnson, 2007) seem to have contributed to what has been termed a 'scrap and build' approach to housing (James Barlow et al., 2003);
- Mass customized not mass produced housing: these structures of land and housing markets have nurtured pre-fabricated housing suppliers since their emergence from Japan's manufacturing sector in the 1950s, summarised in Table 5.6. In part because the majority of housebuilding has happened on family plots, housing developers do not traditionally generate revenues from land banks so have had to innovate in "product and process" such that "[u]nderpinning the mass customised approach is the way the large suppliers have been able to use standardisation (the complete and consistent interchangeability of parts) and pre-assembly of components and complete sub-assemblies (such as timber and steel-frame systems and external cladding), to move from a focus on economies of scale in production towards economies of scope." (J Barlow & Ozaki, 2005);
- Big companies with massive capacity: More than 90 percent of housebuilders are small, local (traditional timber beam and post) contractors supplying fewer than 10 houses annually. Of the remaining 10 percent of companies, 344 have the capacity to deal with orders of more

than 100 units. This was the threshold given in the temporary housing tender (Federation of Housing and Community Centers, 2011) so although this appears to be open to smaller companies, this threshold automatically prioritises national-level, large suppliers.

A number of specific historic, cultural and economic characteristics of the housing market in Japan made it possible for suppliers of temporary housing to react quickly and at scale. This did not prevent bottlenecks in labour and material supplies or in poorly insulated, poorly built units arriving on site (IRP, 2012) but the strategic assumption and public expectation that this temporary housing would arrive within weeks is key to making this a viable programme option.

Critically, seen in the context of housing policy and attitudes to welfare and public housing, temporary housing in the Japanese context is perhaps better described as provision of a temporary housing service for a delimited period of time rather than provision of a housing asset that will become a permanent home, with all the investment and upgrading that this might entail.

The popularity of pre-fabricated housing in Japan - particularly among higher income groups (Johnson, 2007) - does not carry over into acceptability or full occupation of pre-fabricated temporary housing. Temporary housing is based on a standard, low cost specification and as shown by comparing Figure 5.9 and Figure 5.10 is a very different product from customised housing units. Temporary housing was not always the option of choice when there were alternative transitional shelter options available, notably subsidised private rental housing.

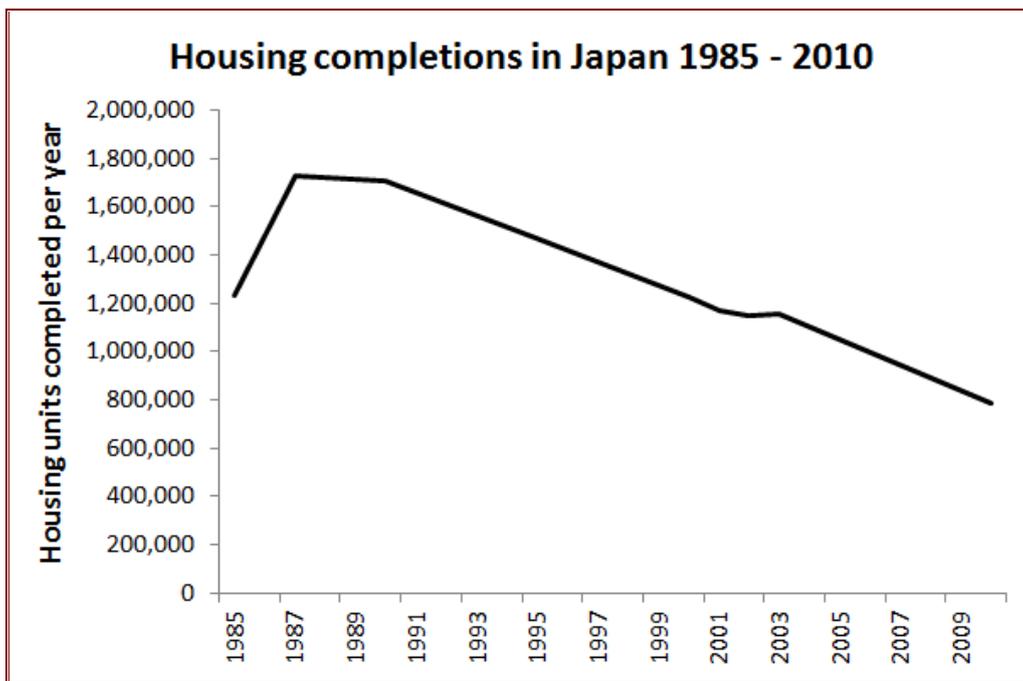


Figure 5.8 Annual rates of house completions in Japan.



Figure 5.9 Evolution of prefabricated housing (Daiwa House).

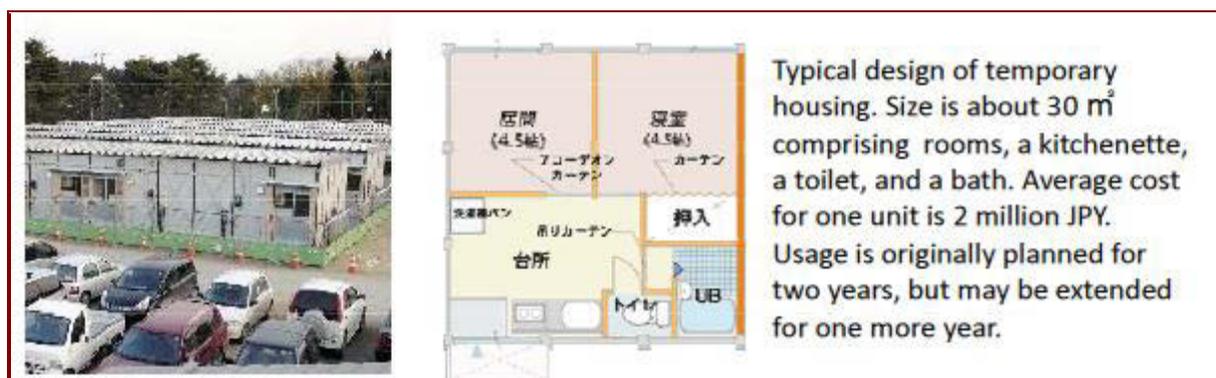


Figure 5.10 Temporary housing after the 2011 GEJE and tsunami taken from (ADRC & IRP, 2011a).

Table 5.6 History of pre-fabricated housing in Japan summarised from (J Barlow & Ozaki, 2005; Iwashita, 2001)

Start-up	Phase 1	Phase 2	Phase 3
1955- 1960	1965-1975	1975-1985	mid-1980s to 1990s
First pre-fab models and suppliers appear.	Rapid growth.	Demand falls.	Second boom as first wave near end of design life.
Manufacturers from other sectors diversifying.	Housing Loan Corporation promotes mass production of low-cost houses. Local housebuilders also benefit (demand grows across market sectors) and national building code favours local builders "by imposing stricter standards and raising quality."	Move from mass production to variety of standard house types. Small builders remain more flexible in design.	Promotion of prefabrication by national housebuilders housing market stimulus (stimulate domestic demand and counter deflation). Mass customisation becomes financially viable (up to 300 standard designs). Larger firms able to innovate. Customer expectations of quality rise. Increased competition for local and regional housebuilders. Labour shortages on site --> super sub-contractors ¹⁰ .

5.4.4. Case studies: alternatives to pre-fabricated housing from large suppliers

Multi-storey containers (ARUP, 2013; Shigeru Ban Architects, 2012)

189 double storey temporary housing units were built in 14 weeks between August and November 2011 in Onagawa. They were designed by the architect Shigeru Ban and engineered by Arup, Tokyo. Normally pre-fabricated housing has been pre-approved so there is no need to satisfy all the building codes and it is not subject to the normal approvals process. Multi-storey units were a first in Japan

¹⁰[super sub-contractors] comprise a subsystem of suppliers of roofs, exterior finishing and carpentry works, who work directly under contract for a homebuilder, these latter doing business in the specific local markets. Companies which previously were acting like grocer's stores have more recently begun acting like supermarkets....both the vertical integration of building component supply and installation and the horizontal integration of e.g. roofing work and exterior finishing work, have been effected.

and although temporary housing was approved at the prefecture level, the city government also had to give permission. This extra process delayed the start of construction and a special approval had to be given for the structural joints between containers. The containers offered standardised sizes and quality defined by ISO and they were reusable, available and transportable. The units were laid out in a chequerboard pattern to reduce the seismic uplift on frames and standard, high capacity vertical and horizontal connections were used¹¹.

Early repair supported by a non-governmental organisation (Ashmore et al., 2012)

A small-scale project to repair 150 houses in Ofunato City was set up for families who missed the window for applying for government aid or needed more money than this fund could offer. Selection of beneficiaries was based on financial need, the cost of repair relative to the government grant and location - houses in prohibited areas were ineligible. Local builders were contracted by households but paid directly by the NGO, funds could go towards the repair of private property (though not the full reconstruction costs) and "houses of evacuated and non-evacuated people were rebuilt".

This last feature of the project is interesting in the context of Japan because, in the past, transitional shelter support has been targeted at people already in evacuation centres. This has meant that people who have avoided evacuation have then been excluded from support, potentially amplifying the vulnerability of people with fewer options by moving them on into temporary housing with high concentrations of vulnerable people and then into public housing with the same demographic mixture (Edgington, 2010; Hirayama, 2000).

¹¹ Key informant interview, Arup 8th June, Tokyo

Table 5.7 Average floor areas by tenure type, Japan (Japan Statistics Bureau, 2008).

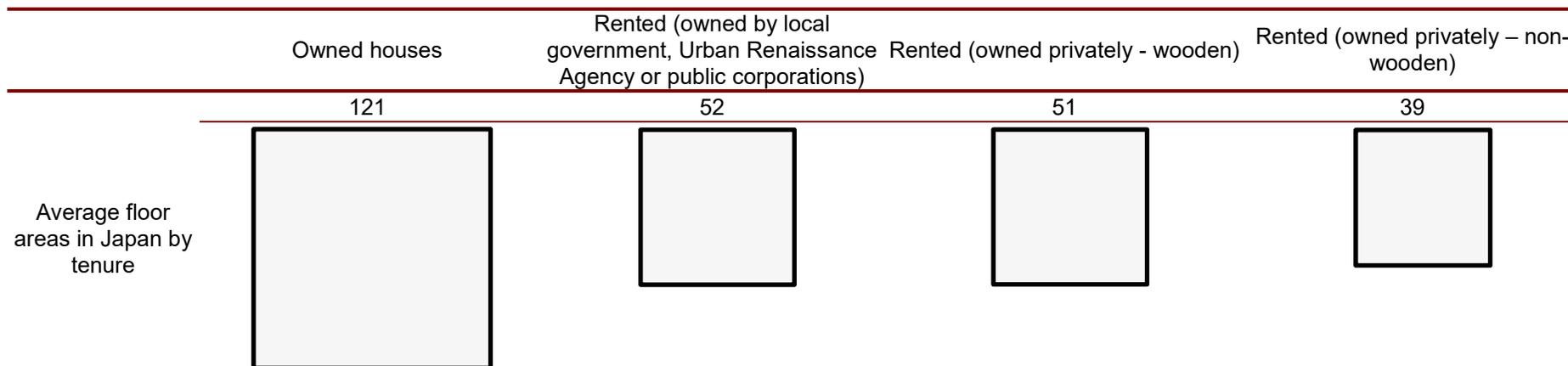


Table 5.8 Average floor areas by prefecture (Japan Statistics Bureau, 2008).

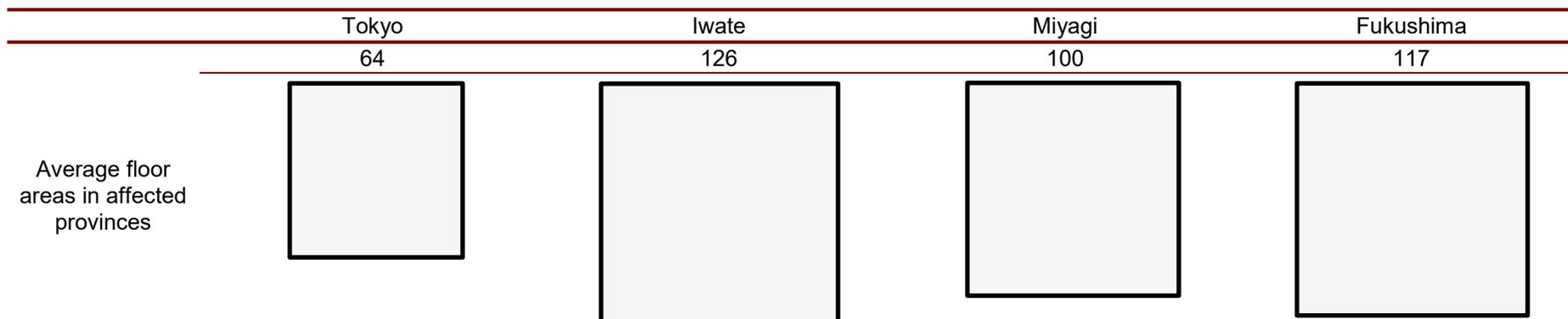


Table 5.9 Post-disaster floor areas by country (Ashmore et al., 2010, 2011; Federation of Housing and Community Centers, 2011).

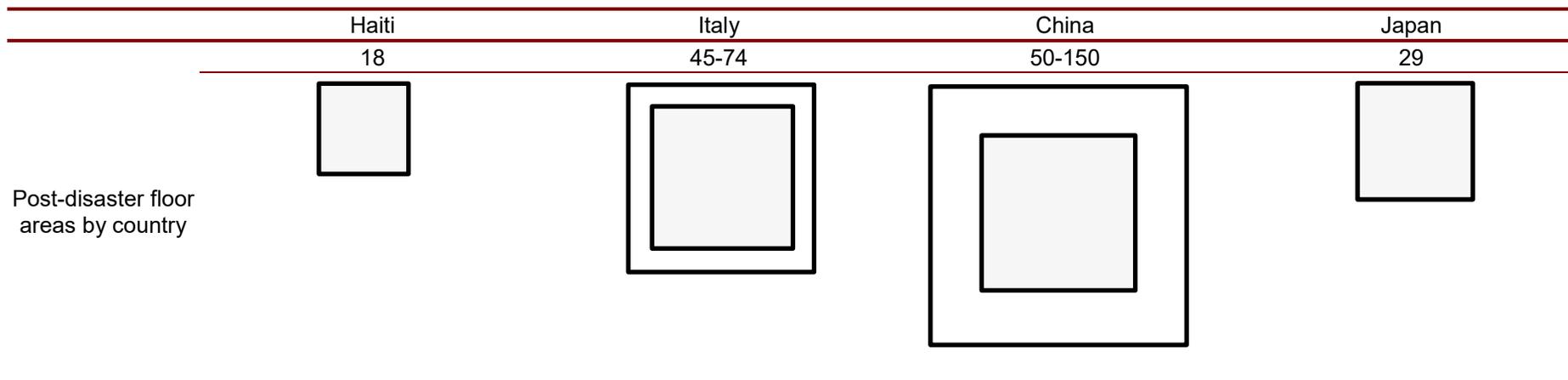


Table 5.10 Minimum standards and targets for floor areas (Fukushige & Ishikawa, 2013; Sphere project, 2011)

	Sphere Shelter and settlement standard 3: Covered living space	Apartments		Detached houses	
		Single person family	Two person or more family	Single person family	Two person or more family
Minimum floor area	People have sufficient covered living space providing thermal comfort, fresh air and protection from the climate ensuring their privacy, safety and health and enabling essential household and livelihood activities to be undertaken.	25m ²	20m ² x (no. people) + 10m ²	25m ²	20m ² x (no. people) + 10m ²
Target floor area		40m ²	20m ² x (no. persons) + 15m ² ¹²	55m ²	20m ² x (no. persons) + 25m ²
Minimum m ² /person	3.5	25	20.6	25	20.6
Target m ² /person		45	21.4	55	23.0

¹² Reduced by 5% for families over 4 people

5.5. Concluding remarks: learning from Japan

Although plagued by challenges common to many transitional shelter programmes – difficulties in finding land, downward pressure on quality and upward pressure on costs of temporary housing and equitably meeting the needs of the most vulnerable with limited resources – several aspects distinguish this transitional shelter response from other cases at a similar scale.

These have been highlighted against a set of indicators that are designed to show which lessons are specific to Japan and to this disaster and which are critical factors in devising transitional shelter strategies in any context.

5.5.1. *Strategic options and individual choice*

- The universal registration of citizens prior to the event and recent census and housing survey data that allowed rental stock to be identified, promoted as an option and then subsidised through direct cash transfers to households;
- Immediate reconstruction and repair were not typically a transitional shelter option, in part because the regulatory framework does not normally allow central government to give financial support for the reconstruction of private property and in part because of the debris and legal restrictions on building across large areas of previously inhabited land.

5.5.2. *Location, livelihood and care*

- There was high-level recognition of the trade-offs between safe sites for temporary settlement and the need to make sure communities are connected to each other and their sources of livelihood (promotion of networked relocations) and between promoting self-reliance and the reality that elderly and low-income groups have fewer options and resources (prioritising vulnerable people for temporary housing);
- There had been analysis from other disasters, and potentially from this one, that allows socio-spatial and disaggregated analysis that goes behind the headline indicators of progress and looks at sub-groups and how high-level policies have played out for different people;
- Data from this and previous disasters allowed not only analysis but also public debate and institutionalised learning about policy, standards and the impacts on different population groups.

5.5.3. *Covered living space and land*

- Not only were there pre-agreed standards for floor space but these standards had been set in a context where national space standards for 'normal' housing existed already; and
- A vast evidence base in the public domain allowed the allocation of housing to be evaluated relative to pre-disaster housing conditions by location and by family type and status.

5.5.4. *Scale and speed, cost and quality control*

- The speed with which rental housing solutions could be identified was possible because rental housing had been surveyed and because information sharing and subsidies were made available almost immediately;
- The speed, cost and quality of temporary housing was achieved through prior agreements with pre-fabricated housing suppliers or tenders based on a standard specification and the internationally unique capacity of these suppliers.

5.5.5. Looking ahead

Transitional shelter programmes work when high-level policies are clear, quickly communicated and supporting a range of options that allow families as much choice as possible and are acceptable and appropriate in the context. This early policy-making was possible in Japan because the regulatory framework and disaster planning were in place already and this in turn meant that the national government could make fairly realistic and public assumptions about the time that rubble clearance, replanning and delivery would take.

Temporary housing was part of the overall strategy because, although direct cash transfers are fungible, flexible and easy to transfer in Japan, the massive loss of land and housing stock meant that private and public rental housing was not available immediately and relocation and migration was challenging because such a vast area had been affected.

Prefabricated housing has played a critical role in this and other Japanese post-disaster responses and pre-positioning transitional shelter materials and standard designs is now being pursued at a strategic level in other countries frequently affected by disasters (USAID, 2012). Where there is no local capacity to delivery pre-fabricated housing in this way, however, assumptions about speed, cost, quality and land availability should be documented in any account of strategic decision-making and then tested and evaluated against the structure and capacity of the firms and builders that were supplying housing before the disaster. In particular, this option should be considered against the possible alternatives that affected people might choose to pursue in the absence of clear policies or funded options and with low expectations of receiving support.

Critically, seen in the context of housing policy, attitudes to welfare and public housing, temporary housing in the Japanese context is perhaps better described as provision of a temporary housing service for a limited period of time rather than provision of a housing asset that will become a permanent home, with all the in-situ investment and upgrading (or reinstallation in a new location) that this might entail.

The transitional shelter policy in Japan played out differently in urbanising areas. This has implications for the future. Japan has been planning for years for its next massive urban earthquake. Sophisticated simulations of the post-disaster shelter options that households might choose after an earthquake in Tokyo have been developed as a way to inform decision-making (Sato, 2011). These simulations suggest that in Tokyo, the need for shelter would outstrip Japan's annual capacity to supply pre-fabricated temporary housing, not to mention the space and land constraints that will make it difficult to install. There is a need, then, to identify spaces and build an inventory of vacant or unoccupied public and private housing stock to inform the post-disaster shelter response. This level of preparedness – one that depends on data, city-wide and community planning – is an essential complement to ongoing efforts to prepare individuals and communities with training, stocking up on household supplies, putting aside "grab-bags" with essential documents and being aware of the needs of vulnerable neighbours.

5.6. References

ADRC, IRP (2011a). Great East Japan Earthquake (GLIDE: EQ-2011-000028-JPN) Update on damage and recovery (2nd report) April 6, 2011.

ADRC, IRP (2011b). Great East Japan Earthquake (GLIDE: EQ - 2011 - 000028 - JPN) Update on damage and recovery (2nd report).

Alexander, D. (2002). Principles of Emergency Planning and Management. Terra Publishing, Edinburgh.

ARUP (2013). Multi-storey Container Temporary Housing [WWW Document]. URL http://www.arup.com/Projects/Multi-storey_Container_Temporary_Housing.aspx

Ashmore, J., Fowler, J., Kennedy, J., Davis, I., Hirano, S. and D'Urzo, S. (2010). Shelter Projects 2009.

Ashmore, J., Fowler, J., Kennedy, J., Davis, I., Hirano, S. and D'Urzo, S. (2011). Shelter Projects 2010.

- Ashmore, J., Urquia, M., D'Urzo, S. and Ashmore, J. (Eds.) (2012). Shelter Projects 2011-2012.
- Asia and Japan Watch (2013). Quake victims allowed to stay in temporary housing another year - AJW by The Asahi Shimbun [WWW Document]. AJW Asahi Shimbun. URL <http://ajw.asahi.com/article/0311disaster/recovery/AJ201302250111> (accessed 9.6.13).
- Baird, A., O'Keefe, P., Westgate, K. and Wisner, B. (1975). Towards and Explanation and Reduction of Disaster Proneness: Occasional Paper No. 11.
- Barlow, J., Childerhouse, P., Gann, D., Hong-Minh, S., Naim, M. and Ozaki, R. (2003). Choice and delivery in housebuilding: lessons from Japan for UK housebuilders. *Build. Res. Inf.* 31, 134–145.
- Barlow, J. and Ozaki, R. (2005). Building mass customised housing through innovation in the production system: lessons from Japan. *Environ. Plan.* 37, 9–20.
- BBC (2012). Japan quake: Loss and recovery in numbers. BBC.
- Bendimerad, F. (2004). The 21 May 2003 Boumerdes Earthquake Lessons Learned and Recommendations:
- Brasor, P. and Tsubuku, M. (2011). Disaster housing proves cash cow for general contractors. *Jpn. Yen Living*.
- BRI, NILIM (2011). Technical Note of National Institute for Land and Infrastructure Management: Summary of the Field Survey and Research on “The 2011 off the Pacific coast of Tōhoku Earthquake” (the Great East Japan Earthquake).
- Burnell, J., Sanderson, D. (2011). Whose reality counts?: Shelter after disaster. *Environ. Hazards* 10, 189–192.
- Clermont, C., Sanderson, D., Sharmu, A. and Spraos, H. (2011). Urban disasters – lessons from Haiti: Study of member agencies' responses to the earthquake in Port au Prince, Haiti, January 2010, Report for the Disasters Emergency Committee (DEC).
- Crawford, C.A. (2011). Can humanitarian responses in urban areas reinforce underlying causes of vulnerability? Tweaking a livelihoods analysis of inequality and infrastructure in splintering cities. *Environ. Hazards* 10, 327–345.
- Davis, I. (2011). What have we learned from 40 years' experience of Disaster Shelter? *Environ. Hazards* 10, 193–212.
- Edgington, D.W. (2010). *Reconstructing Kobe: The Geography of Crisis and Opportunity*. University of British Columbia Press, British Columbia, Canada.
- EEFIT (2011). The Mw9.0 Tōhoku Earthquake and Tsunami of 11th March 2011: A Field Report by EEFIT.
- EPYPSA (2011). An Evaluation of the Haiti Earthquake 2010 Meeting Shelter Needs: Issues, Achievements and Constraints.
- Federation of Housing and Community Centers (2011). Guideline on Acceptance and Listing of Proposals for Emergency Temporary Housing Using Imported Materials.
- Fukushige, M., Ishikawa, N. (2013). Target Standards for Floor Space in a Government Housing Plan: an empirical investigation of the Kanto Area in Japan. *Int. Real Estate Rev.* 16, 208–229.
- Government of Japan (2011). Basic Guideline to Recovery from the Great East Japan Earthquake.
- Habitat International Coalition (1996). Still Waiting: housing rights violations in a land of plenty: The Koko Earthquake and beyond.
- HERR (Ed.) (2011). Humanitarian Emergency Response Review.

- Hirayama, Y. (2000). Collapse and Reconstruction: Housing Recovery Policy in Kobe after the Hanshin Great Earthquake. *Hous. Stud.* 15, 111–128.
- Horita, Y. (2006). Local Authority Housing Policy in Japan: Is It Secure To Function As Safety Net? *Hous. Finance Int.* 20, 34–42.
- IFRC (2013a). About disaster management [WWW Document]. URL <https://www.ifrc.org/en/what-we-do/disaster-management/about-disaster-management/> (accessed 9.16.13).
- IFRC (2013b). Coordinating shelter activities [WWW Document]. URL <http://www.ifrc.org/en/what-we-do/disaster-management/responding/services-for-the-disaster-affected/shelter-and-settlement/coordinating-shelter-activities1/> (accessed 9.16.13).
- IFRC (2013c). How we do shelter [WWW Document]. IFRC Shelter Settl. URL <http://www.ifrc.org/en/what-we-do/disaster-management/responding/services-for-the-disaster-affected/shelter-and-settlement/how-we-do-shelter/> (accessed 9.13.13).
- IRIN (2012). DISASTERS: Learning from Japan's tsunami. IRIN.
- IRP (2012). Transitional Shelter: Knowledge Notes, Cluster 4: Recovery Planning Note 4-3.
- Iwashita, S. (2001). Custom made housing in Japan and the growth of the super subcontractor. *Constr. Manag. Econ.* 19, 295–300.
- Iwate Prefecture (2011). Iwate Prefecture Great East Japan Earthquake and Tsunami Reconstruction Plan Basic Reconstruction Plan.
- Japan Statistics Bureau (2008). Housing and Land Survey.
- Japanese Red Cross Society (2011). Japan: Earthquake and Tsunami Operations Update n° 1 Glide no. EQ-2011-000028-JPN April 13,2011.
- Johnson, W. (2007). Lessons from Japan: A comparative study of the market drivers for prefabrication in Japanese and UK private housing development, report submitted as part of the MSc European Property Development and Planning at University College London.
- Kako, M. and Ikeda, S. (2009). Volunteer experiences in community housing during the Great Hanshin-Awaji Earthquake, Japan. *Nurs. Health Sci.* 11, 357–359.
- Kitamura, M. (2011). Japan's Post-Earthquake Rebuilding Begins With Prefab Housing for Evacuees [WWW Document]. Bloomberg. URL <http://www.bloomberg.com/news/2011-03-27/japan-s-post-earthquake-rebuilding-begins-with-prefab-housing-for-evacuees.html> (accessed 9.16.13).
- Langenbach, R. (2009). Don't Tear It Down! Preserving the Earthquake Resistant Vernacular Architecture of Kashmir. Oinfoin Media.
- Langenbach, R., Mosalam, K.M., Akarusu, S. and Dusi, A. (2006). Armature Crosswalls: A Proposed Methodology to Improve the Seismic Performance of Non-ductile Reinforced Concrete Infill Frame Structures.
- Lyons, M., Schilderman, T., Sanderson, D. (2011). Harnessing time: Reflections on constraints to development. *Environ. Hazards* 10, 213–217.
- Maly, E., Shiozaki, Y. (2012). Towards a Policy that Supports People-Centre Housing Recovery-Learning from Housing Reconstruction after the Hanshin-Awaji Earthquake in Kobe, Japan. *Int. J. Disaster Risk Sci.* 3, 56–65.
- MHLW (2011). The Damage Situation of and Measures Taken Against the Great East Japan Earthquake —116th Announcement.

- Mori, H. (1998). Land Conversion at the Urban Fringe: A Comparative Study of Japan, Britain and the Netherlands. *Urban Stud.* 35, 1541–1558.
- Office of the Prime Minister of Japan, unknown. Frequently Asked Qs: 3.11 Tsunami Debris [WWW Document]. URL http://www.kantei.go.jp/jp/singi/kaiyou/hyouryuu/qanda_eng.html
- OXFAM (2005). *Transitional Settlement: Displaced Populations*.
- Sato, K. (2011). Microsimulation of the Temporary Housing Situation Following an Urban Disaster: Case Study of an Anticipated Tokyo Metropolitan Earthquake. *Soc. Sci. Comput. Rev.* 29, 103–126.
- Schilderman, T. and Lyons, M. (2011). Resilient dwellings or resilient people? Towards people-centred reconstruction. *Environ. Hazards* 10, 218–231.
- Shelter Centre (2010). ALNAP Innovations Case Study No. 5: Transitional shelter: understanding shelter from the emergency through reconstruction and beyond.
- Shelter Centre, UN, DfID (2010). *Shelter after disaster: strategies for transitional settlement and reconstruction*.
- Shigeru Ban Architects (2012). *Container Temporary Housing - Onagawa, Miyagi, 2011* [WWW Document]. URL http://www.shigerubanarchitects.com/works/2011_onagawa-container-temporary-housing/index.html
- Sorensen, A. (2000). Conflict, consensus or consent: implications of Japanese land readjustment practice for developing countries. *Habitat Int.* 24, 51–73.
- Sphere project (2011). *The Sphere Handbook, Humanitarian Charter and Minimum Standards in Humanitarian Response.*, 2011th ed. The Sphere Project.
- UCLBP, IASC CCCM Cluster (2013). *Fact Sheet - UCLBP & Shelter and CCCM Cluster Haiti January 2013*.
- UN (2008). *Transitional settlement and reconstruction after natural disasters*.
- UNDP, UNDRO (1991). *UNDP/UNDR Disaster Management Manual*.
- UNEP (2012). *Managing post-disaster debris: the Japan experience: report of the international expert mission to Japan*.
- UN-HABITAT (2012). *Support for post-earthquake housing rehabilitation and reconstruction: progress and issues HAITI*.
- USAID (2012). *USAID Fact Sheet #1 FY 2012 Disaster Risk Reduction - Latin America and the Caribbean*.
- Washington Times (2011). Japan slow to build housing for tsunami survivors [WWW Document]. Washington. URL <http://www.washingtontimes.com/news/2011/apr/30/japan-slow-to-build-housing-for-tsunami-survivors/> (accessed 9.6.13).
- Wegsheider S. (2011). *Satellite-Based Crisis Information and Risk Assessment* [Online] Available at: www.earthzine.org/2011/03/02/ (Accessed: May 2013).
- World Bank, (2008). *The Growth Report: Strategies for Sustained Growth and Inclusive Development*. World Bank.
- Zetter, J. (1986). Challenges for Japanese Urban Policy: Some Findings from the OECD Review. *Town Plan. Rev.* 57, 135–140.

6. Urban planning and recovery

One of the current issues in Japan is the reform of the city planning system that originated 120 years ago after the 1896 Meiji Sanriku event. The general direction of reform is towards greater 'decentralisation' and 'participation' (Watanabe, 2010). This process may have been accelerated by the Great East Japan Earthquake of 2011.

Urban planning in Japan developed in the early twentieth century in response to strong urban growth. The City Planning Act 1919 had five main components:

- Land Use Zoning (residential, commercial & industrial);
- Urban Buildings Law (height, material etc.);
- Public Facilities designation (improve accessibility);
- Building Line system (build only along 'roads' >2.7m wide);
- Land readjustment system (part of private land as public space).

The result was a strong centralisation of power, a relatively weak civil society and an urban planning system directed from above that has persisted until today (Billsjo et al, 2009). Prefecture Councils were in charge of drawing up regional plans, and there was limited co-operation between prefecture councils and local councils in city planning. However, since 2000 decision-making authority has gradually been transferred from prefecture councils to the local councils, and even to city planning agencies and a more decentralised process was emerging in Japan (Muraki and Takano, 2001).

The prevention of urban disasters is an important feature of urban planning and wooden structures, which account for more than 80 per cent of Japan's housing stock, are exposed to earthquakes, floods, slope failures and to the risk of conflagration (Alden, 1986). Ohsugi (2010) looks towards greater democracy in local planning. If decentralization reform continues there is likely to be further increase in the discretionary powers of local governments and an expansion of their administrative authority, based on the needs of local residents. But Shibata (2008) suggests that all planning objectives in Japan were in the end equated with nation building. While Japan's planners now aim to protect amenity and cultural heritage as well as enhance the quality of life, the legacy of early planning still holds reform. This overriding concern with nationhood may be one of the factors determining the National Government's response to this disaster.

6.1. Post disaster urban planning in Japan

Recovery is to be guided by a new concept that accepts the possibility of disaster and aims at disaster education. It is also to be based on listening to the voices of the people affected. (Reconstruction Design Council, 2011) This report to the Prime Minister also defined five types of region, based largely on topography, for each of which it proposed a different mix of reconstruction measures, particularly in terms of coastal defence and relocation.

Recovering from a disaster involves the kinds of development and planning activities – land use plans, building norms and transport plans – that happen at any time. What is unique in post-disaster situations is that all these activities transpire concurrently in a much more compressed period of time. A key challenge in recovery is balancing the need for both speed and deliberation. Communities must rebuild as quickly as possible in order to maintain existing social and economic networks. But they must also be deliberate in order to maximize the opportunities disasters provide for improvement (Olshansky and Johnson, 2010).

We know from scenario planning with disaster management personnel that people's appreciation of time is disrupted and changed by a disaster and that time is not compressed uniformly, rather it conforms to a logarithmic scale (Platt *et al.*, 2013). In Japan, the initial search and rescue, clean-up, opening of access and provision of relief and temporary shelter was extremely quick and efficient. And the initial modelling, issuance of guidelines and budget allocation by the central government was also exemplary. But the two worst affected prefectures, Iwate and Miyagi, have now entered a more complex and difficult phase of balancing speed and deliberation and this change of pace was noticeable during the field trip and has meant that displaced people will have to spend longer in temporary accommodation than is generally the norm. This may mean that the resulting changes will

more closely match the opinions of local people or it may result in further decline and shrinkage of already fragile economies and communities.

6.1.1. Planning process: coordination, regional strategy, city plans

In Japan the planning process is complex and relatively slow. Japan has a centralized political structure in which the national government maintains close oversight over the prefectures, cities, and other local governments (Sorensen 2004). Pre-tsunami, the three main components of Japanese planning law were: zoning, land development permissions and urban planning projects (Wakamatsu, 2001)

The government immediately sought to broaden the recovery strategy by setting up an advisory panel composed of a team of respected intellectuals, academics, religious figures, and elected officials. Within two months of the disaster, this council issued 'Seven Principles for the Reconstruction Framework'. This in turn became the basis for the government's Basic Guidelines and Basic Act on Reconstruction (GOJ 2011a and 2011b), issued 3.5 months after the disaster (World Bank, 2012a).

The Basic Guidelines for reconstruction were decided by the National Policy Unit three months after the disaster (Government of Japan, 2012). It was decided that the main administrative actors were Municipalities and the role of the central government is to present guidelines for reconstruction and provide support on finance, human resources and know-how. The timeframe for reconstruction is 10 years, with a concentrated period in the first five years. The budget allocated of ¥ 23 trillion overall with ¥ 19 trillion in the first 5 years reflects this emphasis. It was also decided to create a Special Zone for Reconstruction.

A new governmental agency, called the Reconstruction Agency was established in February 2012 that reports to the Cabinet. Its aim is to plan and coordinate all national reconstruction policies and measures and to support the efforts of afflicted local governments by serving as a 'one-stop shop'. Japan's top priority is accelerating the revitalization process and the focus is on policies that benefit economic revival, reconstruction and crisis management. As proof of this commitment the budget for reconstruction in the first five years has been increased from ¥ 19 trillion to ¥ 25 trillion (US\$266 billion) (MOFA, 2013).

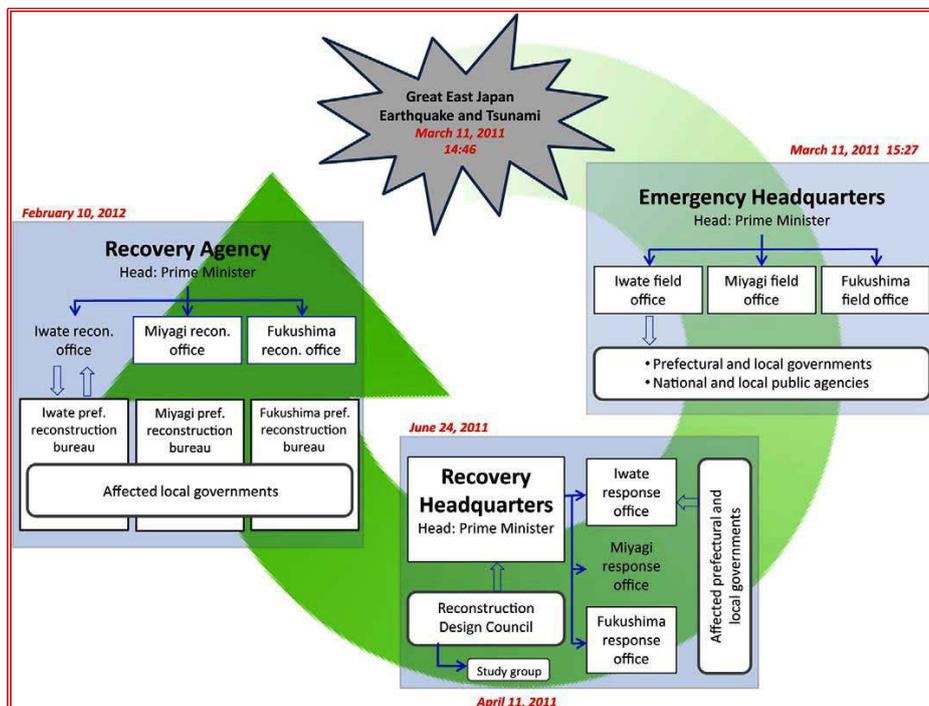


Figure 6.1 Recovery Governance Structure post GEJE (Iuchi, Johnson and Olshansky, 2013).

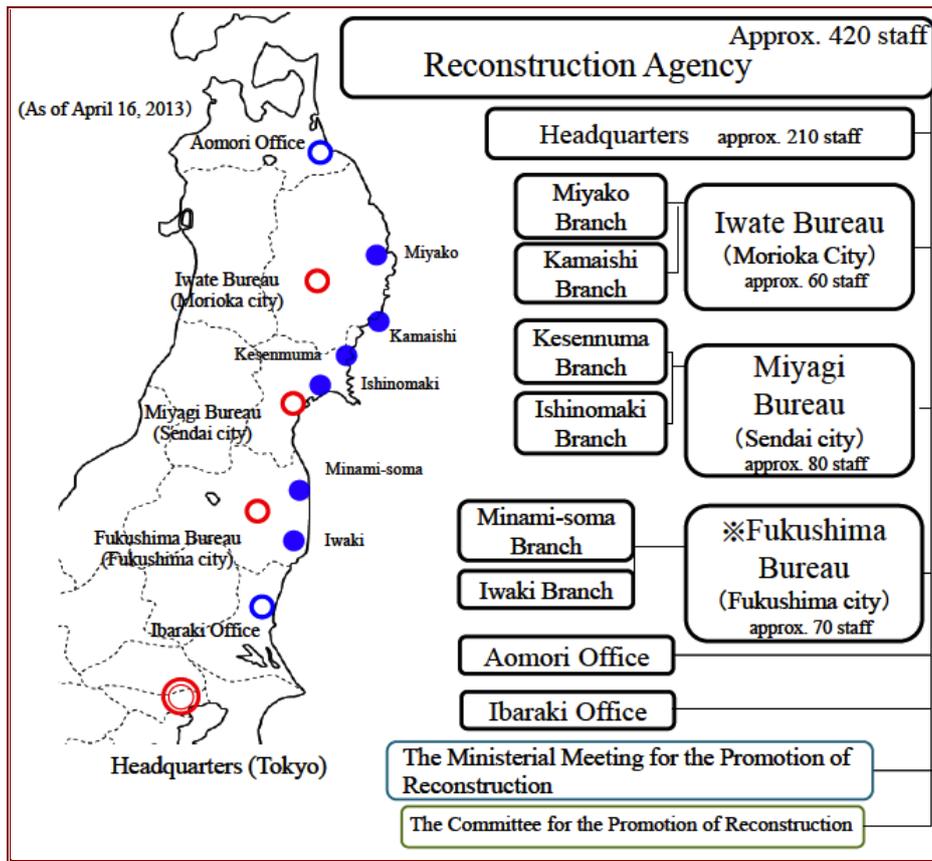


Figure 6.2 Reconstruction Agency Local offices (Reconstruction Agency, 2013) [red circles Prefecture Bureaus; blue dots Branch Offices].

Iwate Prefecture published the final version of its plan for reconstruction on 11 August 2011 (Iwate Prefecture, 2011). Its principles include promoting safety, tsunami mitigation, coastal protection facilities, and city facilities. It also included a set of recommended reconstruction patterns that are generally consistent with the national reconstruction vision. Miyagi formally adopted its reconstruction plan on 19 October 2011 (Miyagi Prefecture, 2011). The plan proposed distinct patterns of reconstruction for urban and rural areas. In urban areas it proposed moving housing to higher ground on the hillsides and locating industry near the water but behind tsunami levee protection structures. In rural areas it proposed tsunami protections using elevated highways or rail lines to protect agricultural areas. The two plans also include a variety of infrastructure and economic development concepts.

6.1.2. Land use and transport

The fundamental national government directive is that industrial buildings are permitted in the hazard zone, but no housing. New housing can only be located 2m below the Level 2 run-up hazard zone. The new building code requires buildings to be no more than 5 stories with a ground floor shop or parking space and living space above.

Political initiatives for building disaster-resilient towns are underway, including the collective relocation of residential areas to safe places such as higher ground, in 276 districts in 26 Municipalities, and the readjustment and levelling of land for residential areas in 58 districts in 19 Municipalities (MOFA, 2013).

To speed up reconstruction a package of special measures are available to 227 designated municipalities that include regulations/procedures, taxation, financial and fiscal assistance as well as land use restructuring. The measures include relaxing and simplifying regulations and procedures, particularly for the conversion from agricultural land to other uses, tax breaks for employees and new

businesses, grants and interest rate compensation for reconstruction and, most relevant for urban planning, special arrangements for land use restructuring beyond existing land use frameworks (urban area, farming area, forests, etc.) and relaxed requirements for floor area ratio for buildings designated for tsunami evacuation (Reconstruction Agency, 2013).

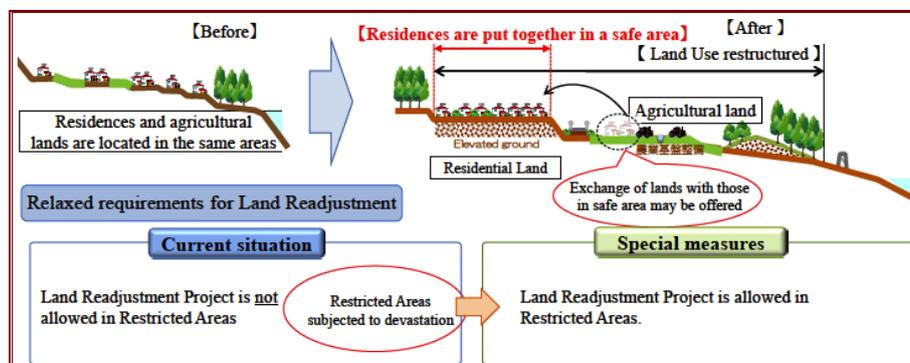


Figure 6.3 Special measure for land readjustment (Reconstruction Agency, 2013).

The most significant aspect of these is that whereas previously it was unlikely that permission would be granted for urban development in restricted areas or to convert agricultural land to urban use, permits can now be granted in special measure Municipalities. And whereas previously authorization for this kind of change of use was needed from multiple authorities, now all that is needed is public consultation at meetings attended by representatives of the national or Prefectural government if deemed necessary after which permits are processed by a single local authority. As well as special permits, revisions to City Plans, Agricultural Land Utilization Plans and Developing Project Plans can be processed by a single authority.

Table 6.6.1 Principle land use changes envisaged.

Land Use Change	Scope	Progress	Comment
Land readjustment	20 Municipalities and 58 districts	61%	Urban planning decisions, not implementation
Collective housing relocation	24 Municipalities and 245 districts	92%	Consent of Minister for Land, Infrastructure and Transport, not implementation

Plans to seek special measures for the authorization of land restructuring can be formulated by Municipalities alone or jointly with the prefecture. The proposed changes have to be announced and displayed in public and there has to be public hearings and consultation before plans are agreed. Special permits are needed for the implementation of reconstruction projects but there is a single point of contact with the authorities instead of the multiple permits needed in normal times.

Municipalities are responsible for detailed land use planning and for producing the plan delineating blue zones where people will be collectively relocated, red zones where there is land readjustment and only commercial or industrial uses will be permitted, and green zones where there are fishermen who are thought to have greater resilience.

Municipalities empowered to apply local regulations, instead of relevant national regulations provided by the Factory Construction Act and the Act for Promoting Enterprise Construction, in terms of the ratio of green belt and environmental facilities provided. Zoning restrictions for industry have also been relaxed if the proposed development is deemed to be 'compliant with the basic policy provided in the Plan for Promoting Reconstruction'. Two examples of this policy are provided. Example one is

in a commercial zone affected by the disaster, authorization is provided for the construction of a fish processing facility alongside restaurants or shops selling fish, in order to concentrate the manufacture and sale of marine products in a particular zone. Example two authorizes the construction of shops and medium-high story buildings in previously exclusive industrial zones where an embankment has been constructed in order to foster clustering of commercial activities (Reconstruction Agency, 2013).

The statutory limit for temporary buildings, such as shops, factories, social welfare facilities and school buildings that are not generally allowed to remain in place for longer than two years and three months, has been relaxed in special measure areas and permission can be extended a year at a time until local infrastructure has been re-established.

In terms of transport-vital infrastructure such as major roads and rail networks, these were quickly restored. The Tōhoku Expressway reopened on 24 March 2011 for limited emergency response use and despite track displacement in over 2,500 places, the Shinkansen was back in operation only 49 days after the disaster (Fischer, 2011). Road transport links are now good and being improved with new highway construction and the national government is building a new motorway. The main railway line is operational but branch lines further up the coast, for example East Japan Railway Company's Kesenuma line, have been abandoned and will not be reinstated. Japan Railways has decided not to restore the train line and the service is being replaced by bus rapid transit (BRT) and small centres, including Shizugawa and Utatsu that we visited, will lose their rail link. In contrast, in Onagawa they are raising the land and reinstating the railway line.

6.1.3. *Use of information and science*

All planning decisions about sea defences or relocation are based on site survey and hazard modelling. The modelling software was developed by IRIDeS and the Prefecture has contracted consultants to run the model for each settlement and the data was given to the city. From this the city made hazard maps. These simulated inundation maps are driving the changes. There are 24 bays in Miyagi Prefecture divided into sections. After consultants produced their findings they were checked by engineers from each Prefecture.

Ideally the consultants would do inundation simulations for different heights of embankment since in some places, the schemes have been opposed the local communities. 2012 legislation obliges local authorities to listen to and to a large extent accept what citizens want. Recovery is to be based on listening to the voices of the people affected and to be guided by a new concept that accepts the possibility of disaster and aims at disaster education. If people want something outside the government's recommended solution then it is important that safety measures are in place and that the community has collectively relocated.

We visited IRIDeS in Sendai and spoke to Deputy Director Fumihiko Imamura; Professors Makoto Okumura, Yuichi Ono and Masato Motosaka; Associate Professors Kanako Iuchi, Anawat Suppasri and Jeremy Bricker.

The two key challenges to smooth land restructuring are that land boundaries are not clearly defined and many people remain unaccounted for or have evacuated to unknown locations. The National Government has been empowered to conduct a cadastral survey on behalf of local authorities. The survey has been completed for 90 percent of areas inundated by tsunami, compared with only 30 percent in Sendai and Miyako City. The clear identification of land boundaries will facilitate land acquisition and reconstruction.

Geographic Information System (GIS) is a basic tool for planning recovery and was first introduced in Japan in the 1970s (Fujisaki, 2011). However, most Municipal government have resources for information management systems (Kugo, Karube and Koshizawa, 2004). A survey of all Japanese local authorities in 1997 showed that 14 percent had implemented GIS. It was being used in three ways: inquiry about the content of urban plan decision, for planning, and for register management (Kohsaka, 2001).

As an example of the many private sector initiatives aimed at supporting local government GIS capability, Hitachi and TerraGo donated their GeoPDF technology to allow local government staff to create a property atlas/database needed to evaluate property losses. TerraGo also combined the

property atlas data with satellite imagery analysis of damage assessment in areas where the radiation levels were too high for field surveys. (TerraGo Technologies, 2011)

The government plans to use data from car navigation systems to monitor post-disaster traffic. Monitoring road and traffic conditions from helicopters and at ground level proved to have limitations immediately after the earthquake and tsunami and the Transport Ministry was able to check conditions on only 79 percent of national roadways by the end of day one. With the data, the transport ministry can find out which sections are impassable, either from damage or traffic jams. Unlike monitoring from helicopters, analysing car navigation data can allow authorities to grasp immediate traffic conditions even at night, and all roads, not just expressways, can be monitored. The information on closed road sections will be shared with expressway operators and local governments (The Japan Times, 2013).

Autodesk Infrastructure Modeller 2012 has been used by various local authorities to create 3D visualisations, for example in Otsuchi, north of the area visited by the EEFIT mission. The modeller can read a variety of data formats, including 2D CAD data, GIS, and raster images such as satellite photographs. It then imports structural models such as embankments and raised roads and produces a 3D image that can be viewed from different angles. This helps non designers understand what proposed engineering works will look like.

Japan is committed to incorporating advanced technologies and new methods into reconstruction initiatives, to ensure that communities are sustainable and energy-efficient (e.g. Future City initiatives in Higashi-Matsushima and others) and that new industries and enterprises benefit from the latest knowledge and technology (MOFA, 2013).

As part of reconstruction efforts, a budget of ¥ 8 billion has been allocated for smart communities that make use of renewable energy. The anticipated schedule is to develop a master plan by April 2013 with selected renewable energy projects, the development of housing that makes the best use of renewable energy and solar power generation.

6.2. Bay of Sendai

In Sendai we visited the main centres from Ishinomaki in the north to Yuriage-Natori and Iwanuma and Sendai Airport in the south. We saw evidence of the terrible power of the tsunami. The whole area looks scarred – the coastal forest we had seen on pre-tsunami aerial photographs has been removed and the few remaining trees are dying and the flat coastal plain has been abraded to a distance of 4-5 kilometres. One can see evidence of previous lives by the side of the road – a toilet brush, a teapot, a shoe. Only the bare footings of buildings and the occasional boarded up house or shrine has survived.

In Arahama, we were told that the government wants to remove everyone back behind a new 6m high embankment, but some people want to return to their homes. There was a woman resident at the roadside seeking signatures to a petition asking the government to reconsider the proposals. Before the tsunami, Arahama Village had a population 2,700. The wave was 10m and the inundation distance 5 km and 200-300 people died. But the four-storey elementary school we visited acted as an evacuation centre and saved the lives of 520 people.

We visited the major works on coastal defence in Yuriage and Iwanuma and also saw evidence of the huge clean-up operation – piles of sorted debris awaiting processing in large well organized processing sites. There was a debris reprocessing plant with an incinerator in Arahama and Yuriage and debris is being sorted into what can be recycled, burnt or buried.

In Yuriage the spit that protected the harbour entrance is entirely gone and the areas near the sea will be abandoned. The main livelihood is fishing and fish processing and we saw some evidence of the return of the fishing fleet. This was a prosperous area with large detached houses and a population of 7,000. But only the most robust concrete structures survived. The government plans to reduce the built-up area by half and raise the land by 5m. Some people want to return, but the majority want to relocate to a safer area.

We visited an ancient hill that had been over topped by the tsunami and a secondary school where the clock stopped at 2.46 when the earthquake struck. We also went to a second school where lost

property had been laid out and sorted into piles: musical instruments, cameras, bags, dresses, family shrines, footballs, and most disturbing, photo albums.

6.2.1. Yuriage Village, Natori City

We met Sato Hiroshi and Aizawa Yuriya, Municipal Planners, Natori City. The following are notes of their verbal presentation (Hiroshi and Yuriya, 2013).

The town is close to Sendai and the international airport and the population in the area is increasing and is already higher than prior to the earthquake. The height of the tsunami was greater than 9 m in the port of Yuriage. There were 958 deaths and 4,500 people are living in temporary housing, either shelters or rented accommodation. The town has a long history as a fishing port. It had a lovely beach, and an area for cycling. They hope to recover the charm and that tourists will visit the area again.

The future coastal defence will be a triple hard system of embankment, raised road and highway. There will be some industrial use in the yellow hazard zone but the key proposal is to relocate new public housing for displaced people to the blue zone. This is defined by the Level 2 100-1000 year return period inundation hazard minus 2metres.

Decisions about land readjustment are made by the Municipal government. Local government planners started to explain the urban plan to the people in March 2012. Before the disaster most families lived in single private houses on its own plot of land. New housing in the blue zone will be built on land raised 5m above sea level. New plots will be smaller, but in better shape, and families can sell the land and move. The question is, will land values increase sufficiently to compensate for the loss? The planners expect land values will increase but they are not sure when. Public housing will be 5-6 stories in height with no ground level living. These buildings will act as tsunami evacuation points.

There were strong objections because people do not want to return to the area devastated by the tsunami and many want to be relocated further inland. In July 2012, 34 percent said they would be prepared to return to Yuriage. In April 2013 the survey was repeated and only 25 percent said they would like to return. 34 families are opposed to the plan and it is not clear what they are going to do. The planners intend to talk to them and give them information about subsidies. If the residents do not want to stay, the government will purchase the land.

The Municipal government cannot agree to abandon the area but because the proposed protection infrastructure is expensive the plan all depends on the numbers of future residents. If much of the housing is relocated further inland it will mean there are fewer people in the old town and it will be difficult to maintain services and justify the high cost of the protection measures.

The Municipality is pushing ahead with the plan, but need the approval of the Prefecture. If approved, the city administration will fill the ground with approval from landowners. They hope to finish the fill and preparation by spring 2016 so that public and private housing can be built. They are considering other options for people fearful of returning, for example constructing some public housing on the western side of the highway (away from the coast). In fact we saw signs of considerable new private housing development in this area and for families wanting to build their own home there is a loan subsidy.

6.2.2. Iwanuma

Iwanuma covers 61 km² and has a population of 44,000. It is near Sendai airport and has a famous shrine. Tamakura Village was the area that suffered most and 181 people died.

We met the Mayor, Tsuneaki Iguchi, and Vice-Mayor, Tetsuo Kikuchi. The following are notes of their verbal presentation (Iguchi and Kikuchi, 2013).

Many residents are afraid of another tsunami and people from the six residential areas in the hazard zone will be moved to a safer area 3km back from the coast on land raised 3m above the surrounding area. We visited the site and saw that work on the platform was nearing completion. House building

will begin in December 2013. The cost of the new land is ¥10 billion including the land purchase and services for 20 ha which will house 400 households.

Other parts of the risk reduction strategy include a 7.2m embankment along the coast, raising the Municipal road by 4-5m and the Millennium Hope Hills project – a series of fifteen 10m high hills linked by a 3m high embankment constructed using tsunami debris, the rationale for which is to protect the airport, create a memorial park and improve the image of the city. There will be evacuation routes to each of the hills and the surrounding area will be replanted by the national government. They plan to build the first six hills in three years' time and the rest within 10 years. The hills are constructed in part of debris and we also visited a prototype hill that has been built to monitor pollution emissions. The total budget cost is ¥4 billion and the government has promised a subsidy of ¥2.6 billion. This means that ¥1.4 billion needs to be raised from donations. The Ministry of Land, Infrastructure and Tourism is managing the project.

The Mayor explained that the hills will reduce the power of a tsunami and provide places of refuge. The idea came from Matushima, where a line of small islands helped protect the inland area. There were two natural hills in Iwanuma before the tsunami and people evacuated here and survived. The idea is also to provide an educational facility and a place for reflection – they are literally using part of people's lives to build these hills and it will be good for people to come and pray and remember their former lives, said Mayor Iguchi. They are in discussion with the Ministry of Environment to change the law about how concrete and timber, that are supposed to be recycled, can be buried in the hills.



Figure 6.4 (Left) The Millennium Hills master plan, Iwanuma.

Figure 6.5 (Right) Pilot demonstration hill built to aid fund raising.

The hope is that with increased safety people will return and new industry will locate here if private companies believe safety issues have been adequately addressed. Most people commute to the city to work. Those households who farmed will have difficulty continuing in their new homes.

6.2.3. *Ishinomaki*

We visited Ishinomaki and saw the elementary school that had been burnt by floating debris and visited the large industrial area near the port. We drove past the paper factory, back in production seventeen months after the tsunami, but whose closure had caused a severe paper shortage. We visited the harbour, where major works are underway to raise the level of the docks by a 1.5m and where fish processing has been relocated in large elegant temporary structures of white canvas on a tubular frame.

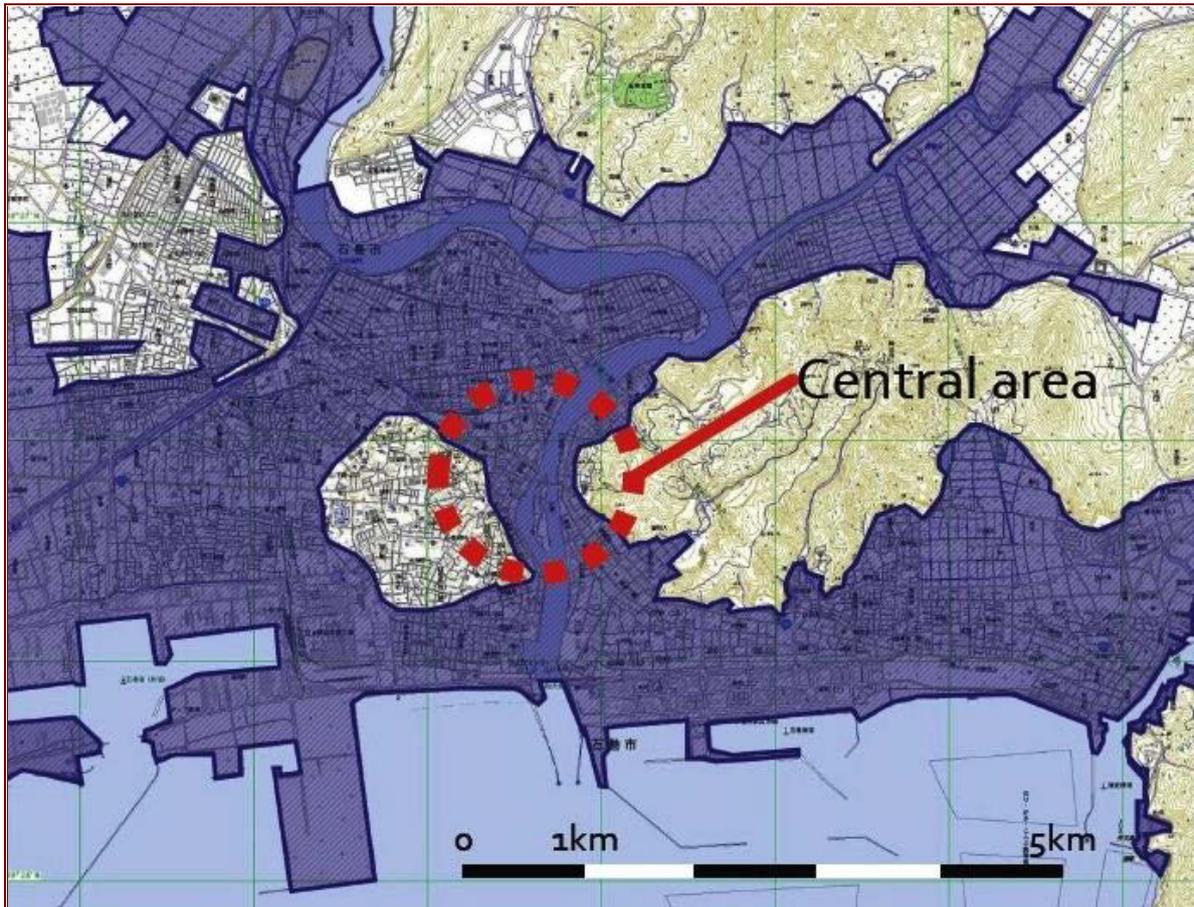


Figure 6.6 Tsunami inundation area in Ishinomaki (Toyoshima et al, 2012).

We met Tomoya Otsuka in the Reconstruction City Planning Office. The following are notes of their verbal presentation (Otsuka 2013).

There has been a fall in population from 163,000 to 151,000 since the tsunami. As well as damage to buildings there has been subsidence on average across the city of 78cm rising to 2m in the fish market and in many areas there is an increased risk of flooding.

About 60 percent of the fish processing capacity is still out of production and because restoration of the fish plants has been delayed, production is only 30 percent that of the previous level. Industrial activity has been much less affected and 48 of the 50 businesses have restarted. Three new residential areas of 108ha have been designated in high safety areas that used to be paddy fields. The city government has already purchased the plots and started construction.

It is responsibility of the Urban Planning Committee of the Municipal Government to prepare a land use plan that goes to the Prefecture for approval. The total budget for reconstruction in the city is US\$10 billion. Because there are so many projects, 2012 was a year of designing and planning and in 2013 they started construction. Prior to the tsunami the Reconstruction Department didn't exist; by February 2011 it had 36 staff and by 2012 it had 137.

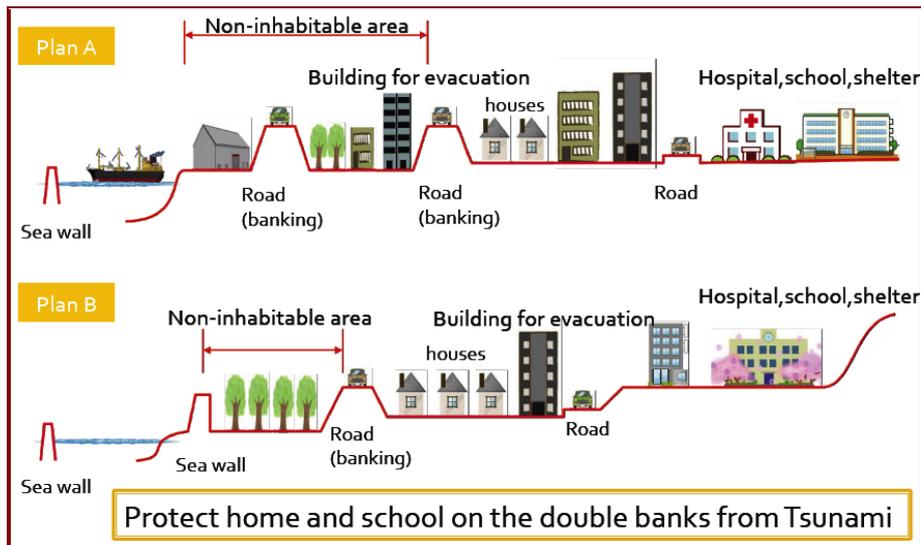


Figure 6.7 Plans for housing relocation in Ishinomaki (Toyoshima et al, 2012).

Relocation decisions are made according to the damage survey and hazard map. In all areas where houses were washed away the Municipality have decided it is too hazardous to relocate and they have prohibited the rebuilding of houses. They will rebuild sea defences for harbours and raise roads. They determine how many people need relocating and identify areas suitable for development as extensions to the existing urban area and compare options before finalising a plan.

The Municipal government is still talking to local communities about the use of the remaining ground and they are still unsure about its reuse. There is time for local people to object and comment in the Urban Planning Council before reaching agreement and there is a chance to submit written questions.

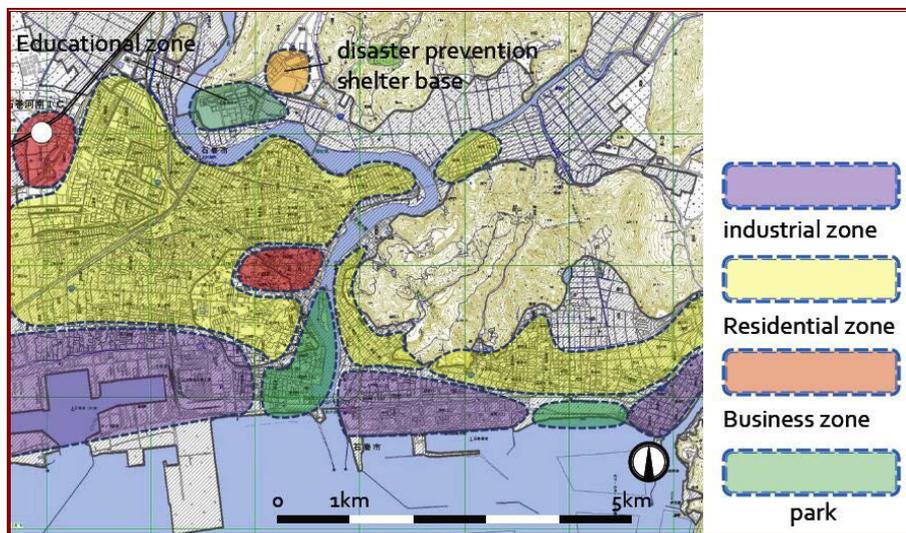


Figure 6.8 Zoning Plan for Ishinomaki (Toyoshima et al, 2012).

Mr Otsuka reported that in Japan formal consultation is fairly superficial and decisions are made by the authorities with only token participation. There has been discussion about keeping the elementary school as a remembrance, but some feel it should be removed and a decision is yet to be made. The junior high school will be relocated and other schools will be raised. They will have community space on the ground floor and the evacuation stairs will be external, so people can access them when the school is closed.

In fishing settlements further along the coast there has been extensive discussion with local fishermen, but it is not always possible to provide alternative places. There are cultural heritage issues and there is also a danger of landslides and soil failure that mean they cannot build on some slopes. Civil engineering experts are involved in these decisions. The Regional Planning Authority of Miyagi Prefecture is responsible for 44 fishing harbours and three towns. To reinstate fishing villages the ground has to be raised and drainage works are needed. The Municipality receives 70 percent of the cost in compensation but it is not possible to redevelop all the settlements and choices will have to be made.

In relation to redevelopment of the central business district (CBD) the city government is a shareholder in the private company managing the process and collaborates with the private sector. A plan was submitted to the Prefectural and the National Government for a memorial park along the river and there will be a river embankment and promenade. They are also planning new lines of protection including a new sea wall 7.2m high along the front and 4.5m high along the river and a new road with an embankment of 3.5-4m. In the port where there was subsidence of 2m and the land will be raised by 3.7m. The total budget is ¥9 billion and it will take 10 years to complete.

We met Tomohiro Kariya of the Machidukuri Manibou Development Company, the private sector partner mentioned by Mr Otsuka. The following are notes of his verbal presentation. (Kariya 2013)

One of their key goals is to recover the CBD and the development company is working with a citizen's committee of stakeholders that includes landowners and business owners, as well as residents, Municipal officials and volunteers. There are about 25 active members who have been discussing how to make the city centre more compact. The local community were also involved in an exercise a year after the disaster in community workshops and there was a good discussion about the future of the city. People had already been thinking about the problem of shrinkage before the tsunami and the committee had been formed to address the problem of decline and already had some projects in hand. The strategy is to increase the number of people living and visiting the centre. The majority of people are living in temporary housing so the current population living in the centre may be less than half what it was before the tsunami.

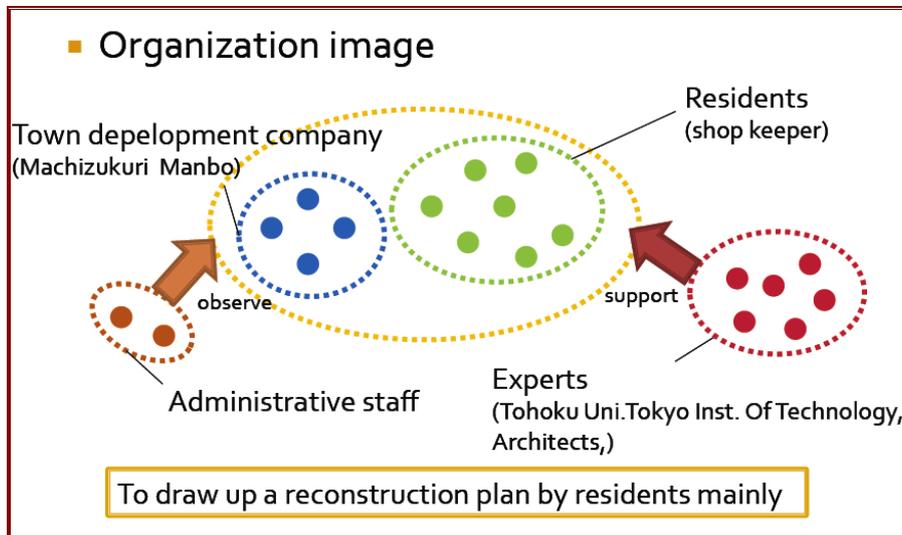


Figure 6.9 Organisation of Stakeholder Committee to redevelop the Ishinomaki CBD (Toyoshima et al, 2012).

There has been discussion about what kind of shops and housing units are needed to make the area more attractive and stable. But it is not easy to decide about the balance because the committee does not have the authority and the city does not involve itself directly government believes these decisions should be market led.

The committee is divided into three groups: street design, open space development, and lifestyle branding and cultural value. The main principles are safety, peace of mind, attractiveness, and the sustainability of the downtown area. They have defined 13 areas for joint reconstruction and there is a

central government subsidy of 40-50 percent of the cost of each project with a deadline of 2015. Two are public and ten are private initiatives. Two are already committed and the others are still being planned. There is also a subsidy for new businesses that includes five years business tax exemption and three years property tax exemption and loan interest assistance for second loans in condominium projects where 50 percent is for social housing.

There are objections to building the proposed 4.5m embankment along the river and discussion about balancing protection and historic value and how to make the area attractive for visitors. Although 13 percent of the city, including most of the CBD was flooded, there was limited damage and this has been repaired. But over 3,000 people died. (World Bank, 2012c) Land in the CBD sank by 10-30cm and there is increased risk of flooding. This is not an easy decision for authorities or the community to make and they are wise to deliberate calmly.

There are plans for a riverfront development with a new fish market and fish food court and a memorial to the tsunami. Ishinomaki has a long history as a port, but there is no particular building or symbol that represents the city. Its strong points are the river, its history, its location near Matsushima, and food – fresh fish.

Young people are leaving the area and the committee has been talking about activities and events to make the area more attractive to the young. They have also discussed activities for visitors. But it is hard to attract new business and it is not clear what the unique selling point of the city is. The main hope is that new people will be interested in moving to the area. Their fear is that they will be unable to resolve the many problems including the increased vacancy, population decline and weak economy. They are afraid of redeveloping too much real estate in case there is insufficient take-up of the shops and there is a difficult balance of investment and viability.

6.3. Towns of the Rias Coastline

In the Iwate Prefecture 66 communities were displaced and located in temporary housing. This is a mountainous area of steep valleys running down to small harbours and the topography dictates where people can be relocated. The city governments are involved in conversation with landowners to find land to relocate.

Along the Rias Coast we visited the towns of Kesenuma, Kamaishi and Rikuzentakata. We also visited the smaller centres of Utatsu, Shizugawa, Ishigawa, Onagawa and Unosumai.

In Utatsu, Minamisanriku, we saw how the 16m tsunami over topped the storm-surge gate on the river, buckling the massive steel structure and demolishing the flyover road.

In Shizugawa (Minamisanriku) the main town was completely destroyed and the 12m high steel frame disaster management agency building was overwhelmed by the tsunami. It was here that a young woman stayed at her post broadcasting the warnings and died.

In Onagawa they are raising the land and reinstating the railway line. We saw where the 16m platform on which the hospital is built was overwhelmed by the tsunami and were told that staff in the bank in the harbour died when the manager insisted they stayed at their posts. There is a ferry terminal from a nearby island. It was four-storey 12m high steel frame on piles and we saw how it had been overturned and smashed by debris.

In Unosumai a vast urban area has been lost. Out of 6,630 households 2,657 have gone and there is a massive debris clearance in progress. Children from the elementary school ran to the first evacuation point but someone must have realised that they had not gone far enough so they continued on to the second and third evacuation points. Many people died in the disaster management centre, despite being set well back from the sea front behind storm gates on the two canalised rivers.

6.3.1. Kesennuma

We met Miura Tomayuki a community worker in Oya District who lost his home and is managing the Amagasawa temporary housing site on a hill near the sea. The following are notes of his verbal presentation (Tomayuki, 2013).

We visited what had been a beautiful beach south of Kesennuma, at Ohyakaigan and a second beach at Koizumi, at the mouth of the Suja River. At both beaches the pine trees and the beach were washed away, but the sand came back after six months to one year. The height of the tsunami in these areas was quite extreme (>15 metres).

We climbed the 3m temporary beach embankment at Ohyakaigan built of 1 ton black ballast bags. The main issue is the height of the proposed embankment – 9.8m high and 40m wide that will separate the community from the beach. Looking from an embankment less than a third of the proposed height we could appreciate his concern. The beach is the symbol of their identity and they feel connected to the sea. Most of the residents oppose the new embankment but some people were so traumatised that it is hard to get consensus. The population of the district is 3,500, 1,324 of whom signed a petition to the mayor asking the government to halt the plan and to reflect the comments of residents.

But the Oya beach is managed by three different organisations – the Municipal Agriculture and Fisheries Department is in charge of the north end where fishing used to be, the National Forestry Department is in charge of the middle section that used to be a pinewood and the Civil Engineering Department of the Prefecture is in charge of the southern end at the river mouth. Six of Kesennuma's districts are in a similar position and there is a similar level of concern about losing access to the beaches.

In the town centre we met Akihiko Sugawara, owner of Otokoyama Honten, a Sake Brewery, Vice President of the Chamber of Commerce and Member of Strategy Committee of Municipal Government. He was accompanied by Toshihiko Abe, Senior Research Fellow at the Institute of Urban and Regional Studies at Waseda University. The following are notes of their verbal presentation (Sugawara, 2013).

Ohshima Island protected the harbour and by the time the wave reached the top end of the bay in Kesennuma it was much weaker and everyone managed to evacuate and there were no casualties. But the plan is to build a 5m embankment that will destroy the character of this charming seaside harbour. The people in the neighbourhood are against the plan because they think the plan will destroy the harbour merely to protect a narrow strip of flat land from an event that may occur once every 1,000 years.

The best view of the town is from here and it is important to recover the tourist industry. The problem is people are worried about the delay and think that a high embankment will destroy the scenic value of the place. People are against this kind of structure because it will separate them from the sea and change the character of the area. Although embankments are meant to protect lives and property the proposals will destroy lives and sustainable living conditions and people may leave. The embankment may also give a false sense of security and it might be better if people are aware of the sea and are ready to evacuate. No one died in the neighbourhood because people are aware of the tsunami risk and evacuated immediately.

There used to be many shops in the town centre but recovery will take 5-6 years and many of the shops and restaurants may not return. There has been discussion about speeding up the procedure – how to recover the housing and how to recover the commerce. It had been hoped to rehouse people quickly and recover lives but 9,000 people from across the city are still in temporary housing. Many shops are in temporary accommodation and want to come back to the area. The dilemma is how to speed up decision-making to recover livelihoods. It would be better if the Japanese legal system helped resolve this kind of issue, but the system is bureaucratic and authority budgets are divided and segmented.

We visited Shibilitachi, a fishing village of 260 households and interviewed a group of eight fishermen from a cooperative of retired men who fish in an amateur way for abalone and sea urchins in the gulf.

The village is set in a beautiful bay of Karakuwa. The wave here was 9m and a costly 9m sea wall has been proposed. When the warning came people ran up the grass slope behind their homes and practically everyone was able to evacuate easily. Only nine people died. Of these, one was in a wheelchair, some were elderly and some went back to collect something. They believe evacuation is the best measure here.

They said that the residents and city government are in conflict with the Prefecture because people's lives will be ruined if the seawall is constructed and they are separated from the sea. The government plan is for a 9m high wall 40m wide at the base that will fill most of the flat area at risk.

We met Ogata Takeshi, an Assembly Member and fish processing plant owner, together with his wife. They lived in the Ogata House a large traditional style house (thatched) built in 1810 that was destroyed by the tsunami and has been adopted by Japan's National Trust. The following are notes of their conversation (Ogata, 2013).

The priority of the Government's Six Year Reconstruction Plan published in October 2011 is to build hard protective structures and to relocate people. After that there are other priorities. The Mayor of Kesenuma is lobbying for a share of the budget. Families have three options: they can reconstruct their own house, they can move into public housing or they can move to another place. Some people are opposed to plans to build embankments and in the assembly there is as yet no consensus. The government has proposed a 7.2m embankment in front of where their house used to be. Around a third of their house has been recovered and materials transported in Yamanashi prefecture for restoration and storage. Japan's History and Folk Museum (in Sakura-shi, Chiba prefecture) is making a replica of their house. The Ogatas have not yet decided where they will rebuild their traditional house.



Figure 6.10 (Left) Ogata House before the tsunami.



Figure 6.11 (Right) Ogata House after the tsunami.

6.3.2. *Kamaishi*

We met three community planning professionals from the Iwate Prefecture: Yuki Kawaguchi, Hiroaki Yagi and Atsushi Onodera. The following are notes of their presentation (Kawaguchi *et al.*, 2013).

The city lacks resources and they are here to support the city. The Prefecture is responsible for infrastructure at various levels for example embankments and roads.

The 2011 tsunami topped the barriers and embankments and the new embankment is designed for a Level 1 hundred-year return period tsunami event and evacuation measures are planned for a Level 2 1000 year return period tsunami event. Evacuation routes and temporary camps have not yet been determined and they are still thinking about road design and hazard zoning. They plan to raise the land for living and working.

The concept for public housing is increased density and people will be less self-sufficient on smaller plots and further from the sea. In principle, people will be relocated as close as possible to their previous homes and neighbours. The variety of public housing depends on the land availability. Single

units are expensive. Prior to the tsunami 40 percent of the population rented their housing and 80 percent of this was private. Potentially, some of these people will be moving from private to public housing.

Public housing is seen as a last option but not a change of status. It's called disaster housing so it carries less of a stigma. In fisherman villages most people own their own homes; in the city more people rent. There was a survey in the city asking people if they wanted to live in public housing or not. The qualification is based on income level.

The first issue for planners is balancing speed with reaching consensus. The second is securing land because it is difficult to identify who owns the land because some people are missing and there is inaccurate cadastral information. The city has a schedule for recovery but is facing so many issues that it is impossible to say how long it will take. The biggest industry is Nippon Steel which was not badly affected. But the main employer is fishing and the priority is on getting the fishing industry back into production.

We met Junicho Kano, founder of a community NGO in Kamaishi called RIAS. The following are notes of their presentation (Kano, 2013).

Place making is important to Kano and he had decided to help the recovery by building a meeting space that is open to the community and where they hold concerts and piano recitals and try to respond to what people want.

In the first two weeks the defence force cleared the roads and access was the first priority.

Kano received government funding to manage the centre until the end of March 2013 and now gets some support from the private sector. The centre is also for shop owners and stallholders whose property was washed away. It provides a place at the centre of the old town and is a symbol of regeneration, a beacon of hope and a resource for community activity.

The younger generation want to go to Tokyo. Even if there were higher education in the town there are still no jobs and there is an expectation that jobs can only be provided by large corporations. Small business owners did not get much support and many people have had to leave the city.

The local newspaper has a full-page information sheet twice a week, but people would like to know about the phasing and timing of recovery in the economy, homes, property and safety program. But the Municipal authority only provides piecemeal information and there is no comprehensive strategy. Coordination and leadership in the city council by the mayor and his staff feels inadequate. Few Japanese cities have strong local community associations and traditionally people want government to decide for them. Non-profit organisations like this centre have to provide coordination by sharing information.

6.4. Conclusions

One of the key issues is how much room for adaptation there is in the application of the central government's template for recovery and reconstruction. Japan is a compliant society and there may be more flexibility than bureaucrats or residents realise. But no one has any inkling about the cost-benefit of the huge investment. This is a national response to disaster, but there is a disconnect in the local area in terms of priorities and decision-making. The government feels that it is doing what is right in saving towns that have been here a long time. But there is a time limit for people to decide what to do as the government has set deadlines for spending.

We visited the International Recovery Platform, UNISDR in Kobe and spoke to Sanjaya Bhatia, Knowledge Management Officer; Yoshiyuki Akamatsu, Senior Researcher; and Recovery Experts Shingo Kouchi, Gerald Potutan and Gulzar Qayyum. The following are notes of their conversation. (Bhatia et al, 2013)

The Reconstruction Agency was established by the Prime Minister's Office. It advises government on all basic strategies based on quick lessons. But hard solutions give a false sense of increased security and early warning is an issue. The reaction of government has been self-critical. Instead of defending the system they have been frank about what failed and it is in the character of Japan to always review and look back and learn lessons. For example, ideas about evacuation are changing.

Japan national broadcasting has changed the way it announces the early warning. Rather than giving precise information that is open to error and misinterpretation it will from now on give much simpler direct warning to evacuate immediately.

To date the focus has been on relocating housing and safety measures, whereas the imperative is to to strengthen the local economy and address economic and demographic decline. Measures that would strengthen existing local businesses, city centre shops, attract new industry and encourage young people to the city might also have been considered. One thing the central government might have considered is founding a college of higher education, either a new university or a branch of a university in Sendai, preferably one that focused on technology and had practical links with industry and enterprise.

There is a proposal from Kobe University to revitalise small business but people in the affected area do not have the resources or money to take action or to exploit new technology. New people would be most welcome. Do people take the initiative and accept responsibility or do they expect people to come and help solve the problem? People with initiative would be a good thing. People have been here a long time and cannot see how to fix the problem.

6.4.1. Demographic and economic issues

About half of victims of this earthquake were elderly people of sixty-five years or more. In planning it is necessary to try to anticipate the future population. Based on the statistics presented by Statistical Information Institute for Consulting and Analysis depopulation has extended over the whole region, excluding large metropolitan areas such as Sendai. Forty percent of all Municipalities will experience a population decrease of 20 percent or more. In coastal areas of Pacific Ocean population is anticipated to decrease even further since local economies were destroyed and young people will leave (Masateru, 2011).

Population emigration due to the disaster is largely occurring among young people. The International Recovery Platform pointed out the issues being faced by the affected areas following the Great East Japan Earthquake are compounded by the problem of shrinkage confronting most rural towns in Japan. In addition to issues of safety and relocating housing, population decline, ageing and economic shrinkage pose special planning challenges (International Recovery Platform, 2012).

It is hoped that tackling these issues by reording land use, improved transportation links and urban centre regeneration projects will have a positive impact on the prospects of these places as well as make them more resilient to a future disaster.

Not all places that were affected by the tsunami are the same, however. The area around Sendai in Miyagi Prefecture is a flat plain and has a strong economy, good transport links and a growing population. Further north in Iwate Prefecture there are steep slopes and fiords, a declining population and a weak economy. In each there are differences of scale with a few larger cities and towns and many more smaller settlements and villages. This suggests that different places face different issues of recovery.

These differences in socio-economic prospects, demography, topography and scale suggest that approaches to both safety issues and economic development assistance might be fine-tuned to meet local circumstances.

Table 6.6.2 Places visited classified by relative strength of economy and size.

	Large	Small
Stronger economy	Iwanuma Natori Yuriage	Villages in Iwate (part of the population commuting to city)
Weaker economy	Ishinomaki Kesenuma Rikuzentakata Kamaishi	Villages in Miyagi (dependent on fishing and agriculture)

6.4.2. Citizen involvement in decision making

In the areas affected by the 2011 tsunami, consultations between governments and communities were the rule, and community representatives were invited to serve alongside experts on recovery planning committees from the earliest stages. The most common ways of collecting residents' opinions were surveys and workshops. The central government and local governments outside the disaster-affected area helped affected Municipalities plan their recovery by conducting research, seconding staff, and hiring professionals to provide technical support. University faculty members, architects, engineers, lawyers, and members of NGOs participated in the Municipal planning process (World Bank, 2012a).

Along the Rias coast the response of the majority is that the government has already decided so they can't do anything. Some even admire the colossal infrastructure. But the younger generation, in their forties, is opposed to large embankments and tall sea walls, but they are not the decision-makers. In Japanese community associations it is elderly men who make the decisions. In Ohyakaigan near Kesenuma the community association meets twice a month and tries to involve children as well as older people. The plan is to collectively relocate the 120 households and to have the land cleared by 2015-16. The Japanese Institute of Architects (AIJ) is considering using this as a model of participation. Unfortunately people can not wait and they are now down to 100 households and the community may fall apart because of the delay. The group decided they would not oppose the proposed embankment but suggested it be moved back. Initially the city was not happy but changed their minds after receiving the petition. The proposed Municipal plan is now for a much lower embankment further back but this needs cooperation between the Ministry of Forestry, Japan Railways, the National Highways Agency and the Prefecture (Tomayuki, 2013)

In Kesenuma the citizens' committee oppose the planned harbour embankment and they are in talks with the Municipality and prefectural government. The majority of residents are against the proposal and it is not settled yet. Planning arrangements cannot proceed while there is a dispute but city officials are making land use plans assuming the embankment will go ahead. Because there has been so much opposition a new deadline has been set for October 2013. In other places plans are proceeding more rapidly.

In Kamaishi the three community workers for the Prefecture explained that local authorities have to accept what citizens want. Ideally they would simulate different heights of embankment since communities in some places have opposed the plans. If people want something outside the government's recommended solution planners have to be careful that safety measures are in place and that the community has collectively relocated.

Partly because of citizen opposition, reconstruction of sea embankments, which suffered extensive damage, has been considerably delayed. Local governments in devastated areas cannot decide on the details of restoration plans, as discussions continue on whether to prohibit people from returning to coastal areas. Reconstruction work has started on only 31 percent of destroyed embankments. According to the Fisheries Agency, which has jurisdiction over sea embankments, the design of embankments will depend on whether people will live nearby (Daily Yomiuri, 2013).

Local governments were tasked with recovery by the National Government who asked them to develop local plans based on consultation. The problem is they lack the technical capacity, especially in effective methods of involving citizens in strategic decision making. Voluntarily urban planners and architects from all over Japan surged to provide missing capacity. Local government has lots of problems with consultation, which is time-consuming and it is not easy to convince communities to relocate. Local governments want to consolidate communities to make it more efficient and economical to deliver services, but many of these places were in decline before the tsunami. They have to provide facilities to each community so the cost is considerable (Bhatia et al, 2013). But the fundamental problem is that the authorities do not really know what size population they are reconstructing for.

6.5. References

- 3D Modeling of the earthquake recovery plans of Otsuchi-cho, Iwate (2013) http://atlandsend.typepad.com/files/otsuchi_20120221_en.pdf.
- Aldern, J. (1986). Some Strengths and Weaknesses of Japanese Urban Planning. *The Town Planning Review*, Vol. 57, No. 2 (Apr., 1986), pp. 127-134,
- Billsjo, R. Diab, N., and Takeuchi, Y, (2009), Urban planning culture of Japan. SGC SSIE SAR ENAC INTER 25 Mars 2009,
- Daily Yomiuri editorials (2013) 2 years on, Reality of recovery differs from official data. March 11, 2013. <http://www.accessmylibrary.com/archive/434970-yomiuri-shimbundaily-yomiuri/march-2013-page4.html> (Accessed 7 September, 2013),
- Fischer, E. (2011). How Japan's Rail Network Survived the Earthquake <http://www.railway-technology.com/features/feature122751>. 28 June 2011 Accessed 11 September 2013,
- Fujisaki, I. (2011). The Brookings Institution, Center for Northeast Asian Policy Studies: Japan's Recovery Six Months After the Earthquake...Recorded Interview transcript of ICHIRO FUJISAKI Ambassador Extraordinary and Plenipotentiary of Japan to the United States. Sept 9, 2011, In Goss E and Teagarden P Lesson 8: Case Study Collaborative Project Recovery from the 2011 Japan Earthquake GEOG 588. <https://www.e-education.psu.edu/geog588/node/2140>. Accessed 11 September 2013.
- Government of Japan (2012). Road to recovery. Reconstruction Agency, Prime Minister's Office. http://www.kantei.go.jp/foreign/incident/road_to_recovery.html. (Accessed 5 September 2013),
- Hiroshi, S. and Yuriya, A. (2013). Municipal Planners, Natori City. Verbal report 6 June 2013.
- Iuchi, K. Johnson, L. A. and Olshansky R. B. (2013). Securing Tōhoku's Future: Planning for Rebuilding in the First Year Following the Tōhoku-Oki Earthquake and Tsunami. *Earthquake Spectra*, EERI <http://earthquakespectra.org/doi/abs/10.1193/1.4000119>.
- Iguchi, T. and Kikuchi, T. (2013). Mayor and Vice-Mayor of Iwanuma. Verbal report 6 June 2013.
- Iwate Prefecture (2011). Iwate Prefecture East Japan Earthquake and Tsunami Reconstruction Plan: Basic Reconstruction Plan (draft), available at http://www.pref.iwate.jp/~hp0212/fukkou_net/kihonkeikaku_an.html (in Japanese).
- Japan Society of Urban and Regional Planners (2012). Guidebook for Using Special Recovery Zone Policy, No. 2, available at <http://jsurp.net/fukkou/seidoguide120130ver2.pdf> (in Japanese).
- Kano, J. (2013). Founder of RIAS, a community NGO in Kamaishi. Verbal report 4 June 2013.
- Kariya, T. (2013). Urban planner with the Machidukuri Manibou Development Company, Ishinomaki, Verbal report 3 June 2013.
- Kawaguchi, Y. Hiroaki Y.,and Onodera, A. (2013). Community planning professionals from Iwate Prefecture, Kamaishi Office. Verbal report 4 June 2013.

- Kohsaka, H. (2001). Applications of GIS to urban planning and management: Problems facing Japanese local governments. *GeoJournal* 52: 271–280, 2001.
- Kugo, T. Karube, T. and Koshizawa, A. (n.d.). The Development of Urban Information Systems in Japanese City Planning.
- Miyagi Prefecture (2011). Miyagi Prefecture Earthquake Disaster Recovery Plan: The bond between Miyagi, Tōhoku and Japan, from recovery to prosperity, Summary, available at http://www.pref.miyagi.jp/seisaku/sinsaihukkou/keikaku/keikakugaiyou_en.pdf (in Japanese).
- MOF (2013). Ministry of Finance Japan. Highlights of the Budget for FY2013 (January 29, 2013) [Online] Provisional Translation. Available from: <http://www.mof.go.jp/english/budget/budget/fy2013/01.pdf> [Accessed on 1st August, 2013].
- MOFA (2013) Ministry of Foreign Affairs. The Great East Japan Earthquake - two years on. February, 2013.
- Muraki, M. and Takano, H. (2001). Regional Planning System in Japan: Regional Associations and Local Councils 43rd Annual Conference Association of Collegiate School of Planning 8-11 November 2001, Cleveland, Ohio, USA.
- Ogata, T. (2013). Assembly Member, Fish Processing Plant owner, Kesenuma. Verbal report 5 June 2013.
- Ohsugi, H. (2010). Local government planning in Japan. Papers on the Local Governance System and its Implementation in Selected Fields in Japan No.15. Council of Local Authorities for International Relations (CLAIR) National Graduate Institute for Policy Studies (GRIPS).
- Olshansky, R. B. and Johnson, L. A. (2010). Clear as Mud: Planning for the Rebuilding of New Orleans, American Planning Association, Chicago, IL, 360 pp.
- Otsuka, T. (2013). Reconstruction City Planning Office, Ishinomaki. Verbal report 3 June 2013.
- Platt, S., So, E., Verrucci, E. and Bevington, J. (2013). Scenario planning disaster recovery decision making. (forthcoming).
- Reconstruction Agency (2013). Current Status and Path Toward Reconstruction May 2013 <http://www.reconstruction.go.jp/english/> (Accessed 5 September, 2013).
- Reconstruction Design Council (2011). Towards Reconstruction “Hope beyond the Disaster” Report to the Prime Minister in response to the Great East Japan Earthquake. 25 June 2011. http://www.kantei.go.jp/foreign/incident/road_to_recovery.html. (Accessed 5 September 2013).
- Redevelopment of downtown Ishinomaki. [Interview]. 3rd June 2013.
- Shibata, K. (2008). The Origins of Japanese Planning Culture: Building a Nation–State, 1868-1945. Research Papers in Environmental and Spatial Analysis, Department of Geography and Environment, The London School of Economics and Political Science (LSE).
- Sorensen, A. (2004). The Making of Urban Japan: Cities and Planning from Edo to the Twenty- First Centuries, Nissan Institute Routledge Japanese Studies Series, Routledge, New York, 400 pp.
- Sugawara, A. (2013). Owner of Otokoyama Honten, a Sake Brewery, Vice President of the Chamber of Commerce and Member of Strategy Committee of Municipal Government. Verbal report 3 June 2013.
- TerraGo Technologies (2013) Maps Accelerate Japan Disaster Damage Assessment www.terragotech.com/case-studies/terrago-geopdf-maps-accelerate-japan-disaster-damage-assessment. Accessed 11 September 2013.
- The Japan Times (2013). August 3 2013. <http://www.japantimes.co.jp/news/2013/08/03/national/government-wants-car-navigation-data-to-monitor-post-disaster-traffic/#.UivN3xbckfQ> (Accessed 4 September 2013).
- Tomayukin, M. (2013). Community worker in Mika Oya District, Kesenuma. Verbal report 5 June 2013.
- Toyoshima, J., Kariya, T., Utsumi, K. and Onuki, T. (2012). Participatory design day. Reconstruction and town planning of Ishinomaki. Tohoku University, Department of Urban Construction. October 23 <http://www.slideshare.net/JunichiToyoshima/reconstruction-and-town-planning-of-ishinomaki> (Presentation downloaded 22 November 2013).
- Wakamatsu, K. (2001). Japanese Experiences in Urbanization and Urban Planning System in Japan. JICA 23 Aug.2001 Jakarta.
- Watanabe, S. J. (2011). A historical and comparative analysis of the basic character of the Japanese planning system: Toward a drastic reform for decentralization and participation. Tokyo University of Science.

- World Bank.. (2012a). Reconstruction Policy and Planning, Knowledge note 4-2, Cluster 4: Recovery Planning [Online] September 2012. Available from: http://wbi.worldbank.org/wbi/Data/wbi/wbicms/files/drupal-acquia/wbi/drm_kn4-2.pdf (Accessed: 4th September, 2013).
- World Bank (2012b). Risk and Damage Information Management, Knowledge note 5-2, Cluster 5: Hazard and Risk Information and Decision Making. [Online] September 2012. Available from: http://wbi.worldbank.org/wbi/Data/wbi/wbicms/files/drupal-acquia/wbi/drm_kn5-1.pdf [Accessed: 4th September, 2013].
- World Bank. (2012c). Reconstruction Policy and Planning, Knowledge note 1-1, Cluster 1: Structural measures against tsunamis [Online] September 2012. Available from: http://wbi.worldbank.org/wbi/Data/wbi/wbicms/files/drupal-acquia/wbi/drm_kn1-1.pdf . (Accessed: 11th September, 2013).

7. Emergency management, disaster response and recovery

7.1. Evolution of emergency management and response in Japan 2011-2013

7.1.1. *Emergency management and response at the time of the tsunami*

As in other countries, the organisation of emergency management and response in Japan tends to evolve in a 'stepwise' manner, with developments concentrated after major disasters. Thus the 1995 Hanshin-Awaji (Kobe) earthquake was a turning point. It induced Japan's Central Disaster Management Council to found the 'Earthquake Disaster Reduction' programme in the affected area. After Kobe, the Cabinet Office of the Japanese Government instituted a repeated survey of disaster preparedness. It found that concern about seismic hazards was rising. The main foci of concern were, in order of attributed importance, post-earthquake fire, structural collapse, food and water supply, gas explosions, infrastructure damage and tsunamis (Suganuma 2006). A magnitude 7.7 earthquake occurred in June 1978 with epicentre off the coast of Miyagi Prefecture. It killed 28 people and injured 1,325. The tremors were accompanied by a tsunami, but the maximum wave height, at Kesenuma, was only 60 cm. As considerable damage was done to buildings despite relatively low peak ground accelerations, this earthquake was a turning point for antiseismic building codes in the Sendai area (Brady 1980). Kesenuma, profoundly affected by the March 2011 disaster, was placed on tsunami alert several times in 2003 and surveys were conducted to examine people's responses. Eighty-six per cent of people did not evacuate, and 41 per cent of residents did not even consider evacuation as a behavioural option (Suganuma 2006).

In Japan, emergency management is based on the 'blue light' services, Japan Coastguard and Japan Self-Defence Forces (Army). In March 2011, more than 525,000 personnel dispatched into the field, as well as 12,000 medical personnel, who were dispatched from elsewhere in Japan (Government of Japan 2011). Foreign humanitarian aid workers and urban search and rescue (USAR) teams supplied a further 16,000 emergency responders. However, the Government of Japan experienced difficulty integrating foreign aid into its operations. In a smaller emergency there might have been no need to do so, but the size of the tsunami disaster meant that operations needed to be ramped up to maximum levels (Lassa 2011).

As might be expected, response to the tsunami was hampered and slowed down by extensive, catastrophic damage to critical infrastructure in the affected area. However, there were also failures at the tactical and operational level, stemming from a lack of leadership at the political level and a lack of overall command that could have created an effective interagency strategic approach. Moreover, the 'top-down' nature of Japan's emergency management made it somewhat bureaucratic and unwieldy (Lassa 2011). Above all, it lacked a clear-cut chain of command. Moreover, the system was not designed to respond to a multiple-hazard disaster (Maki 2013). Where a common operational picture could be obtained, for example at the level of Iwate Prefecture, the system functioned well (Maki 2013, p. S380).

In no endeavour were the shortcomings of leadership more evident than in the response to the nuclear crisis at the Fukushima plant (National Diet of Japan 2012). The owner of the plant, TEPCO, the Tokyo Electric Power Company, failed to create appropriate strategies to manage the radiation leaks and need to contain the damage and environmental radioactivity (Amano et al. 2012). Both TEPCO and the Government of Japan failed to keep the public adequately informed. Hence, despite a long history of harnessing nuclear power, the strategies for dealing with a full-blown nuclear emergency were inefficiently improvised on all fronts (Acton and Hibbs 2012). There are signs that the Japanese Government has accepted these limitations and will strive to remedy them, but this cannot be verified until the next major disaster occurs and the system is tested again (Dauer et al. 2011).

On a different plane, one lesson for the future is that, as one assessment of the disaster concluded (Carafano 2011), "soft measures," such as community awareness and effective risk communications,

may have played a more decisive role in saving lives than extensive protective measures, such as seawalls that were too low to stop the wave. Nevertheless, such measures were clearly intended for a tsunami of much lower magnitude and hence were at least partially ineffective. Despite this, the Japanese earthquake early warning system, which has been active since 2007, is being constantly adjusted to improve its performance from all possible perspectives (Fujinawa and Noda 2013).

Finally, the tsunami produced an instant dividend for research on disaster management and the available budget peaked at more than 100 billion yen after Kobe but in subsequent years declined towards pre-disaster levels (cf. Hein 2013).

7.1.2. Developments in emergency management and response after the tsunami

Knowledge and expertise regarding the management of very large quantities of debris had improved drastically after the 1995 Kobe earthquake. It took another step forward after the 2011 tsunami (Brown and Milke 2009).

The tsunami produced about 25 million tonnes (mt) of debris, of which 15.7 mt was generated in Miyagi Prefecture, 4.8 mt in Iwate and 2.3 in Fukushima (UNEP 2012). Two months after the disaster the Japanese Ministry of the Environment produced guidelines for Municipalities on how to effect the clean-up, segregation, offsite transportation and final disposal of debris. These processes constituted a major logistical challenge that took more than two years of hard work. Wood, metal and concrete made up the principal constituents, but toxic materials were also present in home appliances, vehicles, industrial debris and sites that had undergone fires. Where possible, combustible material was recycled for cement calcination and power generation. Ships needed to be dismantled and special disposal routines used for batteries, asbestos and other sources of toxicity. Sendai Municipality was inundated with 1.3 million tonnes of tsunami sediment and some of this contained toxic materials that had been translocated during damage of facilities. Hence the clean-up needed to take account of the toxicity of sedimentary deposits. Isiniomaki became the site of the construction of Japan's largest incinerator, capable of handling 1,500 tonnes of combustible debris per day. Damage to 53,700 buildings created some 6.2 million tonnes of debris, which was sorted and stored within a year after the disaster, pending subsequent disposal. Wood debris was recycled into local paper manufacture and portions of other debris were used for land reclamation (Asari et al. 2013).

In Iwate Prefecture, Miyako City sent 900 tonnes of debris to Tokyo for recycling in the Super Ecotown district of the capital. Care was exercised in this and all other recycling programmes to ensure that the debris was not contaminated by radioactive fallout from the Fukushima nuclear plant meltdown (UNEP 2013).

Debris that was swept out to sea could not, of course, be recycled. The saturation of large areas of ocean with plastics was a serious danger to marine life, and vessels, debris and toxins were still arriving at coasts on the other side of the Pacific Ocean two years after the disaster, propelled by marine gyres powered by the General Circulation. The magnitude of this problem remains very difficult to estimate either in terms of volume or of clear-up needs (Showstack 2011).

The debris problem involved the removal and disposal or recycling of material from 500 sq. km of devastated urban-industrial land. Among the lessons from this massive exercise was the need to reassess debris volumes continually as operations proceed. A further lesson concerns the importance of environmental monitoring. A rational plan for debris disposal on such a scale requires co-operation between the national and local governments. In Japan after 2011 these did not always follow Government guidelines, for example regarding local employment generation. However, the magnitude of the challenges they were facing needs to be borne in mind. In operations at this scale a high degree of efficiency and integration needs to be created in all parts of the process in order to avoid bottlenecks that slow down the entire chain of activities. This was achieved quite well in Japan. The management of soil deposits was perhaps less successful, as this required analysis of soil characteristics and its redistribution in a way that maximised fertility, a time-consuming process (UNEP 2012).

A report by the Japanese Women's Network for Disaster Risk Reduction (Domoto et al. 2013) levelled a series of criticisms against the authorities at all levels for alleged failure to take the perspective of women and girls into account during the aftermath of the tsunami. For example (p. 4): "Organized solely by men and operated on the basis of bureaucratic expediency, the tightly regimented shelters completely disregarded the women's needs." Furthermore (p. 4): "...we had long been alarmed by the lack of gender sensitivity in plans for disaster risk reduction and reconstruction." The authors of this report lamented that community leaders were mostly "elderly men with outdated values," but also that women in Japan remain unaccustomed to challenging authority. Moreover, emergency management remained in masculine hands in a ratio of one woman to fifteen men. Hence, there was a failure to recognise and accommodate women's roles in society, as carers (for children and the elderly) and as recipients of care (when they themselves were the elderly).

It should be noted that the March 2011 earthquake, tsunami and radiation release was the first major composite disaster to test the coordination and response abilities of Japan's National Government since the Disaster Countermeasure Basic Act was passed in 1962. It revealed a piecemeal system that was badly in need of unifying, simplifying and endowing with decision-making efficiency (Maki 2013).

After the tsunami, the Liberal Democratic Party drafted an amendment to the 1947 Constitution of Japan. In this it was proposed that the Prime Minister be granted the authority to declare a "state of emergency" in a national emergency including foreign invasions, domestic rebellions and natural disasters (Article 98). When in a state of emergency, the Cabinet can enact orders that have the effect equivalent to that of the laws passed by the National Diet (Article 99; Panda 2012). This is an example of the kind of adjustment that is needed in order to remedy the fragmentary and ad hoc nature of national response to potential major disasters in the future (Okada et al 2011, p. 40; Maki 2013).

7.2. Measures against tsunamis within the 'all-hazards' perspective

7.2.1. *Interaction between measures for tsunamis and for other hazards*

The principal structural defences against future tsunami inundation are sea walls and elevation of the land surface. In some cases, for example in two locations at Rikuzentakata, housing is being reconstructed in forested hill tracts well out of the way of inundation. However, other housing is being built upon elevated plinths, which use tsunami debris, particularly soil and sediments (Matanle 2011, p 836). The design of plinths apparently takes into account the need to reduce liquefaction and slump hazards in future earthquakes (Figure 7.1).



Figure 7.1 Elevated plinth for housing under construction at Iwanuma.

In Oya District, a sea wall 9.8 metres high and 40 m wide is being constructed across an arcuate beach that ends in a small port area. Many local residents are opposed to the wall, as the beach has sacred significance and is a defining element in local character. In fact, of the local population of 3,000 people, 1,435 (48 percent) signed a petition to introduce a period of grace to give the opportunity for consultation. However, other residents, traumatised by the tsunami disaster, are strongly in favour of the new sea wall. In the meantime, a temporary sea wall has been built across the beach. Like the planned permanent structure, it risks being undermined by coastal erosion. It will interfere with longshore drift and create, alternately, downstream siltation and beach starvation. This will destroy the natural equilibrium of the beach system.

The emphasis on building sea walls to protect urban areas and infrastructure is pervasive in the areas affected by the March 2011 tsunami (Mori et al. 2013). With regard to other natural hazards, the walls may protect against storm surge, although, as noted, heavy wave action may gradually jeopardise their stability. One presumes that the design and engineering of such structures is proof against liquefaction, lateral spreading and slumping during future earthquake shaking. Of greater concern is the impact of the walls on riverine flooding. Many of the towns and cities, for example, Kesenuma and Rikuzentakata, are situated in delta areas, where river flooding has revitalised sediments and built up the coastal land. If sea walls pond river water, that will deepen and prolong the effects of such floods.

7.2.2. *Environmental protection and disaster reduction*

The question of the interaction of hazards and measures ushers in a consideration of the relationship between disaster reduction measures and stewardship of the natural environment. Relatively few of the people that the EEFIT mission talked to seemed particularly concerned about this aspect. One option that remained virtually unconsidered was that of building no structural defences, other than, perhaps, improved evacuation routes to higher ground and vertical evacuation towers. This has been

used successfully in, for example, parts of the Hawaiian Islands (Jonientz-Trisler et al. 2005). In the event of a tsunami, emphasis would shift abruptly from saving property to sacrificing it and saving lives. However, the material losses would be compensated for by the benefits of having an open and more natural coastal environment in the intervals between tsunamis. Moreover, the lesson of the March 2011 event is that even major structural works can be devastatingly overwhelmed by the largest natural events.

In the areas of coast that we visited, environmental protection has been more vigorously pursued where it has a symbolic significance. For example, at Rikuzentakata, there is a project to plant a line of trees, starting at a hillside Buddhist temple, which will mark the limit of tsunami inundation in March 2011. This is a means of creating both a monument and restoration of the biological environment. It is, however, management of Nature, rather than restoration of natural ecosystems. Rikuzentakata is famous in Japan for its beaches and tall pine trees. One of the latter has survived and is carefully preserved as it is symbolic of the city. Elsewhere, for example, at Yuriage, pine groves acting as natural barriers to inundation were destroyed by the tsunami and will need to be rebuilt as part of the process of creating waterfront parks. However, heavy emphasis on the construction of seawalls has drastically reduced the opportunities for creating more natural barriers. This is understandable, in that woodland is effective in breaking the force only of relatively small tsunamis, not ones as large as the March 2011 event (Chagué-Goff et al. 2012).

Japan clearly has a predilection for binary levels of disaster risk reduction. The country's seismic design is based on two levels of earthquake, moderate and severe (Chock et al. 2013). Likewise, there has been a proposal to base tsunami defences on measures against the 50-100 and 500-1000-year events, again with two levels (Mase et al. 2013). However, a counter-proposal suggests four levels of magnitude for tsunami barrier design criteria (Chock et al. 2013). New proposals are designed to institute national procedures for response to Level 1 disasters, to be directed by the Prime Minister, and Level 2 disasters, to be under the control of the Disaster Management Minister. However, the definitions of these states, and the appropriate responses are not yet clear. Nevertheless, the 2011 earthquake and tsunami was the first time that a Level 1 emergency response headquarters was established by the Prime Minister under the aegis of Japan's Disaster Countermeasure Basic Act (Maki 2013).

7.3. Balance between structural and non-structural measures

Structural measures include sea-walls, berms, armoured channels, floodgates, evacuation roads, breakwaters and towers, and elevation of urbanised land. Non-structural approaches include land-use planning (and prohibition), evacuation planning, emergency management, and training and awareness programmes. Semi-structural measures are those such as flood detention areas, natural wave-surge barriers (e.g. woodland) and the transformation of particularly vulnerable tracts of land into parks and recreational areas. Perhaps the construction and designation of refuge mounds and accessible areas higher above sea level can be described as semi-structural, in that it involves the interaction between the built environment and planning measures associated with evacuation. A viable protection strategy requires these measures to be combined in a comprehensive package that is tailored to the needs and capacities of the local area.

A good example of the difficulties of finding a balance between structural and non-structural recovery measures is given by the city of Ishinomaki (2010 pop. 164,294), in Miyagi Prefecture, which was very severely damaged by the earthquake and tsunami (Faure Walker 2011). Almost half of the urban area was inundated with waves up to 10 m high. Some 3,000 residents were killed and 29,000 were made homeless, which necessitated the building of 7,153 temporary housing units. Moreover, parts of the coast in Ishinomaki Municipality subsided by 10-78 cm as a result of the earthquake and tsunami.

The process of planning urban recovery is complex and has been compounded by the need to find solutions to pre-existing problems. Before March 2011 Ishinomaki was undergoing relative urban decline, with gradual abandonment of plots in the city centre and extension of suburban sprawl. In early 2011, measures were already under examination to halt and reverse these processes.

Regeneration of the city centre requires a strategy to increase the numbers of residents, business proprietors and visitors. Redevelopment after the tsunami involves measures to preserve historical elements, restore attractiveness, give residents peace of mind and ensure sustainability for the future. To further these aims, a citizens' committee was formed to represent the views of residents, owners and other stakeholders. About 150 people are listed as members of the committee and between 20 and 30 regularly attend its meetings. Within the committee, three working groups were established: urban design, redevelopment of open space, and preservation of historic and lifestyle values. Local Municipal officials and members of volunteer associations joined the committee.

The current design code for Ishinomaki requires the height of buildings to be limited to five storeys and for them to be made robust against seismic forces, including tsunami waves. A design code for streets was formulated by the planning committee. In the 13 areas of central Ishinomaki, the ground level of buildings will be used for shops and parking spaces, while the upper levels will be residential. In the committee, discussion concerned what kinds of shops would be permitted and how many residential units would be made available. The overriding aim is to have an attractive and stable urban area.

In the area of the city most at risk of tsunami inundation, the so-called 'red zone', there was a population of 3,000 residents before the tsunami and none directly after it. Although many people are still officially registered as resident in this area, many are in temporary accommodation or have gone elsewhere to live. This will reduce the eventual permanent population of the red zone, but the planning committee is keen to avoid depopulation of the city centre.

It is planned to build a tsunami-protection wall 4.5 metres high around the red zone, with steel flood gates and some elevated accommodation behind the wall. However, there is strong local opposition to the wall. The rationale for the establishment and growth of Ishinomaki is the presence of the sea and Kitakami River, with associated fishing and port facilities. Hence, a structure that separates people from the water will be a divisive element in a situation in which harmony and stability are actively being sought. The compromise solution has been to try to design a sea wall that is relatively attractive and whose landward side can be used for outdoor activities, including café tables. The height and design of sea walls is decided by the provincial government, and this does not allow local committees much room to vary the specifications.

An urban recovery company was set up before the tsunami to try to solve Ishinomaki's decline problems. With the planning committee, it seeks to regenerate urbanisation both inside and outside the red zone. Funding for rebuilding comes from central government (in measure 40-50 per cent) and from building or business owners. The main role of local committees is to coordinate designs so that they form a harmonious group, and then to attract investors, residents and other stakeholders to the area. The main weak points of the recovery process are the long-term trend in urban decline, the extensive damage caused by the tsunami and the need to prepare for continuing natural hazards. However, on the positive side, Ishinomaki has a strong reputation for history, seafood, and the environmental and economic value of its riverine and seaside location.

Rainfall and river floods are an ever-present threat to Ishinomaki, exacerbated by the earthquake-induced subsidence. There is also a tidal and storm-surge hazard that comes from the sea. Hence, Ishinomaki has 103 pumps and spends ¥500mn/yr (US\$4.9mn) on maintaining them (Makita et al. 2014).

Regeneration of Ishinomaki as a port-industrial city is proceeding with the reconstruction of waterfront facilities, and the filling in of subsided areas with debris produced by the tsunami. Two years after the disaster, construction activities in the Municipality had increased twenty-fold with respect to their level before it. Hence, in Ishinomaki there was a degree of qualified optimism about the recovery process. The devastation wrought by the tsunami created a tabula rasa effect that gave free reign to urban planners and designers to create a city that remedied some of the sources of its previous decline. However, at the time of our visit it remained to be seen whether it would then become an attractive option for settlers and resettling populations.

Finally, Municipal government engaged in a long discussion with citizens about where to locate the main memorial to the tsunami. Two years after the event, and with reconstruction largely still at the planning stage, no final decision had been taken.

In the minds of many residents, planners and public administrators in the area affected by the 2011 tsunami is the relative failure of evacuation procedures. In some cases this resulted from people's tendency to fall prey to what psychologists call the 'normalcy bias' (Slovic et al. 1982), while in others it was caused by the inadequacy of arrangements in the face of a tsunami of millennial proportions. Like the top floors of certain buildings, evacuation refuge mounds were simply not high enough relative to the height of the wave. Many people appear to have been slow to recognise that they needed to evacuate to higher ground and thus could not reach it in time. Moreover, the tsunami was a 'near-field' one, in which warning time was limited, in some cases to hardly more than ten minutes.

There is little evidence that in future recourse will be had to evacuation towers. These have the advantage that they can be built in proximity to urban areas but the disadvantage that they may be demolished by massive floating objects, such as a ship borne inland on the tsunami wave. We understand that there is a plan to build 3 to 5 towers near the port of Ishinomaki, but other than that they are not a preferred solution. Moreover, the Ishinomaki towers will be located behind a 7-metre sea wall. Rather more common, and in many cases already prepared two years after the tsunami are refuge mounds. Many of these also fulfil a monumental role and some are landscaped to provide green space. For example, at Yamori, they form part of the Millennium Hope Hills project of converting former urban land into green space and a tsunami barrier for reurbanised terrain on the landward side.

In the coastal Municipalities, considerable thought is being given to the rational planning of urban regeneration (Iuchi et al. 2013). This is therefore one of the primary mechanisms of non-structural protection, but it has to be integrated with the plans for high sea walls. At the time of the EEFIT return mission to Sendai, the balance had, for the most part, not been worked out and consultation was still underway (Nandasena et al. 2012). However, the height and design of sea walls were decided by the provincial governments, mainly on the basis of deterministic simulations, and there was little opportunity for the local administrations or committees to vary the parameters. In addition, the prefectural urban planning committee has the last say on regeneration plans and local objections may not be able to change the outlook.

One impetus to the use of structural solutions is given by the fact that the earthquake and tsunami caused both subsidence and retreat of the beach (i.e. massive scour) in large areas of the coast (Tappin et al. 2012). The first tasks were to build temporary sea defences and to fill in the subsided areas with sorted debris from the tsunami. However, the structural approach was universally taken very much further. In Rikuzentakata the sea front will be covered by a 12-metre high wall. Neighbourhoods are being relocated in elevated land of nearby fluvial sub-basins. Some housing and commercial premises will be elevated on a 12-metre plinth. This probably would not be enough to protect structures against a tsunami of the same magnitude as the March 2011 event, but it will elevate them above the waves of a lesser-magnitude wave with a significantly long predicted recurrence interval. At Kesenuma Beach a 14.7m sea wall is due to be constructed, that will have a significant impact on the outlet of the local river. In this locality there are plans to elevate highways 19 and 25 metres above sea level. In nearby Kesenuma City, a 5-metre wall will change the character of the central area and require the destruction of some heritage buildings.

Very large structural works are achieved at significant cost, both in economic terms and to the natural environment. At Rikuzentakata (original population 33,000), the monetary cost of reconstruction may be about US\$200,000 per family. One justification for this is that it may help halt the demographic decline of a peripheral small city (cf. Matanle 2011), but one could argue instead that it is an excessively large price to pay for the regeneration of an urban area of modest dimensions. Moreover, around the tsunami zone the cost of reconstruction per person may be substantially unequal.

Our mission did not allow us to conduct any social survey, but we understand that young residents are not particularly in favour of some of the structural measures. However, their voice is seldom listened to.

In synthesis, given the scale of the devastation wrought by the 2011 tsunami, a reconstruction process involving massive environmental modification was to some extent inevitable. Nevertheless, the balance was strongly made in favour of structural rather than non-structural solutions. Where the latter are prominent, it is usually in the context, or surrounds, of major structural works.

7.4. Involvement of civil society and NGOs in disaster response and recovery

7.4.1. *Non-governmental organisations for disaster risk reduction and response*

Before the tsunami non-governmental organisations were relatively poorly developed in the civil protection field. That has begun to change with a range of emergent groups that varies from volunteer fire fighters to organisations that are concerned with the general welfare of citizens (Matanle 2011, p. 840; Brittingham and Wachtendorf 2013, p. S438). During the immediate aftermath of the earthquake and tsunami, many volunteers converged on the disaster area, with varying degrees of organisation and autonomy. Overall, it seems that they lacked coordination and direction, and hence were often not well-matched with the tasks that needed to be accomplished (Avenell 2012). Ishinomaki benefited from the presence of 300,000 volunteers, predominantly young people, who came from all over Japan. Many of these people developed a long-term relationship with the town and continue to return there when they can.

In counter-disaster work in Japan, spontaneous voluntarism is gradually being replaced by the organised kind. However, there is still a strong sense in the tsunami area that voluntarism comes from Tokyo. It tends to be coordinated passively rather than actively in the sense of deliberately fostering local connections. However, there are examples of successful local initiatives, such as the Shanti Voluntary Association in Oya District, whose efforts enabled the local community to manage its evacuation centre without support from the government.

Ongoing needs that draw upon voluntary organisations include the care of the elderly and of people with disabilities.

7.4.2. *Local leaders and other elements of civil society*

Although citizens' groups have been established in a number of settlements affected by the tsunami, their importance, inclusiveness and effectiveness for action appear to be quite variable. Consultation on recovery plans was carried out by convening citizens' groups, but the level of participation tended to be either low or variable over time. Natural leaders did emerge in some cases, but it is unclear how much weight would be given to their opinions or to what extent they would be able to articulate the views of the majority of local citizens. The more successful local leaders tended to be middle-class professionals in late middle age and, as one might expect, male.

One of these was the owner of a local retail store in Rikuzentakata. He managed to negotiate with the prefectural government, and eventually also with the national authorities, to create a temporary retail plaza and hence re-establish his business. He submitted a proposal to the National Agency for Helping Small Businesses and it was approved, but only after 15 months of negotiating and insisting with the ponderous bureaucracy. Eventually, permanent reconstruction of shops should be feasible with a 75 per cent combined subsidy from the national and prefectural governments.

In the Natori area, one individual refused to evacuate his damaged home and was holding out against redevelopment in makeshift accommodation on the site. However, this was the only example of such individualism that we encountered.

In Ishinomaki a further element in the recovery was a local company set up before the tsunami to promote the regeneration of the city centre and given a new and more demanding brief afterwards. However, its powers were limited to being able to advise, advocate and coordinate, not plan in an executive mode.

Recovery after the tsunami has inevitably altered the employment structure of the affected areas. Some sources of employment have been destroyed, and some workers have left the area, nobody knows whether permanently or not. The construction and debris management industries have generated a fierce and partly unfulfilled demand for labour, and the wages and salaries paid have diverted people from more traditional occupations, such as fishing, which pay less.

7.5. Balance between national, regional and local involvement in disaster response and recovery

In the post-tsunami administrative milieu, we observed a tension between decisions made at the national level and transmitted to lower levels of government, on the one hand, and a desire to take account of local opinions. Particularly regarding structural defences, the desire to standardise or harmonise measures across the tsunami area led to the imposition of solutions that had not been devised, modified or approved by local residents and business proprietors. Decision-making processes were heavily influenced by a national desire to restore infrastructure and reconnect it to national networks, which further consolidated the top-down approach (Shimizo 2011).

One aspect of the recovery that tended to condition the relationship between the national and local level was that reconstruction funds were dispensed directly by central government to property owners. However, there were instances in which the Municipal governments had a pivotal role, in that land had to be given a designated use in order to enable government funds to be utilised, which required the towns and cities to consult and coordinate with property owners.

The recovery process after the tsunami revealed that decision making in Japanese public administration is not a holistic process, but is instead one that is carried out by segmented agencies, each with its own budget, that struggle to engage with one another and with bureaucratic civil administrations and the legal system (Comfort et al 2013).

7.6. Disaster culture

Culture is a feature of society that takes a very long time to develop. Inherited culture is historical in its roots and is supplemented by people's life experiences, acquired culture, including those that are shared by common endeavour. The unprecedented pace and reach of technological development has created a new cultural dynamism by virtue of its ability to metamorphose culture rapidly and profoundly. However, one question that remains open is whether a disaster such as a millennial tsunami can create culture more or less instantaneously? Sociologists of disaster long ago identified the so-called disaster sub-culture, which brings together people of different ages, social classes and outlooks and binds them to a set of common aims and a common agenda (Granot 1996). They also noted the transient 'therapeutic community' that arises in the immediate aftermath of disaster, and represents a temporary ethical consensus (Barton 1970). In some cases, these phenomena endure: for example, in Ishinomaki, some volunteers and students have developed an attachment to the community that may be permanent.

Disaster is a milestone in the lives of those who survive it. Evidence has long accrued that very large or disturbing events are bigger milestones than smaller disasters--i.e. that they exert a more profound effect on the rest of people's lives. They therefore have the ability to create a more enduring form of disaster subculture. Moreover, the pervasiveness of the impact on people's lives, attitudes, modes of living, and so on, is so great that the effect may be termed a culture in the full sense, rather than a mere subculture.

In the case of the coastal areas of northeast Japan affected by the March 2011 tsunami, there is a sense that the disaster created a sort of 'instant culture', or permanent cultural overlay onto people's lives. This phenomenon was amply chronicled by Oliver-Smith (1986) in his study of how the Mount Huascarán earthquake and landslide in Peru changed people's lives and views of the world. However, it led to a double effect that has created cultural tension in society. On the one hand there is a pervasive desire for security and safety. This is particularly prevalent in the elderly and tends to

override considerations of cost and environmental conservation. The desired outcome is to have the greatest possible defences against future tsunamis. On the other hand, coastal residents need to connect with the sea, which is a vital source of livelihood and cultural and spiritual nourishment. Tall sea walls stand in the way of this need. Hence, these are conflicting tendencies that require mediation by society as a whole. These can be characterised as the static, dynamic and expedient aspects of disaster culture (Figure 7.2).

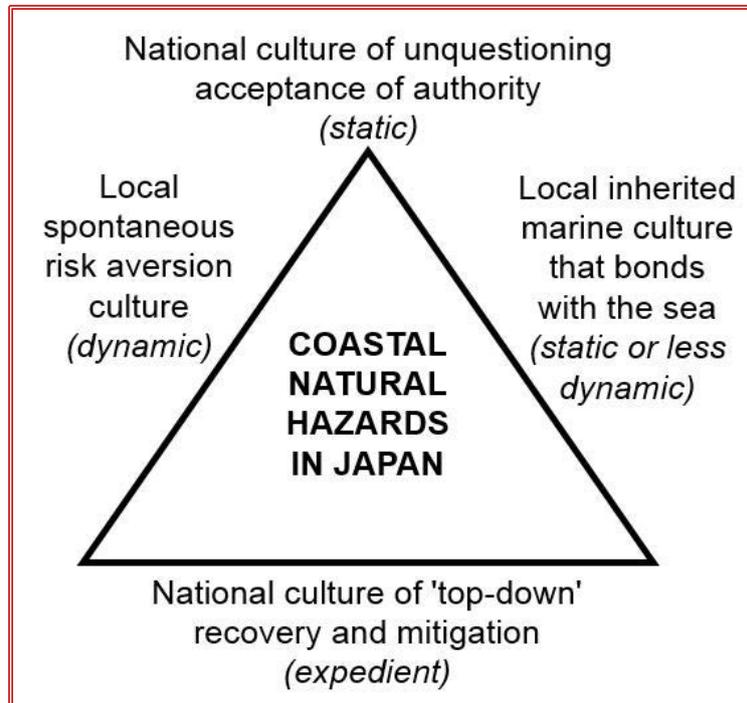


Figure 7.2 Culture in relation to coastal hazards in Japan.

Another aspect of the culture generated or modified by disaster is the prevalence and importance of monuments. In many cases, these were the first elements of the landscape devastated by the tsunami to be regenerated. They vary from small, extempore shrines attached to the remnants of damaged buildings to large sculptures with landscaping around them. The shrines may represent a form of homage to the people who died in the tsunami, for example, at Shizugawa where dispatchers sacrificed their lives in the emergency operations centre in an attempt to broadcast a warning, there is a shrine in the remnant shell of the building. At Ishinomaki, and in many other locations, cemeteries have been partially rebuilt, both as a means of interring the dead and a memorial to them (Figure 7.3).



Figure 7.3 Partially rebuilt cemetery within the unrebuilt devastated area, Ishinomaki.

At Yuriage, a school gymnasium acts as a repository of personal effects recovered from the wreckage of people's houses but never claimed by their owners. School satchels, clothes, family photographs and other items are carefully laid out but remain unclaimed (Figure 7.4).



Figure 7.4 Children's satchels, unclaimed in a former gymnasium, Arahama school.

Iwanuma was a coastal city of 44,000 inhabitants in a Municipality of 60.7 sq. km, which includes Sendai International Airport. During the tsunami, 48 per cent of the city was inundated and 181 residents lost their lives. In this area, the tsunami penetrated 3 km inland from the coast. In the coastal strip, urbanisation has been removed and will be replaced by the Millennium Hope Hills project, in

which an elevated park will be created by mounding up soil 10 metres above the plain. Seventy per cent of the fill will come from tsunami debris. Trees will be planted, a 3-metre high walkway will connect the hills and there will be a broad evacuation road. The coastal road will be elevated 4-5 metres above sea level. The hills will occupy 6 sq. km, or about 10 per cent of the city area. They will form a barrier against inundation and a site for vertical evacuation in the event of tsunamis that are not expected to be large enough to overwhelm them. This project is expected to take a decade to complete and involves a ceremonial aspect (for example, symbolic planting of trees), a monumental component (memorials are placed on the hilltops) and community engagement, in that the landscaping involves a strong community effort. The Millennium Hills project betokens opposition to 'hard' structural approaches to sea defences, and the desire for a solution more in tune with Nature.

Lastly, monuments can also include remnant effects of the disaster. For example, in some parts of the world, notably Italy, ruined buildings are sometimes left unreconstructed as a reminder to local inhabitants of the disaster and the potential for similar events in the future. In Kesenuma City, the presence of a 5,000-tonne ship stranded in the middle of the former urban area was the subject of vigorous debate about whether it should be left as a memorial to the tsunami (Figure 7.5). In the end, the decision was taken to remove it.



Figure 7.5 Ship stranded by the tsunami in Kesenuma City.

It is probable that some of the buildings that preserved life because they functioned as viable evacuation centres may be preserved, possibly without reconstructing them. This is the case for the high-school at Ishinomaki, which suffered severe damage but nevertheless protected its occupants.

7.7. Conclusions

In terms of organisational learning, the Japanese system of crisis management is a hybrid between the professional and bureaucratic models of Lam (2000) (Figure 7.6). This means that it has limitations in terms of narrowness and superficiality (Shimizu 2011). Clearly, it was partially successful, not least

because of the strength and independence of systems at the Prefectural stratum, which partly compensated for deficiencies at the national level (Maki 2013).

The Japanese Government has given considerable thought to future needs for disaster prediction, warning, management, response and recovery (Government of Japan 2012). For example, it is evident that major changes are needed in national command structures (Van Rooyen 2011). However, the next major event will be the only phenomenon that can test developments. In the meantime, it appears that the system remains top-down (which does little to foster local autonomy), bureaucratic (which does little to create efficiency) and dominated by a predilection for structural solutions (which does little to create a good balance between environmental preservation and modification).

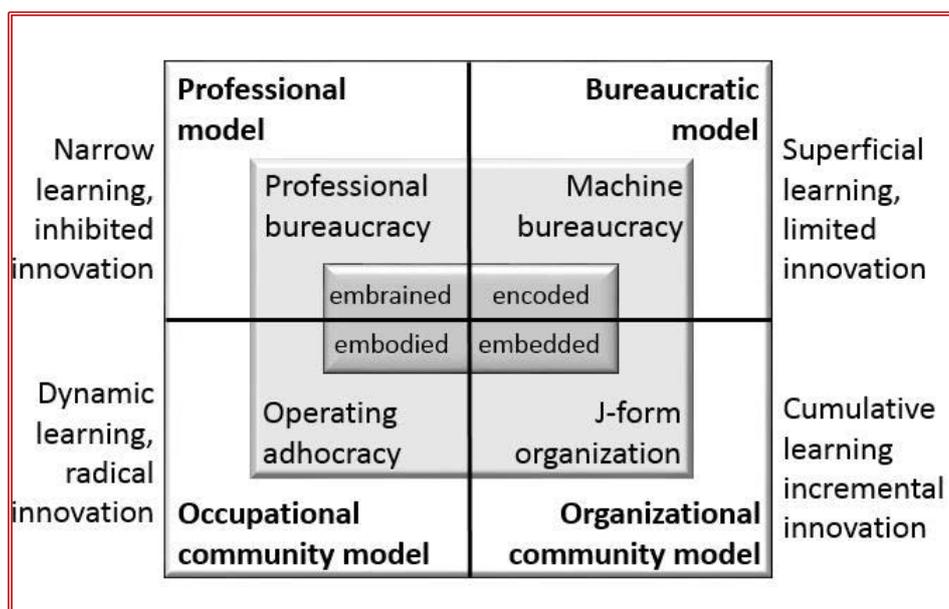


Figure 7.6. A classification of organisational learning (after Lam 2000).

One aspect of preparedness which clearly needs improvement is the care of and provision of assistance to people with disabilities. Studies (UNISDR 2013, Brittingham and Wachtendorf 2013) show that in the March 2011 earthquake and tsunami, and its aftermath, such people were significantly disadvantaged with respect to the rest of the population. They often lacked access to information, practical assistance and social support networks.

Developments beyond the Kobe earthquake are strong in certain sectors, notably voluntarism and debris management, but weak in others (Rubens 2011). For example, gender concerns need to be taken into account much more substantially than at present (Domoto et al. 2013), and decision-making needs generally to be more inclusive.

Many aspects of the response to and recovery from the Tōhoku earthquake and tsunami are exceptionally good, notably the impetus to reconstruct 500 sq. km of devastated land and communities in only seven years. However, the result of this emphasis on rapidity is that many problems that could be tackled systematically during a longer reconstruction will inevitably have to be faced after it is completed, when their resolution will be more difficult.

In the present reconstruction, with its heavy emphasis on building tsunami defence structures, there is little sign that social science had informed engineering decision making. On the contrary, there is a clear indication that risk aversion drives the process of building ever larger structures against tsunami inundation. Environmentalism in the areas under reconstruction has taken a back seat, but the

inexorable power of nature may mean that it eventually reasserts itself against the transformations of nature that are currently underway.

7.8. References

- Acton, J.M. and Hibbs, M. (2012). *Why Fukushima was Preventable*. Nuclear Policy. The Carnegie Papers. Carnegie Endowment for International Peace, Washington DC, 44 pp.
- Amano, H., Akiyama, M., Chunlei, B., Kawamura, T., Kishimoto, T., Kuroda, T., Muroi, T., Odaira, T., Ohta, Y., Takeda, K., Watanabe, Y. and Morimoto, T. (2012). Radiation measurements in the Chiba Metropolitan Area and radiological aspects of fallout from the Fukushima Dai-ichi Nuclear Power Plants accident, *Journal of Environmental Radioactivity* 111, 42-52.
- Asari, M., Sakai, S. Yoshioka, T., Tojo, Y., Tasaki, T., Takigami, H. and Watanabe, K. (2013). Strategy for separation and treatment of disaster waste: a manual for earthquake and tsunami disaster waste management in Japan, *Journal of Material Cycles and Waste Management* 15(3), 290-299.
- Barton, A.H. (1970). *Communities in Disaster: A Sociological Analysis of Collective Stress Situations*. Doubleday, New York, 368 pp.
- Brittinghama, R. and Wachtendorf, T. (2013). The effect of situated access on people with disabilities: an examination of sheltering and temporary housing after the 2011 Japan earthquake and tsunami, *Earthquake Spectra* 29(S1), S433-S455.
- Brown, C. and Milke, M. (2009). Planning for disaster debris management. Manuscript (9 pp.). <http://hdl.handle.net/10092/3669> (accessed 30 November 2013).
- Carafano, J.J. (2011). *The Great Eastern Japan Earthquake: Assessing Disaster Response and Lessons for the United States*. Special Report, Douglas and Sarah Allison Center for Foreign Policy Studies, Heritage Foundation, Washington DC, 13 pp.
- Chagué-Goff, C., Niedzielski, P., Wong, H.K.Y., Szczucinski, W., Sugawara, D. and Goff, J. (2012). Environmental impact assessment of the 2011 Tōhoku-oki tsunami on the Sendai Plain, *Sedimentary Geology* 282, 175-187.
- Comfort, L.K., Okada, A. and Ertan, G. (2013). Networks of action in catastrophic events: the 11 March 2011 Tōhoku-Oki disasters, *Earthquake Spectra* 29(S1), S387-S402.
- Dauer, L.T., Zanzonico, P., Tuttle, R.M., Quinn, D.M. and Strauss, H.W. (2011). The Japanese tsunami and resulting nuclear emergency at the Fukushima Daiichi power facility: technical, radiologic, and response perspectives, *Journal of Nuclear Medicine* 52, 1423-1432.
- Domoto, A., Ohara, M. Rieko, A., Hara, H. and Amano, K. (2013). *Japanese Women's Perspective on 3-11*. Japan Women's Network for Disaster Risk Reduction, Tokyo, 31 pp.
- Faure Walker, J., ed. (2012). UK-Japan Workshop on Disaster Risk Reduction: Learning From the 2011 Great East Japan Earthquake. IRDR Special Report 2013-01, Institute for Risk and Disaster Reduction, University College London, London, 47 pp.
- Fujinawa, Y. and Noda, Y. (2013). Japan's earthquake early warning system on 11 March 2011: performance, shortcomings, and changes, *Earthquake Spectra* 29(S1), S341-S368.
- Government of Japan (2011). *Report of the Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunamis Based on the Lessons Learned from the "2011 off the Pacific coast of Tōhoku Earthquake"*. Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunamis, Central Disaster Management Council, Tokyo, 46 pp.
- Government of Japan (2012). *Final Report: Toward the Reconstruction for Sound and Unwavering Japan*. Committee for Policy Planning on Disaster Management, Central Disaster Management Council, Government of Japan, Tokyo, 53 pp.
- Granot, H. (1996). Disaster subcultures, *Disaster Prevention and Management* 5(4), 36-40.
- Hein, P. (2013). Expecting the unexpected: a case study on tsunami mitigation in Fujisawa (Japan). *Environmental Hazards* 12, 1-20.

- Iuchi, K., Johnson, L.A. and Olshansky, R.B. (2013). Securing Tōhoku's future: planning for rebuilding in the first year following the Tōhoku-Oki earthquake and tsunami, *Earthquake Spectra* 29(S1), S479-S499.
- Jonientz-Trisler, C., Simmons, R.S., Yanagi, B.S., Crawford, G.L., Darienzo, M., Eisner, R.K., Petty, E. and Priest, G.R. (2005). Planning for tsunami-resilient communities, *Natural Hazards* 35, 121-139.
- Lam, A. (2000). Tacit knowledge, organizational learning and societal institutions: an integrated framework. *Organizational Studies* 21(3), 481-503.
- Lassa, J.A. (2011). Japan's resilience to tsunamis and the lessons for Japan and the world: an early observation. Manuscript, 6 pp.
- Maki, N. (2013). Disaster response to the 2011 Tōhoku-Oki earthquake: national coordination, a common operational picture, and command and control in local governments, *Earthquake Spectra* 29(S1), S369-S385.
- Matanle, P. (2011). The Great East Japan Earthquake, tsunami, and nuclear meltdown: towards the (re)construction of a safe, sustainable, and compassionate society in Japan's shrinking regions, *Local Environment* 16(9), 823-847.
- Mase, H., Kimura, Y., Yamakawa, Y., Yasuda, T., Mori, N. and Cox, D. (2013). Were coastal defensive structures completely broken by an unexpectedly large tsunami? A field survey, *Earthquake Spectra* 29(S1), S145-S160.
- Mori, N., Cox, D.T., Yasuda, T. and Mase, H. (2013). Overview of the 2011 Tōhoku earthquake tsunami damage and its relation to coastal protection along the Sanriku coast, *Earthquake Spectra* 29(S1), S127-S143.
- Nandasena, N.A.K., Sasaki, Y. and Tanaka, N. (2012). Modeling field observations of the 2011 Great East Japan tsunami: efficacy of artificial and natural structures on tsunami mitigation, *Coastal Engineering* 67, 1-13.
- National Diet of Japan (2012). *The Official Report of the Fukushima Nuclear Accident Independent Investigation Commission: Executive Summary*. National Diet of Japan, Tokyo, 86 pp.
- Okada, N., Ye, T., Kajitani, Y., Shi, P. and Tatano, H. (2011). The 2011 Eastern Japan Great Earthquake Disaster: overview and comments. *International Journal of Disaster Risk Science* 2(1): 34-42.
- Panda, R. (2012). Japan's disaster response management: lessons for the world, *Journal of Defence Studies* 6(1), 59-76.
- Rubens, D. (2011). *Great Eastern Japan Earthquake, March 11th 2011: A Preliminary Report on the Japanese Government's Disaster Response Management*. David Rubens Associates, London, 37 pp.
- Shimizu, M. (2011). Policy lessons for Japanese disaster responses, *Asia Pacific Bulletin* 121, 1-2.
- Showstack, R. (2011). Oceanographer tracks marine debris from the Japan tsunami and other incidents, *Eos, Transactions American Geophysical Union* 92(37). 306-307,
- Slovic, P., Fischhoff, B. and Lichtenstein, S. (1982). Facts and fears: understanding perceived risk, in Kahneman, D., P. Slovic and A. Tversky (eds) *Judgment Under Uncertainty: Heuristics and Biases*. Cambridge University Press, New York.
- Suganuma, K. (2006). Recent trends in earthquake disaster management in Japan, *Science and Technology Trends - Quarterly Review* 19, 91-106.
- Tappin, D.R., Evans, H.M., Jordan, C.J., Richmond, B., Sugawara, D. and Goto, K. (2012). Coastal changes in the Sendai area from the impact of the 2011 Tōhoku-oki tsunami: interpretations of time series satellite images, helicopter-borne video footage and field observations, *Sedimentary Geology* 282, 151-174.
- UNEP (2012). *Managing Post-Disaster Debris: The Japan Experience*. United Nations Environment Programme, Nairobi, 51 pp.
- UNISDR (2013). *Survey Analysis Report: Focussing on the Responses From Japan to the Survey on Persons with Disability and Disasters - "Living with Disability and Disasters"*. UNISDR Office, Kobe, 22 pp.
- Van Rooyen, M. (2011). *Emergency Response in Japan*. The HHI Emergency and Disaster Response Capacity Development Project, Harvard Humanitarian Initiative, Cambridge, Mass., 5 pp.

8. Financial management and Japan earthquake insurance

This chapter details the economic and insured losses incurred following the Great East Japan Earthquake and places these in the context of how risk transfer is structured and implemented in Japan. It highlights lessons relevant to construction professionals operating in short-, medium- and long- term reconstruction following disasters as well as policy makers and those in the catastrophe modelling and insurance industries.

8.1. Economic losses

The March 2011 Great East Japan Earthquake has caused the highest economic losses of any natural catastrophe worldwide on record and contributed to 2011 being the most expensive year for natural disasters.

In 2011, 175 natural and 150 anthropogenic disasters¹³ caused direct economic losses of about US\$380bn and about 35,000 fatalities (Munich Re, 2012a, Swiss Re, 2012). The previous record was US\$220bn in 2005 (Munich Re, 2012a) in which Hurricane Katrina was a major component. The Great East Japan Earthquake contributed over US\$210bn and 19,000 fatalities towards the year's losses (Munich Re 2012a, Swiss Re, 2012). The total economic loss from the earthquake (including the predicted indirect economic loss over the next few years) has been forecasted to sum to between US\$479bn and US\$710bn (Daniell and Vervaeck, 2012).

62 percent of the direct economic losses were from private buildings (residential, commercial, and industrial) and 13 percent came from public infrastructure (World Bank, 2012b).

Losses were felt internationally, for example, there was US\$50m damage to harbours in California (USGS, 2012) and indirect losses due to disruption to auto (slow down or closure of many auto part factories led to slow down or closure of non-domestic car manufacture factories such as the Toyota Factory in USA), electrical (Japan is the only producer of certain batteries and flash memory and supply 13 percent of semiconductors globally) industries' supply chains that in many cases the Thailand floods later exasperated (e.g. RMS, 2011, Soble, 2011, Suess and Bandel, 2011, Wright, 2012). Note the most heavily affected prefectures (Iwate, Miyagi and Fukushima) produce 8.8 percent and 7.2 percent of Japan's IT devices and electronic devices respectively and lesser affected prefectures (Aomori, Akita and Yamagata) produce 5.6 percent and 5.1 percent of the country's IT devices and electronic devices respectively (RMS, 2011). Business interruption in Japan was also caused by planned blackouts in the service area of TEPCO between 14th March and 7th April 2011 (BOJ, 2011).

8.1.1. *The Great East Japan Earthquake within the earthquake models*

The Great East Japan Earthquake was not within the event sets of any of the three major catastrophe modelling firms' (RMS, AIR, EQECAT) Japan earthquake models. This was because the models were based on the 2007 Japan National Seismic Hazard Maps produced by the Headquarters for Earthquake Research Promotion (HERP), that suggested a maximum magnitude of 7.5 along this section of the trench (Air, 2012, HERP, 2007). The assumption that such large events could not occur along this section of the trench was based on a lack of such events in the historical record. However, in areas where recurrence intervals are long relative to the historical record, historical records cannot be a sufficient approximation for the long-term deformation and hence seismic hazard (e.g. Faure

¹³ Threshold criteria for an event to be included in the *sigma* statistics 2011 must be met in at least one of insured losses, economic losses, or casualties:

Total economic Losses		US\$89.2m
Insured Losses	Maritime disasters	US\$18m
	Aviation	US\$35.9m
	Other losses	US\$44.6m
Casualties	Lost or missing lives	20
	Injured	50
	Homeless	2,000

Walker et al., 2010). The lack of large events in the source model was also based on the fact that the subducting slab is old in this location; it was thought that older slabs that are colder and denser deform via smaller magnitude earthquakes than younger slabs (Monastersky, 2011). However, there was some scientific literature suggesting that such an event were possible and there is palaeoseismic and sedimentation evidence for a large earthquake producing a significant tsunami in 869AD (e.g. Minoura et al., 2001). It should also be noted that deformation rates inferred from geodesy showed that, before the 2011 earthquake, there was a considerable amount of strain that had accumulated that had not been released in earthquakes, aseismic slip and postseismic afterslip (Hashimoto et al., 2009) and therefore an earthquake of considerable size could be imminent (though this was not interpreted so explicitly before the event).

This event highlights the problem of not including uncertainty due to differences in scientific opinion. Even when insurance companies use the model of more than one modelling firm leading to them acquiring different views of risk, if such models are based on the same hazard map then the size of the uncertainty will be understated relative to the true uncertainty.

Note also that the earthquake models did not include a tsunami model and thus probabilistic risk for tsunamis was calculated in a fairly crude way. The Japan Earthquake models did include both shake damage and fire following.

In Japan and other peril regions there can be alternate views of hazard associated with different scientific theories, but the national hazard maps may not include the range of views. It is important to note that a number of current catastrophe models are based solely on national hazard maps rather than incorporating different scientific opinions and therefore may be excluding the uncertainty resulting from different hazard analyses.

RMS has made updates to its Japan Earthquake Model following the Great East Japan Earthquake to represent the current seismic risk associated with stress changes due to the Great East Japan Earthquake such as stochastic event set updates including addition of large magnitude events, event rate changes due to static Coulomb stress changes and new seismic sources, source model updates, and including tsunami scenarios (Artemis, 2012 and RMS, 2012).

AIR are including the HERP updates on seismic hazard due to the changes in stress following the Great East Japan Earthquake and tsunami and liquefaction risk modelling capabilities in their update to the current AIR Earthquake Model for Japan (AIR, 2012). AIR also intends to update the hazard module incorporating both the HERP updates and information from the wider scientific community (AIR, 2012). For details of the updates to the HERP model see section 2.1.2.

8.2. Insured losses

Insured losses from this event were in the range US\$35-40bn (Munch Re, 2012a) making it the most expensive earthquake for the insurance industry on record (Swiss Re, 2012) and contributing to the 2011 insured earthquake losses of US\$49bn, the most expensive earthquake insurance year since records began in 1970 (Swiss Re, 2012). Note the total 2011 insured disaster losses caused by natural (US\$110bn) and anthropogenic disasters (US\$6bn) were about US\$116bn, the second worst year for insurers since *sigma* records began in 1970 (Swiss Re, 2012).

The GiAJ (General Insurance Association of Japan) provide annual earthquake penetration rates by prefecture expressed as the percentage of those insured over total population (GiAJ, 2013*). Residential insurance penetration in Japan was 23.7 percent before the earthquake in 2010, but increased to 26 percent following the earthquake in 2011. This is the greatest penetration annual increase seen since 1994 to 1995 following the Great Hanshin (Kobe) earthquake when the national residential insurance penetration increased from 9.0 percent to 11.6 percent. The prefectures that saw the greatest increase in penetration rates were Miyagi (33.6 percent to 43.5 percent) and Fukushima (14.6 percent to 22.2 percent). As of 2011, the Miyagi Prefecture has the highest penetration of all Japan prefectures.

For a country with a high seismic hazard, insurance penetrations are relatively low; this is in high contrast to New Zealand, where the February 2011 earthquake caused about US\$15bn in damage, 80 percent of which was insured (Swiss Re, 2012). The estimated proportion of insured losses

covered by international reinsurance is 23 percent for the Great East Japan Earthquake, 73 percent for the Canterbury New Zealand Earthquake and 95 percent for the Maule Chile Earthquake (World Bank, 2012b).

AIR estimated that about 30 percent of the total insured losses were a result from the tsunami and the rest was from ground shaking damage (AIR, 2012); this is because, although the tsunami caused very high damage ratios within the inundation areas, the earthquake ground shaking damage covered a far greater area. In many areas there was also high damage caused by liquefaction, but many such areas were inundated by the tsunami so it will be difficult to determine whether it was liquefaction damage or tsunami damage that caused the loss (AIR, 2012).

78 percent of insured losses were from residential assets; the earthquake insurance program managed by the private nonlife insurance companies covered 56 percent of these residential asset losses and cooperative mutual insurers covered the remaining 44 percent (World Bank, 2012b and references therein). 45 percent of the earthquake insurance program's loss (¥1,200bn (approximately US\$15bn)) was retained by the government, 42 percent by private insurers and the remaining 13 percent was retained by the JER (Japan Earthquake Reinsurance) (World Bank, 2012b).

The top five insurers, belonging to three insurance groups had estimated losses of ¥367.0bn (approximately US\$4.6bn) and ¥202.3 (approximately US\$2.5bn) in residential and commercial lines respectively (IMF, 2012).

There were high losses to the marine sector, specifically marine cargo, as thousands of containers (twenty-foot equivalent units, TEUs) were washed away at Sendai port or smashed and inundated by the tsunami (RMS, 2011); note that Japan has 14 percent of the global marine cargo insurance, the highest of any single nation (RMS, 2011).

Most of the life insurance losses came from individual life policies with a predicted 15 percent of these arising from personal accident claims; group life insurance policies are predicted to sum to less than five percent of the total individual life policies (RMS, 2011). Some of the life policy losses to insurers will be counterbalanced by the decreased annuity liabilities due to the fatalities, although it is not guaranteed that the same insurer would cover the different policies so individual insurers may not receive the offsetting benefit (RMS, 2011).

8.3. The Japanese insurance industry

8.3.1. *Primary insurance*

In terms of insurance premiums, the United States of America has the largest market in both life and nonlife insurance (27 percent of aggregate global market) and Japan is second (13 percent of aggregate global market) being second in life insurance (17.5 percent of life global market) and joint second with Germany in nonlife (6.5 percent of nonlife global market) (2010 values, IMF, 2012). However, in terms of premium per capita and percent of GDP, Japan Insurance ranks 6th and 8th globally respectively (2010 values, IMF, 2012 and references therein). In Japan, by the end of 2010, total assets within the insurance sector amounted to 78 percent of GDP, with Life Insurance assets alone representing 61 percent of GDP (IMF, 2012).

Low equity prices and interest rates within Japan put pressure on mid-size insurance companies in the last fifteen years providing merger and acquisition opportunities leading to the 2010 "mega mergers" allowing the three largest nonlife sector groups (Tokio Marine Holdings, MS&AD Insurance Group Holdings (Mitsui Sumitomo, Aioi, and Nissay Dowa), and NKSJ Holdings (NIPPONKOA and Sompo Japan) to control over 90 percent of this market and collect 82 percent of the premiums (IMF, 2012). In the life market, four companies control 65 percent of the market excluding the Japan Post Insurance (JPI, the largest life insurer in the world) and together with the JPI collect 64 percent of the premiums (IMF, 2012). Nearly 7,000 cooperatives offer life and nonlife insurance in Japan for particular industry sectors (e.g. fishery, consumer, agriculture, small business); Zenkyoren (the National Mutual Insurance Federation of Agricultural Cooperatives) is the largest of the 14 full members and one associate member that form the Japan Cooperative Insurance Association (IMF, 2012, RMS, 2011). The FSA and Government ministries are responsible for the supervision of private

insurance companies and mutual cooperatives respectively (IMF, 2012). There is now foreign ownership of about half of the companies operating in the Japanese insurance market, accounting for less than 10 percent of the market share in the nonlife sector and about 20 percent of the market share in the life sector (IMF, 2012).

8.3.2. Reinsurance

In response to the 1964 Niigata earthquake, the 1966 Earthquake Insurance Law was passed, requiring both residential and shop-owners' insurance purchased through private non-life insurers to be ceded to the newly created Japan Earthquake Reinsurance Company (JER) that acts as an earthquake reinsurance pool (EQECAT, 2011, RMS, 2011, World Bank, 2012b). The proportion of loss that is paid by the insurer, the JER and the government is determined by the amount of insured event loss as shown in Figure 8.1. Note for an event with a loss up to ¥104bn (¥115bn before 6th April 2012), all the losses are ceded to the JER. As the total event loss increases, the proportion of the total loss that the government is liable for increases. The total capacity of the program is assumed to be sufficient for an earthquake comparable to the 1923 Great Kanto Earthquake (JER, 2012). Following the Great East Japan Earthquake, half the earthquake reserves in the program were removed (World Bank, 2012b) and hence the proportion that the government is liable for increased in May 2011 and again in April 2012.

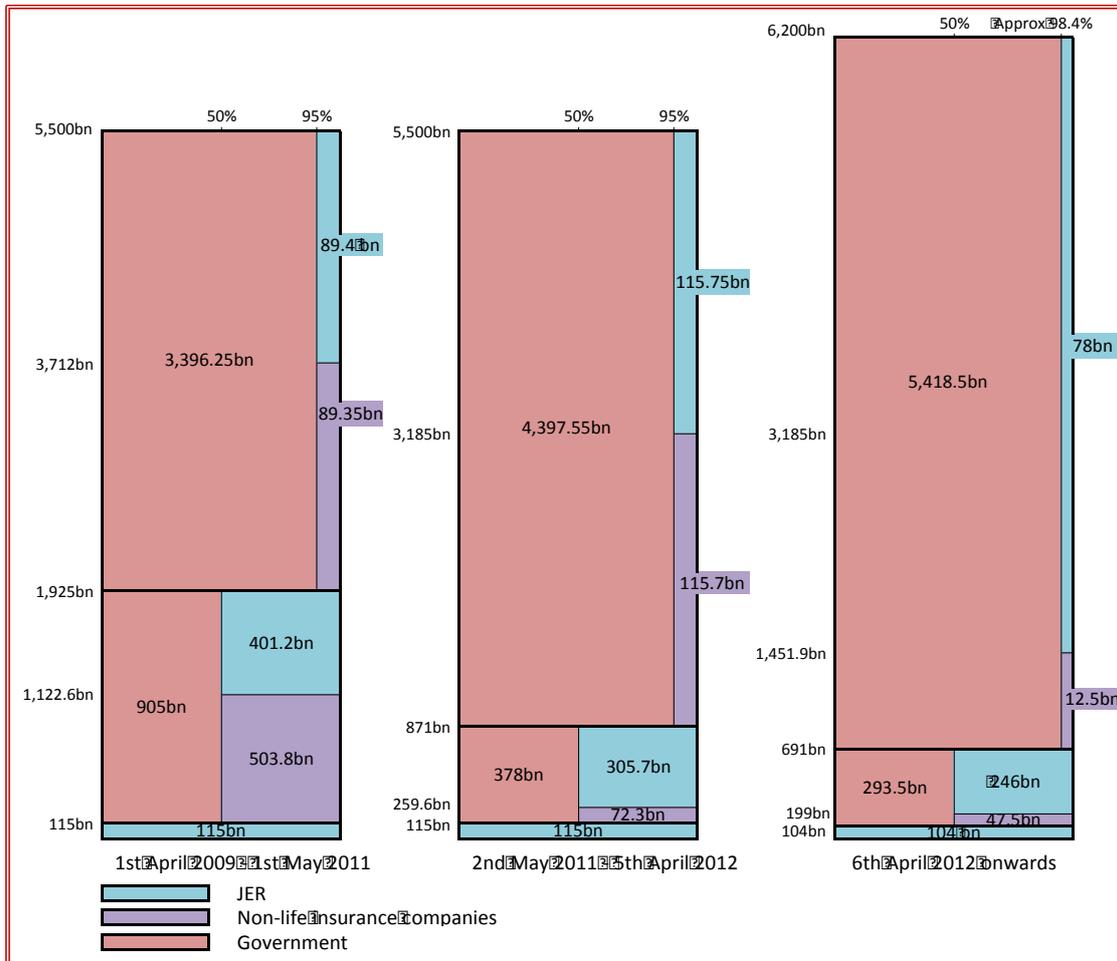


Figure 8.1 How insured losses are ceded for different levels of insured event loss. All values are in Japanese Yen (exchange rate at time of 2011 Great East Japan Earthquake approximately ¥80 per US\$). Note for insured losses above the capacity of the programme (¥5.5bn at time of Great East Japan Earthquake, ¥6.2bn since 6th April 2012) claims will be paid in proportion to the capacity of the programme divided by the total claims payment limit (GIROJ, 2011). Figure uses data from JER (2011) and JER (2012).

Cooperative mutual insurers are not subject to the Earthquake Insurance Law and although they are unregulated by insurance regulators, they must report to their respective ministries (World Bank, 2012b).

Industrial insurance policies written by non-life companies, mutual cooperative insurer (Kyosai) policies (including residential) and international insurers' policies are not ceded to the JER and hence they use the global reinsurance market to transfer a large proportion of their risk (EQECAT, 2011, RMS, 2011).

8.3.3. *Capital markets*

A catastrophe bond (cat bond) is a vehicle of transferring risk from an insurer or reinsurer into the capital markets thus increasing the amount of insurance that can be written. Cat bonds are an attractive investment for large funds such as pension funds because they provide a means of diversifying their portfolios. In addition to Cat bonds, insurers sponsor private ILS (Insurance Linked Securities) to transfer risk to the capital markets.

The catastrophe bond market is dominated by US hurricane and to a lesser extent US earthquake and Europe windstorm; Japan earthquake and typhoon exposure is included in some bonds with other perils and in a limited few on their own. Following the Great East Japan Earthquake, the Muteki Cat Bond (a single peril three-year Japan earthquake bond that had a parametric trigger mechanism based on the amount of shaking measured at particular sites which ultimately provides protection to Zenkyoren, the National Mutual Insurance Federation of Agricultural Cooperatives of Japan) was triggered and suffered a total loss (US\$300million). This was the first Cat Bond to be triggered by an earthquake (World Bank, 2012b) and one of only nine of the 194 issued between 1996 and March 2012 that have been triggered (Pensions World, 2013 and reference therein). Note a number of bonds with exposure to Japan earthquake at the time of the earthquake were not triggered (e.g. Vega Capital Ltd Series 2010-1). The triggering of the Muteki Cat Bond does not appear to have discouraged investors from Cat Bonds with Japan earthquake exposure, for example Kibou Ltd (a single peril US\$300million Japan earthquake cat bond with a parametric trigger) was issued in January 2012 (Artemis, 2013) and a number of multi-peril bonds have been issued including Japan earthquake since the March 2011 (e.g. Sector ReV Ltd Classes A and B, Loma Reinsurance Ltd. Series 2011-1).

8.4. Insurance policy structures

The insurance coverage (which perils are covered within insurance policies) varies significantly between the different lines of business and among the different prefectures of Japan (RMS, 2011). Cooperative insurance programs that work on a non-profit basis are available for certain industries (RMS, 2011). Insurance cover for business interruptions (for example when supply chains are interrupted because suppliers cannot fulfil their obligations) is not widely adopted in Japan (Munich Re, 2012b, Munich Re, 2012c), but international companies were affected by the interruptions of supply chains demonstrating the need for more awareness of their major suppliers' risk exposure (Munich Re, 2012b).

8.4.1. *Residential*

Mutual cooperatives and private insurers together provide residential dwelling and content insurance to a total of 39 percent of the estimated 51 million Japanese households (World Bank, 2012b and references therein).

Private non-life insurers offer residential earthquake and tsunami structure and contents insurance as a single endorsement to the standard fire policy (EQECAT, 2011, RMS, 2011). It is not possible to purchase the earthquake endorsement without the fire policy. Fire insurance is generally obligatory for mortgages, while the earthquake endorsement is not. The premium is risk-based (determined by which of the four risk zones it is located within and whether it is wooden or non-wooden construction and can be subject to one of the following discounts: 30 percent if the building is built with base-isolation construction; 10-30 percent if compliant with recent earthquake resistant codes; 10 percent if

built since 1st June, 1981; or 10 percent if older but considered earthquake resistant), the claims are calculated using a simple three-step system in accordance with the Earthquake Insurance Law and policy limits that vary between 30 percent and 50 percent of the fire insurance limit and are capped at ¥50 million per residential building and ¥10 million per personal property (GIROJ, 2011, RMS, 2011, World Bank, 2012b). About 25 percent of Japanese households have this earthquake endorsement (13 million residential earthquake insurance policies), which is equivalent to 48 percent of the homeowners who have their fire policy with private non-life insurers (RMS, 2011, World Bank, 2012b).

In contrast to this, residential earthquake, fire, flood and other natural disasters insurance is automatic for cooperative mutual insurers, who offer flat rate premiums, calculate claims in proportion to the damage and have policy limits of 50 percent of the fire coverage limit (World Bank, 2012b). Under this scheme, a partial refund of the premium is paid back at the end of the policy term (generally multi-year) if no claims were made. 14 percent households are covered by earthquake insurance in this way, one particular cooperative, JA Kyosai, writes about 85 percent of these policies (World Bank, 2012b).

8.4.2. *Non residential*

Unlike for residential properties, separate endorsements for tsunami and earthquake are needed for non-dwelling property policies, note not all those who purchase the earthquake endorsement also purchase the earthquake water damage endorsement (EQECAT, 2011). Except for warehouse insurance, the Earthquake Fire Expenses Insurance (EFEI) is automatically included in fire policies and tsunami insurance is included for all dwelling and general risks, however the coverage is capped at five percent of the fire policy limit (EQECAT, 2011, World Bank, 2012b). Under standard motor insurance, earthquake damage is not included, however fleets and dealers will often add this to their policies (EQECAT, 2011, Munich Re, 2012b). Cargo and engineering insurance generally include earthquake damage (World Bank, 2012b).

Industrial and commercial buildings have historically been insured by indemnity policies with limits less than the property value, but since the deregulation following the Insurance Business Law in 1996, first-loss policies have also been written leading to increased policy limits (World Bank, 2012b).

Insurance for business interruptions has low penetration in Japan relative to other comparable regions (World Bank, 2012b).

8.4.3. *Life, health and accident*

Japanese life insurance does cover earthquake damage (Munich Re, 2012b). About 90 percent of households in Japan have life insurance policies with an estimated average limit of US\$300k-US\$360k (EQECAT, 2011, RMS, 2011), with the amount decreasing with age. The Japanese government provides health care insurance and workers coverage and it is usually employers who provide group policies for personal accident, of which about 25 percent have the extra endorsement required for earthquake and tsunami cover (RMS, 2011).

8.5. Claims management

In order to provide rapid payment of claims and in accordance with the Earthquake Insurance Law, private insurance companies implement a simple three-step claims adjustment system. In this system, damage is categorized into three levels: full damage (> 50 percent of reconstruction cost), half damage (20-50 percent of reconstruction cost), and partial damage (3-20 percent of reconstruction cost), which leads to 100 percent, 50 percent and 5 percent respectively of the earthquake insurance policy limit being paid to the insured (RMS, 2011, World Bank, 2012b). This system allows for efficient use of loss assessors, however, it also increases basis risk (the difference between the actual loss and the amount paid out by the insurer). Under a public-private partnership that has been active for a number of years, the Geospatial Information Authority of Japan (GSI) and the major aerial survey companies jointly collect damage information following a disaster (World Bank, 2012a). Following the Great East Japan Earthquake, the General Insurance Association of Japan used the images of the

Tōhoku region coastline that were captured within the month following the event, to define total loss zones that did not require assessors to confirm the damage level (World Bank, 2012a). Outside of the total loss zones, residential damage assessments could be carried out by laymen nominated by an insurance company; however, commercial and industrial facilities required an engineer and certified specialized adjuster and the payout is based on the rebuild cost. Other efficiency measures adopted following this event included: (1) Within hours of the earthquake, life, nonlife and cooperative insurers set up a disaster response headquarters (IMF, 2012); (2) The FSA agreed to relax formal requirements for payments, including waiving of the earthquake exclusion clause (IMF, 2012); and (3) Insurance companies worked with police for victim identification (IMF, 2012).

The simple claims adjustment system, the simplified approach to assessing total loss zones, and the other measures adopted following the event helped with quick claim payments: 60 percent of claims were paid within 2 months, 80 percent within 10 weeks and 90 percent of the 741,000 non-life private insurance claims with a value of ¥1,200bn were paid within five months of the disaster (IMF, 2012, World Bank, 2012a).

Efficient management through reinsurance and defined policy limits led to the total sum of residential claims being within the capacity of the private and mutual residential earthquake insurance programs, however many industrial losses exceeded their limits (Munich Re, 2012b).

8.6. Catastrophe models

8.6.1. *The Great East Japan Earthquake within the earthquake models*

The Great East Japan Earthquake was not within the event sets of any of the three major catastrophe modelling firms' (RMS, AIR, EQECAT) Japan earthquake models. This was because the models were based on the 2007 Japan National Seismic Hazard Maps produced by the Headquarters for Earthquake Research Promotion (HERP) that suggested a maximum magnitude of 7.5 along this section of the trench (Air, 2012, HERP, 2007). The assumption that such large events could not occur along this section of the trench was based on a lack of such events in the historical record and the fact that the subducting slab is old in this location; it was thought that older slabs that are colder and denser deform via smaller magnitude earthquakes than younger slabs (Monastersky, 2011). However, there was some scientific literature suggesting that such an event were possible [e.g. Minoura et al., 2001]. This highlights the problem of not including uncertainty due to differences in scientific opinion. Even when insurance companies use the model of more than one modelling firm leading to them acquiring different views of risk, if such models are based on the same hazard map then the size of the uncertainty will be understated relative to the true uncertainty.

Note also that the earthquake models did not include a tsunami model and thus probabilistic risk for tsunamis was calculated in a fairly crude way. The Japan Earthquake models did include both shake damage and fire following.

In Japan and other peril regions there can be alternate views of hazard associated with different scientific theories, but the national hazard maps may not include the range of views. It is important to note that a number of current catastrophe models are based solely on national hazard maps rather than incorporating different scientific approaches and therefore may be excluding the uncertainty resulting from different hazard analyses.

RMS has made updates to its Japan Earthquake Model following the Great East Japan Earthquake to represent the current seismic risk associated with stress changes due to the Great East Japan Earthquake such as stochastic event set updates including addition of large magnitude events, event rate changes due to static Coulomb stress changes and new seismic sources, source model updates, and including tsunami scenarios (Artemis, 2012 and RMS, 2012).

AIR are including the HERP updates on seismic hazard due to the changes in stress following the Great East Japan Earthquake and tsunami and liquefaction risk modelling capabilities in their update to the current AIR Earthquake Model for Japan (AIR, 2012). AIR also intends to update the hazard module incorporating both the HERP updates and information from the wider scientific community (AIR, 2012). For details of the updates to the HERP model see section 2.1.2.

8.6.2. Early loss estimates

Following the Great East Japan Earthquake some early loss estimates were made with the data available at the time. Note that early loss estimates are challenging due to the lack of information which in an event of this severity is exasperated by issues such as loss of power to seismic recording stations and a breakdown of communications; an example of this was that ground motion data from K-NET (the Kyoshin network) was initially unavailable as the network was offline for a week following the earthquake due to power failures (AIR, 2012).

RMS' economic loss estimate on 14th March 2011 was based on the earthquake footprint and their industry exposure database (RMS, 2011). AIR's early estimated insured losses were also made using a footprint created from high resolution wave height and elevation data and verified by aerial photography, satellite imagery and the numerical grid point Princeton Ocean Model (POM) (AIR, 2012). These estimates were updated on March 24th using ground shaking data from K-NET, that had been previously unobtainable.

Some of the early loss estimates of total economic losses were US\$200bn-300bn (RMS, 14/03/2011) and US\$197bn-308bn (Japan Government, 24/03/2011). Some examples of early estimates for total insured losses were US\$21bn-34bn (RMS 14/03/2011) and US\$12bn-25bn (EQECAT, 16/03/2011); these losses include US\$3bn-8bn and US\$2bn-3bn in life insurance respectively. Early estimates of insured property losses were US\$18bn-26bn (RMS, 14/03/2011) and US\$20bn-30bn (AIR, 24/03/2011 (revised from US\$15bn-35bn)). RMS also published early estimates (14/03/2011) of the insured losses by sector: Residential US\$4bn-5.5bn, co-operatives US\$6.5bn-8.5bn, commercial/industrial US\$5.5-9.0bn and other (railway, marine, aviation, auto) US\$2bn-3bn (RMS, 2011). It was the variation in policy types between domestic and international insurers and the uncertainty surrounding potential business interruptions claims that led to greater ranges in estimations in the early expected loss estimates within commercial and industrial lines compared to the residential line of business (RMS, 2011).

AIR's modelled insured loss of US\$20-30bn is (within their model) at an exceedance probability of 1.7-2.5 percent (roughly equivalent to a 40-80yr return period), which is within the probability range that companies manage their risks (AIR, 2012).

8.7. Financing of post disaster recovery

8.7.1. *Where the recovery costs are coming from*

Most of the recovery work is being paid for by the national government. Local governments are contributing to local projects, but the large-scale construction is funded by the national government. For example, in Ishinomaki, the reconstruction plan is estimated to cost ¥900bn over ten years – this will be subsidised by national government (Osaka, 2013). Where ground levels are being raised this is all being funded by the national government. For example, in Rikuzentakata, the national government is funding the landfill to raise ground level by 8-10m so that it is 12m above mean sea height; the cost will be 10s of billions of yen – perhaps ¥50bn (Kikuchi, 2013). Initially, the government was concerned about the confidence in the bond market and therefore did not issue extra bonds to pay for the reconstruction (MOF, 2011a); however, since then the government has enforced extra taxes for the reconstruction (Special Corporate Tax for Reconstruction and Special Income Tax for Reconstruction) and issued Reconstruction Bonds (MOF, 2011b, 2013). Although it has a high amount of domestic debt, the government has not used overseas borrowing. It has also enforced pay cuts for national public employees and has asked local governments to cut salaries (Tate, 2013). The government set up a Special Account for Reconstruction from the Great East Japan Earthquake (MOF, 2013). Table 8.1 summarises the government's anticipated spending on the different components of the Great East Japan Earthquake recovery.

The building of private residences or commercial buildings must be paid for privately. Some businesses paid for the early construction costs themselves in order to decrease business interruption costs. Some of this money may be recoverable from the government later.

The Japan Red Cross had been the biggest domestic aid provider. As of 31st May 2013, they have received ¥327.2bn (US\$3.2million) from direct donations and ¥59.8bn (US\$596million) through National Red Cross and Red Crescent Societies around the world (as of December 2012, the largest donations came from the American Red Cross (¥23bn), the Taiwan Red Cross Society (¥6.8bn), the Canadian Red Cross (¥3.6bn), the German Red Cross (¥3.3bn), the Republic of Korea National Red Cross (3bn), the Red Cross Society of China (¥2.6bn), the Australian Red Cross (¥2.2bn)the Swiss Red Cross (¥2bn), the French Red Cross (¥1.9bn) and the British Red Cross (¥1.8bn) respectively (JRCS, 2012)) (JRCS, 2013). Donations made through the Japanese Red Cross Society are donated to people affected by the disaster through cash grants via the Municipal governments, with the amounts determined by benchmarks set by the prefectural governments (JRCS, 2013). Some money has come from other international aid.

Table 8.1 Special Account for Reconstruction, Main Expenses related to the Great East Japan Earthquake (Adapted from MOF, 2011c and MOF, 2013).

Category	1st Supplementary Budget for FY2011 (April, 2011) (billion yen)	3rd Supplementary Budget for FY2011 (October, 2011) (billion yen)	Budget for FY2012 (billion yen)	Budget for FY2013 (billion yen)
Disaster Relief (majority for temporary housing)	482.9	94.1	76.2	83.7
Disposal of Disaster Waste	351.9	386.0	344.2	126.6
Public Works related to Reconstruction (including rebuilding of facilities)	1,617.9	1,473.4	509.1	879.3
Disaster-related Public Financing Program	640.7	671.6	121.0	96.3
Local Allocation Tax Grants	120.0	1,663.5	549.0	605.3
The Great East Japan Earthquake Reconstruction Grants	-	1,561.2	286.8	591.8
Expenses related to Reconstruction from the Nuclear Damages	-	355.8	481.1	709.4
National Disaster Preventions Measures	-	575.2	482.7	-
Other Expenses related to the Great East Japan Earthquake	801.8	2,463.1	399.9	625.5
Total	4,015.3	11,733.5	3,250.0	3,717.8

8.7.2. *Financial services and economic stability*

Demands for liquidity are common in disaster scenarios. To prevent the financial markets from being destabilized by such demands, the Bank of Japan provided record levels of liquidity following the earthquake, leading to the daily offer on the first business day following the earthquake (Monday, 14th March, 2011) and the outstanding balance of current accounts on Thursday 24th March reaching record highs (BOJ, 2011). A high number of ATMs were put out of order and local branch closed, banks put considerable effort into opening local offices and neighbouring financial institutions agreed to temporarily share cash-delivery cars and facilitated customers using competitors' facilities in order to help with liquidity availability (BOJ, 2011). Other precautions to help financial stability included an international concerted intervention in foreign exchange markets (BOJ, 2011). High trading volumes on the stock markets in Japan continued for two weeks following the earthquake; the market infrastructure had sufficient capacity to cope with this (BOJ, 2011).

8.7.3. *Compensation*

The government is providing temporary housing and buildings for businesses at very low cost. However, for those residents without insurance there is no financial compensation for the loss of their homes. The government typically pays unemployment insurance that is a fixed percentage of the salary for six months to a year.

In Ishinomaki, it has been determined that it is not possible to protect 47 of the residential fishing areas against a 1 in 100 year event and therefore these villages will be relocated – it is hoped 9 of these villages will be moved to higher ground in 2014 (Osaka, 2013). Where the Municipal government declares the land as unsafe to live, they will pay approximately 70 percent of the price to the owner for the unusable land and lease the new location cheaply (Osaka, 2013). The Municipal government hopes to be able to turn the properties they buy into industrial facilities (Osaka, 2013). The government will provide public housing for those who cannot afford to reconstruct their homes or buy a condominium (Osaka, 2013). The average cost for rebuilding a house lies between ¥15million and ¥30million and repair costs mostly cost above ¥3m; those people who have bank loans can receive a ¥3m subsidy and those without a bank loan a ¥1.5m subsidy towards rebuilding their homes (Osaka, 2013). There are also subsidies of ¥1m for those who have had to adjust their floor heights in response to ground subsidence.

8.7.4. *Examples of private-government partnerships for commerce*

In Ishinomaki, a company was set up before the disaster to address the issues of a declining city centre by planning its redevelopment. The committee making the decisions comprises citizens, stakeholders, landowners, small business owners and residents. There are also plans to build a river wall to protect the city as much of the damage came from the tsunami travelling up the river. 40-50 percent of the cost for the redevelopment will come from a government subsidy that became available after the disaster (Marimuro, 2013). Other incentives for commerce include: Funding and subsidies from national government for commerce; business tax free for 5yrs for new businesses; property tax free for 3yrs (may be extended to 4-5yrs); and 2nd loan assistance, but unlikely help for original loans (Marimuro, 2013).

In Ishinomaki, the government will provide subsidies for new commercial buildings that can be used for vertical evacuation (must have outside stairs and space for people on top of building) if a tsunami occurs (Osaka, 2013).

In Rikuzentakata, the national government is offering 75 percent subsidy for rebuilding of large shops, however small businesses cannot get these subsidies and therefore the Municipal government is offering 50 percent of the capital required for reconstruction, note the subsidy can be used to build elsewhere if the original location is declared unsafe by local government, but you must want to go back to old town centre if possible (Ogasuwara, 2013). In Rikuzentakata, after 1 year and 3 months, local shop owners were given modular temporary structures to form a shopping arcade by the national agency for small businesses assisted by the national government (Ogasuwara, 2013).

There are some small subsidies for businesses from the national government for sales activities (approximately enough for travel expenses) (Nakase, 2013). Some international companies are interested in Miyagi Prefecture, but the companies complain there are not big enough subsidies and not enough infrastructure, such as international schools or information in non-Japanese languages, in place for workers (Nakase, 2013). Contamination rumours are causing problems for producers in Miyagi; it is likely the rumours will cause the products from Miyagi to take a long time to recover economically because fear is leading to people not buying Miyagi products; distributors are trying to use these products, but equivalent products from Fukushima and Miyagi are cheaper than from other regions now (Nakase, 2013).

8.7.5. NGO example from Rikuzentakata

Rikuzentakata was one of the worst affected towns in the Iwate Prefecture. As of June 2013, a number of NGOs that were set up following the disaster currently meet through monthly committee meetings to share their knowledge.

During the first month after the disaster, although public services were able to provide large-scale food and services, additional help was needed to assist with smaller donations and to reach small groups that needed help. People outside the affected region wanted know how to make donations (along with information about the residents' safety). While communications were limited, 'Save Takata' was set up¹⁴ to help with the coordination of relief work, but with time developed to help with the long-term goal of rejuvenating Rikuzentakata because even prior to the tsunami, young people were leaving the city due to a lack of creative opportunities for them. It currently has a number of activities to:

- (1) Help the town and its residents receive financial aid
 - a. They act as a conduit and passive coordinator for potential financial and expertise donors (such as teaching and entertainment) in Tokyo.
 - b. They inform residents and businesses about relevant schemes available to help them from around the country).
- (2) Grow the local economy
 - a. They make up-to-date maps (originally updated every two months, but from June 2013 updated every six months) of Rikuzentakata permanent and temporary structures showing shop locations and distributing them to residents to help boost commerce.
 - b. They promote Rikuzentakata products and sell them in Tokyo and other big cities. Note that products from the disaster zone have been shunned by the nation following the nuclear scare leading to decreased sales and price drops. (In 2011, 200,000 volunteers went to Rikuzentakata and in 2012 there were 130,000; Save Takata hopes to use this network).
 - c. They provide internet services and I.T. training for small businesses.
- (3) Rebuild the community
 - a. They coordinate entertainment events such as festivals.
 - b. They have rented a house for visiting volunteers; which acts as a hub for activities for young people.
- (4) Plan how to help future NGOs in post disaster environments be more effective
 - a. They plan to produce a manual comprising the lessons learnt from setting up and running a NGO in a post disaster situation.
 - b. They are preparing to be a NGO coordinator in potential future disasters as they recognize in a large disaster it is important to have good communication, coordination and organization between the different parties in the recovery process.

¹⁴ It was founded by Okamoto Shoma and his classmates in Tokyo. Okamoto Shoma grew up in Rikuzentakata but at the time of the Great East Japan Earthquake, he was an architecture student in Tokyo; his mother's home in Rikuzentakata was destroyed by the tsunami and she ended up in an evacuation centre.

In order to reduce unemployment and to help with local recovery, the Prefectural Government started a scheme in which they employ people to work in NGOs, for example, they provide three of Save Takata's eight full-time staff. Save Takata also has two part-time staff and 30 volunteer members. Initially, work was voluntary, but as of June 2013 some salaries are being paid. In the early stages they relied on donations from private companies, however now they need to apply for support from both the private and public sectors. The organization is trying to transform from being a voluntary organization to having an increased amount of self-funding from the activities it organizes.

8.8. Conclusions

The Great East Japan Earthquake was the most expensive disaster ever recorded. Earthquake insurance penetrations in Japan are lower than in comparable peril regions. Following the earthquake, there was an increase in national earthquake insurance penetration rates, with increases of up to 10 percent in affected prefectures. The insurance market in Japan is highly concentrated among the few largest companies in both the life and nonlife sectors. The Japanese Earthquake Reinsurance Company (JER) - that reinsures residential and shop-owners' insurance - aims to have a capacity sufficient for an event equivalent to the 1923 Great Kanto Earthquake; following the Great East Japan Earthquake, the reserves of the JER were reduced so the government has increased its earthquake reinsurance liability. Mutual insurers play an important part in the Japanese insurance market, these rely on the global reinsurance market for reinsurance. Residential earthquake and tsunami insurance is offered as a single endorsement to the standard fire policy, however for commercial and industrial earthquake insurance a separate policy is required. A simple three-step claims management system allowed for quick claims payments. An earthquake of such high magnitude was not accounted for along this section on the Japan Trench within commercial catastrophe models, although there was evidence of its possibility within the scientific literature. Most of the recovery is being paid for by the national government, but there has been help from international aid, NGOs within Japan and public-private partnerships.

8.9. References

- AIR Worldwide (2012). Understanding Earthquake Risk in Japan Following the Tōhoku-Oki Earthquake of March 11, 2011. [Online] 2012. Available from: <http://www.air-worldwide.com/Publications/White-Papers/Understanding-Earthquake-Risk-in-Japan-Following-the-Tōhoku-Oki-Earthquake-of-March-11-2011/>. [Accessed: 1st July, 2013].
- Artemis (2012). RMS updates Japan earthquake model with lessons from Tōhoku, ARTEMIS. [Online] 4th October 2012. Available from: <http://www.artemis.bm/blog/2012/10/04/rms-updates-japan-earthquake-model-with-lessons-from-tohoku/>. [Accessed: 1st July, 2013].
- Artemis (2013). Artemis Deal Directory. [Online]. Available from: http://www.artemis.bm/deal_directory/kibou-ltd-series-20121/. [Accessed: 2nd July, 2013].
- BOJ (2011). Bank of Japan, Responses to the Great East Japan Earthquake by Payment and Settlement Systems and Financial Institutions in Japan, *BOJ Reports and Research Papers*. [Online] October 2011 (original in Japanese published 24th June, 2011).
- Daniell, J. and Vervaeck, A. (2012). Damaging earthquakes database 2011 – the year in review, CEDIM Earthquake Loss Estimation Series Research Report 2012-01. [Online]. Available from: <http://www.cedim.de/> [Accessed: 27th November, 2012].
- EQECAT.(2011). M9.0 Japan Tōhoku Offshore Earthquake of March 11, 2011, Catastrophe Reports, March 16th 2011, Catwatch. [Online]. Available from: <http://www.eqecat.com/catwatch/estimated-total-insured-losses-at-12-25-billion-usd-2011-03-16/> [Accessed: 2nd July, 2013].
- Faure Walker, J.P., Roberts, G.P., Sammonds, P., and Cowie, P. (2010). Comparison of earthquake strains over 100 and 10,000 year timescales: insights into variability in the seismic cycle in the central Apennines, Italy, *Journal of Geophysical Research*, 115, B10418, 2010.

- GiAJ (2013*). General Insurance Association of Japan. [Online]. Available from: http://www.sonpo.or.jp/archive/statistics/syumoku/pdf/index/kanyu_jishin.pdf, (in Japanese), [Accessed: 23rd July, 2013].
- GIROJ. (2011). Earthquake Insurance in Japan. [Online]. Available from: <http://www.giroj.or.jp/english/earthquake.html>, May 2011 [Accessed: 1st July, 2013].
- Hashimoto, C., Noda, A., Sagiya, T., and Matsu'ura, M., (2009). Interplate seismogenic zones along the Kuril–Japan trench inferred from GPS data inversion, *Nature Geoscience*, 2, 141-144.
- HERP.(2007). Headquarters for Earthquake Research Promotion, Prime Minister's Office, Government of Japan.
- IMF (2012). International Monetary Fund, Japan: Insurance Core Principles – Detailed Assessment of Observations, *IMF Country Report* [Online] No. 12/228, August 2012 [Accessed: 4th July, 2013].
- JER (2011). Japan Earthquake Reinsurance Co, Ltd. Annual Report 2011, Reinsurance of Earthquake Insurance. [Online]. Available from: http://www.nihonjishin.co.jp/disclosure/2011/en_03.pdf [Accessed: 1st July, 2013].
- JER (2012). Japan Earthquake Reinsurance Co., Ltd. Annual Report 2012, Reinsurance of Earthquake Insurance. [Online]. Available from: http://www.nihonjishin.co.jp/disclosure/2012/en_03.pdf [Accessed: 4th July, 2013].
- JRCS (2012). Japanese red Cross Society, Japan: earthquake and Tsunami, Operations Update 9 [Online] Available from http://www.jrc.or.jp/vcms_lf/Ops_Update_No9_20121206_FINAL.pdf [Accessed 1st August, 2013].
- JRCS (2013). Japanese red Cross Society, Support Survivors through the Red Cross [Online] Available from: <http://www.jrc.or.jp/eq-japan2011/donation/index.html> [Accessed 1st August, 2013].
- Kikuchi, M. (2013). Rikuzentakata Townhall [Interview]. 4th June 2013.
- Marimuro, T. (2013). The redevelopment of downtown Ishinomaki. [Interview]. 3rd June 2013.
- Minoura, K., Imamura, F., Sugawa, D., Kono, Y. and Iwashita, T. (2001) The 869 Jogan tsunami deposit and recurrence interval of large-scale tsunami on the Pacific coast of northeast Japan, *Journal of Natural Disaster Science*, 23, 2, 83-88, 2001.
- MOF (2011a). Ministry of Finance Japan. Outline of the Supplementary Budget for FY2011 (April 22, 2011) [Online] Provisional Translation. Available from: <http://www.mof.go.jp/english/budget/budget/fy2011/11sb01.pdf> [Accessed on 1st August, 2013].
- MOF (2011b). Ministry of Finance Japan. Outline of the Third Supplementary Budget for FY2011 (October 21, 2011) [Online] Provisional Translation. Available from: <http://www.mof.go.jp/english/budget/budget/fy2011/11sb03.pdf> [Accessed on 1st August, 2013].
- MOF (2011c). Ministry of Finance Japan. Highlights of the Budget for FY2012 (December 24, 2011) [Online] Provisional Translation. Available from: <http://www.mof.go.jp/english/budget/budget/fy2012/e20111224a.pdf> [Accessed on 1st August, 2013].
- MOF (2013). Ministry of Finance Japan. Highlights of the Budget for FY2013 (January 29, 2013) [Online] Provisional Translation. Available from: <http://www.mof.go.jp/english/budget/budget/fy2013/01.pdf> [Accessed on 1st August, 2013].
- Monastersky, R. (2011). Giant shock rattles ideas about quake behavior, *Nature* 471, 274 (2011), doi:10.1038/471274a, Published online 15 March 2011.
- Munich Re (2012a). Review of natural catastrophes in 2011: Earthquakes result in record loss year, Munich. [Online] 4 January 2012. Available from: http://www.munichre.com/en/media_relations/press_releases/2012/2012_01_04_press_release.aspx [Accessed: 1st July, 2013].
- Munich Re (2012b). Topics Geo, Natural catastrophes 2011 Analyses, assessments, positions, February 2012, http://www.munichre.com/publications/302-07225_en.pdf [Accessed: 1st July, 2013].

- Munich Re (2012c). One Year after the Tōhoku earthquake: A review of the disaster and its consequences. [Online] 7 March 2012. Available from: http://www.munichre.com/app_pages/www/@res/pdf/media_relations/press_dossiers/japan-one-year-after/one-year-after-the-tohoku-earthquake-en.pdf [Accessed: 1st July, 2013].
- Nakase, Y. (2013). JETRO (Japan External Trade Organization) [Interview].
- Ogasuwara, O. (2013). Modular Temporary shopping arcade in Rikuzentakata [Interview] 4th June 2013.
- Oska, T. (2013). Town hall, Reconstruction development of Ishinomaki Municipality Office. [Interview]. 3rd June 2013.
- Pensions World (2013). ALTERNATIVES The year of the cat [Online] January 2013. Available from: <http://www.pensionsworld.co.uk/pw/article/alternatives-the-year-of-the-cat-12322431> [Accessed: 4th July, 2013].
- RMS (2011). Estimating Insured Losses from the 2011 Tōhoku, Japan Earthquake and Tsunami, RMS Special Report. [Online] April 2011. Available from: https://support.rms.com/Publications/2011TōhokuReport_041111.pdf [Accessed: 2nd July, 2013].
- RMS (2012). The M9.0 Tōhoku, Japan Earthquake: Short-Term Changes in Seismic Risk, RMS Special Report. [Online] February 2012. Available from: https://support.rms.com/Publications/2011_Tōhoku_Seismic_Risk.pdf. [Accessed: 2nd July, 2013].
- Soble, J. (2011). Thai floods threaten Japanese supply chain, Financial Times. [Online] 12th October 2011. Available from: <http://www.ft.com/cms/s/0/a82973f0-f4a7-11e0-a286-00144feab49a.html>. [Accessed: 27th November, 2012].
- Suess, O. and Bandel, C. (2011). Floods, Tsunami May Dent 'Black Box' Supply-Chain Insurance, Bloomberg. [Online] 9th December 2011. Available from: <http://www.bloomberg.com/news/2011-12-08/floods-tsunami-may-dent-black-box-of-supply-chain-insurance.html>, [Accessed: 27th November, 2012].
- Swiss Re (2012). Natural catastrophes and man-made disasters in 2011: historic losses surface from record earthquakes and floods, sigma No2/2012. [Online]. Available from: http://media.swissre.com/documents/sigma2_2012_en.pdf [Accessed: 3rd July, 2013].
- Tate, Y. (2013). "Pay Cuts for Local Government Employees" hakumon Herald [online] 3rd April 2013. [Accessed 1st August 2013].
- The Insurance Insider (2011). "Tokio Marine's quake loss soars by \$780mn". [Online] 28th November, 2011. Available from: <http://www.insuranceinsider.com/-1236075/22>. [Accessed: 8th July, 2013].
- USGS (2012). The March 11 Tōhoku Earthquake, One Year Later. What Have We Learned?, [Online] 9th March 2012. Available from: http://www.usgs.gov/blogs/features/usgs_top_story/the-march-11-tohoku-earthquake-one-year-later-what-have-we-learned/ [Accessed: 27th November, 2012].
- World Bank (2012a). Risk and Damage Information Management, Knowledge note 5-2, Cluster 5: Hazard and Risk Information and Decision Making. [Online] September 2012. Available from: http://wbi.worldbank.org/wbi/Data/wbi/wbicms/files/drupal-acquia/wbi/drm_kn5-1.pdf. [Accessed: 4th July, 2013].
- World Bank (2012b). Earthquake Risk Insurance, Knowledge note 6-2, Cluster 6: The economics of disaster risk, risk management, and risk financing. [Online] September 2012. Available from: http://wbi.worldbank.org/wbi/Data/wbi/wbicms/files/drupal-acquia/wbi/drm_kn6-2.pdf. [Accessed: 3rd July, 2013].

This page is intentionally left blank.