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Earthquakes
Impact, Community Vulnerability and Resilience

Edited by Jaime Santos-Reyes

Earthquakes - Impact, Community Vulnerability and Resilience

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IntechOpen Book Series

Earthquakes

Volume 2

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Scope of the Series

The book series addresses the multi-disciplinary topic of earthquake hazards and risks, one of the fastest growing, relevant and applied fields of research and study practiced within the geosciences and environment. It also addresses principles, concepts and paradigms of the earthquake connected disciplines, as well as operational terms, materials, tools, techniques and methods including processes, procedures and implications.
This book series aims to equip professionals and others with a formal understanding of earthquake hazards and risk topics, to clarify the similarities or differences in fundamental concepts and principles in the discipline, to explain the relevance and application of primary tools and practices in earthquake risk study, to direct geologists, engineers, architects, planners, teachers, students, and others interested in the earthquake discipline to authoritative and vetted sources, and last but not least, to capture the wide range of expanding disciplinary activities under a single umbrella of earthquake hazard, disaster and risk concept.

Contents

Preface

Earthquakes may be regarded as one of the deadliest natural hazards on Earth. Literally, within a few seconds, hundreds (in some cases thousands) of lives could be lost. Earthquakes are particularly disastrous when they affect communities that are exposed and vulnerable. How are these cities and communities dealing with earthquakes? Are they prepared to mitigate the impact of them? This book attempts to answer these and other questions about earthquake preparedness.

Organized into four sections, the thirteen chapters of this book describe the current state-of-the-art of themes related to earthquakes, including preparedness, vulnerability, resilience and risk assessment.

Chapter 1 in Section 1 provides an introduction to the volume. Section 2 includes Chapters 2 and 3, both of which deal with earthquake preparedness. Chapter 2 presents a conceptual model for designing earthquake early warning messages that are delivered via mobile phone apps. The chapter uses America's West Coast as a case study. Chapter 3 presents the results of a study conducted in Mexico City regarding risk perception and how knowledgeable the participants were in relation to earthquake prediction. Section 3 includes Chapters 4–6, each of which includes a case study of a community affected by earthquakes. Chapter 4 discusses the long-term effects of the 2010 earthquake in Chile on the country's rural male population. Chapter 5 describes the lessons learned from the 2015 earthquake in Nepal. Chapter 6 presents a methodology for assessing lifeline interactions for the case of the 2011 earthquake in Japan.

Section 4 includes Chapters 7–10 and deals with different approaches to building community resilience. Chapter 7 presents a methodology to build resilience in countries prone to disasters. Chapter 8 puts forth a methodology of community-based resilience reconstruction based on the experiences gained after the 2011 earthquake in Japan. Chapter 9 addresses how corporations can contribute to community resilience, again using the Japan earthquake as an example. Chapter 10 presents the role of placemaking as a tool for post-disaster regeneration and resilience, and applies it to three case studies following the 2010 and 2011 earthquakes in Christchurch, New Zealand.

Finally, Section 5 deals with the 'hard' science of the study of earthquakes. Chapter 11 puts forward a probabilistic framework for assessing seismic scour effects on bridge structures in rural areas. Chapter 12 discusses large earthquakes generating landslides and tsunamis. Chapter 13 presents the state-of-the-art of the kinematics of slow-slip events.

Written by international experts in their respective fields, this book provides comprehensive information on a wide range of issues related to earthquakes. It is hoped that it will become a valuable resource for academic researchers, postgraduate students involved in research on seismic risk, NGOs, and key decision-makers involved in disaster management systems at national, regional and local levels.

Many people have made this book possible. I gratefully acknowledge the assistance provided by Ms. Ivana Barac, author service manager, the technical staff, and all the authors who contributed to the volume.

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Section 1

Introductory Chapter

Chapter 1

Introductory Chapter: Earthquakes - Impact, Community Vulnerability, and Resilience

Jaime Santos-Reyes

1. Earthquake trends 1998–2017

Earthquakes may be regarded as one of the most devastating and terrifying natural forces on earth. Past earthquake disasters (including tsunamis triggered by earthquakes) have demonstrated that literally within a few or a fraction of seconds, many people can be killed or injured; further, the psychological impact on communities can last for years. Furthermore, due to its force of destruction, any physical infrastructure could be (and have been) damaged or destroyed.

But what are the trends? In the UNISDR report [1], some of the key conclusions relevant to earthquakes during a 20-year period (i.e., 1998–2017) were the following (**Figure 1**):

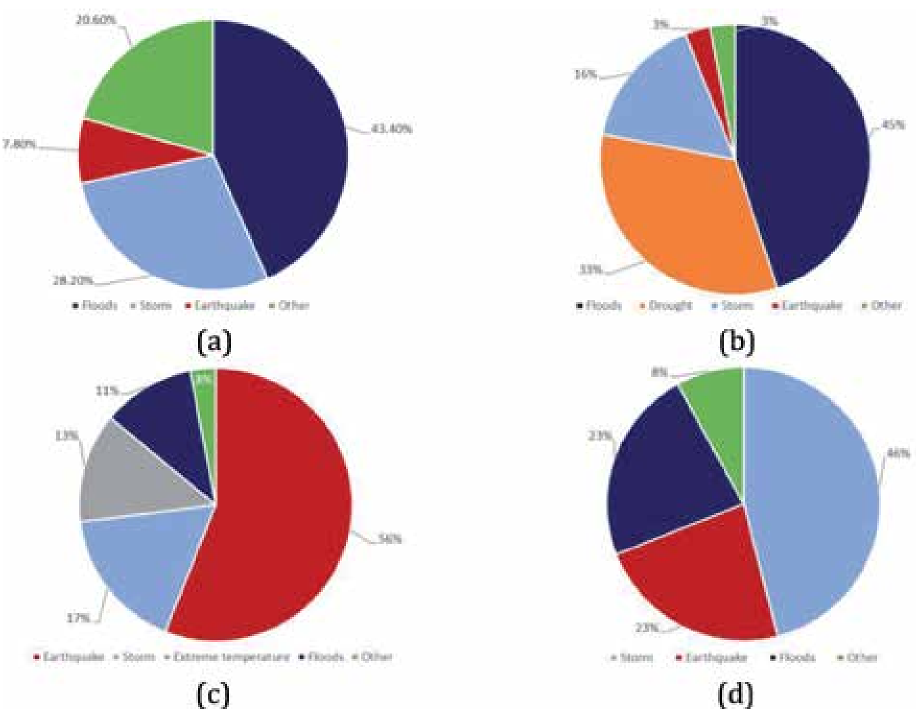

Figure 1.
(a) Number of earthquake disaster occurrence and other types of natural disasters in the 20-year period between 1998 and 2017. (b) Number of affected people by earthquakes and other natural disasters. (c) Deaths caused by earthquakes and other types of natural disasters. (d) Economic losses caused by earthquakes and other natural disasters, during the same time period, in US$.

a. There was a total of 7255 natural disasters between 1998 and 2017.

b. The number of earthquake disasters during the 20-year period was 563 (7.8%) (it is believed that 91% of "climate"-related disasters occurred during the 20-year period, and floods accounted for 43%).

c. The number of affected people by earthquakes was 125 million (3%).

d. Earthquakes have killed 747,234 people (56%) (17% of deaths were caused by storms and 13% by "extreme temperature," among other disaster types).

e. Earthquakes have caused economical losses of US$ 661 billion.

It is clear from the abovementioned conclusions that earthquakes have killed more people than any other type of natural hazards during the 20-year period.

2. Unpredictability of earthquakes

Following the two deadly 2017 earthquakes in Mexico (i.e., M8.2 on 7 September and M7.1 on 19 September) [2], there has been a debate on the "unusual cause" of these events [3–5]. However, what is less debatable is the fact that earthquakes occur at "unpredicted times in unpredicted places" [6]. This may be one of the reasons why earthquakes are so terrifying.

The 2017 earthquakes in Mexico may illustrate the above:

a. The quake on 7 September (M8.2) was not expected (see above) (the earthquake is considered as the strongest occurring in more than a century).

b. It occurred at mid-night when most of the residents of the capital city were at home (and probably in bed) (i.e., at 23:49:17 local time). Fortunately, the earthquake early warning (EEW) system worked as expected (see the next sub-section).

c. A second earthquake occurred on September 19th, this time during a daytime (i.e., 13:14:40 local time), but the warning was not issued in time [2]; further, it occurred the same date (i.e., on 19 September) as the 1985 earthquake that caused death and destruction in the capital city.

d. The time in between these two earthquakes was very short; i.e., only 12 days. We were still recovering from the earthquake on September 7th, then came the second one, which caused panic among the residents of the capital city.

e. We were expecting a "big' earthquake with the epicenter occurring along the "Guerrero gap," in the Pacific coast of the country, but the epicenter of the M8.2 earthquake was in fact in "Tehuantepec" [2]. Similarly, we were expecting a strong earthquake (or the "big-one") coming from the "Guerrero gap" [7]; however, the September 19th earthquake occurred inland, causing death and suffering.

Some similar experiences, in the context of the unpredictability of earthquakes, have been experienced by communities exposed to seismic risk world-wide. Although not directly associated with earthquakes, it is worth to mention that in 2018, a landslide caused a tsunami in Indonesia, killing hundreds of people [8]. These events show the unpredictability of mother nature.

The above has illustrated communities' vulnerabilities, lack of resilience capacity to such events. We must learn to live with seismic risk, by building community resilience, among other things, to mitigate the impact of these events; also, governments should invest, for example, in EEW systems to warn communities of an earthquake occurrence.

3. Resilience and vulnerability, earthquake early warning systems

Cities, communities, have experienced the destructive force of earthquakes, not only in terms of human life, but also, in the disruption of critical infrastructure facilities (roads, bridges, power and gas supply, transport systems, supply chain, etc.). In short, earthquakes can, in principle, bring down the functioning of a whole city/community.

The concept of resilience has gained increasing importance in earthquake disaster management. The UNISDR, for example, has defined it as "The ability of a system, community, or society exposed to hazards to resist, absorb, accommodate, adapt to, transform, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management" [9]. It has been argued that EEW systems have the potential to improve communities' resilience to seismic risk [2, 10], given the fact that earthquakes cannot be predicted.

However, to be effective, EEW systems should be people-centered [2]; i.e., people should be well educated on the basic functioning of the system, among other things. Further, an effective EEW system should be able, in principle, to warn people a few seconds before the ground shaking. As any technical system, EEW systems have limitations; for example, during the September 19th earthquake, the warning (i.e., the "siren") was issued almost simultaneously with the ground shaking, given not enough time to seek protection or safety [2]. Had the system worked at the time, it is very likely that lives could have been saved. Similarly, with the case of the most recent 2018 tsunami in Indonesia, where there was not a tsunami early warning system installed [8].

Within the resilience literature, it is worth mentioning the "science of resilience" [11], which is quite relevant to earthquakes; it essentially stresses the need to integrate "basic science" (e.g. physics, mathematics, seismology, volcanology, etc.) and "social science" (sociology, psychology, economics, etc.) to build a "resilient society" [11]. In a way, the content of the book covers the multidisciplinary approaches aiming at a better understanding of seismic risk and to contribute to the mitigation of the impact of earthquakes.

It is widely recognized that the degree of communities' vulnerability is "determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of an individual, a community, assets, or systems to the impacts of hazards" [9]. A good example is provided in [1], where it has been reported that those communities that were not prepared to earthquakes were the most affected; i.e., 2004 tsunami, which occurred in the Indian Ocean, and the 2010 earthquake in Haiti. On the other hand, countries that are prepared for seismic risk (e.g., earthquake resistant buildings, people's preparedness, etc.), the impact, for example, of the 2010 earthquake in New Zealand was zero in terms of human loss [1].

4. Some final reflections

a. It may be highlighted that earthquakes will occur at any time and are effectively unpredictable.

b. We must learn to live with seismic risk. In this regard, and in relation to earthquake occurrence, we might ask ourselves, "what-if here and now" and "what-if there and then" and be prepared for the unthinkable.

c. Earthquake early warning (EEW) systems should be people-centered.

d. Learning from past earthquake disasters (including tsunamis).

e. Learning from success stories worldwide.

f. Engage in "creative thinking" in devising creative solutions, aiming at the mitigation of the impact of earthquakes.

g. Continuously assessing seismic risk since everything is continuously changing.

h. Other.

Finally, all of what has been given in the introductory chapter, explicitly or implicitly, are covered in the book, which may be considered as an important source.

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Section 2

Preparedness

Chapter 2

The IDEA Model as a Conceptual Framework for Designing Earthquake Early Warning (EEW) Messages Distributed via Mobile Phone Apps

Deanna D. Sellnow, Lucile M. Jones, Timothy L. Sellnow, Patric Spence, Derek R. Lane and Nigel Haarstad

Abstract

Short response time available in the event of a major earthquake poses unique challenges for earthquake early warning (EEW). Mobile phone apps may be one way to deliver such messages effectively. In this two-phase study, several hundred participants were first randomly assigned to one of eight experimental conditions. Results of phase one afforded researchers the ability to reduce the number of conditions to four. Phase two consisted of five experimental conditions. In each condition, a 10 second EEW was delivered via a phone app. The four treatment conditions were designed according to elements of the IDEA model. The control condition was based on the actual ShakeAlert EEW computer program message being used by emergency managers across the US west coast at the time. Results of this experiment revealed that EEW messages designed according to the IDEA model were more effective in producing desired learning outcomes than the ShakeAlert control message. Thus, the IDEA model may provide an effective content framework for those choosing to develop such apps for EEW.

Keywords: IDEA model, risk communication, crisis communication, disaster warnings, earthquake early warning, communication and technology

1. Introduction

Effective earthquake early warning messages can empower target populations to take appropriate actions for self-protection and, ultimately, save lives. The communication challenges facing those who wish to design warning messages involve both content and access. Content focuses on gaining attention and providing appropriate instructions for self-protection. Access depends on sending the messages through a channel or channels and a medium or media that can be retrieved quickly and easily. A team of researchers completed a project designed to develop such content and access. The project was based on previous warning message testing research. Specifically, researchers attempted to apply the IDEA model to create brief, easily accessible earthquake early warning messages via a mobile phone app.

The IDEA model for effective instructional risk and crisis communication is an acronym that stands for internalization, distribution, explanation, and action [1]. According to the IDEA model, such messages ought to include appeals to internalization (e.g., proximity, personal relevance, impact, timeliness), be distributed over multiple channels deemed appropriate based on crisis type and target audience(s), and offer cogent explanations about what is happening. These explanations should be offered by credible sources and the scientific information provided in them be both accurate and translated intelligibly for the target population(s). These messages also must include specific action steps receivers are to take (or not take) for self-protection [2–7]. The following paragraphs describe the message design and testing project processes, results, and conclusions based on the timeline under which it unfolded.

2. The IDEA model message design and testing experiment

The design and testing process occurred in two phases. Thus, this section first describes the study design process followed by the results of the two-phase experiment. It closes with a discussion of the results as they may inform the design of effective EEW messages delivered via phone apps.

2.1 Designing the study

To launch the project, a multidisciplinary group comprised of seismologists, instructional risk and crisis communication scientists, graphic artists, and emergency managers from the US west coast states met in Pasadena, California to participate in a 3-day design storm focused on earthquake early warning messaging. This design storm was essentially a synergistic brainstorming session to formulate an ecologically valid plan based on a broad cross-section of expertise represented in crisis communication and earthquake science that would inform earthquake early warning message design.

Ultimately, the group agreed that message content **distributed** via a phone app would likely be a predominant interface for US west coast residents. Thus, message content (both visual and aural) would be designed for a phone app. The group also agreed that the content would need to be developed based on social science crisis communication best practices research.

Message content would address **internalization** components as follows. To test proximity, some conditions will include a map and others will not. To test timeliness, the conditions will include a countdown to when the strong shaking is expected to occur. Timeliness would also be tested by providing no more than 10 seconds for the entire message. Personal relevance would be addressed by focusing on "very strong shaking" (i.e., "7" or higher Intensity level shaking).

Message content would address **explanation** components as follows. To address source credibility, Dr. Lucy Jones' voice was recorded and applied as she is a known and credible earthquake expert among many throughout the US west coast states. The accurate science provided by seismologists was translated into simple, easily comprehended language. Also, intensity level was selected rather than magnitude because intensity is directly related to very strong shaking that can harm individuals that do not enact the appropriate actions for self-protection. Finally, some conditions used a verbal message–very strong sharking—and others a numerical message—"7"—to signal the kind of shaking to occur. This allowed researchers to test for potential lack of understanding regarding what "7" might mean. Existing research suggest that less numerate people—those that lack the ability to process mathematical concepts—tend to trust verbal risk information that they can comprehend more than numeric information that may be unintelligible to them and, consequently, make poorer decisions based on numerical data than highly numerate people [8]. Thus, it seemed critical to test intensity comprehension based on numeric versus verbal reporting.

Message content would address **action** components by a visual graphic accompanied by a verbal message—Drop! Cover! Hold on!—reinforced orally by a speaker saying "Drop, take cover, hold on." All experts in the design storm agreed that all conditions testing high intensity earthquake early warning message should include this specific action statement in some way. Thus, all treatment conditions included this message.

The graphic artists created eight visual representations of a smart phone app screen, which the instructional risk and crisis team would test during the fall semester. The team would create an online survey to collect responses to the various versions and measure their effectiveness based on affective, cognitive, and behavioral learning outcomes. A snowball sample of participants would be invited via Lucy Jones' Facebook page and the Shakeout website. The survey collected quantitative and qualitative data and employed a mixed methods analysis.

2.2 Message testing: phase one

The results for phase one of the project were collected using a survey distributed via an invitation on Lucy Jones' Facebook page and the Shakeout website. Both outlets targeted users across the US west coast. Of the 469 surveys entered, 198 were completed in entirety and, thus, usable for the analysis. The usable data resulted in 22–28 responses per condition for the eight varieties tested. The sample was comprised of 106 (56%) females and 92 (44%) males. A majority of the participants (80%) were Caucasians from Southern California (n = 153). Notably, 37% (n = 66) of the participants reported earning incomes over $100,000 annually.

Eight message conditions were manipulated in ways that indicated the location with or without a map, intensity in numerical or non-numerical form, and countdown in graphic or numerical form. All eight conditions used the same aural warning alert sound and voice command. All eight conditions offered actionable vocal instructions to "drop, take cover, and hold on."

Survey responses were examined using both quantitative and qualitative methods. Statistically significant quantitative results and dominant qualitative themes emerging in open-ended responses are reported here. The quantitative analysis produced five sets of meaningful results. The subsequent qualitative examination of open-ended responses provided additional insight to inform message refinement. In total, 87 participants (44%) offered open-ended responses to the prompt, "Please provide any additional feedback you believe would be helpful concerning the quality of the app." These comments ranged from 3 to 328 words (M = 50) Exemplars from these responses are reported with the corresponding quantitative results. These sets of results focus on intensity, location, countdown, perceived helpfulness of visual images, and perceived helpfulness of aural components.

2.2.1 Intensity

A chi-square test revealed that participants were more likely to recall earthquake intensity level correctly when the message included a numerical representation of intensity ($\chi^2 = 78.049$, df = 7, $p < 0.0001$). In other words, participants more accurately recalled the numeral "7" than the phrase "strong shaking." Qualitative responses indicated confusion, however, regarding what the number "7" actually means. Some noted that "the number was important," but many also claimed that "many people don't known what INTENSITY means." One respondent wrote, for example, "I assume the 7 means 7 out of 10?" Thus, although respondents could recall seeing the number "7," many did not know what it meant. Therefore, if a numerical representation is present in the warning message, the message must also somehow indicate its meaning and/or prior instruction may be necessary for it to be truly meaningful/effective.

2.2.2 Location

Four of the eight conditions tested included a map indicating the epicenter of the earthquake in relation to well-known California cities and highways and four did not. Participants viewing a message without a map were more likely to recall the earthquake's location incorrectly or not at all than those viewing a message that included a map ($\chi^2 = 43.831$, df = 7, $p < 0.0001$). Qualitative analysis of open-ended responses confirmed the value of the map. Participants viewing the map reported, for example, that "the map showing the general area of the quake was important" and "the map helped me realize where the earthquake was occurring." Moreover, some commented about the size of the map saying, "the map was far too small to be useful." Those viewing a message without a map made queries such as: "Did I miss the location?" Based on these results, then, the prototype messages should include a map and the map should be large enough to see easily via a smart phone app.

2.2.3 Countdown

Four conditions provided countdowns represented numerically and four offered countdowns represented in graphic form. The quantitative analysis revealed no statistically significant differences in terms of message recall or effectiveness. The qualitative analysis of the open-ended responses provided insight as to why. When participants viewed the numerical countdown, some reported that the static image was confusing because it did not actually count down from 6 to 5, 4, 3, 2, and 1. Moreover, participants that viewed conditions that conveyed both the countdown and the intensity in numerical form were confused about the meaning of each one. When participants viewed the graphic countdown, they also indicated confusion due to the fact that it was static and did not actually move as the number of seconds to impact declined. Many commented as this participant did: "I'm not sure what the pie graph was supposed to represent." Regardless of the version participants viewed, many suggested using a countdown clock (stopwatch image or digital clock face: 06, 05, 04 that actually ticked down with each second). As one participant noted, "a countdown clock would underscore the importance of acting quickly." Clearly, additional message refinement using an active countdown was warranted.

2.2.4 Perceived helpfulness

Perceived helpfulness was measured using a Likert-type scale ranging from 1 to 5, where 1 was least helpful and 5 was most helpful. In addition, open-ended responses were collected and analyzed for recurring themes. Perceived helpfulness results were analyzed and reported for visual images and aural components.

An Analysis of Variance test revealed significant differences among conditions. Regarding visuals, messages that did not include maps and numerical intensity indicators were perceived as least helpful ($F(7,188) = 7.789$, $p < 0.0001$). These results support previous findings regarding location and intensity indicators.

An Analysis of Variance revealed no significant differences in the perceived helpfulness of the app based on the alert sound or the speaker's voice. Since this phase one experiment did not examine different alert message sounds or speaker voices, this result is not surprising. The qualitative analysis did reveal several dominant themes, however, regarding aural components that may inform future message design and testing. Regarding the alert sound, for example, participants responded it "was too light and high pitched" and "should also vibrate the phone." Some also argued "it should be the same as other national emergency radio announcements." Others contended that it should be the same as the sound used in Japanese earthquake warning messages. Regarding the speaker's voice, some claimed that recognizing the voice of Lucy Jones provided a sense of credibility. In other words, the voice "has meaning because I recognize it is Dr. Lucy Jones I find her voice compelling and reassuring." Thus, this qualitative analysis suggests that the familiar voice of a noted expert may be most important for fostering trustworthiness. These preliminary findings support the meta-analysis of hundreds of communication studies drawing similar conclusions that there are, in fact, negligible differences in perceived credibility and effectiveness based on sex and perceived gender [9].

2.2.5 Phase one summary and next steps

The results of phase one of this research project revealed several findings:

- Participants were significantly more likely to recall the location of the earthquake when the app included a map. They also perceived the apps that included a map to be most helpful.

- Participants were significantly more likely to recall the intensity level of the earthquake when a numerical indicator was included. However, a qualitative analysis of open-ended responses revealed a great deal of confusion about what this number means.

- No significant differences were found among apps that used numerical versus graphical countdown imaging. The qualitative analysis of open-ended responses revealed confusion because neither countdown approach actually counted down by seconds from 6, to 5, 4, 3, 2, and 1. Participants indicated a desire to see the seconds dropping via an image that represents a digital clockface or stopwatch-type image.

- This phase one pilot project did not test different alert sounds or voice commands statistically as the project was already comprised of eight conditions. However, a qualitative analysis of open-ended responses revealed that participants believed the alert sound should be familiar (e.g., similar to the one used in the US for other warning messages or similar to the one being used already in Japan for earthquake warning messages).

Based on these results and input from risk and crisis communication specialists, seismologists, and emergency manager practitioners, the research team moved into phase two of the project. More specifically, the researchers used this information to refine the prototype IDEA model messages down from eight to four conditions and created a control message based on the existing ShakeAlert warning message computer program used by emergency managers throughout the US west coast states at the time.

2.3 Message testing: phase two

Based on the results of phase one message testing and focused feedback from crisis and risk communication subject matter experts, seismologists, and practitioners, the original eight conditions were reduced to four. These four treatment conditions were manipulated as follows:

1. Japanese alert sound with numerical intensity display

2. US alert sound with numerical intensity display

3. Japanese alert sound with verbal intensity display

4. US alert sound with verbal intensity display

The map either rotated with the numerical intensity display or with the verbal intensity display. All other elements were the same across the four conditions (map, countdown, action steps).

The demographics for the sample (N = 294) for phase two was 62.5% female and 37.5% male, 88% Caucasian, and age (M = 47.5; SD = 14.04). Regarding socio-economic status, 52% of the sample reported an annual income of $70,000 or more and 32% currently live in southern California. Of the 294 respondents, 133 provided comments in response to the prompt: "Please provide any additional feedback you believe would be helpful concerning the quality of the app." Key findings from this round of message testing focus on perceived quality of the app overall, as well as intensity (verbal/numerical), location (map), and behavioral intentions (drop/take cover/hold on).

2.3.1 Perceived quality of the app

A series of stepwise regression analyses were conducted to examine the research question about perceived quality of the app. The single item asking about the quality of the app used a five-point Likert type response scale (1 = very effective to 5 = not effective). Overall, 75% of the participants across conditions rated the app as "effective" or "very effective" and only 2% rated the app as "not effective." On the first block, demographic variables were entered in order to account for any variance attributable to respondent characteristics. These included sex, age, race/ethnicity, and income. The second predictor block included these variables, as well as experimental condition. The examination focused on significant models and predictors, as well as potential improvements based on the addition of experimental condition.

The results for the first predictor block indicate a significant model, $F(4, 223) = 6.775$, $p < 0.001$. $R^2 = 0.108$. Of the demographic variables only sex $\beta = -249$ $p < 0.000$, and age $\beta = -175$ $p < 0.01$ were predictive of ratings of app quality. When experimental condition was added to the predictor block a significant model was also produced, $F(5, 222) = 4.32$, $p < 0.001$, $R^2 = 0.112$. However, the change in variance accounted for was not significant $\Lambda R^2 = 0.004$. Of the variables in the predictor block, only sex $\beta = -245$ $p < 0.000$, and age $\beta = -176$ $p < 0.01$ were predictive of ratings of app quality.

A t-test was conducted for the variables of sex and overall quality across conditions. Women (M = 1.73 SD = 0.81) were more likely than men (M = 2.14, SD = 1.04) to rate the app as being of high quality $t(2) = 3.592$, $p < .001$. Sex differences in perceptions of app quality were then broken down by each condition. Differences were found for condition 2, where women (M = 1.61, SD = 1.12) reported higher perceptions of app quality than men (M = 2.30. SD = .74) $t(2) = 2.696$, $p < 0.01$, and condition 5 where women (M = 1.70, SD = 0.65) reported higher perceptions of quality than men (M = 2.19, SD = 1.01) $t(2) = 2.190$, $p < 0.05$.

Perhaps most important here is that participants in all treatment conditions rated the quality of the app as high. Since all treatment conditions used similar content based on the IDEA model (i.e., alert sound, oral and visual countdown, intensity level, map, actionable instructions), it seems the appropriate content is being included. Moreover, a thematic analysis of the open-ended responses revealed that those viewing the control (ShakeAlert) condition were "overwhelmed by the visuals" and wanted to see and hear directions to "duck, cover, and hold on." These themes suggest that (a) too much information, although accurate, can defeat the purpose of the warning and (b) specific action steps need to be included. In addition to perceived quality of the app, the researchers sought to learn more regarding numerical versus verbal intensity displays, the effect of the map in location cognition (proximity), and behavioral intentions to take appropriate self-protective actions.

2.3.2 Intensity

Key findings from this round of message testing regarding intensity are as follows. First, there were no significant differences among conditions regarding intensity. However, an exploration of descriptive statistics shed additional light on this issue. When asked "how important is it to know the kind of shaking," 76–87% reported it as very important across all conditions. Moreover, 77–85% of the respondents across conditions answered correctly (i.e., 10 seconds or less) when asked when the shaking would begin.

Important findings emerged when asked what kind of shaking would occur. It is encouraging to note that 77–93% of the respondents reported correctly that very strong shaking was going to occur. The researchers placed a screen shot before entering the survey that summarized the meaning of the numerical intensity numbers. When respondents that viewed the verbal intensity display were asked about the numerical intensity level (8), only 15 and 22.4% recalled the correct number. Of the respondents that viewed the numerical intensity display, 69 and 80% recalled the correct number. Of the respondents that viewed the control (ShakeAlert) message, only 35.5% recalled the correct number. This low percentage may be impacted by the amount of detailed information being displayed in the control message. So much information may be difficult to process in 10 seconds or less and, thus, may result in misunderstanding.

Subsequently, when asked how well they understand the meaning of intensity level numbers, 48.4 and 38.8% of those viewing the verbal display marked "very well." Respondents that viewed the numerical intensity display reported knowledge comprehension of "very well" at 56.7 and 56.5%. Those viewing the control (ShakeAlert) message reported knowing the meaning very well at 45.9%. These results suggest the verbal intensity display is more meaningful than the numerical display. These results also suggest that displaying both (as in the control ShakeAlert message) appears to be too much information to process accurately in a short amount of time.

2.3.3 Location

All conditions included a map identifying where the shaking was going to occur. There were no significant differences among the conditions regarding the importance of the map or for accurate location identification. Across conditions, 74–92% reported a map as "important" or "very important." A somewhat troubling finding, however, was that when asked where the shaking was going to occur, only 33–55% answered correctly (Los Angeles area) across conditions. When the researchers drilled down to include only participants currently living in southern California, the results improved slightly among the four treatment conditions (64–74% correct). However, only 29% of the respondents that viewed the control (ShakeAlert) message answered correctly. Moreover, when asked how helpful the visual images were in conveying information about location, only 27.9–50% said "very helpful" across conditions. However, in all four treatment conditions, respondents reported more preference for the visual images (M = 1.90, SD = 1.82) than those in the control condition (M = 2.26, SD = 1.30) $t(2) = -2.106 = p < 0.05$. Moreover, a thematic analysis of the open-ended comments revealed a desire for a simple map that merely showing a familiar city with a bullseye target or location flag would be more helpful than one showing both the epicenter and location where shaking will occur. Taken together, these results suggest that a simple map highlighting the location may be more effective than a detailed one showing lots of information.

2.3.4 Behavioral intentions

A series of stepwise regression analyses were conducted to examine the research question regarding behavioral intentions. The composite measures were used to assess perceptions of behavioral intentions. The measure for behavioral intentions used nine items with a response scale of 1 = "Very Unlikely" to 5 = "Very Likely." On the first block, demographic variables were entered in order to account for any variance attributable to respondent characteristics. These included sex, age, race/ethnicity, and income. The second block added experimental condition to these possible predictor variables. The analyses focused on significant models and predictors, as well as possible improvement to the model based on the addition of experimental condition.

The results for the first predictor block did not indicate a significant model, $F(4, 227) = 0.989$, p = n.s. $R^2 = 0.017$. None of the demographic variables were predictive of behavioral intentions. When experimental condition was added to the predictor block the model did not improve, $F(5, 229) = 0.788$, p = n.s., $R^2 = 0.017$. None of the variables in the predictor block were predictive of behavioral intentions.

The fact that no significant model stood out as a better predictor for behavioral intentions combined with the descriptive statistics suggest that the including the IDEA model components as we did in each condition may be effective for earthquake early warning messages delivered via a smart phone app. Although the means reported are encouraging, the fact that the pretest self-efficacy (M = 4.44) also may point to a respondent pool comprised of members of a disaster sub-culture that is already pre-disposed to taking appropriate actions for self-protection.

3. Conclusions

Several promising conclusions may be drawn from these two rounds of message design and testing. First, a phone APP can be designed in ways that employ the IDEA elements of effective instructional risk and crisis messages for earthquake early warnings in 10 seconds or less. Second, the elements of the IDEA model do appear to positively influence affective (perceived value/importance), cognitive (comprehension), and behavioral (efficacy and intention) learning outcomes.

Also based on these message testing results, however, more honing of some particulars are still warranted. For example, with regard to internalization, the design of the map (proximity) needs to be simplified to ensure accurate comprehension of location. Regarding explanation, it appears that verbal intensity displays are more effective than numerical displays unless a comprehensive educational campaign could be conducted to teach users what the different numbers mean.

The sample for both rounds of message testing was not representative of the entire population in southern California. Additional message testing targeting more representative demographic diversity and marginalized populations is warranted in order to be certain about ultimately launching the most effective warning app.

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Chapter 3

Knowledge and Perception on Seismic Risk of Students in Mexico City Before the 2017 Earthquakes

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Abstract

This paper presents some of the results of a cross-sectional study conducted in Mexico City in 2015–2016. The approach has been the application of a questionnaire to a sample size of $n = 1489$. Six high schools participated in the study that are located within the seismic zones of the city. Some of the results and conclusions are given below: (a) 95% of the students have experienced an earthquake and 71% considered that earthquakes cannot be predicted; however, 29% did not know this fact; (b) 82.2% of students were all aware of the likelihood of an earthquake occurrence sometime in the future. (c) One of the key conclusions is associated with the need to educate the residents of the capital city on a more realistic scale of the size of an earthquake; this could be the "Modified Mercalli Intensity Scale" or similar. (d) More generally, the residents of the city should be educated with urgency on these basic concepts. The more effective is the communication on risks and consequences, the better may be their preparedness to earthquakes.

Keywords: risk perception, earthquake, Mexico City, students, education

1. Introduction

Communities have been exposed to disasters and extreme events. For example, earthquakes have caused destruction worldwide in recent years [1–7]. Some of them have triggered tsunamis with catastrophic consequences, such as in the cases of Indonesia in 2004 [1] and Japan in 2011 [3]. More recently, it is believed that a tsunami was triggered by a landslide caused by a volcanic eruption in Indonesia in 2018 killing hundreds of people [8].

Preparedness to natural disasters is essential to mitigate the impact of earthquakes. Research has shown that, for example, culture belief has an influence on people's reactions to risk [9–12]. Moreover, some studies have shown that in some cultures people shows a fatalistic attitude to earthquake disasters as acts of God [12] and that nothing can be done about it.

On the other hand, some scholars argue that emergency preparedness and reduction of vulnerability, among others, are strongly influenced by both past disaster experience and risk perception [13]. Moreover, it is thought that risk perception is a function of communication [13, 14]. That is, risk communication plays an important role between those in charge of making decisions, for example, on preparedness, disaster knowledge, and people exposed to seismic risk [13, 14].

This chapter presents some preliminary results of seismic risk perception and other natural hazards (e.g., volcanic eruption and floods). It also presents some results on the knowledge on some basic concepts related to the earthquake prediction, among others. The approach has been the application of a questionnaire to a sample size of n = 1489; the study has been conducted in 2015–2016. The results are discussed in the context of past earthquakes (i.e., those that occurred before the study was conducted) and the 2017 earthquakes that hit the capital city.

2. Research methods

A cross-sectional study was conducted in 2015–2016 in Mexico City; the sample size considered in the analysis was n = 1489. Six high schools decided to participate in the study, and all of them were located within the critical areas of the city, i.e., the seismic zones defined as "zones I, II, and III." A questionnaire was designed to capture the data on several issues related to seismic risk perception, other natural hazard perceptions, and knowledge on actions to take during the occurrence of an earthquake, among others (however, the results of the few questions are reported here). The questionnaire was pretested before the final application to the sample; it took about 25 min to complete. The questionnaires were applied from December 2015 to March 2016.

The analysis of the collected data was done by conducting frequency analysis, and the relationship among the variables was performed by conducting cross tabulations. Overall, a basic descriptive statistical analysis of the variables considered in the analysis is presented here; some of the results associated with an inferential analysis are presented elsewhere.

The results related to the following questions are presented in the next section:

a. "Have you experienced an earthquake?"

b. "How does the magnitude of an earthquake being measured?"

c. "Can an earthquake be predicted?"

d. "How likely an earthquake will occur in the future?"

e. "If any of these events happen in the future, how likely is it that it will affect you?"

3. Results and discussion

3.1 Experience and earthquake prediction

As mentioned in the previous section, the questionnaire was applied to a particular kind of population, i.e., students from six high schools in the capital city. The demographic characteristics were the following: the range of age were from 14 to 19 years old; the highest percentage of them was for the case of students with 16 years

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old (34.1%) and the lowest was represented by students from 14 years old (3.1%). Regarding the gender of the participants, 48.6% were women and 51.5% men.

When considering the experience of the participants in relation to earthquakes, **Figure 1a** shows the results. It can be seen that 95% of the students have experienced an earthquake; only 5% did not. This is consistent with the fact that the frequency of earthquake occurrence before the study was conducted in 2015 was unusually high.

For example, according to the "National Seismological Service" (SSN) statistics, from 1 January to 31 December 2014 (a year before the study), there were about 7588 earthquakes [5], that is, an average of 632 earthquakes per month. It also should be emphasized that there are seven strong earthquakes of magnitudes > 6.0. Moreover, earthquakes on the range of magnitudes 3.0–3.9 (i.e., 6343 events) were those that occurred most frequently in 2014. This was followed by those in the range of 4.0–4.9, with a total of 955 events [5].

When asked the following question, "can an earthquake be predicted?", the possible responses to the question were the following: "Yes," "No," and "I do not know" (**Figure 1b**). The results showed that about 71% of students responded "No," which may be regarded as the right answer. Interestingly, 29% of the participants did not know this fact (i.e., 9.4% "Yes"; 19.5% "I do not know"). Effectively, earthquakes still cannot be predicted. There has been a vast amount of studies published in the literature on this very topic [15–19].

3.2 Seismic risk perception

Also, we were interested to know how the participants perceived the seismic risk threat at that time of the study. The following question was included in the questionnaire, "how likely an earthquake will occur in the future?" The possible answers to the question were the following: "Not likely," "Somewhat likely," and "Very likely." The results are shown in **Table 1** and **Figures 2**-**4**.

Overall, students were aware of the likelihood of an earthquake occurrence sometime in the future when the study was conducted. That is, 82.2% (1212/1475) responded "Very likely" and 15.2% (227/1475) "Somewhat likely," and 2.4% (36/1475) considered "Not likely" for the occurrence of an earthquake.

The relationship between seismic risk perception and those variables related to gender, age, and schools is presented in **Table 1** and **Figures 2**-**4**. For example,

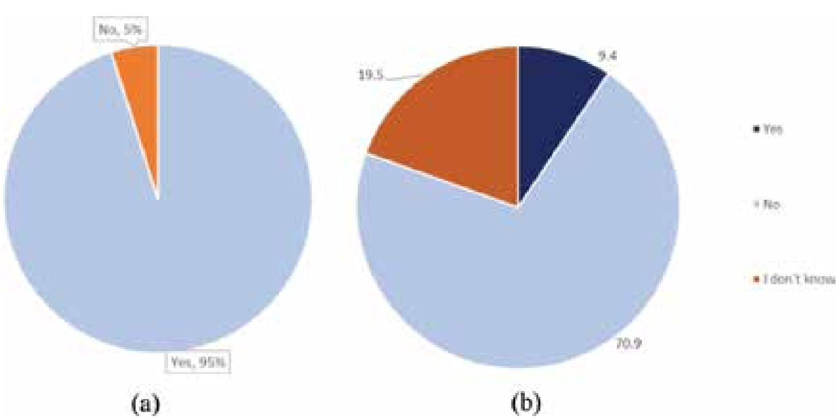

Figure 1.
Experience and the magnitude of an earthquake: (a) experience on earthquakes and (b) scale of the magnitude of an earthquake.

	"Not likely", N (%)	"Somewhat likely", N (%)	"Very likely", N (%)
Age			
14	0 (0.0)	12 (26.1)	34 (73.9)
15	17 (5.2)	67 (20.7)	240 (74.1)
16	9 (1.8)	65 (12.9)	430 (85.1)
17	5 (1.3)	62 (15.6)	329 (82.9)
18	4 (2.6)	15 (9.7)	136 (87.7)
19	1 (2.1)	6 (12.5)	41 (85.4)
Gender			
Women	10 (1.3)	107 (14.1)	644 (84.2)
Men	26 (3.6)	120 (16.8)	566 (79.3)
Schools			
School 1	2 (1.1)	20 (11.4)	154 (87.5)
School 2	2 (1.0)	16 (7.8)	186 (91.2)
School 3	5 (1.4)	37 (10.7)	303 (87.3)
School 4	8 (2.7)	29 (9.7)	262 (87.6)
School 5	13 (4.9)	111 (41.7)	142 (153.4)
School 6	6 (3.3)	14 (7.7)	163 (89.1)

Table 1.
Seismic risk perception.

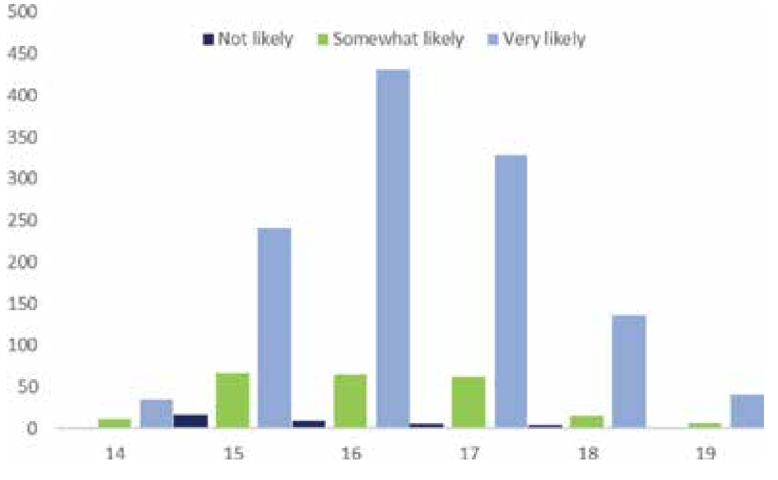

Figure 2.
Seismic risk perception and age of the participants.

when considering the age of the participants, interestingly, participants whose age was 16 years old were the ones that score the highest percentage (29.2%, 430/1473), which was followed by students from 17 (22.3%, 329/1473), 15 (16.3%, 240/1473), and 18 years old (136/1473). On the other hand, only 2.5% of the participants were unaware of the threat of seismic risk at the time of the study. Overall, it may be argued that about 70% of the participants are aware of the seismic risk (**Figure 2**).

Figure 3 shows the results of the relationship of the variables related to earthquake risk perception and the variables related to the gender of the students.

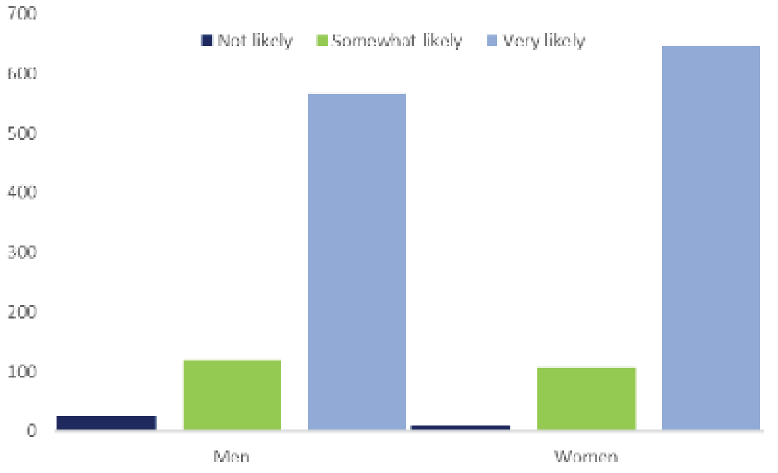

Figure 3.
Seismic risk perception and the gender of the participants.

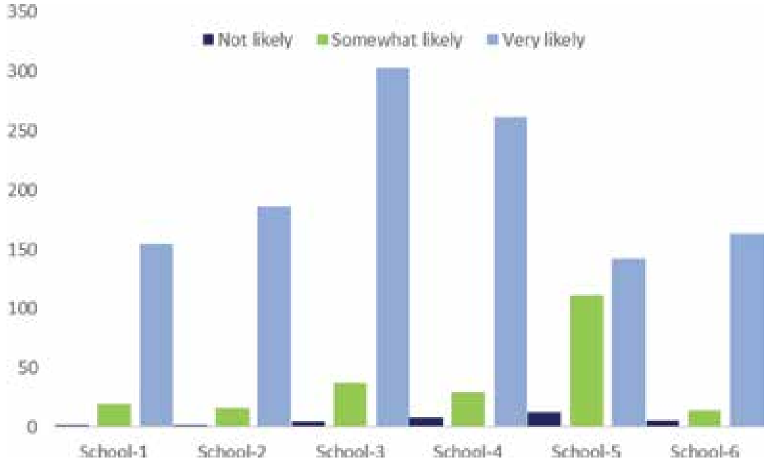

Figure 4.
Seismic risk and the schools located in different seismic risk zones of the city.

From the figure, it can be seen that women were more aware of the seismic risk (i.e., "Very likely") than men, with 43.7% (644/1473) and 38.42% (566/1473), respectively.

Finally, when considering the schools (**Figure 4**), the one which is located within the zone of highest seismic risk (i.e., school 3) scores the highest percentage of the likelihood of an earthquake occurrence (20.6%, 303/1473); this was followed by school 4 (17.8%, 262/1473).

3.3 Seismic risk vs. other natural hazards

As in many places in the world, Mexico City may be affected with a number of natural hazards, and among them are earthquakes, floods, and volcanic eruptions (e.g., the "Popocatépetl" volcano, which is located at about 72 km from the capital city). In order to assess the awareness of the participants of the study on these hazards, the following question was included in the questionnaire: "If any of these events happen in the future, how likely is it that it will affect you?"

The results showed that earthquakes were regarded as an event "Very likely" to occur in the future at the time of the study, that is, "Very likely" (82%, 1210/1475), "Somewhat likely" (15.5%, 228/1475), and "Not likely" (2.5%, 37/1475). Then it was followed by floods ("Very likely" (27%, 398/1475); "Somewhat likely" (53.9%, 795/1475); "Not likely" (19.1%, 282/1475)). Finally, volcanic eruption came third ("Very likely" (18%, 265/1474); "Somewhat likely" (43.4%, 639/1474); "Not likely" (38.7%, 570/1474)).

Table 2 shows, on the other hand, the results of the relationship between the participants' perception on other natural hazards and the gender of the participants.

Overall, it can be argued that the participants of the study were aware of the likelihood of the occurrence of these events. Effectively, seismic events were at the top of this likelihood, given that earthquakes occurred very often prior to the study (i.e., in 2014 as shown in Section 3.1).

Regarding floods, usually the capital city is heavily affected with heavy rains (and in particular during the raining season). For example, apart from the households and avenues being flooded, the public transport system is also affected and consequently the urban mobility. In particular, the Metro transport system, for example, during the raining season, the metro lines (some of them) are usually flooded. For example, in relation to this problem a politician said this:

> *"The strongest crisis due to rain that occurred in the Metro last year began in May, when due to the saturation in the drainage network, the water flooded in from outside to the corridors of Cuatro Caminos, Pantheons, and Tacuba stations. (Metro) Line 2 reaching up to 15 cm in height. This week in Mexico City we have already started with the first heavy rains of the year, and due to the climate change, that we are experiencing, it is difficult to know exactly when storms can occur, so the Metro must be prepared not to suffer damages, guarantee the service and protect (the) users." [20]*

Finally, the participants' perception on the occurrence of a volcanic eruption was "Not likely" (38.7%, 570/1474). Interestingly, there was an eruption in 2017 and 2018. That is, at about 17:54 in 2017, the Popocatépetl volcano exhaled a "fumarole" of about 4 km [21]; similarly, in 2018, the volcanic registered an explosion at about 18:58 [22]. It is important to mention that every time an eruption occurs, usually the areas where the participants came from are unaffected by these eruptions.

	"Not likely", N (%)	"Somewhat likely", N (%)	"Very likely", N (%)
Earthquake			
Women	10 (1.3)	107 (14.1)	644 (84.6)
Men	26 (3.6)	120 (16.8)	566 (79.3)
Volcanic eruption			
Women	298 (39.2)	335 (44.1)	127 (16.7)
Men	272 (38.1)	304 (42.6)	138 (19.3)
Floods			
Women	162 (22.7)	120 (15.8)	235 (30.9)
Men	120 (15.8)	389 (54.5)	162 (22.7)

Table 2.
Seismic risk perception on other natural hazards.

Given the results presented above, it may be argued that participants considered seismic risk as their top threat when compared to floods and volcanic eruptions. Effectively, the two powerful earthquakes in 2017 that hit the capital city demonstrated that their worries came true.

3.4 Richter vs. Mercalli scales

Regarding the question "how the magnitude of an earthquake is measured?", the possible responses to the question were the following: "Mercalli," "Richter," and "I do not know" (the results are presented in **Figure 5**). As expected, most of the participants considered "Richter" (i.e., 96%). Only 3% did not know, whereas only 1% considered "Mercalli."

However, the above raises the question as to whether the high percentage of the participants (96%) really knows the meaning of the Richter scale. Two key concepts regarding the measure of the size of an earthquake are magnitude and intensity [23]. The seismic energy released during an earthquake occurrence is measured by the magnitude, and it is commonly measured in a Richter scale. However, "Richter magnitude" (it is believed that it was named after Charles Richter who proposed the measure), may be regarded a measure only appropriate for earthquakes originating in California, USA [23]. Given this confusion, the moment magnitudes have become a universally appropriate scale (M_w) [23].

But what is the intensity of an earthquake? How is it measured? It is thought that intensity measures the consequences of an earthquake; that is, it is based on the observations made by people (as opposed to the Richter scale which employs instrumental measurements), and, consequently, it varies from place to place. The intensity is measured by what is known as the "Modified Mercalli Intensity Scale" (MMIS) [24].

What can we say about this in the context of the earthquakes that occurred in Mexico City in 2017? Was the Richter scale meaningful to the participants of the study? Was it meaningful to the residents of the capital city? The answer may be probably no. In fact, following the 2017 earthquakes, there was a debate on the mass media on this very issue. That is, it was a confusion among the residents of the city regarding the "intensity" felt by them during the two earthquakes that occurred on 7 and 19 September 2017. That is, for the earthquake on September 7 (magnitude of 8.1), with epicenter on the Pacific coast, the shaking was felt not that strong as the one on September 19 (with a magnitude of 7.1). Moreover, the consequences of the

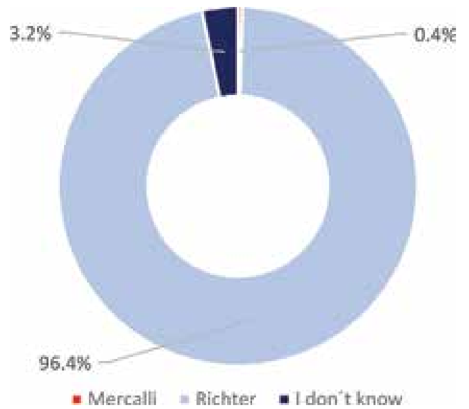

Figure 5.
Responses on the magnitude of an earthquake.

latter were severe in the city killing hundreds of people, but with a 7.1 of magnitude. These facts caused confusion among the residents.

For example, in an interview, the head of the "National Seismological Service" (SSN) argued that in relation to the earthquake on September 19, 2017

> *"although it was smaller (the one on 19 September) than (the one on) the 7th of this month (September) and emitted less energy, "it was more intense for Mexico City because we are closer to the epicenter and because of the vulnerability of some areas (of the city) because are located in the lacustric soil." [25]*

Moreover, the head of the SSN went on saying that

> *if people say it (the one in 19 September) was stronger than the one on 7 September or the one in '85 (1985), they are right, it is their perception, but it was smaller in size and energy released [25].*

The above clearly illustrates the difference between magnitude and intensity of an earthquake. Moreover, it may be argued that for the general public, it may be easier to understand the effects brought about, for example, by the two earthquakes just mentioned above in the context of the Mercalli Scale. Furthermore, it may be argued that people need to be well educated on these basic concepts. Also, it is of paramount importance to educate the residents of the capital city, for example, that damages caused by earthquakes depend on the distance from the epicenter, the type of soil, etc. Ultimately, the more effective is the communication on seismic risks and consequences, the better may be their preparedness to earthquakes.

3.5 Education on seismic risk

Respondents of the study were also asked whether they would like to be further educated on topics associated with seismic risk (the possible responses were "Yes" and "No"). The results showed that 83.5% of the students wanted to learn more on earthquakes and 16.5% showed no interest at all on this (**Figure 6**).

Table 3 shows the results of the relationships of the variables considered in the analysis. Overall, when considering the age of the participants of the study, those whose age were 15, 16, and 17 years old showed more interest in learning more on earthquakes (69.5%, 1027/1479). On the other hand, women score a higher percentage than men in the willingness to learn more on seismic risk (i.e., 44.9%, 664/1479 vs. 38.6%, 571/1479). Finally, when considering the location of the participant schools, school 3 scored the highest percentage on their willingness to be educated on this very important and necessary subject (i.e., 19.6%, 290/1479).

Effectively, the results showed that there was (and still is) a great interest in learning more on seismic risk, for example, on what actions to take before, during, and after the occurrence of an earthquake. Moreover, the recent earthquakes in 2017 demonstrated that Mexico City's residents lacked an adequate preparation. Furthermore, it may be argued that organizations in charge of responding to the emergency (i.e., after the earthquake) were deficient in many respects, for example, the capacity of the rescue team in dealing with rescue during the emergency (e.g., in both aspects of "human" and infrastructure capacity). In most of the cases, the affected residents were themselves looking for their friends, relatives, etc., under the rubble. This clearly showed that emergency response teams need to be better prepared and well trained to cope with emergencies, such as those after the occurrence of the two earthquakes.

Students were also asked in which ways they would like to learn more on the subject; the possible answers were the following: "books," "the Internet," "at school,"

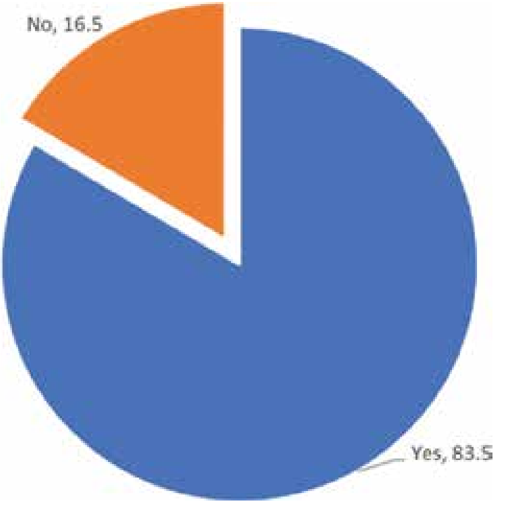

Figure 6.
Learning more on seismic risk.

	Yes, N (%)	No, N (%)
Age		
14	35 (2.8)	10 (4.1)
15	272 (22.0)	58 (23.8)
16	424 (34.3)	82 (36.6)
17	331 (26.8)	64 (26.2)
18	133 (10.8)	22 (9.0)
19	40 (3.2)	8 (3.3)
Gender		
Women	664 (53.8)	95 (38.9)
Men	571 (46.2)	149 (61.1)
Schools		
School 1	160 (13.0)	18 (7.4)
School 2	173 (14.0)	29 (11.9)
School 3	290 (23.5)	57 (23.4)
School 4	244 (19.8)	56 (23.0)
School 5	211 (17.1)	57 (23.4)
School 6	157 (12.7)	27 (11.1)

Table 3.
Relationship between the variables regarding to the willingness to learn more on seismic risk.

"civil protection," "radio-TV," and "others" (the results are shown in **Figure 7**). The frequency data showed that the participants considered "civil protection" as the preferred option to learn more on earthquakes (44.1%, 549/1245). This was followed by "school" (22%, 274/1245) and finally "the Internet" (20%, 249/1245).

Table 4, on the other hand, shows the results of the relationships between variables considered in the analysis. In general, when considering the age of the participants of the study, those whose age was 16 years old showed more interest in

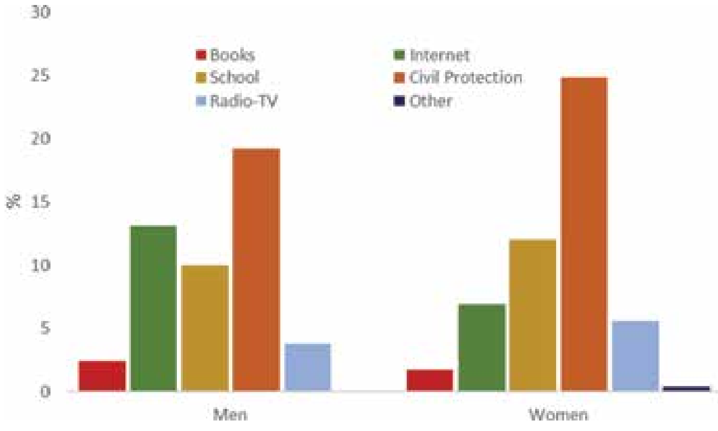

Figure 7.
Preferences in learning more on seismic risk.

	Books, N (%)	The Internet, N (%)	School, N (%)	Civil protection, N (%)	Radio-TV, N (%)	Others, N (%)
Gender						
Women	21 (41.2)	86 (34.5)	149 (54.4)	310 (56.5)	70 (59.8)	5 (100.0)
Men	30 (58.8)	163 (65.5)	125 (45.6)	239 (43.5)	47 (40.2)	0 (0.0)
Age						
14	6 (11.8)	11 (4.4)	8 (2.9)	15 (2.7)	0 (0.0)	0 (0.0)
15	12 (23.5)	59 (23.7)	53 (19.3)	124 (22.6)	25 (21.4)	2 (40.0)
16	16 (31.4)	80 (32.1)	92 (33.6)	195 (35.5)	34 (29.1)	2 (40.0)
17	14 (27.5)	66 (26.5)	73 (26.6)	139 (25.3)	37 (31.6)	1 (20.0)
18	3 (5.9)	24 (9.6)	42 (15.3)	59 (10.7)	14 (12.0)	0 (0.0)
19	0 (0.0)	9 (3.6)	6 (2.2)	17 (3.1)	7 (6.0)	0 (0.0)
Schools						
School 1	7 (13.7)	22 (8.8)	31 (11.3)	89 (16.2)	7 (6.0)	2 (40.0)
School 2	4 (7.8)	22 (8.8)	60 (21.9)	65 (11.8)	15 (12.8)	1 (20.0)
School 3	10 (19.6)	80 (32.1)	54 (19.7)	129 (23.5)	28 (23.9)	1 (20.0)
School 4	15 (29.4)	47 (18.9)	48 (17.5)	107 (19.5)	23 (19.7)	0 (0.0)
School 5	7 (13.7)	51 (20.5)	52 (19.0)	100 (18.2)	25 (21.4)	1 (20.0)
School 6	8 (15.7)	27 (10.8)	29 (10.6)	59 (10.7)	19 (16.2)	0 (0.0)

Table 4.
Preferences in learning more on earthquakes.

learning more on earthquakes through "civil protection" organization (35.5%), followed by "school" (33.6%), "the Internet" (32.1%), and "books" (31.4%). Further, women score a higher percentage than men in the willingness to learn more on seismic risk through "civil protection" (i.e., 56.5% vs. 43.5%). Finally, when considering the location of the participant schools, school 3 scored the highest percentage on their willingness to be educated by "civil protection" on the subject (i.e., 23.5%).

The results clearly showed the need to educate the residents of the capital city, that is, not only students but also the general public, on issues such as those topics covered here and others relevant to specific actions to take before, during, and after an earthquake occurrence.

4. Conclusions

This chapter has presented some of the results of a cross-sectional study conducted in Mexico City in 2015–2016. The approach has been the application of a questionnaire to a sample size of $n = 1489$. Six high schools participated in the study are located within the seismic zones of the city. Some of the results and conclusions are given below:

a. About 95% of the students have experienced an earthquake, and 71% considered that earthquakes cannot be predicted; however, 29% did not know this fact.

b. About 82.2% of students were all aware of the likelihood of an earthquake occurrence sometime in the future; the occurrence of the two strong earthquakes that hit the city in 2017 confirmed their perception.

c. In relation to the question related to how the size of an earthquake is measured, as expected, 96% of the participants considered the "Richter" scale; however, this raises the question as to whether the participants really know the meaning of the scale.

d. One of the key conclusions is associated with the need to educate the inhabitants of the capital city on a more realistic scale of the size of an earthquake; this could be the "Modified Mercalli Intensity Scale" (MMIS).

e. More generally, the residents of the city should be educated on these basic concepts. Moreover, the more effective is the communication on risks and consequences, the better may be their preparedness to earthquakes.

f. It appears that civil protection should take the lead in designing an education program on seismic risk, which could be implemented at schools; moreover, it should be implemented with urgency.

Some future research is needed, such as that associated with an inferential analysis of the collected data.

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Conflict of interest

The authors declare that they have no competing interests.

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Section 3

Vulnerability

Chapter 4

Earthquake Disasters and the Long-Term Health of Rural Men in Chile: A Case Study for Psychosocial Intervention

Oscar Labra, Robin Wright, Danielle Maltais, Gilles Tremblay, Ray Bustinza and Gabriel Gingras-Lacroix

Abstract

The article focuses on the long-term health of a rural male population exposed to a major earthquake event in Chile, in 2010. The results show that a majority of the male study participants considered that their physical and mental health had deteriorated over a 7-year span following the earthquake and that these impacts were strongest in men aged 65 years or more. In considering potential lessons for intervention, the results must be interpreted within the context of the construction of male identities in a rural community, informed by generally conservative values and binary male-female gender roles. The article concludes that health and social services workers and administrators providing interventions to male populations following earthquake must work to reduce the gap between the service offer and men's real needs, which are frequently insufficiently understood and inadequately coded.

Keywords: helping professionals, men, rural community, natural disaster

1. Introduction

The present article aims to describe the long-term health impacts of a earthquake on men in a rural community. Survivors of natural disasters experience traumatic effects, whose intensity and gravity can vary in relation to risk factors present before, during and after the disaster event [1]. Previous studies have found that individuals exposed to a disaster event exhibit comparatively high incidences of depressive and somatic symptoms, emotional distress, memory impairment [2–7]. For example, in a study of 302 adults living in rural Australian communities, he was demonstrated that psychological distress levels were higher in individuals exposed to a disaster event than in those who were not [8]. Lazaratou et al. [9], for their part, found that over half of survivors exhibited post-traumatic stress (PTS) symptoms during a 6-month period following an earthquake and that, in some cases, the symptoms could persist up to 50 years after a disaster. Within populations of male disaster survivors, elderly individuals appear to be the most vulnerable [10–14], due to such factors as the presence of various health problems, reduced physical and cognitive autonomy, and hearing loss [15–18]. Other studies have also confirmed that the elderly are at higher risk of injury and death during and following exposure to a disaster event [13, 19–23].

A number of the health impacts of disasters identified in previous studies of rural populations appear to be linked with socio-demographic trends specific to these communities. According some studies, the stress levels of rural community residents in Canada are higher than those of individuals living in other types of communities [24]. This finding appears to be associated with the growing exodus of younger rural populations towards urban centres, resulting in such changes as economic restructuring and loss of social capital. Studies conducted [25, 26] found also that men living in rural regions in Québec, Canada exhibited rising levels of stress and depression. These results parallel those of similar studies conducted in Australia and Norway, which also demonstrate high levels of stress and depression in rural populations [27, 28]. In the case of Chile, although the overall number of suicides is higher in urban centers than in the less populous rural zones, the proportional suicide rate is higher in rural communities [29].

In terms of differences between the sexes, studies conducted in Australian rural communities show that men's suicide rates are significantly higher than women's [30–32]. As certain authors have argued, higher suicide rates among men than among women point to high levels of mental anguish and greater difficulties in facing changing circumstances, such as those linked with social, economic, and environmental crises [30, 33, 34]. Moreover, suicide rates appear to be particularly high for men involved in specifically rural professions, such as fishing, agriculture, and forestry [35, 36].

In terms of the physical health of men living in rural communities, a study carried out in the United States has shown that the prevalence of diabetes and mortality linked with coronary diseases was higher in rural than in urban communities [37, 38]. It appears also that residents of rural regions exhibit higher rates of chronic illnesses than do their urban counterparts [39–43] and that obesity is a major contributing factor in these disparities [44]. In addition, rural men exhibit higher rates of oral health problems [45], a trend that seems particularly pronounced among men with low levels of education [46, 47]. The health risk factors most commonly identified with men residing in rural regions are poverty, obesity [37, 44, 48] and tobacco use [49, 50].

Based on the results noted in the available literature, research suggests that men living in rural regions present higher incidences of physical and mental health problems than do men living in urban centers; the same finding also holds for rural men when compared with both rural and urban women. Although the impacts of natural disasters on survivors have received attention in the literature, little has been discerned as to long-term health outcomes for men exposed to natural disasters specific to rural contexts. The present article seeks to bridge that gap in the research.

2. Natural disaster management in Chile

On 27 February 2010, at 03:45 AM local time, one of the strongest earthquakes ever recorded (magnitude 8.8 Mw) occurred off the coast of Chile's Maule region (United States Geological Survey—USGS). The earthquake affected three of Chile's administrative regions, with a total population of 4 million people, or 23% of the country's population.

The earthquake caused enormous damages: 81,444 homes were destroyed and another 108,914 were severely damaged [51]; public infrastructures also suffered significant damages. The destruction most severely affected those most vulnerable, highlighting and often exacerbating pre-existing socioeconomic inequalities.

Public health infrastructures were affected, as well: of the 132 hospitals located in the disaster zone, between The Santiago Metropolitan Region in the centre and Araucanía to the south, 18 were rendered unusable, 31 sustained significant damage but remained functional, while 83 were largely unaffected [52].

The Chilean earthquake of 2010 prompted countries such as Australia, New Zealand and China to develop comprehensive earthquake response initiatives. The Chilean response was to adapt the scope of certain institutions in the event of natural disasters. Most notably, before 27 February 2010, natural disasters were the purview of the National Office of Emergencies, created in 1974. Following the earthquake, however, a separate National Civil Protection Agency was formed and tasked with, among other responsibilities, disaster preparedness under the National Civil Protection System, with aim of improving the country's disaster response capacity. However, the highly centralized administration structures of these state institutions results in substantial delays in terms of resource management, communications, and collaboration with other federal, provincial, and community actors. Chile's position remains precarious in terms of governance indices and public policy on risk and disaster management [53]. The author concludes that, when faced with major emergencies, the Chilean state has been more preoccupied with strengthening its communications system and maintaining the operational continuity of its institutions, rather than with investing in human capital. It is worth noting, as well, that the organization of Chile's public health system as a decentralized network produced both benefits and drawbacks in the aftermath of the earthquake: hospitals and health centres were able to react quickly at the local level, but the system lacked an integrated, inter-sectorial approach through which to reduce social inequalities affecting the delivery of care [54].

3. Conceptual framework

The present study's conceptual framework, which guided the collection and analysis of data, is informed by the salutogenic approach developed by Antonovsky [55]. The majority of explanatory theories of the male gender fail to acknowledge its positive aspects, which can be harnessed preventively to counter concomitant negative aspects, salutogenic approach provides a way of rectifying this lacuna [55]. The salutogenic approach is predicated on two key elements: the first is a focus on positive environmental factors conducive to health, rather than those that engender illness [56]; the second is termed the sense of coherence [56], that is, each individual's personal understanding of the surrounding world as consistent [57, 58]. According to the salutogenic model, an individual who perceives life as a coherent and meaningful whole is more likely to respond positively to difficulties than someone who perceives life as ruled by random events and, consequently, considers challenging situations to be the result of uncontrollable misfortune [55]. Salutogenesis has become a widely adopted concept in public health, particularly in health promotion.

Applying the ideas of some authors [55, 59] to men's health, Macdonald [59] argues against a focus on pathologies in attempts to understand men's health and for an approach that instead takes into account the economic, political, and social spheres in which problems arise in order to explain recurrent problems and work at creating environments conducive to better health. Macdonald states further that analyses should acknowledge 'spotlight cases' of men who faced life challenges positively, employing their personal strengths and qualities to overcome adversity. Within the scope of the present study, salutogenesis constitutes a conceptual framework centred on men's optimal well-being [60].

4. Methodology

The present study was mixed, exploratory in nature, and involved a small number of participants. Moreover, the dearth of data on the health of men exposed to earthquake events in rural communities did not allow for comparative analysis in light of previous results.

4.1 Participant recruitment methods

The sample was constituted using a non-probabilistic procedure. The initial participants (n = 15) were recruited through a local community health centre in Lo Figueroa, a rural community located within the municipality of Pencahue, in central Chile. Every participant received all information necessary to fully understand the objectives and implications of the study. They were also informed of the means by which their anonymity would be protected. Additional participants were recruited using the snowball method [61, 62], that is, the initial participants referred additional respondents. Individual interview locations and schedules were established with each participant. Data collection took place in the period December 2016–February 2017.

The primary researcher collected the study data in the course of semi-directed, face-to-face interviews recorded on audio media. The interviews addressed a range of themes in order to draw a comprehensive portrait of participants' views of the consequences of the disaster on their physical and mental health. For the purposes of the study, an interview guide originally developed in French was adapted into Spanish using a double back-translation method, which maximized the validity of questions presented to participants [63]. The sociodemographic characteristics of respondents were collected through a brief questionnaire containing exclusively closed questions. A second instrument served to identify the presence or absence of post-traumatic stress manifestations using the Impact of Event Scale-Revised (IES-R) [64]. The IES-R includes 22 items assessing PTS intrusion and avoidance experiences in the week preceding the application of the questionnaire.

4.2 Data analysis

The collected qualitative data were processed using a thematic analysis procedure. The information collected using the IES-R self-administered questionnaire [64] were analyzed in terms of proportion as a relative frequency and subjected to binary classification, by age group, into men aged 54 and younger and men aged 55 and older. Based in Canada, the researchers established this grouping on the basis of the Canadian government's statistical classification of individuals aged 55 and older as senior citizens [65]. All study participants were citizens and residents of Chile.

4.3 Ethical considerations

The present study was validated by the UQAT research ethics committee (CER-UQAT) and posed no risks to the physical or psychological health of participants. No ethical certificate: 2016-0. All participants were presented with a consent form informing them of the implications of their choice to participate in the study. Participation was entirely voluntary and all participants were informed that they could withdraw from the study at any moment without justifying their decision and without negative consequences. Data collected during interviews were kept, unaltered, in a locked file cabinet accessible by only one designated member of the research team. Pseudonyms were attributed to each participant in order to safeguard their confidentiality. All collected data will be destroyed 5 years after study completion.

4.4 Sociodemographic characteristics of respondents

The sample (*n* = 45) was composed of men aged 54 and younger (55.6%) and 55 and older (44.4%). A non-negligible proportion of participants were single (40%), while others were either married (28.9%), had common-law spouses (11%), were divorced or separated (13%), or were widowed (6.7%). Education levels among the sample were relatively low: only eight participants had completed a secondary education. A significant majority (75.6%) reported monthly incomes below minimum wage levels, equivalent to US$464. In terms of occupation, 40% of participants were retired, 33% were self-employed in agricultural activities, 22% were employed, and 2% were students.

5. Results

The present section presents health data collected from male respondents residing in rural communities in the Pencahue municipality, in Chile's Central Valley, who had experienced exposure to a major earthquake event in 2010. The event occurred in the night of 27 February, at 3:45 AM local time, off the coast of the Maule region. The tremors persisted for 3 minutes and attained a magnitude of 8.8 Mw (moment magnitude scale). It was one of the strongest earthquakes ever recorded and caused severe damages across the coastal region. The first part will address participants' physical health prior and subsequent to the event. The second part will address the consequences of the event on respondents' mental health.

5.1 Physical health before and after the event

The physical health problems described in the present section were self-declared by participants. The data collected during participant interviews show that the male respondents suffered from a variety of illnesses prior to the earthquake event of 27 February 2010. Twelve (26.6%) men (average age: 67.3) reported having experienced health problems prior to the event, the majority of which were linked to hypertension and diabetes. These health problems had a negative impact on the professional life of some respondents, as expressed in the following testimony:

> *I've had this thing [diabetes] since some time. Before, I was someone who could work without any difficulty, but since I got sick things changed a lot; I have to watch what I can and can't eat. This has also had an impact on my work. You know, farming work is difficult and the days are long! (Manuel).*

In addition, 10 men who declared other illnesses, in addition to hypertension and diabetes, reported feeling misunderstood at work, which translated into feelings of uselessness:

> *For me, the fact of having an irregular heartbeat limits me a lot and cuts my hands off, as the saying goes, for working in what I like best: agriculture. Because I have a series of limitations and things that mean that I can't be available for all kinds of work. But, you see, I can do things, but people don't understand that. Even at home my wife is always saying do this, don't do that, be careful! In the end you become a burden for others. I'm 68 and I still feel capable of working (Victor).*

Others were troubled by feelings of defeat, since their health condition had forced to them to terminate their professional activities and find employment outside their community.

> *Since I got sick I only pick up odd jobs [pololos]. Before I had a permanent job, but I don't have that now. It's difficult for us when these things happen! I try to get by doing occasional work in construction here, because now you don't find people who know much about maintenance on a house and I take care of that. It's little things, like for example, putting stucco on a wall, redoing a floor, etc., little things I can do at my own rhythm (Andrés).*

Although these 12 men were experiencing health problems at the time of data collection, the majority (*n* = 7) occupied salaried positions, while the remainder were self-employed (*n* = 5).

For the sample overall in the post-disaster period, **Table 1** shows that the incidence of health complications rose considerably for respondents during the 7 years following the disaster. Indeed, the majority of respondents (*n* = 25) stated that their health had deteriorated significantly since the event.

Close to half (*n* = 21) of participants reported having developed new health problems after the event. Their testimonies reflect a negative perception of the effects of the disaster on their health:

> *After the earthquake, everything changed for me, in the sense that I feel more vulnerable than before. I get sick often, but before I never had anything. For example, last year I spent a month in hospital with fever and headaches. I'm sick more than before and I don't know why (Efraín).*

> *I always considered myself as someone who didn't know hospitals or health centres or places like that. But everything changed from 1 day to the next after I had a heart attack. It happened 2 years ago and I haven't been the same since. Here we say that when one bad thing happens, all bad things happen! I say that because after the earthquake a lot of people became sick. My wife, for example, spent her days crying because she was afraid that another one [earthquake] would come (Ernesto).*

It is important to note, however, that although many respondents reported that their health had deteriorated significantly in the 7 years following the disaster, there is no direct evidence for a causal link between increasing health problems and exposure to the event, since new health problems reported by participants may be associated with ageing or external factors other than the event.

Physical health problems	Before	After
	• Cardiac arrhythmia	• Vascular accidents
	• Diabetes	• Osteoarthritis
	• Lumbar disc disease	• Hip pain
	• Bone pain	• Muscle and bone pain
	• Epilepsy	• Physical fatigue
	• Gout	• Hemorrhoids
	• Vision impairments	• Heart attacks
	• Blood pressure problems	• Back pain
	• Psoriasis	• Joint pain
		• Kidney diseases
		• Varicose leg ulcers

Table 1.
Principal physical health problems reported by respondents as present before and after the earthquake.

5.2 Mental health before and after the event

During the interviews, respondents were asked to describe their mental health before and after the event. None of the participants reported suffering from psychological health problems before the event. A majority (n = 35), however, stated that they experienced mental health problems afterwards. The problems most commonly cited by respondents were stress problems (n = 15), manifestations of emotional pain (n = 7), a permanent fear that an earthquake would re-occur (n = 5), depressive and anxious manifestations (n = 5), and sleep disorders (n = 3).

Among those experiencing emotional pain, those who stated that the manifestations occur without apparent immediate cause associated the occurrences with their advancing age.

> *For example, when I get up in the morning, I feel something squeezing in my heart. It's as if I wanted to cry. I don't know why I feel like this. I don't say anything to my viejita [wife] but it's a feeling that just comes sometimes; maybe it's because I'm old, I don't know! [80 years of age at time of interview] (Alberto).*

Others associated their emotional pain with the fact of having irrecoverably lost all their material and immaterial goods during the earthquake. These respondents reported feelings of defeat.

> *When I think about what I lost [his house], it hurts. It hurts to lose everything and to be powerless to do anything about it. It hurts to lose your house and all your things, and that your house is in a bad state now! (Diego).*

Participants also spoke of a feeling of fear that presented itself following the earthquake; this feeling was still present for a third of respondents at the time of data collection. Manifestations of fear were most clearly associated with the possible recurrence of an earthquake of similar intensity (8.8 Mw):

> *Sometimes I go to bed thinking that another earthquake might happen, just as strong as the one in 2010. This scares me a lot and I think about what might happen, being sick like me, with all the difficulty I have moving around! (Lamberto).*

In terms of stress disorders, as well as depressive and anxious manifestations, participants reported pervasive feelings of sadness, which impact their ability to function, and persistent thoughts about the finality of life. As one respondent put it: 'I do not have much. Why keep on living? I keep feeling more and more sick. I've been feeling like that for a while. I feel alone!' (Orlando). Although mentioned only by a few (n = 3) respondents, sleep disorders were also present within the range of mental health complications declared during the interviews and seemed closely related to the fear of another severe earthquake:

> *I have trouble getting to sleep because I think about what will happen if we have another earthquake in the middle of the night! Thoughts about this, they just come on by themselves; it keeps me from sleeping. You sleep by fits and starts, as they say! I wake up at the smallest noises (Demiro).*

5.3 Post-traumatic stress manifestations and concomitant physical and mental health problems

Table 2 illustrates IES-R results for the two age groups in the sample. As the results show, all respondents aged 55 or more (n = 20) suffered from PTSD (score

Average age	IES-R	Age		
		Total (*n* = 45)	**54 and younger (*n* = 25)**	**55 and older (*n* = 20)**
25.7	1–11 (*n* = 3)	7%	12%	0%
21.3	12–32 (*n* = 7)	16%	28%	0%
62.5	33 or over (*n* = 35)	78%	60%	100%
	Total	100%	100%	100%
	IES-R average	52.3	42.2	65.0

Table 2.
Impact of event scale-revised (IES-R).

of 3 and higher) 7 years after the disaster event. For participants aged 54 or less, the PTSD rate was 60%, while another 28% of participants in this age group obtained scores ranging between 12 and 32, indicating that they presented a number of PTS symptoms, but did not suffer from the disorder.

As **Table 3** demonstrates, participants who obtained IES-R scores of 33 or higher declared greater numbers of physical and mental health problems than did participants who scored lower on the scale. Respondents aged 70 and older presenting PTS manifestations were the group reporting the greatest number of physical health problems, specifically: visual impairments, diabetes, osteoarthritis, bone pain, heart problems and hypertension.

Presence of PTS manifestations (*n* = 35)	**Absence or low occurrence of PTS manifestations (*n* = 10)**
Physical health problems self-declared during data collection: • Vascular accidents • Cardiac arrhythmia • Osteoarthritis • Diabetes • Hip pain • Lumbar disc disease • Muscle and bone pain • Epilepsy • Gout • Hemorrhoids • Hypertension • Heart attacks • Back pain • Joint pain • Psoriasis • Visual impairments • Blood pressure problems • Physical fatigue • Kidney problems • Varicose leg ulcers	Physical health problems self-declared during data collection: • Diabetes

Presence of PTS manifestations (n = 35)	**Absence or low occurrence of PTS manifestations (n = 10)**
Mental health problems self-declared during data collection: • Anguish • Depression • Persistent nervousness • Persistent emotional pain • Loss of motivation • Permanent fear • Extreme preoccupation • Feelings of loneliness • Stress • Sleep disorders	Mental health problems self-declared during data collection: • Emotional pain • Fear, anguish • Fatigue

Table 3.
Self-declared post-disaster health problems as a function of post-traumatic stress manifestations.

In summary, following exposure to the disaster event, the majority (35/45) of men participating in the study reported a progressive deterioration of both their mental and physical health. However, given that 7 years had elapsed between the disaster event and the data collection period, the results must be interpreted with caution. It is not possible to determine with any degree of certainty whether the health problems self-reported by respondents were linked directly with exposure to the earthquake or whether they were more closely linked with other factors, such as natural ageing or negative experiences since the earthquake. Nevertheless, the results suggest that the physical and mental health of men aged 55 or older who have been exposed to earthquake events are particularly at risk.

6. Discussion

The results of the study suggest that a majority of men living in rural communities in central Chile declared that their health had deteriorated significantly since their exposure to the earthquake of 27 February 2010. Nearly half of participants declared suffering from physical and mental health problems that had not been diagnosed prior to the disaster. It is worth noting, as well, that, overall, men living in rural communities are more likely to suffer from certain health problems, such as diabetes and coronary diseases [37, 40]. Moreover, the sample presented the additional health risk factor of poverty: 75.6% of men participating in the study reported monthly incomes below Chilean minimum wage levels. Some authors point out, poverty remains one of the most common health risk factors among men living in rural communities [37]. Thus, age, economic status, and post-disaster trauma may all account for participants' declining health and feelings of increased vulnerability.

It is important to note, as well, that, although respondents' physical and mental health had deteriorated in the 7 years following the event, it is not possible to establish a direct link between the reported health problems and exposure to the disaster, since they may be more closely associated with natural ageing processes or other, external factors. Further research will be necessary to pinpoint more definitively the causes of health problems reported by rural men in post-disaster contexts, especially since they are more vulnerable then women in the same communities and more vulnerable than both men and women in urban communities [30, 31].

Participant testimonies show that their mental health had also deteriorated following exposure to the disaster. These results parallel those of other studies, which show that exposure to natural disasters can have significant consequences for the health of survivors [66, 67]. Within the scope of the present study, the majority of participants cited mental health problems, such as anguish, depression, emotional pain, constant fear, and stress disorders, as factors that had contributed to the deterioration of their quality of life since the event (**Table 3**). Emotional pain, depression, anguish, and stress were the mental health problems most commonly reported as having emerged in the 7 years following the disaster. As a previous study has shown, the deleterious consequences of natural disasters on the lives of survivors can persist as long as 50 years following the event [9]. A longitudinal study comparing the health of survivors with the health of individuals not exposed to the event would allow for a more thorough verification of this hypothesis. Previous studies have reported similar results in terms of the presence of depressive and somatic symptoms, as well as emotional distress, among natural disaster survivors [2, 4, 68]. Elsewhere, it has been noted that the deterioration of the natural environment seems linked to depression in adults living in rural communities [8].

IES-R results (**Table 3**) show that respondents aged 55 or more (20 of 45, average age 62.5 years) presented elevated levels of post-traumatic stress when compared with the rest of the sample, providing evidence of a deterioration of their mental health. This group, moreover, reported numerous physical health problems (e.g., vascular accidents, cardiac arrhythmia, osteoarthritis, visual impairments). The results, which parallel those of Labra et al. [68], point to two conclusions: (1) that the deleterious consequences of natural disasters on the physical and mental health of male survivors intensify with age; and (2) that, within the framework of the salutogenic model [57–59], the men in the sample have since the disaster lived in environments that are not conducive to good health; that is, they do not have access to an offer of services likely to motivate psychosocial consultation or to medium- or long-term psychosocial post-disaster intervention programmes. These factors may account for the negative overall results obtained through the IES-R.

Thus, advanced age appears to be a factor affecting the vulnerability of men in natural disaster contexts, particularly in connection with health problems and the loss of physical and cognitive autonomy [1]. It appears, as well, that men aged 54 and younger fare better with the consequences of a disaster event, since 60% suffered from PTSD, while 28% obtained scores ranging between 12 and 32, that is, presenting certain PTS symptoms without developing PTSD. This observation leads to the following question: what are the factors that account for the ability of younger men to better avoid the deleterious health effects of a disaster event? Within the perspective of the salutogenic model [55–60], answers to this question could help to identify the positive forces and elements of the environment that benefit younger men in order to extrapolate them in working towards creating healthier environments for older individuals.

6.1 Implications for psychosocial intervention

The consequences of natural disasters on men's physical and mental health vary depending on the level of exposure, the losses suffered, the survivors' age, as well as their physical, psychological, social and financial capacities to effectively face the various stress factors that follow a disaster event [69]. Older men are frequently more vulnerable than are other groups in these situations [68]. In addition, men as a group are frequently reluctant to seek help, whether from their family and social circles or from professionals in the public and community health networks [66]. This reluctance is frequently motivated by norms and beliefs rooted in traditional notions of masculinity that cause men to underestimate their health needs and there is evidence to suggest that these trends are stronger in rural communities [70].

The social work approaches used in disaster-context interventions must vary in relation to different clienteles and different stages of intervention, including prevention, preparation and recovery [71]. In practice, psychosocial intervention with disaster survivors is generally focused on immediate needs (e.g., access to basic resources and shelter) and only rarely takes into account holistic perspectives that acknowledge individuals and their social environment [12]. Consequently, disaster interventions fail to address the long-term consequences of disaster events for survivors' health, including various effects on their personal, conjugal, family and professional lives. In developing interventions, helping professionals can benefit from approaches such as ecosystemic [72] or salutogenic models [55], to name just two of the available options that may be applicable, depending on the specific needs and conditions of men experiencing physical or mental health problems and social interaction difficulties following exposure to a disaster event. As pointed out by [73], however, interventions tailored to the needs of men should also take into account their specific strengths and abilities.

Given the nature of the problems identified among participants in the present study, group interventions may also offer an effective approach. In group interventions, helping professionals must remember that their clientele, in this case men, are 'the experts of their own lives' [73], but in need of guidance towards effective mutual self-help.

The nature and intensity of exposure to a given disaster event are determining factors in the extent of consequences for survivors and must enter into consideration in the deployment of psychosocial intervention measures to minimize the deleterious effects on men's health. Helping professionals must devote particular attention to the psychosocial support necessary to overcome various difficulties specific to given groups, particularly, in the light of the results presented above, those specific to older men; intervention objectives, by the same token, must be formulated clearly in relation to specific clienteles and tailored to the pre-disaster, emergency assistance, and recovery phases of intervention. The testimonies of male survivors indicate that they continue to suffer from post-traumatic stress 7 years after exposure to a disaster event. In order to contribute to the reduction of consequences such as depressive manifestations and other mental health problems, intervention programmes should foresee the need and integrate the availability of psychosocial support services for the long term. Helping professionals involved in post-disaster interventions with men can also contribute to reduce disparities between available services and real needs, which are inadequately understood and inefficiently coded within health and social services networks.

7. Conclusion

The present article addressed the long-term post-earthquake health of men in a rural community and its implications for helping professionals' interventions. The study found that, among the sample, 7 years after a major earthquake, men 55 and older remained the group most adversely affected by the event. It is important to note that a factor contributing to the reluctance of men to seek help and thus potentially to reduce these impacts, particularly in rural areas, is a predominant notion of masculinity, typified by the image of strong and self-sufficient man, informed by conservative values in which gender roles are binary and fixed. This presents particular challenges for helping professionals who seek to reduce the existing gap between available service offers and men's real needs, which remain insufficiently understood and imprecisely coded.

The standards of traditional masculinity prompt men to conceal their private lives, seek to maintain control, and project strength [73], as well as deny suffering or pain and attempt to maintain independence, as ascertained above. Based on the findings of the present study, psychosocial intervention targeted towards men should:

1. Work on strengths rather than weaknesses [55] by focusing on the positive attributes of the environment that are conducive to health, rather than on negative elements conducive to disease.

2. Acknowledge men's needs and communicate to men that health professionals are willing to listen and elaborate interventions and treatments based on men's needs.

3. Work incrementally on specific elements so that men can understand their progress throughout the intervention process.

4. Include men's spouses and partners as facilitators in the intervention process, since women often play decisive, positive roles in men's help-seeking.

Lastly, the consequences of the natural disaster described above on the physical and psychological health of participants were not uniform, varying according to factors specific to individuals. It is thus important that intervention programs be designed to include flexibility and adaptability to individual needs.

The authors consider that further developing the following research avenues may contribute to facilitate men's help-seeking following disaster events: (1) to identify factors facilitating older men's use of health services and (2) to examine sociosanitary services and programs, in particular their adaptation to specific clienteles, in particular as defined by age and gender.

Conflict of interest

The authors declare that they have no conflicts of interest.

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Chapter 5

Impacts of the 2015 Gorkha Earthquake: Lessons Learnt from Nepal

Shiva Subedi and Meen Bahadur Poudyal Chhetri

Abstract

Nepal is highly vulnerable to a number of disasters for example: earthquakes, floods, landslides, fires, epidemics, avalanches, windstorms, hailstorms, lightning, glacier lake outburst floods, droughts and dangerous weather events. Among these disasters—earthquake is the most- scary and damaging. The effects of a disaster, whether natural or human induced, are often long lasting. The Gorkha earthquake of 25 April 2015 enormously affected human, socio-economic and other multiple sectors and left deep scars mainly in the economy, livelihood and infrastructure of the country. Besides the natural factors, the damages from disasters in Nepal are in increasing trend due to the human activities and inadequate proactive legislations. Fundamentally, the weak structures have been found as the major cause of damage in earthquakes. This underlines the need for strict compliance of building codes. Thus, proactive disaster management legislation focusing on disaster preparedness is necessary. This paper analyses and shows the critical gaps and responsible factors that would contribute towards seismic risk reduction to enable various stakeholders to enhance seismic safety in Nepal. Additionally, this chapter aims to pinpoint the deficiencies in disaster management system in Nepal with reference to the devastating Gorkha earthquake and suggest appropriate policy and advanced technical measures for improvement.

Keywords: earthquake, proactive, impact, management, legislation

1. Introduction

Nepal is facing the fury of natural and human induced disasters with greater frequency and intensity. Disasters are so pervasive in every Nepalese geographic and societal framework that the people are mostly in the verge of known and unknown disasters. The earthquake of 1934, 1980, 1988, 2015 and the flood of July 1993, 2008, 1913, 2014 and 2017 AD are the most destructive disasters which not only caused heavy losses to human lives and physical properties but also adversely affected the development process of the country. The lessons of the earthquakes of 1988 and 2015 and the floods and landslides of 1993, 2008, 2013, 2014 and 2017 have cautioned the concerned authorities and agencies for a coordinated disaster preparedness and response mechanism. Climate change, on the other hand, has become 'extreme.' Nepal is ranked as the fourth most climate vulnerable country in the world in the climate change vulnerability index [1]. Fire is another disaster which occurs on a regular basis and wild fires are damaging to already severely exhausted forests and biodiversity of Nepal which results on economic loss, land degradation and environmental pollution. The government data show that since the year 2000, annually, an average of 329 people lost their lives due to various disasters and property loss of more than 1 billion rupees. Hence, Nepal is considered as the 'hot spot' of disasters.

It is evident that earthquakes do not kill people; rather the weak structures kill the people. Hence, if we stay in a well-constructed earthquake resistant building and the surroundings, we can live safely even in an earthquake prone area. Hence, people living in an earthquake prone country like Nepal must consider of this simple but basic fact. Many countries of the developed world, like Japan, Canada, and USA also have faced several large earthquakes in the past but, when we compare the number of casualties and property losses between the developed and developing countries, the damage is many times higher in the latter. This difference is mainly due to the levels of preparedness between them. In general, disaster preparedness is still not in the priority list of the developing countries like Nepal; as a result, they pay relatively higher price in terms of loss of lives and infrastructures.

2. Historical trend of earthquakes in Nepal

Nepal was placed at the eleven-top earthquake vulnerable countries in the world, paralleled as sitting on a time-bomb. Kathmandu, the capital city, is considered as one of the most vulnerable city in the world; and is being put on a red alert. No earthquake had hit the city for over eight decades and was thus considered overdue for an earthquake to occur. Records show that since 1255 AD Nepal experienced 19 earthquakes with significantly large impacts. The last two big earthquakes that hit Nepal were that of 1833 (7.7 Magnitude, killed 414 people) and 1934 (8.3 Magnitude, killed 8519 people). The other earthquakes that occurred

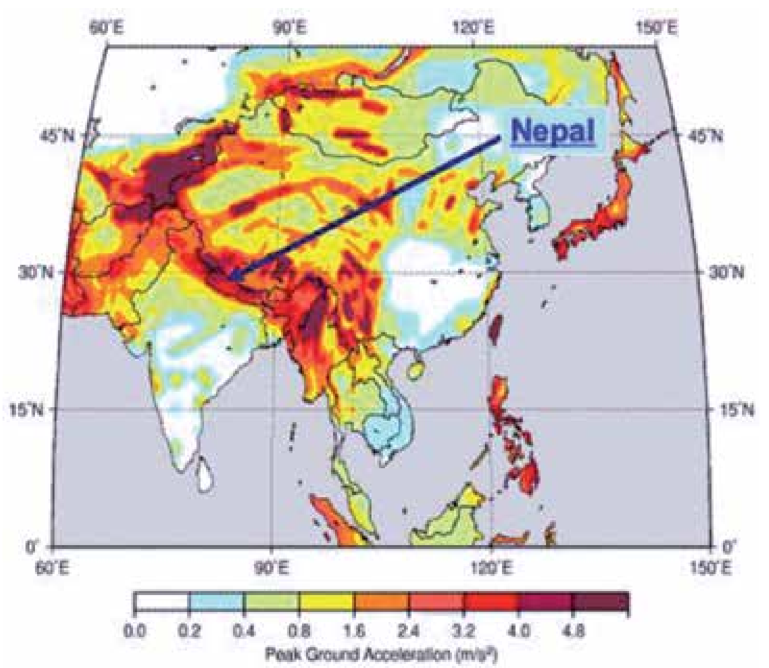

Figure 1.
Location of Nepal and showing the seismically active zones along the Himalaya and the surrounding region [2]. Source: https://www.researchgate.net/figure/The-seismic-hazard-map-of-Asia-depicting-peak-ground-acceleration-PGA-given-in-units_fig2_236145995 uploaded by Dina Francesca D'Ayala.

in 1980 in Far Western Nepal (6.5 Magnitude, killed 103 people), and in 1988 in Eastern Nepal (6.5 Magnitude, killed 721 people) were comparatively much smaller in magnitude [2, 3].

The most recent one, we Nepalese people experienced is the 2015 Gorkha-Nepal earthquake which has left a trail of miseries that the affected people will continue to combat for years.

Nepal is a small mountainous country in the South Asia, which lies at the center of the 2500 km long Himalayan range. The entire Himalayan terrain and its surroundings is a highly active seismic zone on earth (**Figure 1**). Nepal's proximity to earthquake hazard is mainly due to her young and fragile geology. Haphazard and unplanned settlements and poor construction practices are the other factors that have made her highly vulnerable to earthquakes. Earthquake is the biggest threat to Nepal as it has encountered 19 major earthquakes since the twelfth century.

3. Gorkha earthquake 2015

The devastating Gorkha Earthquake measuring to 7.8 ml having the epicenter occurred near Barpak village of Gorkha district which is 181 km northwest of Kathmandu on 25 April 2015. It was the worst quake to hit the country after the 1934 mega earthquake (8.3 ml). On 12 May 2015, a 6.8 ml strong aftershock caused further damage and sufferings. These earthquakes took the lives of 8970 people where 198 people are missing, and 22,303 people were seriously injured. The earthquakes destroyed 604,930 houses completely and 288,856 houses were partially damaged. It is estimated that the total value of the damages caused by the earthquakes is NPR 706 billion or equivalent to US$ 7 billion [4]. Around 800,000 people displaced by the earthquake in Nepal were struggled to survive in a context of persistent, a severe lack of safe and adequate housing [5].

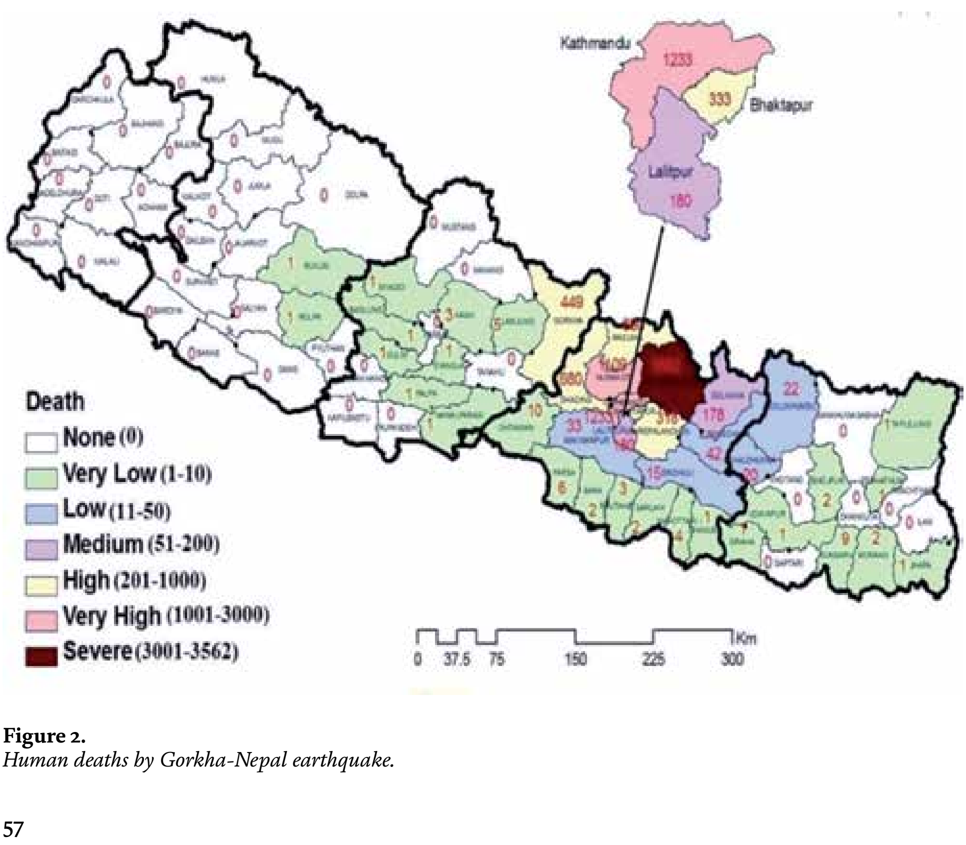

Figure 2.
Human deaths by Gorkha-Nepal earthquake.

Mostly, old, non-engineered, adobe and masonry buildings collapsed and/or were severely damaged by the earthquake. In addition, some engineered buildings also damaged or collapsed due to poor workmanship and quality of construction materials. The earthquake severely affected 14 districts (Gorkha, Dhading, Rasuwa, Nuwakot, Kathmandu, Lalitpur, Bhaktapur, Kavrepalanchowk, Sindhupalchowk, Dolakha, Sindhuli, Makawanpur, Ramechhap and Okhaldhunga) and another 31 districts affected to varying extents. In this way, this devastating earthquake has affected vast parts of Nepal and left deep scars in the economy and infrastructure of the country.

The 25 April earthquake was followed by a number of aftershocks throughout Nepal, with one shock reaching a magnitude of 6.7 on 26 April at 12:54 am local time. The 25 April earthquake affected the entire Nepal and also affected some parts of India, Bangladesh and the Tibet Autonomous Region of China. Tremors were also felt in Bhutan and Pakistan. All these major earthquakes proved the fact that the casualties were mainly due to the failure of infrastructures.

On 26 April 2015, the Government of Nepal declared the 14 districts as disastrous area and called for international humanitarian assistance (**Figure 2**) [2].

3.1 Some scientific facts behind the Himalayan earthquakes

The Himalayan Mountain was formed by the crash between the Indian plate, and the Eurasian plate consisting of nearly the entire continents of Europe and Asia. Once the vast sea-floor of Tethys that lay between the Indian and Asian

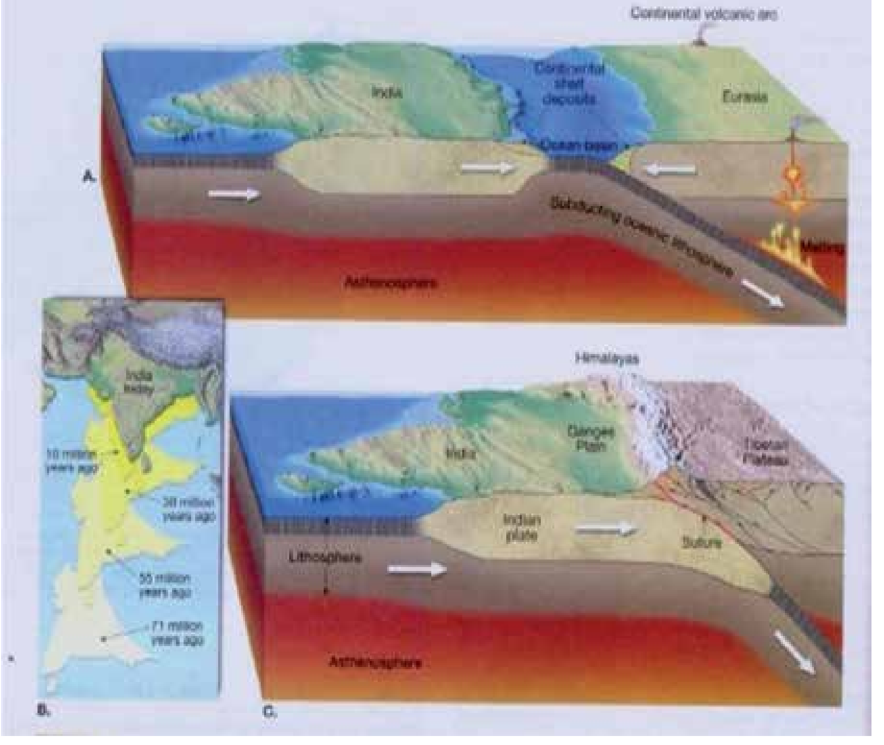

Figure 3.
Collision of Indian plate and Eurasian plate. (a) Before the collusion: Subducting Indian plate (left) under Asian plate (right). The gradually closing Tethys sea lies between the two plates. (b) Rise of the Himalaya and Tibet after the collision of the two plates. Indian plate still continues to subduct under Tibet. (c) Progressive northward movement of the Indian plate from near South Pole to the present location [6].

continents, was subducted and consumed underneath Eurasia some 50 million years ago, the northern edge of Indian sub-continent reached the southern shore of Eurasia to collide.

Nowadays, the Indian crust has reached far to the north beneath Eurasia that caused the uplift of the region, and ultimately created the Himalaya (i.e., "For example, see "in **Figure 3**" the north beneath Eurasia (Tibet)"). Gradually, the powerful push of the Indian continental crust forced itself to break into slices at a depth and created a lower and upper-blocks. The breaking plane separating these two blocks of the Indian crust is called the Main Himalayan Thrust (MHT). This gently northward sloping fault in the Indian crust reaches beneath the Tibetan Plateau which is shown in **Figure 4**.

Now, India continues to move towards north at a speed of about 5 cm/year, and this movement constantly creates a stress build up within the Himalayan region. As a result, it causes to store enormous amount of energy within it. "For example-the breaking of the Indian crust into the lower and the upper blocks along the Main Himalayan Thrust (MHT). During an earthquake the block below the MHT will slip to the north beneath Tibet and the upper block moves to the south. The MHT emerges at the Main Frontal Thrust (MFT) [3]."

Figures 3 and **4** and the text related thereof have been extracted from the article of Professor Dr. Bishal Nath Upreti which has been cited below in Ref. [3].

On 12 May 2015 at 12:50 local time another strong aftershock measuring 7.3 Magnitudes struck with the epicenter in Sunkhani of Dolkha district. The epicenter was just 76 km northeast from the Kathmandu. This area was already affected by the jolt of 25 April's earthquake. The initial quake was followed by several aftershocks. This quake toppled already weakened buildings, triggered a series of landslides, which further hindered relief efforts. This quake alone killed more than 100 people [2].

The movement of tectonic plates that triggered massive earthquake in the country on 25 April caused the altitude of Kathmandu Valley to increase by 80 cm. In total 438 numbers of aftershocks with local magnitude ≥4 have been recorded till 6 March 2016 [7].

As shown in **Table 1**, it is estimated that the total loss by the Gorkha earthquake is NPR 706 billion (US$ 7 billion) [2, 4].

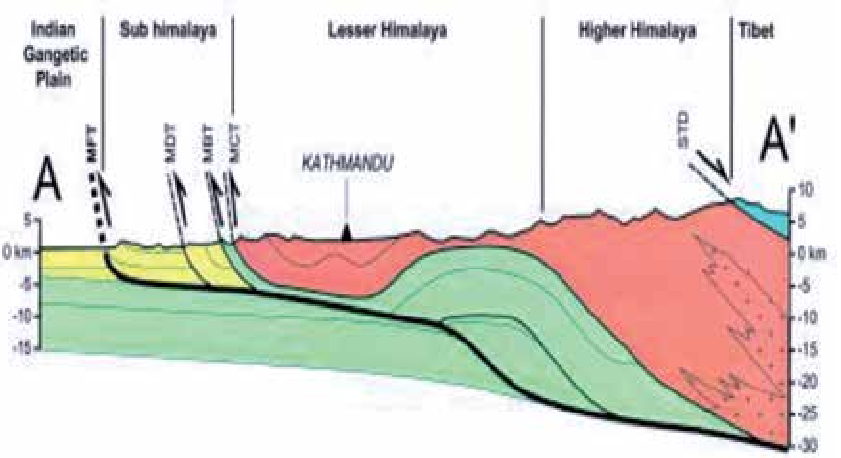

Figure 4.
The breaking of the Indian crust into the lower and the upper blocks along the Main Himalayan Thrust (MHT). During an earthquake the block below the MHT will slip to the north beneath Tibet and the upper block moves to the south. The MHT emerges at the Main Frontal Thrust (MFT) [8].

Particulars	Number/amount
Persons dead	8970
Missing	198
Injured	22,302
Affected families	8,86,456
Displaced families	6,49,815
Houses damaged (fully)	6,04,930
Houses damaged (partially)	2,88,856
Total material loss (in US $)	7 billion

Table 1.
Losses due to the Gorkha-Nepal earthquake [2].

3.2 Causes and consequences of Gorkha earthquake

The 2015 Gorkha Nepal earthquake took place in between the boundary of Indian tectonic plate and the Eurasian plate. The two plates stuck together by friction building up energy that only a major earthquake could release. Increasing population, unplanned settlements, poor construction practices, untrained human resource, lack of search and rescue equipment and medical services are the other major reasons of the devastating earthquakes.

Some scientists believe that the Gorkha earthquake did not release all the stress that had built up underground and some of this stress has shifted west to an area stretching

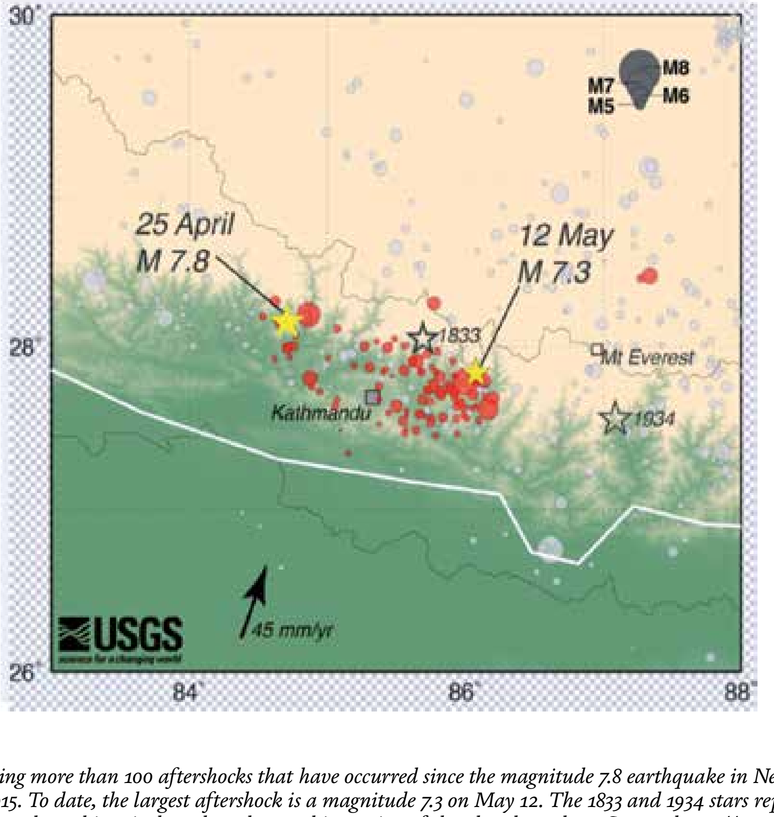

Figure 5.
Map depicting more than 100 aftershocks that have occurred since the magnitude 7.8 earthquake in Nepal on April 25, 2015. To date, the largest aftershock is a magnitude 7.3 on May 12. The 1833 and 1934 stars represent the most recent large historical earthquakes on this portion of the plate boundary. Source: https://www.usgs.gov/news/magnitude-78-earthquake-nepal-aftershocks.

from the west of Pokhara in Nepal to the north of Delhi in India. The research is published in the journals Nature Geoscience and Science. Its authors say more monitoring is now needed in this area. Therefore, there is already long overdue of a major earthquake. The last mega earthquake happened in 1505 which is estimated to have exceeded M8.5. The scholars say the new stress that has moved as there could already be accumulating to the tension that has been building up over five centuries [7, 9].

Figure 5 reflected above clearly indicates the scale of the 25 April 2015 Gorkha-Nepal Earthquake and the major aftershocks of 12 May 2015. Tremors which scattered in various area (has been highlighted in red color) what felt or noticed by many people inside and outside the buildings. These effects corresponded to an intensity with a high magnitude.

4. Problems related to the Gorkha-Nepal earthquake

Although the Nepalese security forces, volunteers and others worked hard- days and nights, the response work was as not well organized and prompt. A key criticism was of a slow and inadequate relief effort, which failed to reach in due time to many of the affected people of remote, rural and hilly areas. It was basically because of the lack of road network, transport resources, and adverse weather condition. Major delays were also caused by bureaucratic procedures and even bitter mutual accusations - both in public and private—over who was to blame and who should be in control of funds and resources. Thousands of people in the affected districts were lacking basic needs. Rainy season and cold-winter and morbidity caused the earthquake victims daily life much more difficult.

On the other hand, the earthquake victims repeatedly complained that the rice distributed in some districts by the food distributing organizations (World Food Program (WFP) through Nepal Red Cross Society (NRCS) was "substandard and inedible" as highlighted by the media from time to time, which also caused in deteriorating health status of the earthquake victims in the vulnerable settlements and; led to increase more morbidity [2]. There were high number of injured people or caseload recorded during the first day, so the orthopedic service and treatment was the most urgent for majority of patients after earthquake. However, the proportion of reported death at hospitals was relatively low [10].

In addition, there was a painful moment of family isolation, and collective cremation as most of the family members could not follow the ritual practice in that emergency which is so vital in human life from cultural and religious point of view.

4.1 International cooperation and disputes

For any government, it would be difficult to cope alone with such a huge disaster. In such a situation, international assistance is important for response and recovery works. So, on 26 April 2015, the Government of Nepal declared an emergency in the worst affected districts and called for international humanitarian assistance. However, it is more difficult in Nepal due to some of its inaccessible landscape and difficult terrain. Unfortunately, it risks adding a human induced calamity to a devastating natural disaster. During the mission of search and rescue efforts, an American helicopter crashed near the Nepal-China border resulting in the sad demise of five American soldiers, two Nepali soldiers and five disaster victims.

In course of the response phase, the relationship between Nepal government and the international community was not encouraging. There was the problem of mutual trust and allegation between the two sides. The international communities did not fully trust the government; questioning its ability to deliver services while the government wasn't happy because the donor communities wanted to distribute relief assistance through their agents whereas Nepalese government sought any assistance to be collected into the Prime Minister Relief Aid Fund and then distribute to the affected areas. Actually, the government wanted to adopt one door policy. However, the relationship between the Nepal Government and International Community did improve as time elapsed.

4.2 Foreign aid commitments

There was a donor community meeting on 25 June 2015 in Kathmandu, Nepal. The highest-profile international donor conference ever held in the country amassed more than 300 delegates from 56 nations, development partners and the donor community. In a major boost to Nepal's reconstruction and recovery efforts, development partners and the donor community have pledged $4.4 billion in aid during the International Conference. This has come as a huge relief to the reconstruction and recovery bid and brought cheers to the government. However, till now, except a small portion, the committed amount has not been provided by the international community to the Government of Nepal [2].

4.3 Formation of reconstruction authority

A high-level National Reconstruction Authority (NRA) has been formed under the chairmanship of Prime Minister (PM), including four ministers picked by PM, a chief executive officer, Vice-chairperson of the National Planning Commission, Chief Secretary and three experts having 15 years of experience in related field. The roles and responsibilities of the NRA are to find out the total loss from the Gorkha earthquake; acquire necessary land following legal procedures; order concerned authority to remove physical structures after providing compensation to the owners; coordinate with different bodies for effective implementation of reconstruction work; order owners to remove their damaged structures or to remove them at their own cost; and direct the concerned agencies to accomplish necessary work of recovery providing them with necessary budget.

5. In post-earthquake recovery and reconstruction progress

Within exactly 2 hours, the Central Natural Disaster Relief (CNDRC) Committee headed by the Acting Prime Minister met and declared a state of emergency and commenced the Search and Rescue (SAR) and relief operations. During a disaster, obviously, the priority was to save lives and providing medical support to the injured. In this respect, the government of Nepal did well. However, when it came to the relief works, it was caught in a midst of heavy criticism; and which was not without reason. Lack of proper management of relief goods, weak distribution mechanism, alleged corruption in procurement of tarpaulin sheets, tents for shelter and food etc. added up to the chaos in relief work. Even the capital city where the Command and Control Centre was functioning, and all relief supplies landed at the nearby airport, people did suffer due to inadequate management of relief work. The performance outside the capital was even poorer [3]. The chaos continued for weeks and months. Even 3 months after the earthquake when rainy season had already begun, majority of the people lacked shelter. It is also important to note that the following five phases were adopted right after the Gorkha earthquake:

I. Search and rescue (as mentioned in above paragraph).

II. Humanitarian relief work (immediate treatment, water, sanitation, shelter, food and protection).

III. Early recovery part (rehabilitation of schools, regaining access to health service, restarting and restarting business as usual).

IV. Recovery and reconstruction (restructuring homes, buildings, infrastructure development etc.).

V. Long-term socio-economic development process (restoring income, improving livelihood and so on).

The recovery efforts are still underway in post-disaster setting. All identified recovery and reconstruction activities were expected to be completed on time, but it is being slow. The livelihood recovery strategy is being followed as a two-pronged approach—a livelihood restoration package and employment creation. Similarly, owner driven reconstruction, integrated habitat approach, relocation of village, urban reconstruction to improve cultural settlement, cash transfer, community outreach, social inclusion and capacity build-up are main aspects. The NRA coordinating for interacting with the NGOs and civil society organizations and implement specific measures in partnership with these agencies were important policy approaches adopted during the rehabilitation and recovery phase [11]. Despite the claimed of lots of tasked achieved, many studies pointed out that satisfactory results have not been achieved as expected with NRA and much remain to be done.

In a big disaster, when the initial phase of SAR and immediate relief operations are over, rehabilitation and reconstruction phase begins seriously. For a successful implementation of this phase, a national government must show a firm commitment, careful planning and adequate resource mobilization. Rehabilitation and reconstruction is a long-term process, require a huge investment and it may last for years to complete. A low-income country like Nepal also needs to ensure financial resources not only from its internal resource but also through grants from international bi-lateral and multilateral agencies.

5.1 Recovery from 2015 Gorkha earthquake: still long way to go

Several efforts have heightened in post-earthquake scenario since 2015, by the government with support from international and national partners. Three years after the catastrophic earthquake left a pain for the society, and an equal number of injured, this traumatized nation appears to be in a bit recovery mode now; a 45% of the quake-damaged houses have been rebuilt, and another 32% of houses are under construction [11] as of December 2018. The NRA has signed the government's private housing grant agreement with 742,135 beneficiaries, out of which 337,319 have completed rebuilding their houses while 233,343 houses are currently under construction. Seventy seven percent of the earthquake-damaged houses are already rebuilt or being rebuilt, and people have taken ownership of this reconstruction campaign. 4172 out of the 7553 earthquake-damaged schools have been rebuilt, and another 2498 schools are under construction.

The post-earthquake reconstruction could not gain momentum immediately due to institutional constraints and the lack of adequate resources. At the beginning, the absence of elected representatives of people at local levels and the lack of clear policies and procedures also slackened the speed of reconstruction.

Many people were exposed to risks due to poor shelter, poor hygiene, and trauma. Moreover, people did not receive recovery support immediately, and had to spend monsoon season without a house. Since political commitment has always been weak in Nepal, leaders often focused on party politics and direct their effort to change the government [12]. Consequently, weak government and leadership have direct effect in the reconstruction and recovery efforts.

As Nepal was moving towards a new administrative set up and election process at that time, leaders could not give enough attention to reconstruction and recovery efforts. Some weaknesses found in planning, coordination and management which need to be improved in the future [13]. The process of reconstruction of health facilities became a bit slow than expectation.

The slow progress of post-earthquake reconstruction is in part the outcomes of resonant socio-political scuffles in the Nepali society identified mainly by following reasons. Firstly, political dysfunction has worsened in the post-earthquake time, and secondly, the lack of trust between the State and NGOs has led to many possible reconstruction projects being turned down.

In the international context of emergency and system resilience, Professor Deborah MC Farland from Emory University, said, "the trust is one of the most important prerequisites for resilient health/system in any emergency or disaster. In her presentation, she evidently linked this example with Ebola outbreak of 2015. A community where engagement and ownership are the keys to building the resilient system which is important to strengthen at the time of system breakdown" [14]. Congruently, we observed some gaps on mutual trust among government, community and stakeholders in terms of system recovery process herein Nepal during the phases of post-earthquake.

In other words, post-disaster governance has played a crucial role in the reconstruction performance [15]. However, the slow reconstruction pace has been met with substantial criticism both inside and outside Nepal, and many organizations, including donors, have urged the Nepali government to accelerate the reconstruction and the delivery of grants.

The dearth of progress strongly contrasts with the promises what made at the time of donors' conference held in June 2015, in Kathmandu. During this conclave, donor countries pledged nearly about 4.1 billion USD for the long-term recovery of Nepal after having made serious discussion on cross-sectoral part, a level of commitment that surprised many, and covers just under half of the 9.18 billion USD the Nepali government now expects will be required to rebuild the country. In return, the Nepali government promised to establish a national reconstruction authority that centrally governs all the reconstruction efforts; and to safeguard all the activities they carry out expeditiously and impartially. Certainly, the government was able to quickly map the needs and damage immediately aftermath of the earthquake and communicate those needs to intercontinental contributors mainly for fund, which was promising. This makes it even more unsatisfactory that the rebuilding progress has been slow, despite the availability of wide resources [16].

As a matter of fact, there are several factors responsible for the slow recovery such as—the dominance of government control, weak governance, lengthy bureaucratic process, lack of long-term commitment among NGOs and wait-and-see attitudes of the affected people—all these things weaken the community's capacity and ability to rebound. In a resource-poor community, public involvement from inhabitants, NGOs and private sectors are crucial for post-disaster recovery cycle. An encouraging framework to govern NGOs that should have developed by the Nepal government so that they could have mobilized others to help the residents to rebuild their communities. Poor coordination among major reconstruction actors also influenced the promptness of work in terms of recovery work.

In such a way, the slow pace of progress has been blamed on a number of factors from the political willingness, to the lack of legal or administrative, resource and technical stuffs. Likewise, structural problems remain the same and we are too late in accomplishing the task in due time.

6. Strengths, gaps and challenges

There were psychosocial consequences of that devastating earthquake disaster. The nightmare and traumatic situation caused by the disaster upon many people particularly among the children and adolescents are still going on and may remain further. The below mentioned gaps and challenges were identified after the earthquake:

- Nepalese people showed resilient capacity and self-recovery from the earthquake.

- Search and Rescue (SAR) works carried out by the security personnel of Nepal and others was commendable although it was slow and inadequate while they failed to reach in due time in the remote, rural and hilly areas. It was also compounded by the lack of equipment, road network, transport, and well-trained human resources.

- Damage and need assessment was delayed.

- Gap between the need of the affected people and delivery of services was predominant all the time.

- Open spaces for temporary settlement of the displaced population were also lacking.

- Although there were 4521 foreign team members from 34 countries, they were able to save only 16 lives. So the performance of the international SAR team is not encouraging.

- Emergency warehouses, prepositioning of relief materials with proper inventory were also lacking.

- Debris management was found as one of the big problem basically because of the lack of debris management equipment, tools and techniques.

- Accurate and proper communication between District Emergency Center (DEOC) and Central Emergency Operation Centre (CEOC) was not effective.

- A weak database and an absence of modern technology were other bottlenecks for effective response during Gorkha earthquake.

- Cumbersome administrative process between the government, donor agencies, contract agencies and beneficiaries were one of the problems to set-up the pre-fab buildings which delayed in restoring the schools and health facilities.

- Lack of local technical persons/technicians for fixing up pre-fabricated building/s.

7. Lessons learnt from the Gorkha earthquake

- Lack of awareness, preparedness as well as coordination among disaster management stakeholders was evident.
- Weak law enforcement and monitoring of building codes and town planning and lack of training for professionals in earthquake resistant construction practices have been found as the major factors of infrastructure damage; lack of adequate preparedness and response capacity among various stakeholders.
- The biggest lesson is that to be safe from earthquake is to build earthquake resistant infrastructures. There should be no COMPROMISE in building compliance.
- Arrangement of appropriate and essential equipment/s based on the nature of disaster can assist for the quick search and rescue works.
- Modern technology and strategic communication/risk mapping/satellite mapping/earth observation are also important tools and techniques in reducing the disaster risks; and in life-saving.

All most all casualties were due to the collapsed infrastructures. This emphasizes the need for strict compliance of town planning bye-laws and building codes in Nepal.

8. The takeaway message

Nepal should adopt long-term and sustainable efforts to mitigate the hazards occurring following the major disasters, for instance, the devastating Gorkha earthquake. Even though disaster management and risk reduction may be considered expensive in view of the competing demands for resources in a developing country like Nepal, this is high time for the government to invest into preparing for and responding to expected and unexpected disasters before the human and economic consequences of inaction are extensive, and unmanageable. This book chapter suggests some basic principles and guidelines to reduce the impact of the potential future earthquake disaster not only in Nepal but also for other earthquake prone countries as well. Following are the basic and fundamentals for earthquake management in Nepal and beyond:

- Construction of earthquake resistant infrastructures.
- Licensing system for engineers and masons.
- Selective seismic strengthening and retrofitting of existing structures and lifeline structures – a priority list for structural safety audit, seismic strengthening and retrofitting is required.
- Effective implementation of Building Code and other legislations.
- Mass awareness and preparedness.

- Capacity development through education, training, research & development (R&D).
- Data collection, documentation and information sharing.
- Effective and efficient response during and after emergency.
- Build Back Better (BBB).
- Strengthening a society with social, capital and community resilience would be the safe and sustainable approach against disasters.
- Effective disaster governance is highly necessary not only during response phase but also important to capacitate the institutional efficiency in all phases (preparedness, response recovery and reconstruction) through technical and institutional strength.
- Public and private partnership for DRR ensures the risk management and developmental activities in the affected communities via small-micro-entrepreneurship (i.e., trained local people can support to other community's reconstruction process).
- To provide psycho-social support for the traumatized persons, disabled, and body part amputated people is very important. As it is long term and directly associated with the family, and his or her individual livelihood, it is needed to pre-plan from the respective government in post-disaster context from the humanitarian point of view.

The above basics are necessary to reduce the impact of earthquakes in the short-term, medium-term and long-term. They recognize the enormous challenge in improving seismic safety because of the inadequate numbers of trained and qualified civil engineers, structural engineers, architects and masons proficient in earthquake-resistant design and construction of structures [2].

Despite some efforts made from Government, local people, INGOs, NGO in reducing risk reduction, disaster specific needs, priorities and plans have not been well addressed from disaster management perspective.

9. Conclusions

The Nepalese and their neighbors and friends all over the globe, have to reconcile themselves to the fact that tens of kilometers beneath where they live, the Indian and Eurasian plates will continue to tussle. Hence, they must build on the fundamental strengths they possess—social capital and community resilience. In mega disasters, a nation can be socially and economically affected not just for days or months, but for years. Effective implementation of Building Codes to make earthquake resistant buildings and other infrastructures is highly desirable. Educating the people to Build Back Better (BBB) must be the motto of the government. Henceforth, the government should call on experts inside and outside the country to engage in interdisciplinary collaboration for BBB. Non-governmental organizations, the private sector, experts, intellectuals, media and international community can contribute in the rebuilding and disaster-preparation efforts by working together.

Conflict of interest

The authors declare that they have no competing interests.

Limitation

This chapter may not cover earthquake impact associated all the cross-cutting sectors what readers can expect.

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Chapter 6

Lifeline Interrelationships during the Tohoku Earthquake: Management of Disaster Analysis Reports Using Text Mining

Yasuko Kuwata

Abstract

Although many studies have been undertaken in the area of lifeline interrelation, examinations based on the quantitative evaluation of post-earthquake lifeline interrelations have been limited. In this study, we present a new methodology to evaluate lifeline interactions, with an emphasis on the aspects of earthquake disasters. Terms related to other lifelines used in disaster reports are somewhat influenced by post-earthquake behaviors. In this study, the number of related terms was counted, and the relationships between the lifelines were quantitatively assessed for the 2011 Tohoku earthquake that occurred in Japan. The validation process included checks through academic reports as well as government reporting. We found that many lifelines were strongly dependent on the electric power systems, which gave no consideration to the accident at the Fukushima nuclear power plant. We confirmed further that the similar lifeline interrelation results could still be obtained regardless of the reporting used.

Keywords: lifeline interrelation, Tohoku earthquake, disaster report, text mining, tsunami, blackout

1. Introduction

Damage to a lifeline system during an earthquake can cause widespread physical damage, with functional interruptions among systems causing many consequences. At the time of the 2011 Tohoku earthquake, strong ground motions were observed throughout a large portion of Japan, causing a large tsunami in the Pacific coast in 2011, with consequent lifeline damage expanded and spatiotemporally spread.

Other researchers, including Nojima and Kameda [1], had studied lifeline interrelations during an earthquake in the urban areas of Kobe in 1995. Based on these studies, the structure of lifeline interrelations was modeled systematically, with the interrelation structure additionally analyzed qualitatively based on the damage caused by the Kobe earthquake [2]. However, the interrelation over all lifelines had not yet been quantified at this time.

To date, only a few studies have modeled earthquake events of lifeline interrelations using system dynamics, which have attempted to quantitatively evaluate the impact on other lifelines by stopping the supply of one lifeline [3]. Although a part of the restoration process can be understood using this method, the model becomes

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more complicated when the interrelationship is explained as if the entire lifeline of the urban area is overlooked. If the model became complicated, multiple individual parameters are also required; thus, many assumptions may be involved to set the system correctly.

Nevertheless, there are indices which further quantify the influence of an earthquake on lifeline disruptions. For instance, the "resilience factor" of the Applied Technology Council document ATC-25 [4] was improved based on the "importance factor" proposed in the United States in ATC-13 [5]. The lifeline resilience factor, as defined by Kajitani et al. [6, 7], was additionally improved for the Japanese version of the resilience factor in ATC-25. In ATC-13, the importance factor was suggested on the basis of a questionnaire administered to 13 specialists regarding the influence of 1985 earthquakes in California. This factor ranged from 0 to 1, indicating a decreased rate of production for 35 different industries when each lifeline service was interrupted. However, these values were not based on the results of an actual earthquake. When this was applied to the affected areas in the 2004 Sumatra earthquake and tsunami, difference between the factor and the real results was observed, though the industrial type and scale were not the same as those of the ACT target set [8].

While several studies have been conducted on lifeline interrelation, as described above, only a few have focused on the quantitative post evaluations of lifeline interrelations after earthquakes, much less those which quantitatively appraise the entire lifeline before an earthquake. By using the report on the damage and restoration of lifelines after the Tohoku earthquake in 2011, this study relates the terms of other lifelines included in such reports to quantify lifeline system interdependencies and frequency-based incidents, proposing a new method to make this visible. Some studies have recently related the major research field of academic societies by way of text analysis [9].

Typically, the lifeline interrelation that occurs at the time of a disaster can change according to the type and scale of the hazard and the extent of each lifeline service outage. It has been considered that the extent of these influences is different for each earthquake shake; thus, it is necessary to examine the degree of hazard together with the lifeline outage. This study also aims to quantify the number of detected terms, as the meaning and usage of these terms and phrases are not always elucidated in detail. Therefore, while the value of the detection frequency has not always explained the interrelation directly, this method may then be useful to create relatively visible relationships across all lifelines.

2. Interrelation analysis in disaster reporting systems

2.1 Disaster reports

We infer that each lifeline system was considerably damaged as a consequence of the 2011 Tohoku earthquake. In Japan, individual lifeline authorities, local governments, and departmental ministries all published disaster reports due to this earthquake, describing the events in different volumes and various contexts. Here we use the disaster report prepared by a specific joint committee composed of seismology, civil engineering, geological engineering, architecture, mechanical engineering, and urban planning societies [10]. One of the volumes in the report comprises of six chapters (**Table 1**), with one volume focused on lifeline systems (see in **Figure 1**).

This particular chapter is composed of the same material as that of a report prepared by a similar joint committee after the 1995 Kobe earthquake. In Part 3 of this report, some physical damage to roadways, railways, airports, harbors, and other transportation systems was not included, as they formed part of other volumes.

Chapter	Title of chapter	Number of pages	Number of writers
1	Water system	86	20
2	Sewage system	75	10
3	Waste management system	59	14
4	Electric power system	63	6
5	Gas system	22	4
6	Telecommunication system	32	10

Table 1.
Chapters in Part 3 "Damage to Lifeline Facilities and its Restoration" from the "Report on the Great East Japan Earthquake Disaster" [10].

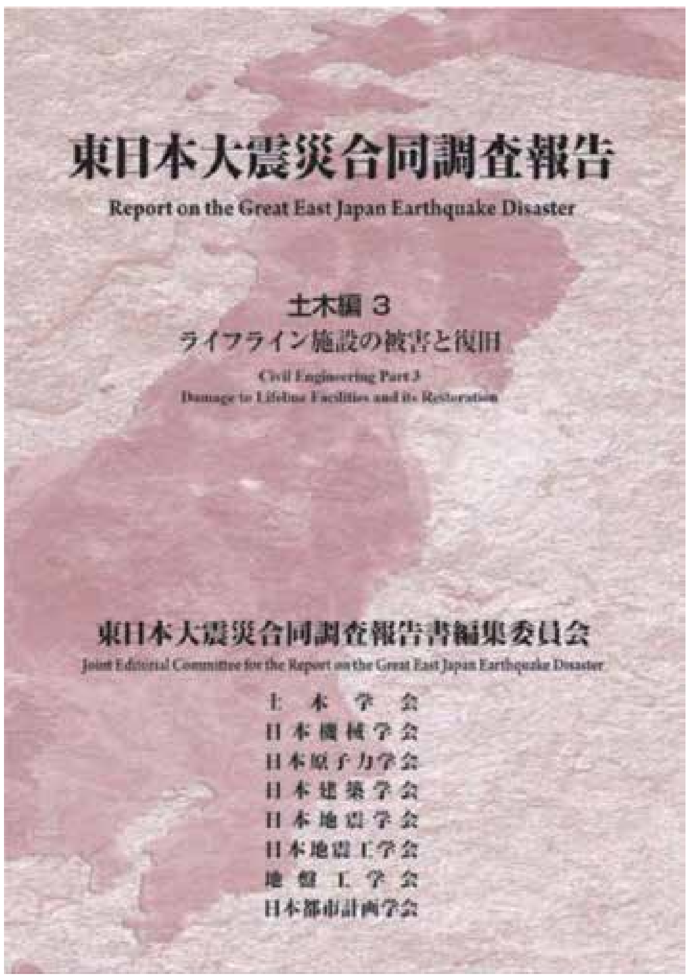

Figure 1.
Capture of the report, titled "Report on the Great East Japan Earthquake Disaster: Volume of Civil Engineering Part 3, Damage to Lifeline Facilities and its Restoration."

The urban gas system was briefly described comparing with other lifeline systems, because a propane gas tank was used in many of the affected areas. The number of affected consumers of gas systems in the Tohoku earthquake was found to be half of those found for the Kobe earthquake.

In Japan, the water, sewage, and waste management systems are all managed by local governments or regional governments, whereas the electric power systems, telecommunication systems, and parts of the gas systems are widely managed through private companies. The report (referred to in **Table 1**) was mainly written by these governments or companies, with the number of writers for chapters on electric power, telecommunications, and gas systems being fewer than those for the chapters of other lifelines. There are 2250 characters per page in the report.

2.2 Hazard classifications

To explain the influence of hazards, such as earthquakes and tsunamis, in the context of this study, "hazard term" was defined as in **Table 2**, and the number of hazard term in Ref. [10] report was detected. Selected terms were basically provided as nouns, with the terms displayed in **Table 2** being English translations. These definitions were used as either single terms or as part of other terms.

These hazard definitions were then classified into four different categories: (1) earthquakes, (2) tsunamis, (3) geo-hazards, and (4) liquefaction. As liquefaction was found particularly remarkable for this earthquake, it was considered within other categories except for geo-hazards. When the term "damage" was used to express geological damage that was not associated to a lifeline facility, the term was omitted from text detection process.

Table 3 lists the number of detected "hazard" definitions used in each chapter of lifeline system. **Figure 2** shows the composition ratio of these terms. The number of hazard terms detected per page was found to be low for the chapter on waste management while exceeding beyond ten words per page for the chapters regarding gas, electric power, and telecommunication systems. The chapter on waste management systems focused on the processing and management methods of waste after the tsunami. The description of the hazard and the extent of damage were also quite brief. Conversely, the chapter on gas systems comprised of the damage analysis caused by seismic ground motion, while the chapter on electric power systems comprised of the damage to the facility as a function of seismic intensity. The frequency of the terms found in the earthquake category also increased for the chapters related to the gas and electric power systems. For the chapters regarding sewage and waste management systems, the terms related to the tsunami were more frequent than those related to the earthquake, where their composition ratios reached approximately 60% or more of the total. While damage to the other lifelines was mainly caused by ground motion, as the waste management plants were all located along the coast, they were unfortunately subjected to flood damage due to the resultant tsunami. For the chapter

Category	Earthquake	Tsunami	Geo-hazard	Liquefaction
Number of words	4	4	3	2
Hazard word	Earthquake Shaking Motion Seismic intensity	Tsunami Inundation Flood Scouring	Subsiding Damage to ground/ground surface Falling out of slope/ embankment/ wall	Liquefaction Sand boiling

Table 2.
A category of hazard term definitions.

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	Water	Sewage	Waste	Electric	Gas	Telecom
Earthquake	256	88	47	404	206	122
Tsunami	208	266	163	256	107	135
Geo-hazard	27	23	6	14	0	7
Liquefaction	78	42	0	63	19	55
Total N_{haz}	569	419	216	737	332	319
N_{haz}/pages	6.6	5.6	3.7	11.7	15.1	10.0

Table 3.
The number of hazard terms detected within the chapters on lifelines.

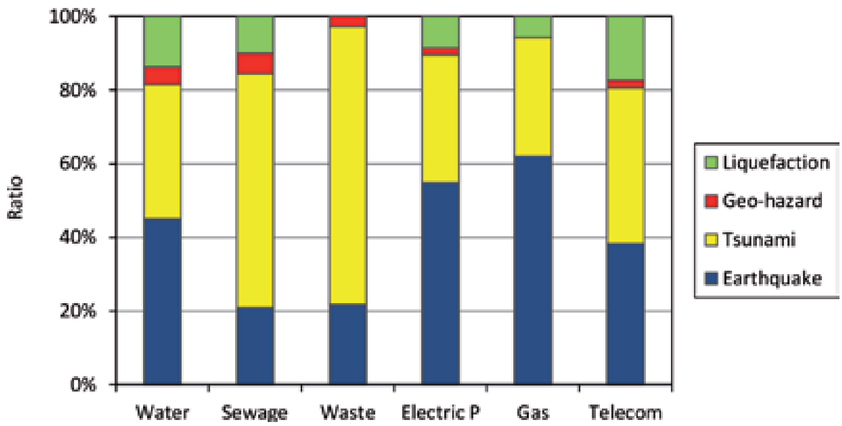

Figure 2.
Composition ratio of key hazard terms detected in chapters related to lifelines.

on waste management systems, many terms related to the processing of tsunami deposits were used. References related to liquefaction were also relatively high.

2.3 Lifeline interrelation analyses based on academic reports

An assessment analyzing lifeline interrelations was conducted using the terms detected from the aforementioned report. First, the lifeline-related terms were identified not only from the lifeline itself but also when the terms were associated with a given lifeline. Second, it was assumed that the use of lifeline-related terms implied that all other lifelines were affected. Last, the number of terms related to the lifelines was counted. The report also described physical damage, suspension, and restoration of lifelines, and not necessarily those of other lifelines.

The lifeline-related terms are divided into sets, as shown in **Tables 4** and **5**. The term related to nuclear power systems was set separately from those related to general electric power, considered the accident at the Fukushima nuclear power plant, which was caused by an earthquake. It is important to examine the lifeline interrelations for the transportation system mentioned in Part 3, regardless of its exclusion in the civil engineering volume. The terms related to the transportation system were added and classified into those associated to roadways and bridges as well as those of traffic functions.

In this case, several lifeline-related terms were set, where terms that were not detected (or only detected two times or less) were omitted in order to accurately identify the number of terms. In addition, when terms were not being used in accordance to the author's intent, its contents were omitted (see notes in **Tables 4** and **5**).

	Water	Sewage	Waste	Electric power	
				General	Nuclear power
Number of terms	8	7	7	11	9
Lifeline-related terms	Water system Water outage Passing water Water supply Water purification Usage restrictions Cooling water Receiving water	Drainage*1 Treatment plant Treatment facility*2 Rain water Sewage Sanitation Sludge	Garbage Waste Debris Human waste Disposal facility Repository site Clean center	Electric power Electricity Power generation Power transmission Power supply Utility pole Power distribution Power outage Resuming Power Power receiving	Nuclear power plant Nuclear power Radioactivity Cesium Radiation Radioactive substance Pollution Precaution district Decontamination

*1: Excludes ground water, *2: Excludes waste water treatment plants

Table 4.
Lifeline-related terms of water, sewage, waste and electric power.

	Gas	Telecom	Transportation	
			Physical	Functional
Number of terms	6	10	9	7
Lifeline-related terms	Gas Leak Fire LNG LPG Incineration	Communication NTT Congestion Mail Wireless LAN Telephone Internet Home page Base station Receiving call/mail	Roadway Bridge National highway Pier Hanging cable*1 Railway Station Airport Harbor	Traffic Transit Vehicle Ship Congestion Gasoline Fuel

*1: Excludes pipes hanging on a bridge

Table 5.
Lifeline-related terms of gas, telecommunication and transportation.

Table 6 shows the number of detected lifeline-related terms in each lifeline chapter. In total, approximately 7518 terms were detected, where about 500 of those were detected in the chapters of the gas and telecommunication systems, smaller number rather than other lifelines: however, no significant difference was found in terms of detected frequency per page.

Figure 3 shows that the ratio of own lifeline-related terms, N_{self}, relative to the detected terms was the same for each lifeline chapter. For example, the ratio indicates the number of water-related terms relative to all other terms in the water systems chapter. The ratio of N_{self} was accounted for approximately 60 to 80%, which describes damage to and the restoration of the lifeline itself. These ratios were neither dependent on the type of lifeline nor the number of writers. Moreover, from the chapter on electric power systems, 10% only of the chapter had described the Fukushima nuclear power plant accident, in addition to radioactivity dispersal.

Subsequently, the terms excluding the own lifeline-related terms from detected terms are summarized in **Figure 4**, which shows the composition ratio of the

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	Water	Sewage	Waste	Electric	Gas	Telecom
Total N	2002	1629	2009	900	448	530
N/Pages	23.3	21.7	34.1	14.3	20.4	16.6

Table 6.
The number of detected lifeline-related terms from each lifeline chapter.

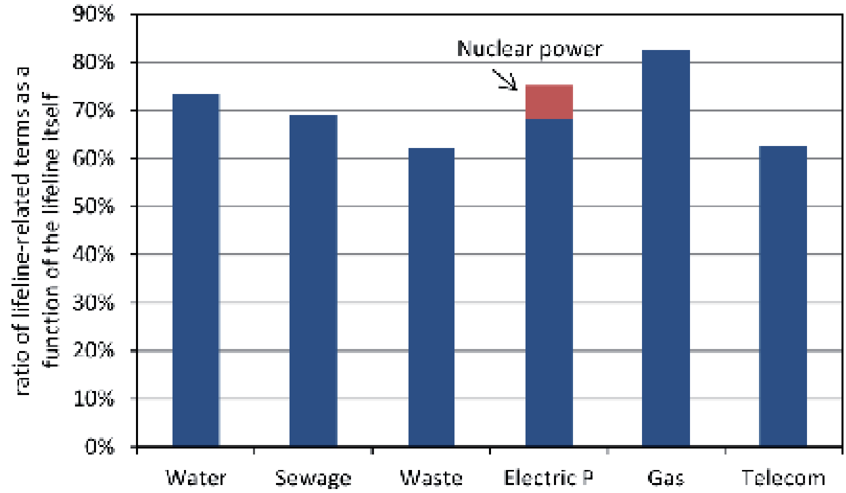

Figure 3.
The ratio of lifeline-related terms as a function of the lifeline itself, N_{self}, within each lifeline chapter.

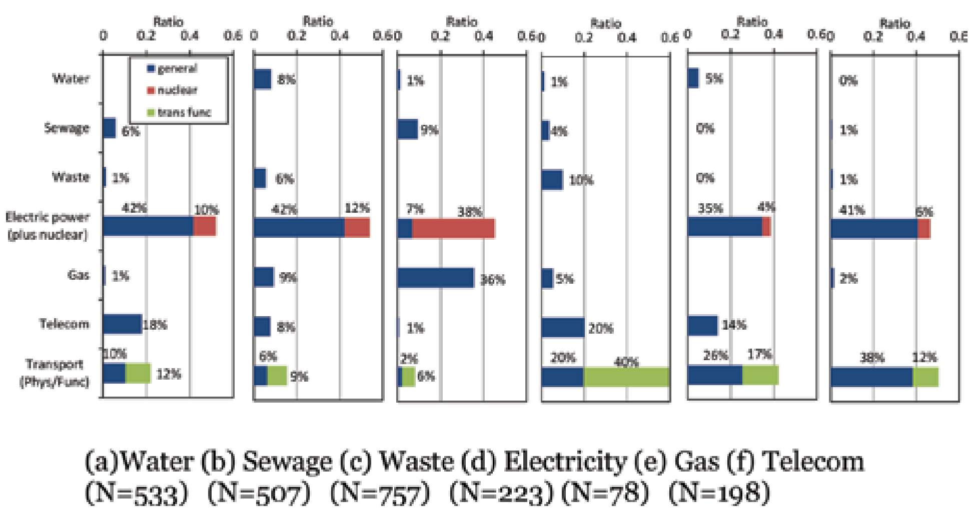

Figure 4.
The compositional ratio of lifeline-related terms for all other lifelines.

lifeline-related terms in each chapter. **Figure 4(a)** summarizes the number of detected lifeline-related terms, excluding water-related terms, for the chapter on water systems. The number of terms, excluding those related to the lifeline itself, was found at a minimum (N_{else} = 78) for the gas systems chapter because the chapter was short. The number of terms in all other lifelines ranged from N_{else} = 198 to N_{else} = 757.

The composition ratio for electric power (i.e., general + nuclear power plant) in **Figure 4** shows the ratio of each term related to general electric power and nuclear power. The ratio of electric power was found to exceed 39% for all lifeline chapters. The most influential lifeline was the electric power system. Here, many terms related to electrical power systems were detected because the electrical equipment in all other lifeline systems were damaged directly by the earthquake and tsunami and operations of other lifeline services were suspended by the power outage.

Terms such as "blackout" (i.e., power outage) and electricity were detected. As a response to the power outage, the terms "power generation," related to an emergency power generator, and "power," in terms of power acquisition and power loss, were also encountered. In this case, the electric power supply had the strongest effect on all other lifelines from the previous studies referenced. Our findings also confirm this. The waste management system, however, was found independent of the electric power system when a nuclear accident was not perceived.

Here, many disaster responses were conducted for the waste management related to the Fukushima nuclear power plant. Within the chapter on waste management systems, no remarkable differences were observed for the nuclear power lifeline-related terms. For the chapters on water and sewage systems, many terms for "radioactive substances" were noticed, with the responses to water purification processing and sludge disposal found to increase due to the accident. It is necessary to study the lifeline interrelation for the case of the other earthquake, which did not result in a nuclear accident, in a similar situation to check the effects in both cases.

The transportation system was also found to have a large influence on all other lifelines. The physical terms "roadway" and "bridge" as well as the functional terms "fuel" and "vehicle" were also detected frequently, regardless of the lifeline system used. For example, the underground pipeline under the roadway along the coast and river was found to be damaged along with the hanging pipeline on the bridge because of the destruction from the earthquake. The electric power, telecommunications, water, and gas systems were all quickly restored, requiring fuel to dispatch the relief goods and personnel to repair the destruction.

Apart from electric power, transportation systems and telecommunication system were then found to be the most common terms. Here, "telecommunication," "telephone," and "wireless" were all extracted several times. While satellite phones were available, telephone services were suspended in a certain area; then, communications among organizations could not be achieved.

3. Lifeline interrelation analyses based on government reports

The degree of influence from lifelines obtained in **Figure 4** shows a different tendency toward disaster scales and the type change. If the same trend was shown for the same earthquake, however, the results of this analyses were found to be valuable. Therefore, similar interrelated tendencies were confirmed in other reports.

In this study, one report (shown in **Table 7**) has used all the other aforementioned reports. These reports (hereinafter referred to as "governmental report") were basically ones in which the jurisdictive ministries and agencies of each lifeline summarized the earthquake/tsunami damage in different types of ways. Therefore, the format of each report differed along with the quantity per page for the academic society report, as mentioned above (herein referred to as the "academic report").

Table 8 shows the counts detected for the lifeline-related terms observed in **Table 4** for the government report. The government reports for sewage and waste were found to have less than the total detectable number compared to that of the academic report. However, the number of all other lifeline-related terms ended up being over 100 words, which was deemed enough to discuss in the composition ratio.

Lifeline	Name of report
Water	The Ministry of Health, Labor and Welfare: *Final report of damage investigation of water supply system during the Great East Japan Earthquake*, 2013
Sewage	The Ministry of Land, Infrastructure and Transport: *Summary of damage to sewage system during the Great East Japan Earthquake*, 2012
Waste	The Ministry of the Environment: *Regional management of disaster waste*, 2014
Power	Tohoku Electric Power Company: *Restoration records of Great East Japan Earthquake*, 2012 Tokyo Electric Power Company: *Restoration records of electric facility due to Tohoku earthquake*, 2013
Gas	The Ministry of Economy, Trade and Industry: *Report of disaster measure committee of city gas supply based on the Great East Japan Earthquake*, 2012
Telecom	The Ministry of Public Management, Home Affairs, Posts and Telecommunications: *White paper on telecommunications*, 2011
Transport	The Ministry of Land, Infrastructure and Transport: *Records of Great East Japan Earthquake*, 2012

Table 7.
A list of governmental reports on the Tohoku earthquake [11–18].

	Water	Sewage	Waste	Electric Tohoku EPCO	Electric TEPCO	Gas	Telecom	Transportation
N	4067	508	782	3398	2790	1441	2621	4955
N_{self}/N	78%	42%	35%	60%	66%	34%	74%	91%
N-N_{self}	897	244	569	1027	694	552	687	426

Table 8.
The number of detected lifeline-related terms from governmental reports.

Figures 5 and **6** show the lifeline-related terms (excluding the related terms) in our own lifeline analysis. In regard to electricity, both Tohoku Electric Power Company and the Tokyo Electric Power Company (TEPCO) were shown separately. An analysis of the transportation system was only included in the academic report. In the water supply and sewage report, the lifeline with the highest composition ratio was found to be electricity, with 55% and 54% including nuclear-related terms that were similar to the composition ratio found in the academic report.

According to the waste report, the ratio of gas system was found higher than those quoted in the academic report; however, the composition ratio was monopolized by electric power system and gas system in a similar way. Regarding the report on electric power system, the composition ratio distribution between Tohoku Electric Power and TEPCO was very similar, showing almost 70% for the terms related to the transportation and telecommunication systems.

The transportation system was found to be monopolized in the academic report, but within the governmental report, telecommunication was slightly higher. In the report on gas system, the electric power system and transportation system were much more superior and akin to the academic report where the composition ratios also showed similar values. According to the telecommunication report, the electric power-related term (as with the academic report) was very high at 75%. The fact that the electric power system and transportation system dominated in this report was also similar. For the transportation system, while this was not handled in the academic report, the proportion of electricity was still monopolized at 52%, with sewage, waste, and telecommunications following this.

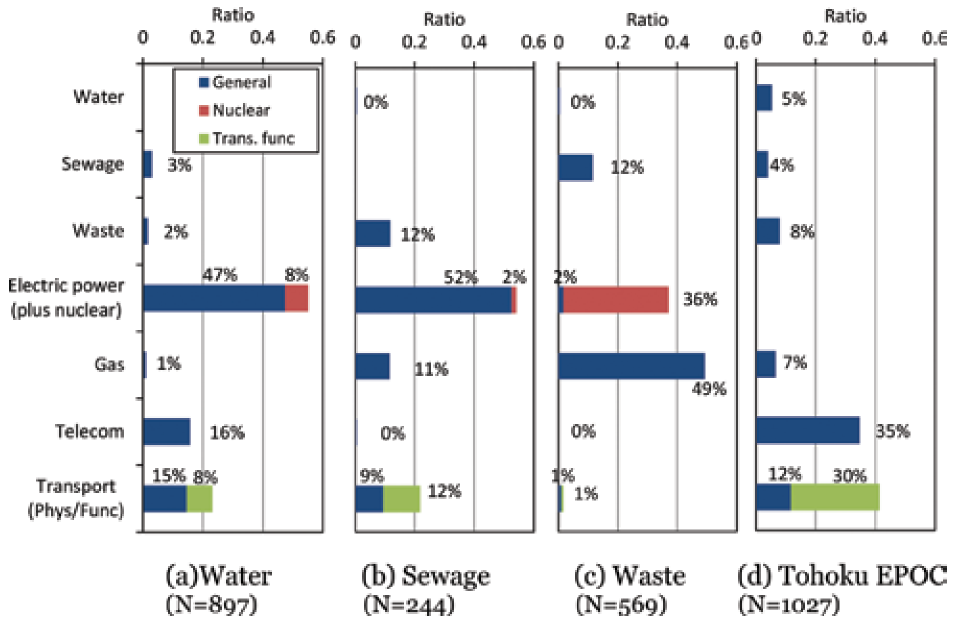

Figure 5.
The composition ratio of lifeline-related terms for all lifelines.

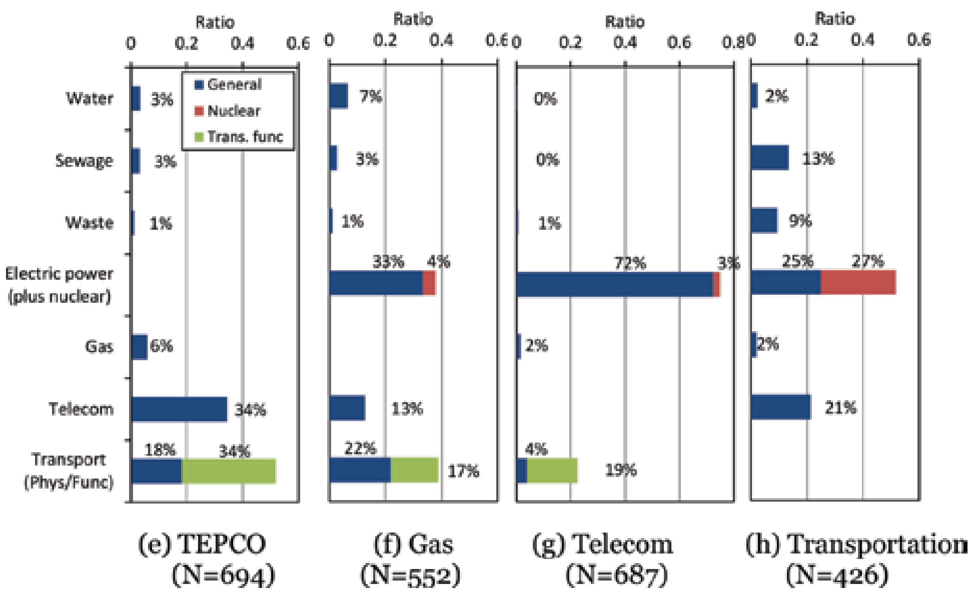

Figure 6.
The composition ratio of lifeline-related terms for all lifelines.

In terms of electricity-related terms in the governmental reports, besides the term "electricity," "blackout," and "power generation" were also used. The latter was perhaps associated with a halt in business operations due to a power outage, where the installation of generators was put into place as a countermeasure. This trend was the same as those for the academic report. In this case, "power supply" was used widely; however, in the governmental report, the term "electric power" was used more than the term "power supply." The composition ratios for power-related terms was found to be similar in both reports, even though the content varied somewhat.

Even if differences were acknowledged for the composition ratio of the related terms between the academic report and the governmental report, this was verified nonetheless by the 5% dangerous rate [19]. Consequently, the premise that a difference in the composition ratio was evident was not readily dismissed for these lifelines (i.e., $8.83 < \chi_{5,\,0.05}^2 = 11.07$ in the water, $6.52 < \chi_{3,\,0.05}^2 = 7.81$ in sewage, and $0.67 < \chi_{2,\,0.05}^2 = 5.99$ in the gas). In other words, the differences were not recognized between repots for these lifeline systems. However, the differences were acknowledged for waste, electric power, and telecommunication systems in the 5% dangerous rate. It has been thought that the reason for these, especially within the governmental reports, was it made it purposefully different from the academic report. These same disasters were understood to have a lifeline where the level of influence between them did not change due to the report issued. Moreover, when the level of influence changed due to the same disaster discussed in the report, it was shown to exert a more dominant lifeline.

4. Discussion

In this study, the evaluation method used for lifeline interrelations was applied to the Tohoku earthquake and quantitatively assessed. This evaluation method was found to quantify the interrelations between all supply systems and transportation lifelines as well. It was found that the influence of the term “electric power” had a large effect and was stated in various reports and academic papers frequently. However, its effect among the lifeline authorities and companies was not shown to be comparable with other lifelines. The value of the composition ratio shown in this study could not be directly used to evaluate a model of lifeline interrelations to predict future lifelines; however, it did become possible to visualize the relationship relatively well across all lifelines.

Lifeline authorities and associated companies have typically provided adequate earthquake countermeasures for their own lifeline facilities; however, a consideration of functions for all other lifelines is usually not sufficient. Based on the results of this study, it was expressly understood that the interrelations for earthquakes with all other lifelines apart from electric power were motivated to prepare backup facilities. Conversely, in an academic sense, modeling the mutual influence among a few lifelines as well as parts of a lifeline resulted in new interrelations that were sometimes overlooked. Indeed, this result can only be inferred as basic material for the modeling of interrelated structures, as we do not consider the physical or functional structures. For future studies, various viewpoints would then be necessary to analyze this perspective in more detail.

Although this study focused on the Tohoku earthquake, comparing the results with other reports such as flood disasters could also be a future task. Since these issues are likely to be affected by the differences in the hazards, as well as the degree of damage to the lifeline (as mentioned previously), consideration should still be given.

5. Conclusions

In this study, lifeline-related terms in disaster reports were detected and quantitatively evaluated to observe the relationships among lifelines during the 2011 Tohoku earthquake disaster. The study can be summarized as follows:

- The composition ratio of each term related to electric power exceeded 39% for all lifelines. This shows that the electric power system was the most influential of all other lifelines.

- A small influence from nuclear power plant accidents was mentioned for all lifelines. This influence was the highest for the waste management system. The effect of water and sewage systems was also high, with many references to radioactive substances found within each chapter.

- An influence on the transportation system for all other lifelines was the strongest after the electric power system. As the earthquake-affected areas were found to be vast, restoration was a timely process. The disaster assistance from all other areas was also influenced.

- With regard to water supply, sewage, and gas, no difference in composition ratio for lifeline-related terms were found, regardless of the type of report for the same disaster. Conversely, in the case of electric power, telecommunications, and waste, while the composition ratio varied depending on the report, it was shown that the dominant lifelines were similar.

- The result of this study could be used as basic data for modeling the interrelated structures. However, since it cannot be guaranteed that similar results will be obtained for any of the disasters mentioned, it will be necessary to verify the reproducibility of this method by applying it to other disasters.

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Section 4

Resilience

Chapter 7

Resilience Science for a Resilient Society in Natural Disaster Prone Countries

Yoshiyuki Kaneda

Abstract

Recently, many destructive natural disasters occurred in the world. Therefore, the damage reductions and disaster mitigation for resilient society are very important and significant. For the implementation of these issues, we propose the resilience science including science, engineering, medicine, and social science. In social science, there are sociology, economics, psychology, law, pedagogy, etc. After 2011 earthquake in East Japan in which severe tsunami damages in a broad area occurred, the reconstruction and restoration activities in each area have been done; however, the progress speeds are not so rapid generally. One of reasons in which delayed reconstruction and restoration occurred is the shortage of pre-recovery plan and concept of future community in each area. In this chapter, we propose the resilience science for resilient society. The resilience science is based on multidisciplinary research fields, and the resilient society is defined as the society equipped with redundancy, robustness, elasticity, and safety. Especially, human resource cultivation is very important in resilience science for the resilient society. For the bright future, the resilience science for the resilient society based on human resource cultivation is indispensable.

Keywords: resilience science, natural disaster, disaster mitigation, recovery, restoration, human resource cultivation, philosophy, bright future

1. Introduction

The world experiences many natural disasters, such as tsunamis, earthquakes, volcanic eruptions, tornados, hurricanes, floods, landslides, and droughts.

Attention has been particularly drawn to destructive tsunamis and earthquakes, such as the 2004 Sumatra earthquake and tsunami, the 2010 Chile earthquake, and the earthquake and tsunami of East Japan in 2011. Recently, destructive earthquakes and tsunamis occurred at Lombok Island, Sulawesi Island, and Sunda Strait in Indonesia.

As per my personal experience, people, buildings, environment, and societies in coastal areas suffered severe damage with disasters, tsunamis, and earthquakes.

Following what has happened after the Great East Japan earthquake in 2011, having the huge damage by the natural disasters, the rapid restoration and the revival could not be seen in the coastal areas.

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Many reasons can be mentioned here, such as the lead times, the reconstruction budgets, and the time spent generating agreement for the restoration plans among the national government, local government, and people living in coastal areas.

Farther, for each individual, it is much far from attaining their ordinal mental and economic conditions back to their state before the disaster [1].

What is indispensable in advance of the coming mega earthquakes, tsunamis, and heavy rain/storm/landslide, etc. is more advanced, progressive countermeasures for disaster mitigation, restoration, and revival in coast regions. I would like to define the natural disasters and mitigation as follows:

1. Natural disasters are events beyond human assumptions:

    - Disasters are various events caused by lack of common recognition, knowledge, and information.

    - Disasters are events caused by incomplete countermeasures.

    - Disasters are events that can be reduced by research/technology, countermeasures, enlightenment/education, human resource cultivation, etc.

2. For disaster mitigation:

    - Preparedness

    - Awareness

    - Science and technology

    - Early warning and proper evacuation/behavior

    - Knowledge and drill

    - Pre-reconstruction/resilience plan

    - Human resource cultivation

In this chapter, we will discuss certain measures for disaster mitigation, such as resilience science [2].

1.1 Tsunami and earthquake damage in the world

As I have already mentioned in a previous publication, "there are records of the 1575 Valdivia earthquake and tsunami in Chili, the 1700 Cascade earthquake and tsunami in Western Canada and Northwestern United States, the 1707 Hoei earthquake/tsunami in Southwest Japan, the 1755 Lisbon earthquake/tsunami in Portugal, the 1960 Chilean earthquake/tsunami, the 1964 Alaskan earthquake/tsunami, the 2004 Sumatra earthquake/tsunami, and the Great East Japan 2011 earthquake/tsunami (**Table 1**). In Japan, recently, many natural disasters included earthquakes and tsunamis have occurred and have caused serious damage [3] (**Figure 1**).

Based on the lessons we learned from the 2011 Great East Japan disaster, we discuss tsunami disasters and the recovery efforts.

Table 2 shows the examples of tsunamis caused by great earthquakes in the history of Japan. These historical tsunamis caused enormous damages over wide areas, especially along the coast.

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Year	Earthquake/tsunami	Area	M
1498	Meio earthquake	Japan	M8.2–8.4
1556	Shaanxi province earthquake	China	M8.0
1693	Catania earthquake	Italy	M7.4
1700	Cascadia earthquake/tsunami	US/Canada	M9.0
1703	Genroku earthquake	Japan	M7.9–8.2
1707	Hoei earthquake	Japan	M8.6
1716	Peru earthquake	Peru	M8.8
1739	Ningxia earthquake	China	M8.0
1746	Peru earthquake	Peru	M8.6
1755	Lisbon earthquake/tsunami	Portugal	M8.5
1759	Lebanon/Syria earthquake	Lebanon/Syria	M7.4
1771	Yaeyama earthquake/tsunami	Japan	M7.4
1778	Iran earthquake	Iran	M7.4
1783	Messiah Italy earthquake	Italy	M6.9
1789	Antakya earthquake	Turkey	M7.0
1850	Szechwan earthquake	China	M7.5
1854	Ansei earthquake	Japan	M8.4
1855	Ansei Edo earthquake	Japan	M6.9
1868	Chile/Peru earthquake	Chile/Peru	M8.8
1868	Ecuador/Columbia earthquake	Ecuador/Columbia	M7.7
1891	Nobi earthquake	Japan	M8.0
1896	Sanriku earthquake/tsunami	Japan	M8.2
1899	Alaska earthquake	USA	M8.6
1906	Off Columbia earthquake	Columbia	M8.8
1908	Messina earthquake	Italy	M7.1
1920	Haiyuan earthquake	China	M8.5
1923	Kanto earthquake	Japan	M7.9
1938	Alaska earthquake	USA	M8.3–M8.7
1939	Erzincan earthquake	Turkey	M7.8
1952	Kamchatka earthquake	Russia	M9.0
1960	Chile earthquake	Chile	M9.5
1964	Alaska	USA	M9.2
1995	Kobe earthquake	Japan	M7.3
1999	Izmit earthquake	Turkey	M7.8
1999	Chi-Chi earthquake	Taiwan	M7.7
2001	Indian/Pakistan earthquake	Indian/Pakistan	M8.0
2001	Bam earthquake	Iran	M6.8
2004	Sumatra earthquake	Indonesia	M9.1
2008	Wenchuan earthquake	China	M8.0
2010	Haiti earthquake	Haiti	M7.3
2010	Chile earthquake	Chile	M8.8
2011	East Japan earthquake	Japan	M9.0

After SSJ chronological scientific table, excerpt.

Table 1.
The destructive earthquakes and tsunamis.

Figure 1.
Damages by 2011 East Japan earthquake (after associate professor Sakamoto of Nagoya University).

Year	Earthquake/tsunami	M	Area
684	Tennmu earthquake/tsunami	M<8.25	Nankai Trough
869	Jyogan earthquake/tsunami	M8.5	East Japan
887	Ninna earthquake/tsunami	M8–8.5	Nankai Trough
1498	Meio earthquake/tsunami	M8.2–8.4	Nankai Trough
1596	Keicho-Bungo earthquake	M7.0	Nankai Trough
1611	Keicho Sanriku earthquake/tsunami	M8.1	East Japan
1707	Hoei earthquake/tsunami	M8.6	Nankai Trough
1703	Genroku Edo earthquake	M7.9–8.2	Kanto Area
1771	Yaeyama earthquake/tsunami	M7.4	Ryukyu Trough
1854	Ansei earthquake/tsunami	M8.4	Nankai Trough
1896	Meiji-Sanriku earthquake/tsunami	M8.2	East Japan
1923	Kanto earthquake	M7.9	Kanto Area
1933	Showa Sanriku earthquake/tsunami	M8.1	East Japan
1944	Showa Tonankaki earthquake/tsunami	M8.0	Nankai Trough
1946	Showa Nankai earthquake/tsunami	M8.1	Nankai Trough
1968	Off Tokachi earthquake/tsunami	M7.9	East Japan
1983	Central Sea of Japan earthquake/tsunami	M7.7	Sea of Japan
1993	Hokkaido-Nansei-oki earthquake/tsunami	M7.8	Sea of Japan
2011	East Japan	M9.0	East Japan

After SSJ chronological scientific table, excerpt.

Table 2.
Historical tsunami in Japan.

At the Sumatra 2004 earthquake and tsunami, they had 200,000 deaths. One of the coastal cities in Indonesia damaged by the tsunami is shown in **Figure 2**. At the 2011 Great East Japan earthquake, 20,000 died or got missing in the tsunami. One of the damaged cities along the coast and the destroyed bank of Kitakami River are shown in **Figure 3**.

From the lessons learned from historical earthquakes and tsunamis, restorations take a long time for severely damaged areas with large numbers of victims. In particular, in coastal cities and places where large numbers of people are impacted by

Figure 2.
Damage by 2004 Sumatra tsunamis (after the Ministry of Foreign Affairs in Japan).

large tsunamis, the restoration of cities and communities must first involve evacuation and then recovery as per the plans for reconstructing cities, and the recovery of damaged cities confront each other because of different opinions and methods; therefore, it takes a long time to reach consensus.

We must discuss restoration from many points of view, such as those of safety, resilient and cozy cities, scenarios of the recurrence of natural disasters, economics, communities, legality, human resource cultivation, the future, and so on. For restoration, at first, we must reconstruct buildings and cities. In the process of reconstruction, cities must approach representatives from engineering, scientific, and legal fields for newly constructed cities and communities.

Thanks to engineering, earthquake-resistant structured buildings will increase, the reconstruction of breakwaters will advance, and liquefaction damages will be reduced compared to that of the present. Further, research on earthquakes and tsunamis will progress, thanks to lessons learned from disasters of earthquakes and tsunamis.

However, the restoration of the coastal area is halfway down the road to recovery from the catastrophic damages in the 2011 East Japan earthquake/tsunami.

Therefore, what are essential and indispensable for us are engineering, scientific and medical fields, as well as social science fields, such as sustainable economics, the mental recovery of people in damaged areas, sustainable communities, disaster mitigation education for communities, and plans for future regions, cities, and countries for many generations.

In addition, the agriculture and fishery industries, so-called primary industries, hold the key to the rapid recovery from natural disasters and reconstruction.

I will discuss later the integration of these fields, "resilience science," as a disaster mitigation science which is indispensable for the bright future in damaged areas and its rapid restoration.

1.2 Disaster mitigation countermeasures in coastal area for tsunamis and earthquakes

How can we reduce the damage caused by a tsunami or an earthquake? Many different measures are being implemented in each field. Among them, scenarios for tsunami and earthquake and the explicit danger based on scientific research must be the top priority.

For instance, for the Nankai Trough megathrust earthquake, **Figure 4** shows the simulation of tsunami propagation and inundation from the Nankai Trough in Southwest Japan to the coastal region.

Figure 3.
Damages by 2011 East Japan earthquake. (Above) Damaged Onagawa city in Miyagi Prefecture (after associate professor Sakamoto of Nagoya University). (Middle) Damaged Otsuchi city in Iwate Prefecture (after Mr. Satoshi Nagao). (Below) Damaged Kitakami River in Iwate Prefecture (after associate professor Sakamoto of Nagoya University).

By examining this simulation based on a recurrence scenario, it is possible to imagine the expected damages of the coastal region and think of the effective countermeasures.

Experimental research is also as important as the simulation research, and it is possible not only to validate the expected damage but to verify the simulation.

As I have already introduced previously in the other publication, "Many tsunami researchers have inspected the damage of the 2004 Sumatra earthquake and tsunami and the 2011 East Japan earthquake and tsunami using field surveys and simulations.

In **Figure 5**, a tsunami simulation for Kesennuma, Miyagi Prefecture used the actual damage done in the 2011 East Japan earthquake and tsunami. **Figure 6**

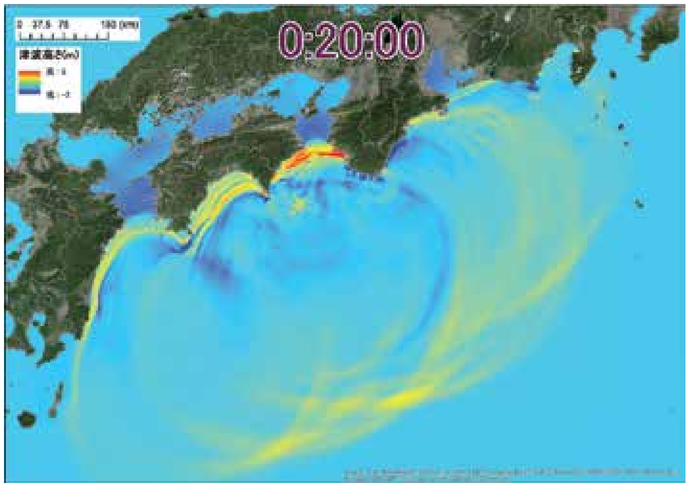


Figure 4.
Tsunami simulation around the Nankai Trough (after Prof. T. Baba University of Tokushima).

indicates how the sediment behavior in the city of Rikuzen-Takata, Iwate Prefecture would affect the environment on the shoreline and offshore around the bay" [3].

The behavior of sediments on-and offshore occurred due to environmental changes, such as damages to agriculture due to salt water and damages to fishery due to changes in nutrients.

Restoration and revival in coastal areas will be delayed more due to environmental damages and changes.

"Of course, before the tsunami struck the coastal area, strong motion and a long-period seismic wave from the huge earthquake will cause damage such as the collapse of buildings (**Figure 7**), liquefaction (**Figure 8**) and fires (**Figure 9**)" [3].

Measures to prevent liquefaction before the earthquake are very important as the recovery is very difficult for damage due to liquefaction. Different types of damages in local areas like subsidence and elevation can be expected.

When a massive earthquake occurs, compound damages will be caused (**Figure 10**), and comparing to other ordinal sizes of earthquake, the restoration and revival can be delayed for much longer time.

Thus, we can say that the preparation of a city restoration plan and its revival plan are urgent matters in a coastal region.

"**Figure 11** indicates the process of restoration in Kesennuma, Miyagi Prefecture after the 2011 East Japan tsunami and earthquake. From **Figure 11**, we can understand that restoration is not always rapid. Due to the severe damage in many areas of East Japan the restoration has been slow" [3].

Natural disasters occur anytime and anywhere; recently, in 2015 in Nepal, M7.8 of destructive earthquake occurred. With that event, internationally it was recognized that the spread of disaster knowledge, rapid rescue, well-organized countermeasures, and restoration plans are very essential and significant issues in the case of such huge natural disasters.

In 2016, a destructive earthquake occurred in Kumamoto Prefecture with multiple shocks that generated huge seismic waves, which caused additional damages.

Recently, multinatural disasters occurred in Indonesia such as 2018 Lombok Island earthquake, 2018 Sulawesi Island earthquake/tsunami, and 2018 Anak Krakatau volcano eruption and tsunami, which generated many victims (**Figures 12** and **13**).

To revitalize communities in coastal areas damaged by tsunamis and earthquakes, we must promote sustainable economic activity, training of human

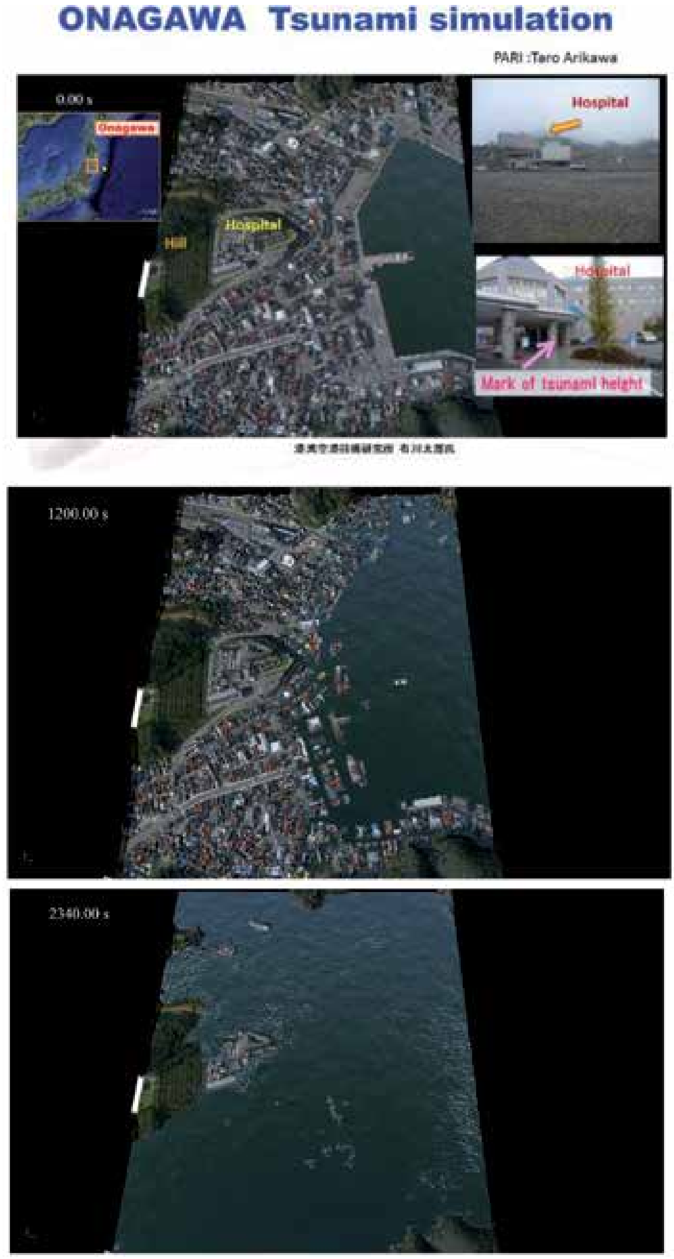


Figure 5.
Simulated tsunami damage at Onagawa city by 2011 East Japan earthquakes (after Prof. Arikawa Chuo University).

resources, and environmental control innovations in technology and local characteristics.

For example, in Sendai regions seriously damaged by the East Japan earthquake and tsunami in 2011, some people and communities started to turn the troubles to their advantages by cultivating salty tomatoes or using hydroponic culture.

Through an intervention of a Japan International Cooperation Agency (JICA) project (**Figure 14**) between Banda Aceh, Indonesia, damaged by the Sumatra earthquake in 2004 and tsunami, and Higashimatsuyama, Sendai, Japan, damaged by the East Japan earthquake in 2011, great mutual empowerment and cooperation have been ongoing.

Figure 6.
The sediments behavior of Rikuzen-Takata city of Iwate Prefecture in Tohoku district by the East Japan earthquake (after Prof. Takahashi Kansai University).

Figure 15 shows a model of empowerment. Empowerment means the act of conferring legality or sanction or a formal warrant and procuring power even in disadvantageous situations.

In Japan and many other countries, destructive natural disasters such as earthquakes, tsunamis, volcanic eruptions, and floods occur, but damage reduction measures are insufficient, and recovery is not always rapid and resilient.

For damage reduction and resilient recovery, we must construct and push resilience science and disaster mitigation forward. Resilience science will be explained in the next section.

Figure 7.
Collapses of buildings in Kobe at 1995 Kobe earthquake (after Kobe damage database).

Figure 8.
Liquefaction damage in Chiba Prefecture at East Japan (after Funabashi city data in Chiba Prefecture).

1.3 Resilience science as disaster mitigation science

Resilience science and disaster mitigation science are synthetic sciences. These sciences are based on multiple disciplines and fundamental and advanced research fields.

These research fields are significant and important at each stage, such as before, during, and after the natural disaster.

In the context of disaster mitigation, I would like to propose the concept of resilience science and disaster mitigation science (**Figure 16**).

We define disaster mitigation science as follows:

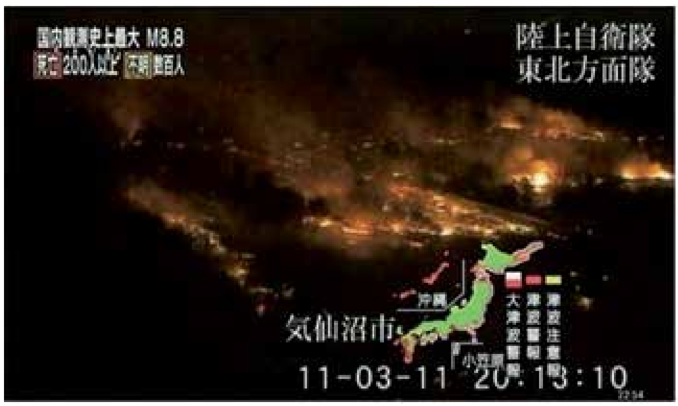
Disaster science includes science, civil engineering, medical science, and social science.

Science includes many research fields, such as geophysics with seismology, geology, volcanology, meteorology, physics, mathematics, hydrodynamics, etc.

For understanding and elucidating the mechanisms of earthquakes, tsunamis, heavy rains, and other natural hazards, these research fields are quite fundamentally important and significant. Based on research fields, we can provide some scenarios of natural hazard occurrences such as earthquakes, tsunamis, and so on. Therefore, scenarios from science are very useful for the planning and preparation of countermeasures.

Many researches on the utilization of big data with real-time data have focused on disaster mitigation and restoration, especially for earthquakes, tsunamis, heavy rains, etc.

a



b

Figure 9.
Fire damage at (a) 1995 Kobe earthquake (after Kobe database), (b) fire damage at 2011 East Japan earthquake (after JGSDF—Japan Ground Self-Defence Force).

Then, we discuss about engineering fields. There are many research fields such as architecture and civil engineering fields within structural design, structural mechanics, geotechnics, computer science with IT/AI, earthquake resistance structure and isolating countermeasures, tsunami and river engineering, etc. These engineering fields and technologies involve IT/AI, and countermeasures, finally, can lead to proper/rapid disaster mitigation for infrastructure and individual buildings, etc.

As real-time monitoring systems, many observatories for early warning of earthquakes and tsunamis will be developed and deployed offshore, for instance, DONET and S-NET in Japan, MACHO in Taiwan, NEPTUNE in Canada, etc.

For disaster mitigation, many technologies in engineering fields are mainly focusing on countermeasures with hardware and software.

Actually, the reasons why only these fields and technologies in science, engineering, and medicine would be insufficient for disaster mitigation, restoration, and revival are that evacuation drills, education, reconstruction of communities damaged by natural hazard, and the mental health care of victims also require social science approaches.

In social sciences, there are many research fields, such as sociology, pedagogy, economics, medicine, informatics, psychology, public administration and politics,

Figure 10.
Compound disaster

philosophy, and others. For instance, public administration or politics or law is justly deemed indispensable.

Moreover, pedagogy is very fundamentally important for disaster education and human resource development. It must be the ultimate countermeasure for disaster mitigation [4] against future natural disasters.

It is indispensable for disaster mitigation and for science, engineering, medicine, and social sciences in societal resilience and evolution. It is also needed in each field for continuous evolution and bright future.

To achieve disaster mitigation, restoration, and revival, collaboration and integration of the different fields, which are also needed in resilience science, will be conducted. The human resource cultivation must be the final countermeasure for societal resilience and evolution [5].

Again, I would like to propose the objectives of resilience science as shown in **Figure 16**, including the following details from (1) to (14) which I have already introduced before in the other publication [3]:

1. **Science:** Studying natural disaster scenarios, risk, and human resources development.

2. **Engineering:** Developing technology on measures, restoration correspondence, damage reduction, and quick restoration of community.

3. **Medical care:** Conducting disaster medical care, including methods for medical treatment and measures for health promotion.

4. **Agriculture/fisheries:** Studying measures to restore agriculture and marine products for local revival and reconstruction after a disaster.

5. **Sociology:** Investigating social disaster correspondence as it had occurred in the past and suggesting future social routes and disaster correspondence.

Figure 11.
Restoration of Kesennuma City of Miyagi Prefecture in Tohoku district during 4 years (after associate professor M. Sakamoto of Nagoya University).

6. **Economics:** Developing damage reduction predictions and construction of a hybrid decreasing disaster economic system over a wide area supply chain and with a local supply based on damage predictions and creating an industry that resists disasters like that of business continuity plan (BCP)/data continuity plan (DCP).

7. **Geography:** Examining disaster geographical feature studies (local walks, virtual town walks using aerial photograph, satellite photos, and so on).

8. **Informatics:** Using disaster information systems (use of ICT and AI) and human science.

9. **Public administration and politics:** Exploring administration and politics for a society resilience against disasters.

10. **Literature/philosophy:** Exploring literature for information archives, communication techniques, and future hearsay technology. In philosophical education, people learn to think by themselves, to make judgments by themselves, and to act properly by themselves. Finally, philosophical education cultivates human resources.

11. **Art:** Healing damaged people and communities, carrying unambiguous information, and archiving the damage.

12. **Law:** Examining resilience law for effective legal action and examination of extralegal measures for revival plans.

13. **Psychology:** Applying research on communication and psychological effects between transmitters and recipients.

14. **Pedagogy:** Promoting human resource development for the leaders of disaster mitigation science.

This resilience science focuses on rapid rescue, disaster mitigation, rapid recovery, and cultivation of human resources.

Figure 12.
Indonesia Sulawesi Island earthquake and tsunami damage (after Reuters/Aflo).

Figure 13.
Indonesia Anak Krakatau volcano. The eruption of this volcano generated tsunami (after Reuters/Aflo).

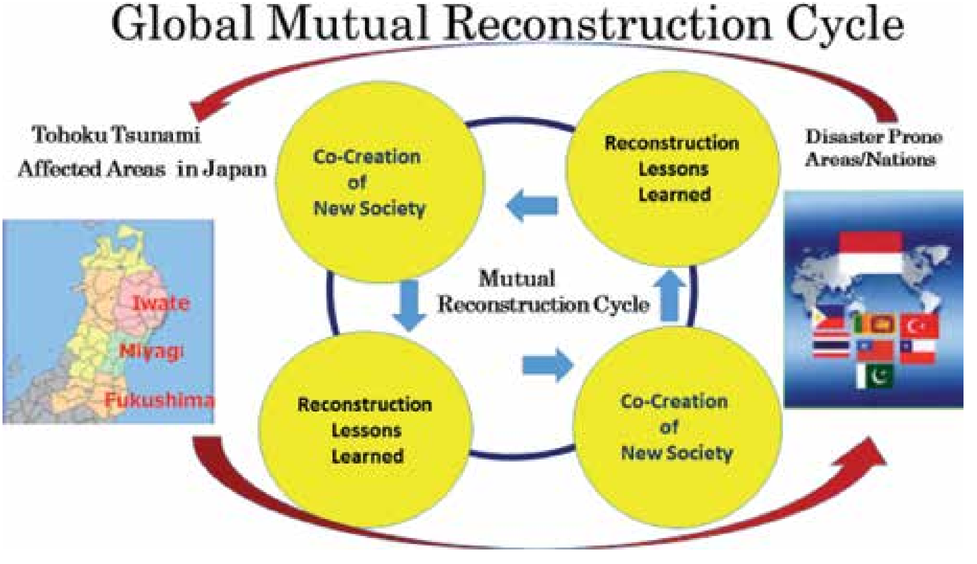


Figure 14.
Empowerment model in JICA project.

The cultivation of human resources is most important for disaster mitigation against many kinds of hazards.

We will expand the concept of resilience science to countries that are prone to natural disasters [6].

Recently, according to the global warming, huge storm and flood occurred frequently in the world. Therefore, the compound natural disasters such as the earthquake, tsunami, volcanic eruption, storm, and flood within a short term might have been supposed easily. So, we have to consider the compound disasters for disaster mitigation and resilient society.

1.4 Resilient society

For the realization of a resilient society, a continuity plan (CP) is indispensable. Varieties of continuity plan (CP) are defined below:

1. Personal continuity plan (PCP)

2. Family continuity plan (FCP)

3. Community continuity plan (CCP): BCP + DCP + Mentality

4. National continuity plan (NCP)

5. Asian continuity plan (ACP)

6. International continuity plan (ICP)

After natural disasters, individuals and families are damaged mentally, economically, and environmentally.

As a result, people and families move to new areas.

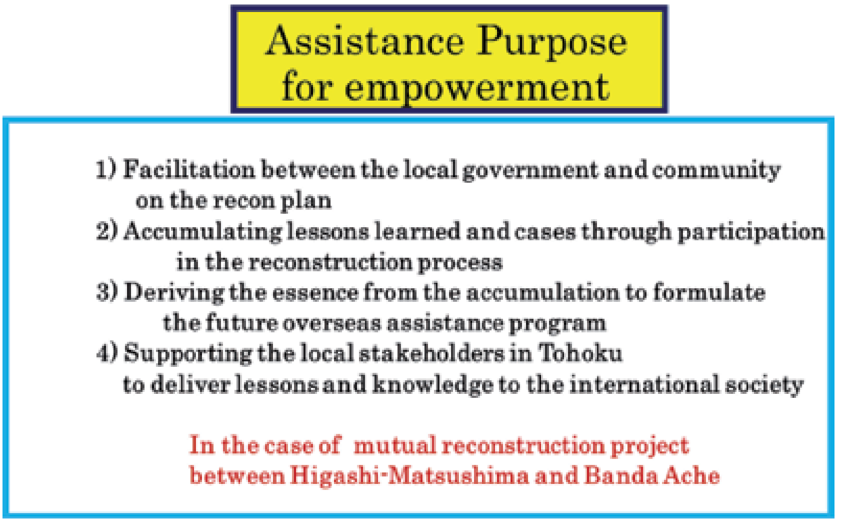


Figure 15.
Assistance purpose (after JICA).

Figure 16.
Disaster mitigation science.

Figure 17.
Continuity program/plan.

Therefore, PCPs and FCPs are important for the protection of individuals and families from being broken and disappointed.

CCPs are indispensable for the resilient society and bright future. CCP is a CP that includes BCP and DCP, which utilize regional strengths such as resilient human resources, environment, culture, industry, and community.

In a more expanded concept of CP, NCP, ACP, and ICP focus on a national, Asian, and international continuity plans (CP) (**Figure 17**). Natural disasters are occurring in anywhere without boundaries. This is the reason why that we propose the expanded concept of CP.

Finally, to hedge against social issues in the near future, such as depopulation, aging, and huge natural disasters, resilience science and disaster mitigation science must include cultivating academia, industries, and culture as indispensable concepts and measures for a resilient society [7].

For individuals, families, local communities, the nation, Asia, and the world and finally the bright future, we must construct and realize a resilient society.

2. Conclusion

Recently, many natural disasters generated severe damages in the world. After these natural disaster damages, many people worked frantically for rescues, recoveries, and future societies.

Actually, they are excellent and respective activities. However, the extent of progress is no always speedy in recoveries and reconstructions especially. So, we recognize that pre-reconstruction plans and human resource cultivation are significant and important.

The lessons learned from 2011 East Japan earthquake are as follows:

1. Rapid evacuation from tsunami
2. Countermeasures against tsunami
3. Necessity of safety evacuation places and buildings
4. Bonds with family and community
5. Speedy recoveries and reconstructions
6. Necessity of pre-reconstruction plans

Especially, for the future society, speedy recoveries and reconstructions and pre-reconstruction plans are very important and indispensable.

Therefore, we propose the resilience science for resilient society.

The resilience science has multidisciplinary fields based on human resource cultivation for resilient society, which will lead to a bright future. Finally, against destructive natural disasters, we have to progress resilience science furthermore.

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Chapter 8

Methodology for Community-Based Resilient Reconstruction

Mikiko Ishikawa

Abstract

This chapter is to clarify the methodology of community-based resilient reconstruction based on 8 years of experiences after the Great East Japan Earthquake disaster occurred on March 11, 2011. Five stages had been clarified. The first stage is pairing support and grand design, which shows ideal perspectives on the area. It should be based on the scientific information and the historical and cultural accumulation of the area. It is better to prepare this stage before the disaster had occurred. The second stage is community-based workshop, for opening up refugees' mind. It is essential to understand that the reconstruction should be carried out by refugees themselves. The third stage is decision-making process, together with refugees, local government, university, NPO, etc. How to create consensus building is the most critical issue. The fourth stage is the implementation. Supporting system should be created for the sustainability of community. The fifth stage is to develop the new community ties for the future generation and to return the benefits which they have received during the reconstruction.

Keywords: community, resilient reconstruction, relocation planning, Great East Japan Earthquake disaster, tsunami

1. Introduction

The Great East Japan Earthquake had occurred on March 11, 2011. The dead are 19,630 (including the dead related with disaster) and the missing are 2569. The number of refugees who still have not settled in the permanent places is 54,000 [1].

The reconstruction has been carried out mainly from the following four points: the first is the reconstruction of infrastructure, such as transportation system, seashore bank, coastal forest, river system, sewers, and living environment; the second is the support for refugees, housing, employment, welfare, education, and mental care; the third is the revitalization of agriculture, fishing industry, and commerce; and the fourth is the reconstruction of Fukushima where the radial problems are the critical issue.

This chapter analyzes the reconstruction process of living environment, especially focusing the community activities on how they found a way to reconstruct from the completely destroyed situation, attacked by tsunami.

1.1 Geological characteristics of tsunami-devastated areas

Figure 1 shows the geological characteristics of tsunami-devastated areas. It is important to recognize that there are two different regions, namely ria coastal area and alluvial flat area. Aomori Pref., Iwate Pref., and the northern Miyagi Pref.

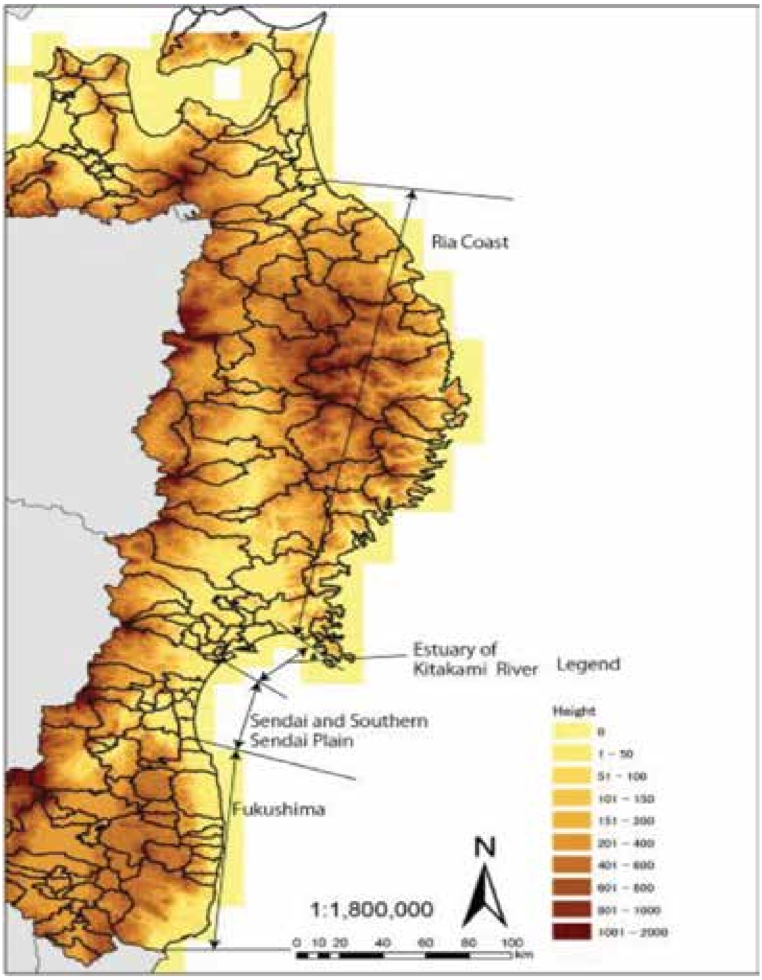

Figure 1.
Geological characteristics of devastated areas by tsunami in 2011.

belong to ria coastal area. There are many tiny fisher villages developed since the Edo era (the beginning of the seventeenth century). Historically, these areas had been attacked by tsunami frequently and many experiences had been accumulated. It is a tragedy that some community survived based on their learned experiences and others had destroyed since they forgot it completely (**Figures 2** and **3**). The only way to reconstruct new safe village in this area is the relocation planning to the upper land or rising up of the existing village ground level. Since adjacent hills in this area are very steep, it took long time, and the cost was enormous (**Figure 4**).

From middle to southern Miyagi Pref. is the alluvial flat area. The city of Sendai has over 1,000,000 populations and consists of metropolitan Sendai region. The problem of this area is there is no higher land to escape from tsunami (**Figures 5** and **6**). Also, during the modernization period since 1868, there were few damages by tsunami. Therefore, no planning methods, which they could apply, existed when the Great East Japan Earthquake had occurred.

1.2 Decrease of population and increase of the ratio of elderly people

In addition to the difference of geological characteristics, there exist strong tendencies which the Japanese society is now facing, that is, the decrease of population

Figure 2.
Victims of tsunami (1896) [2].

Figure 3.
Devastated area (Kesennuma, May 2011).

Figure 4.
Community removing project (ria area) [3].

and the increase of elder generation. **Figure 7** shows the change of population in devastated areas, compared between 2005 and 2015. It is clear, even though the reconstruction took place, most of cities and towns have been suffering about the

Figure 5.
Devastated area in Iwanuma City.

Figure 6.
Devastated area in Natori City.

rapid decrease of the population. The only area where the population has increased is the Sendai Metropolitan region. As for the ratio of elder people, cities in Sendai Metropolitan area are 18–20%, but other areas are 28–35% (**Figure 8**).

Figure 9 shows the comparison between the Great Hanshin-Awaji Earthquake in 1998 and Great East Japan Earthquake. The number of destroyed houses is not drastically different, i.e., the former is 100,000, and the latter is 130,000, whereas the number of reconstruction projects of living environment in the former is 20 and in the later is 435. This number tells us the characteristics of the reconstruction of the Great East Japan Earthquake as the problem of historical community, which has been succeeded from generation to generation.

1.3 Study site: Iwanuma City located in the alluvial flats in southern Sendai region

Based on the above background, we selected Iwanuma City as the study site which is located in the alluvial flat area of the southern part of Sendai City and analyzed the reconstruction process from 2011 to 2018, mainly focusing the methodology of reconstruction planning and how the community made a decision and created new village.

The reconstruction process is divided into five stages, the first stage is the grand design (March–August 2011), the second stage is refugees' workshop (November 2011–November 2014), the third stage is the planning process by the

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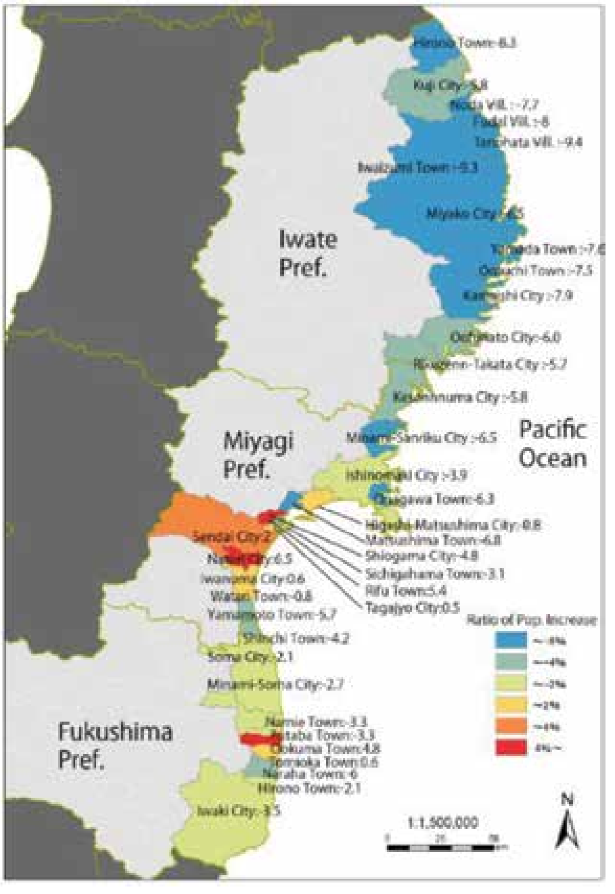

Figure 7.
Change of population in tsunami-devastated municipalities [4] (2005–2015).

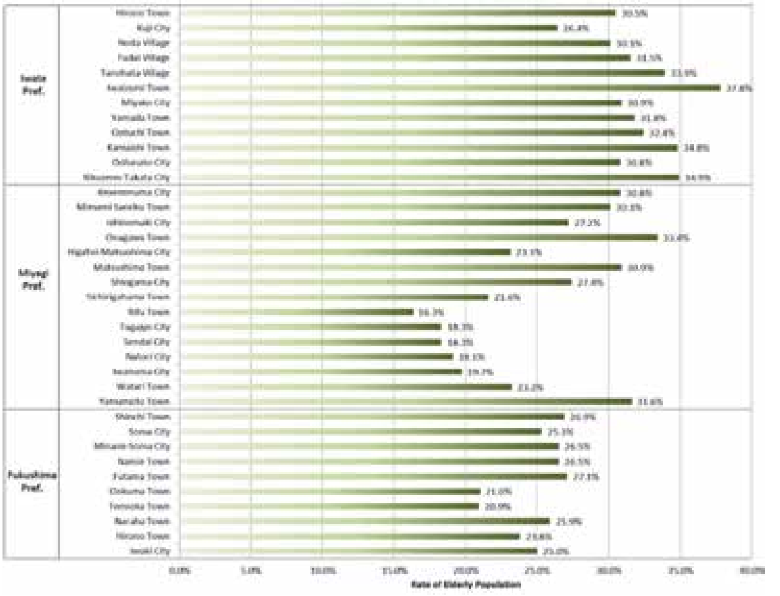

Figure 8.
The ratio of elder generation in tsunami-devastated area in 2015 [4].

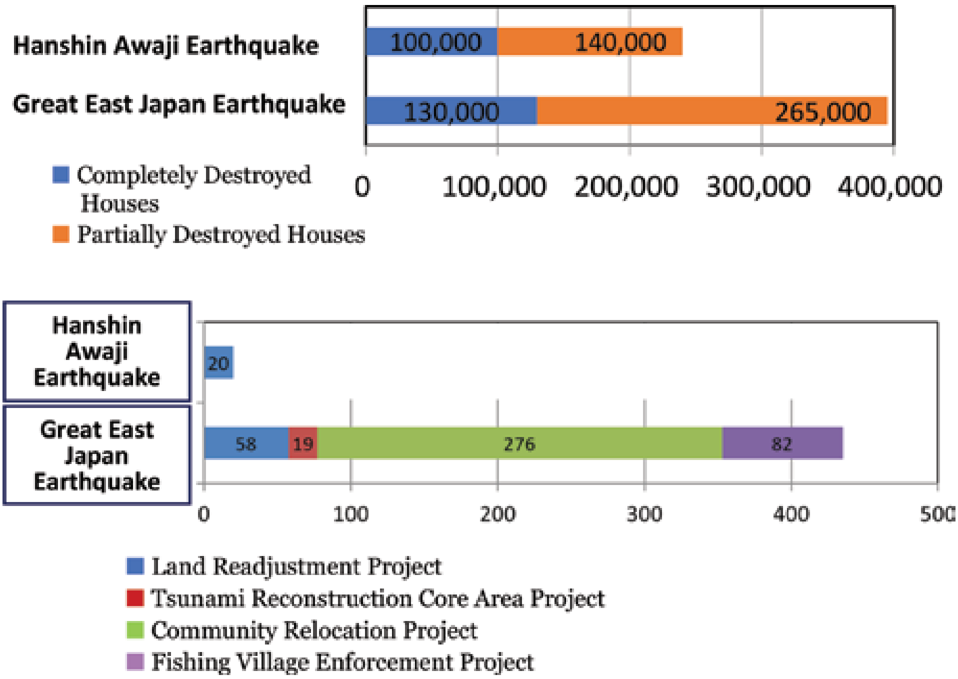

Figure 9.
Comparison of the number of reconstruction project between the Great Hanshin-Awaji Earthquake and Great East Japan Earthquake [5].

formal committee (June 2012–November 2013), the fourth stage is Machizukuri Committee by survivors (January 2014–July 2015), and the fifth stage is the new community creation (August 2015–present).

2. Pairing support and grand design (first stage: March–August 2011)

2.1 Strong will of community and pairing support

Figure 10 shows the location of cities and towns in the southern area of Sendai City, Natori City, Iwanuma City, Watari Town, and Yamamoto Town. This area had been created as alluvial flats of the Natori River and the Abukuma River (**Table 1**).

Iwanuma City is located at the crossing point of Oshu Kaido and Rikuzen Hamakaido. The population is approximately 44,000 and city area covers 60 km^2. There were six villages located along the Pacific Ocean, but it was completely destroyed by tsunami; 186 people died, and 5426 buildings were destroyed. Soon after the tsunami on April 17, 2011, disaster survivors presented the request to the mayor that it is impossible to live in the coastal area and they wanted to remove the inner area as community. Based on these strong requests, the mayor set up the reconstruction committee on April 25, 2011, calling refugees, citizen, agricultural representatives, commercial representatives, city officers, prefectural officers, and professors in universities. The reason why the mayor asked the help of the university was the team of The University of Tokyo had started the so-called pairing support on March 12, 2011, for helping the reconstruction planning. The author belonged to this team, and the concept of pairing support came from the experiences of the reconstruction of the Great Sichuan Earthquake that occurred on May 12, 2008. The damaged area of this earthquake covered a huge area; therefore, the

Figure 10.
The location of cities and towns in southern Sendai region [6].

Chinese government decided to establish pairing support system. The concept is that a certain city in undamaged area will help a certain city in damaged area and provide various supports for the reconstruction. It means the face-to-face support, and this system had worked effectively in the Great Sichuan Earthquake.

2.2 Natural land use planning and multi-defense system

As mentioned, there existed no methodologies on how to reconstruct the safe living environment in the alluvial flat area. The team of The University of Tokyo had started

	Dead	Missing	Population
Natori City	954	38	72,106
	1.32%		
Iwanuma City	186	1	44,138
	0.40%		
Watari Town	283	4	34,832
	0.81%		
Yamamoto Town	700	18	15,269
	4.58%		

Table 1.
Cities and towns in southern Sendai region.

Figure 11.
Remained shrine.

Figure 12.
Remained shrine gate.

the scientific survey just after tsunami, and we found that the microgeography was the key factor to survive in the alluvial flat area. **Figures 11** and **12** show that community shrines had remained from tsunami, since they were located on a slightly higher site (1.5–2.5 m higher compared with adjacent areas), namely, on seashore bank or river bank. Owing to these slight differences of ground level, the depth of tsunami changed, and it made the buoyant forces toward the buildings to weaken.

Figure 13 shows the tsunami-induced areas, and **Figure 14** shows the geological map of the same area. It shows that this area had been created by the flooding and accumulation by the Abukuma River over 8000 years. Complicated landform exists as the hidden structure of this area. **Figure 15** is the historical successions of villages. Comparing with the geological map, villages had historically developed on the river bank or sea bank where people knew as the safe place to live.

Based on the above surveys, we identified natural land use unit, combining geological map, soil map, vegetation map, and land use map (**Figure 16**).

Since this natural land use map was made in a very precise scale (1/2500), it becomes possible to excavate the most appropriate place to remove for refugees and municipalities.

2.3 Grand design

The first meeting of Iwanuma Reconstruction Committee was held on May 7, 2011, and the final proposal was established on August 7, 2011, taking only 3 months. The seven goals proposed are as follows:

1. to build temporary houses as soon as possible;

2. to create a safe city and find the appropriate site for the refugees;

3. to reduce salt damages in rice fields and activate the agriculture;

4. to create new employment, utilizing the advantage of Sendai Airport;

5. to promote natural energy project;

6. to develop multi-defense system from tsunami by creating "Hills of One Thousand Hopes" along seashore; and

7. to renovate the cultural landscapes, historically succeeded.

Among the seven goals, to find a safe place for refugees was the most important issue. Six communities had a strong will to move from seashore to the inner area. Their

Figure 13.
Tsunami induced area in southern Sendai region.

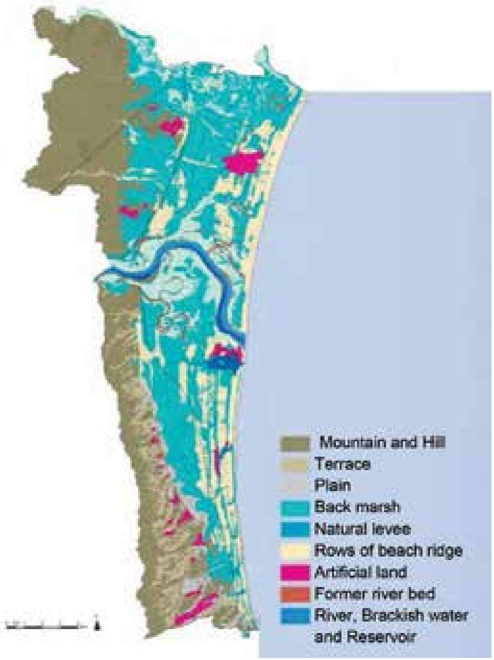

Figure 14.
Geological map of southern Sendai region.

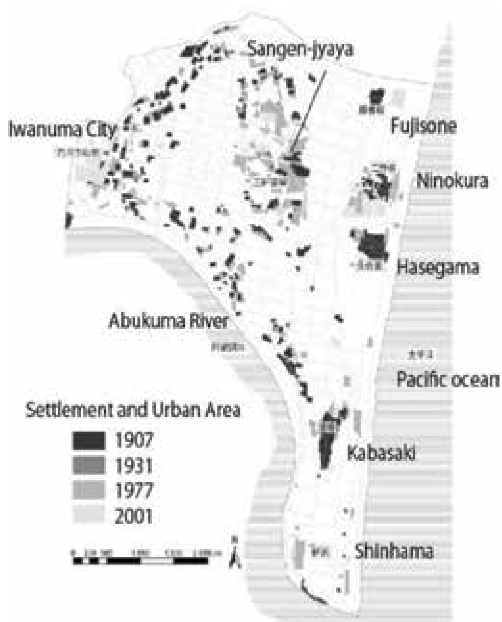

Figure 15.
Historical succession of villages [7].

experiences and scientific study worked together, and in the final meeting in August 7, the ideal plan, i.e., grand design for the reconstruction, had been established.

Figure 17 shows the basic concept of multi-defense system. Multi-defense system is to weaken the power of tsunami by introducing forests, hills, canals, and upgraded roads along seashore. This idea came from **Figure 18**. In the middle, there

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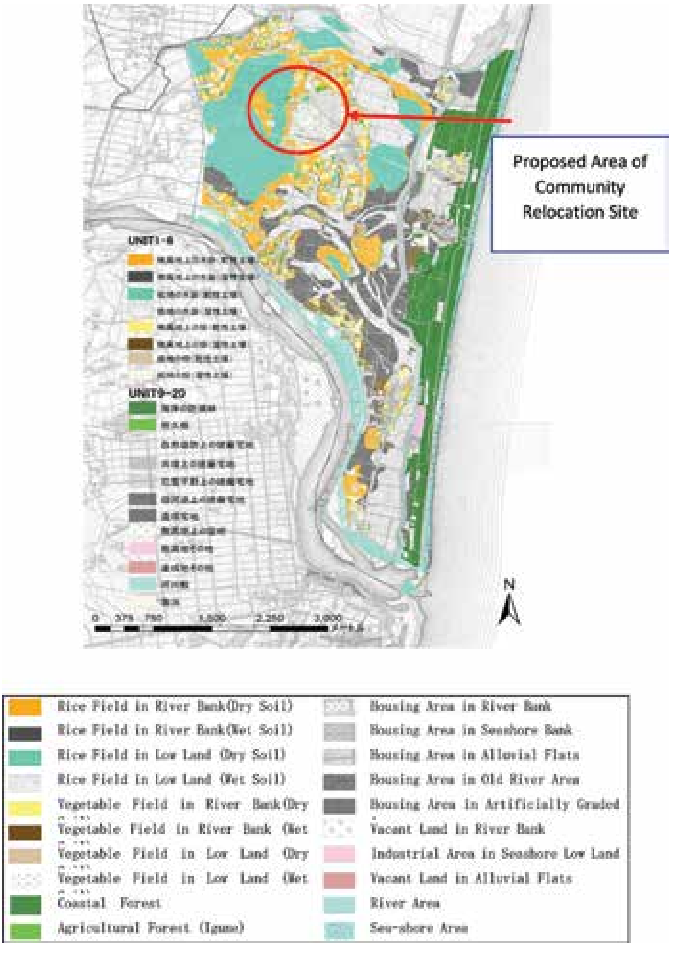

Figure 16.
Natural land use unit.

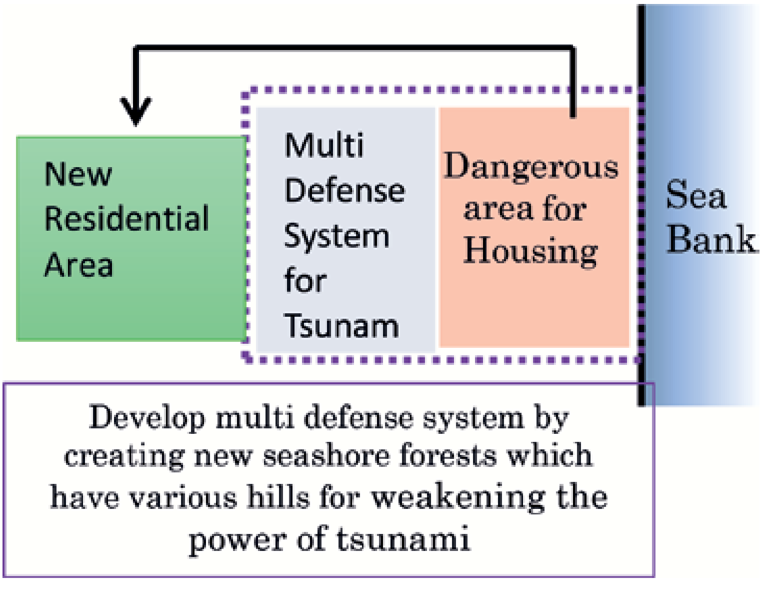

Figure 17.
Concept of multi-defense system.

Figure 18.
The hill in coastal area where village people survived from tsunami.

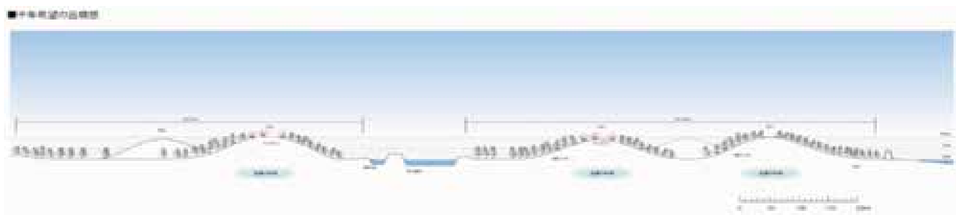

Figure 19.
Image of Hills of One Thousand Hopes [8].

Figure 20.
The grand design of the reconstruction plan in Iwanuma City (August 7, 2011) [9].

are small hills created before tsunami. Some residents escaped to this tiny hill and survived. **Figure 19** is the image of Hills of One Thousand Hopes as a multi-defense coastal forest. Finally, the grand design was proposed on August 7, 2011, from the Committee of Reconstruction of Iwanuma City (**Figure 20**).

3. Refugees' workshop for thinking about a new community (second stage: October–November 2014)

3.1 Process of workshop

The grand design was established. In September 2011, Iwanuma City established the fundamental reconstruction plan based on the grand design. However, nothing had occurred. The reason was, at that time, that the national government and local government could not proceed the reconstruction process immediately, since we had faced serious problems in Fukushima.

In Iwanuma City, all refugees could move in temporary houses on June 3, 2011. The allocation of temporary house was kept on the former group of six communities. Therefore, it was easy to talk together and think about the new village. In October, they started to have a meeting for creating a new community. The first meeting was held on November 12, the second was on December 3, and by the end of February 2012, five meetings had held and they set up principles (**Figures 21** and **22**).

Figure 21.
Image of the new location of new village.

Figure 22.
Refugees' workshop in December 2011.

Five principles were as follows:

1. to create a safe community;
2. to succeed the community tie of former six villages;
3. to create natural symbiosis town;
4. to create attractive town for children; and
5. to replant community forest, Igune, as cultural landscape.

3.2 Finding the importance of cultural landscape

It was very important that the refugees considered not only about their own houses but also they had thoughts about the importance of the tie of community which they had kept on from generation to generation and thoughts about children for the future. Also they thought to recreate community forest, Igune, as a symbol of their new village. **Figure 23** is the map of Natori City in the seventeenth century, and we could recognize that community forest, Igune, had been planted for preventing the north winds. **Figure 24** was taken just after tsunami on August 23, 2011, and we could clearly recognize that Igune prevented tsunami and the farm house had survived. Refugees workshops kept on and they had reached the following image of their new community.

- The new community is surrounded by Igune.
- Six former villages keep the same cluster.
- Small roads are carved like their former village.
- In the middle of new village, it would be ideal if tiny stream flows.

(Teizan Canal was the symbol of their former village, since the Edo era.)

3.3 Location of the new community

Based on the grand design and refugees' workshop, the location of the new community was decided by March 2012. **Figure 25** is the location. It is important that six villages move together and create "compact town," together with adjacent

Figure 23.
Agricultural village in Natori City in the seventeenth century.

Figure 24.
Igune in Iwanuma City (farmhouse survived from tsunami, August 2011).

tsunami-devastated areas where damages were partial. There exist Tamura Elementary School and Junior High School as a symbol of community. In order to sustain their school, the only way was to remove together. **Figure 26** shows the image of the new community, created by refugees in September 2012.

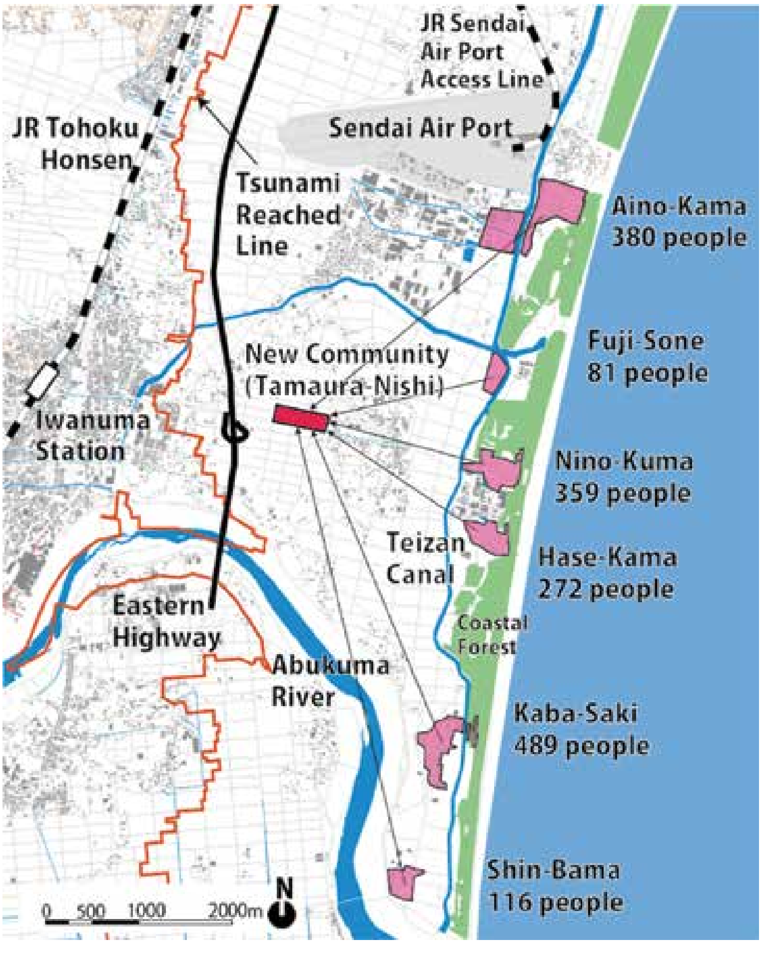

Figure 25.
Location of the new community [9].

Figure 26.
Image of new village by refugees (September 12, 2012).

4. Formal committee and consensus building (third stage: June 2012–November 25, 2013)

4.1 Planning process and goals of the new community "Tamura-Nishi"

Community Removing Project (CRP) in Iwanuma City was officially approved by the Ministry of Land Use and Transportation in March 2012. Based on this designation, it became possible to purchase the land for the new community and to start the reconstruction. On June 11, 2012, the formal reconstruction committee was established. Members were appointed by Iwanuma City, 18 representatives from 6 villages, 3 from adjacent areas, and 3 advisers.

The process is almost the same as informal workshops. Usually, refugees do not know how to build the village, but in this case, they learned and reached a kind of vision which they found by themselves and shared to each other.

It took 1½ years to make the consensus and establish the formal reconstruction plan. A total of 28 meetings were held, and on November 23, 2013, the reconstruction plan was approved. The new community was named "Tamura-Nishi" by refugees' ballot. The goals were decided as follows [10]:

1. a safe town from tsunami;
2. a natural energy using town;
3. a beautiful town where people could see the wide skyscape;
4. a town having parks, assembly halls, and vegetable gardens;
5. a town having rich green spaces and clean waterway;
6. a town having easy access to daily shopping; and
7. a town having welfare for elderly people and children.

4.2 Characteristics of the reconstruction plan of "Tamura-Nishi"

The characteristics of the reconstruction plan of "Tamura-Nishi" could point out from the following three aspects. The first aspect is the community tie regarded as the most important factor. There were six villages along seashore, and even though they were tiny villages, they kept on their own tradition and culture for generations. The reconstruction plan introduced "community cluster planning," and refugees

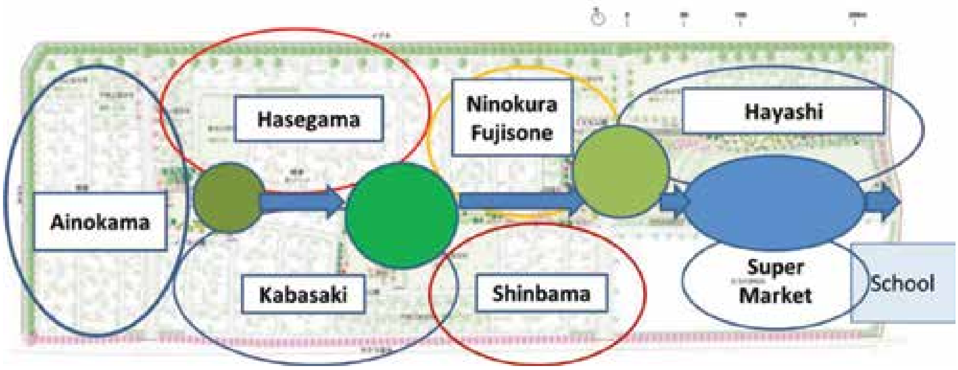

Figure 27.
Community cluster planning in Tamura-Nishi.

Figure 28.
Allocation of houses, parks, greenway, and Igune [11].

of six villages, Aino-Kama, Fujisone, Ninokura, Hase-Kama, Kabasaki, and Shin-Hama could live as neighbors (**Figure 27**).

The second aspect is to create commons where people could meet together. Four small parks have allocated and combined by the greenway in the center of community. This greenway symbolizes the Teizan Canal, but it was impossible to create tiny stream. However, this greenway combines six clusters and provides safe access to the elementary, junior, and high school. In the northwest part, community forest, Igune, was proposed as a cultural landscape (**Figure 28**).

The third aspect is the allocation planning of detached house and public house. We adopted the policy to build these two types house carefully. The design of houses is different, but in the case of public house, two family houses are built together. Therefore, in size, there is no difference between detached house and public house. It provides a kind of equity as a new home town of survivors, since before tsunami, they lived together for generations.

5. Machizukuri start and implementation (fourth stage: January 2014–July 2015)

The reconstruction plan had been established. But the refugees knew the most difficult stage was how to implement their ideals into the reality. Within the community, there were two different groups. Those who had enough economic background started

Figure 29.
Greening parks.

Figure 30.
Planting Ginkgo biloba as a symbol tree of small park (July 2015).

to build new house and moved out from the temporary house. The others were those who had to stay in temporary house until the public house would be constructed. This clear difference might cause a serious crisis on the tie of community.

Considering this situation, Tamura-Nishi-Machizukuri Association was formed on January 18, 2014. Since then, this association worked as the core of the new community. They had to work for solving many problems, together with the municipal government. Greening town was their idea, but, because of the deficiency of the reconstruction budget, the city told that there were no budget for greening parks and planting Igune.

The association made open discussions and finally decided to plant trees by themselves, asking supports from outside, collecting fund.

Figures 29 and **30** show the activities for greening parks. On July 19, 2015, opening festival of Tamura-Nishi had been carried out.

6. Develop Machizukuri activities (fifth stage: July 2015–present)

Machizukuri is the Japanese word which means the activities to work for community, town reformation, greening, promoting welfare, etc., by citizens, rapidly getting common from the 1980s.

By 2015, almost refugees moved to the new community and temporary house had closed. Daily life had returned. They kept on the activities of greening commons. (**Figures 31** and **32**) show Igune in 2014 and 2018. Every month, they meet together, cut grasses, and take care of Igune, and these activities provide a new tie of community.

Figure 31.
Ninokura Village (August 2011) (just after tsunami).

Figure 32.
Ainokama Village (August 2017) (starting to plant trees in former village).

Figure 33.
Igune just planted (August 2014).

Another change of the community is the drastic reformation of agricultural land. Before tsunami, there were many farmers having small rice field and vegetable field. Generally speaking, it was impossible to earn enough revenue, only depending on the agriculture. Therefore, the characteristic of the agriculture in Iwanuma was partial, by having another main job outside. Since their land was damaged by tsunami and they lost agricultural machines, it was impossible for them to invest money for agriculture. In addition to this situation, the international market becomes very competitive; the agriculture in Japan should have a power to

Figure 34.
Igune (August 2018).

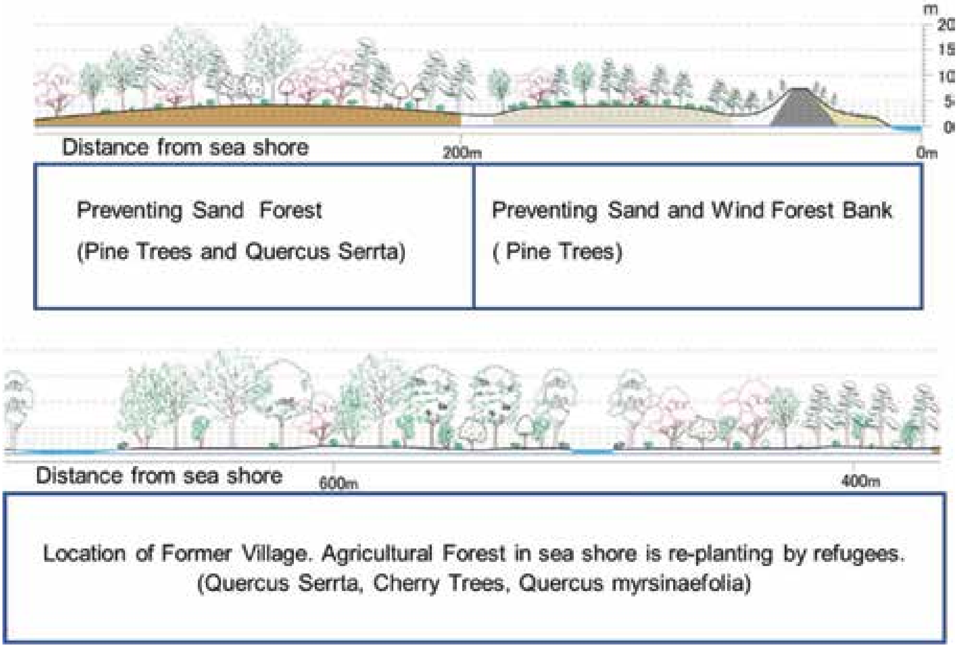

Figure 35.
Ecosystem of coastal forest [12].

compete with international market. The national government deeply understood this situation, and the Ministry of Agriculture implemented the project of farmland reformation. Right now, agricultural lands are being operated by six firms, and they are becoming new young leaders of the community.

The third is the replantation of coastal forest where they lived before **Figures 33** and **34**. **Figure 35** shows the ecosystem of coastal zone, and the refugees had started to replant coastal forest.

7. Conclusions

In this chapter, the author defined resilience as follows: "Resilience is the power of the recovering, which would be activated when community or society faced to crisis, people accept the situation, make decisions and proceed the recovering process, based on the will created from the consensus building and various supports from outsides."

Based on this definition, the author will summarize the community-based resilient reconstruction, from "environmental resilience," "social resilience," and "cultural resilience."

7.1 Environmental resilience

In this case, the most important issue is how to create a safe town from tsunami. There existed no modern methodology in the alluvial flat area. We found the methodology of "combination of multi-defense system and community removing project (CRP)." This is a totally different concept compared with "the protection method from tsunami."

The multi-defense system is as follows. If same scale tsunami comes in future, the area would accept tsunami, but fatal damages would be avoided. This is the core concept of environmental resilience. However, to introduce this system, CRP is an indispensable requirement to be introduced.

The consensus building process which the author mentioned in this paper makes it possible to implement CRP, quickly and peacefully.

By introducing this method, the cost became far cheaper, compared with building high sea bank or cutting mountains for creating safe place. The speed of reconstruction accelerated and the refugees could settle within 3½ years. It was the fastest case in the entire tsunami-devastated area.

7.2 Social resilience

As the author mentioned, the rapid decrease of the population and the increase of elder generation are the critical issue in this region. **Figure 7** shows, in Iwanua City, the population stays the same in 2005 and 2015 and the ratio of the elder generation is 19.7%. **Figure 36** is the comparison of population of six villages. A total of 168 people passed away, but about half residents moved in the new town. They selected the formation of compactness and tried to avoid the scattering. Also, by introducing new commercial facilities (**Figure 37**) in the eastern corner of the new community, many people from outside, now, tend to visit, and the new employment

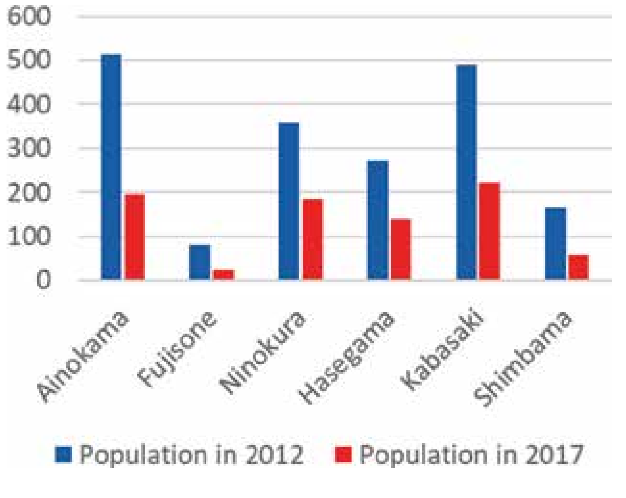

Figure 36.
Population of six villages in 2012 and 2017 [13].

has been created. The decision-making of compactness and allocation planning of community-based reconstruction led to social resilience against the rapid population decrease. As for the increase of the ratio of elder generations, Iwanuma City and Tamura-Nishi-Machizukuri Association decided to open up remaining lots to younger generation, who were not refugees. Young families having children have moved in, and it will help the sustainability of the community.

7.3 Cultural resilience

It is very difficult to understand what cultural resilience is. Culture is usually regarded as intangible. However, in this case, refugees found that landscape of community forest, Igune, is the essence of their culture since they totally lost. During the process of five stages, how to create Igune was always discussed, and after removing the new town, they kept on taking care as a community event. Also, small parks are regarded as their commons. Lots of activities are now going on in these tiny commons. Tsunami seems to destroy everything, but reformation of cultural landscape is one of the powerful methods for cultural resilience.

7.4 Methodology of community-based resilient reconstruction

As a conclusion, the author points out four important factors about the methodology of community-based resilient reconstruction.

The first is "process planning." In this paper, five stages were clarified. Disaster differs, and of course, community differs. Therefore, the stage would not be same,

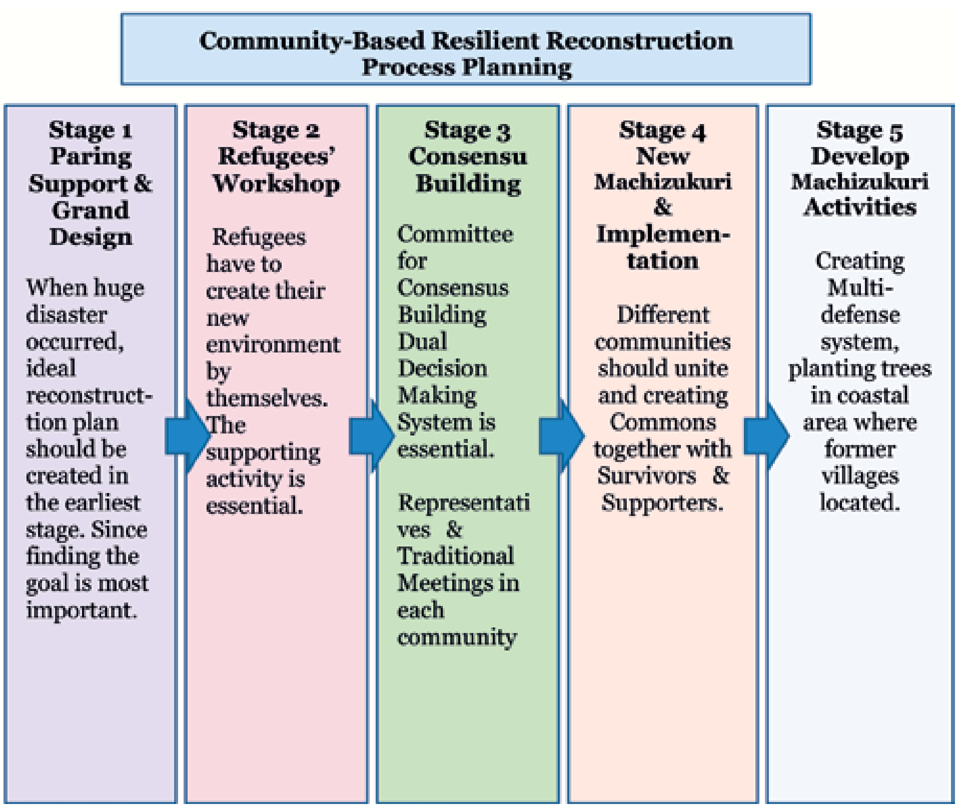

Figure 37.
Process planning.

but the important principle is to acknowledge that in case huge disaster occurs, the situation changes quickly, and appropriate decision-making is required. Introducing "process planning" is essential. **Figure 37** is the summary of process planning in this case.

The second is "consensus formation method." The most difficult problem is how to make consensus formation. In this case, we introduced grand design, community workshop, formal committee, and Machizukuri Association. In each stage, the contents of the consensus differ, and the responsibility which made the decision is different. The innovation of this case is to introduce the refugees' workshop before the fundamental plan is established. Refugees learned how to create their own community and started to have a responsibility for the reconstruction.

The third is "implementation of small reality." Since the reconstruction of a new town takes a long and complicated process, it is important to show the reality which people understand clearly. We introduce many small realities, such as planting tomato in the salted field, turfing lawn in a small park, and many festivals in the new community. The accumulation of tiny reality would gradually grow in people's mind.

The fourth is "pride of place." The new community should be the place where refugees clearly recognize beautiful and peaceful place to live. They have to tell their ancestors that they had rebuilt the village and transfer to the next generation.

The reconstruction from huge disaster is a very tough process and complicated. However, "community-based resilient reconstruction" is one of the fundamental methods, and it should be developed in many places in the world.

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Chapter 9

Corporate Contributions to Community Resilience after the Great East Japan Earthquake Disaster

Rui Fukumoto

Abstract

In the Great East Japan Earthquake of March 11, 2011, municipalities in the northeastern coastal area of Japan suffered serious damage from the disaster. During such a huge disaster, it is difficult that the municipalities lead the regional recovery, and in order for the regional society to recover autonomously and efficiently from natural disasters, it is important that the communities in the devastated areas have the resilience. This paper focused on "corporate contribution" because the corporations have various resources that can support disaster recovery. Questionnaire surveys were conducted by mail to 1020 corporations including various industries and various sizes of corporations located in Iwanuma City and Natori City, which had been damaged by the Great East Japan Earthquake, analysis of memorial collection of sentences in which the emotions of disaster victims could be grasped, analysis of corporate network contribution, and analysis of corporate behavior based on the continuous interviews in the long term. Based on the results, I will give you a new concept "Gyo-Jyo (corporate contribution to community resilience)" and the information about what are the characteristics of corporate contributions to community resilience after the Great East Japan Earthquake disaster.

Keywords: corporate contribution, community, resilience, earthquake, tsunami, the Great East Japan Earthquake

1. Introduction

This chapter reports the results of empirical research on corporate contributions that contributed to the resilience of local communities after the Great East Japan Earthquake that occurred in Japan in 2011. Among the self-help, mutual-help, and public-help based on the spirit of "San-Jyo" that has existed for a long time in Japan, the author focused on mutual-help and advocated "Gyo-Jyo" as mutual-help by corporations. In order to examine the structure of Gyo-Jyo and social implementation requirements, based on the analysis of data obtained through data surveys, questionnaire surveys, and interview surveys, the actual status of contributions is identified by corporations located in the affected areas to local community recovery. Section 2 describes the outline and damage of the Great East Japan Earthquake as basic information. Section 3 gives an overview of the concept of mutual-help. Section 4 explains the concept of "Gyo-Jyo" that the author advocates. Section 5 reports on the role of corporations in regional mutual-help relationships based on material analysis. Section 6 reports on the actual state of the corporate contribution as community resilience targeting 1020 corporations located in Iwanuma City and Natori City. Section 7 reports on the identification of the actual conditions of the corporate contribution by the corporate network based on material analysis. Section 8 reports on trying to supplement important findings on corporate contribution that have contributed to community resilience, which may have been discarded using questionnaires and materials, from findings obtained through continuous interviews since 2012. Section 9 summarizes the role of "Gyo-Jo" based on the characteristics of corporate contribution to community resilience that has been identified.

2. Toward realization of a community that enables autonomous recovery from disaster

The Great East Japan Earthquake occurred at 14:46 on March 11, 2011, and the moment magnitude of the earthquake was 9.0. Moreover, the great tsunami occurred in accordance with the earthquake. Accordingly, municipalities in areas along the northeast coast of Japan were severely affected by the disaster. Nineteen thousand and six hundred sixty-seven people were killed, 2,666 people were

Figure 1.
Number of killed and missing people caused by the Great East Japan Earthquake.

missing, and 6,231 people were injured [1]. In addition, 121,783 houses were completely destroyed, 280,965 houses were partially destroyed, and 745,162 houses were damaged [1]. **Figure 1** shows the number of killed and missing people caused by the disaster. The victims were in a state of being confused because they were not able to accurately judge the situation immediately after the disaster, and since the damage was wide and severe from the viewpoint of local governments, the public-help against each victim did not function.

Therefore, it is important that local communities in Japan are required to have resilience in order to reduce the damage and to recover the damage autonomously and efficiently.

3. "Kyo-Jyo" as a structure to reduce damage and recover from the disaster

While Japan has many natural phenomena, it has a past where various natural disasters have occurred and has developed its own concept of disaster preparedness (**Table 1**). Some of them are the concept of "self-help: protect one's own life," "mutual-help: neighbors help each other," and "public-help: administrative relief." The above concepts are based on "spirit of San-Jyo: three help spirits," which is advocated by Yozan Uesugi, who was the lord of Yonezawa, declared in 1767 as a basic policy, that is, "self-help: help themselves," "mutual-help: neighboring communities help each other," and "feudal clan-help: Yonezawa feudal clan's relief" [2–4].

Regarding the concept of self-help, mutual-help, and public-help, it is not effective that discussion of which concept is the best, for the purpose of reducing damage at the time of disasters. However, it is important to discuss optimal combinations and disaster prevention and respond to disasters [5]. Regarding the operating actors, self-help is carried out by individuals, and public-help is carried out under the responsibility of the society such as the state and local governments. On the other hand, the concrete operating actors of mutual-help are unclear. Therefore, it has been considered difficult to establish a stable system for practicing mutual-help in previous studies [5, 6]. However, in the disasters that caused major damage such as the 1995 Great Hanshin-Awaji Earthquake, the 2004 Niigata Chuetsu Earthquake, and the 2011 Great East Japan Earthquake, the results and importance of mutual-help are often noted. So the importance of identifying the structure of mutual-help and preparing for the next disaster is obvious. When dealing with regional recovery from disaster, it can be considered that the operating actors of mutual-help are the local community; however, the previous researches focused on the residents and volunteers for mutual-help in the case of making the local society, and the findings have been accumulated. Regarding mutual-help between local

Three help spirits (1767)	Ji Jyo 自助 Self help	Go Jyo 互助 Mutual help	Fu Jyo 扶助 Feudal clan help
Operating Actor	Every individuals	Near neighbors	Yonezawa Feudal clan
Japanese concept of preparation against natural disaster (1995)	Ji Jyo 自助 Self help	Kyo Jyo 共助 Mutual help	Ko Jyo 公助 Public help
Operating Actor	Every individuals	Regional Society	Society Including Goverment

Table 1.
Concept of disaster preparedness in Japan.

residents, if the condition of "live together in a shelter immediately after the disaster" or "to continue living with the residents in temporary housing after 3 to 6 months from the disaster occurred" is satisfied, relationships between local residents have been shown to be inherited to their lives after the disaster [7]. Regarding mutual-help between local residents and volunteers, it is indicated that the social welfare council has played a coordinating role in various supports. On the other hand, it is reported that there is "a situation where priority is not given to the action of helping nearby people but the action of evacuating a car with a family." Therefore, it is implied that even if there is a community, as a case of mutual-help does not function, and there is concern over the loss of community cohesion [8]. Also, with regard to volunteers, there is a difference in the function of mutual-help among the affected areas, such as easy access to disaster areas with good access [9] and concentration in areas where volunteer support systems are in place [10]. Furthermore, in a dialogue with the author, Tamaura Junior High School's principal said "There were two cities with big damage next to each other and there was little external support at the beginning of period after the earthquake" on June 28, 2011. Based on the above statement, it is possible that there are many issues in the uneven distribution of volunteers and the development of the support system in each area. On the other hand, it has been pointed out that in the local community, corporations that exist universally are actors that greatly affect the disaster prevention and mitigation power of the local area on a human scale and economic scale [11, 12]. Nevertheless, reporting on the actual state of corporate contribution to the recovery of regional society is insufficient, and the role and significance of corporations that contribute to community resilience are not positioned. The author has experience in emergency medical care and restoration support activities in Minami-Sanriku Town (Miyagi Prefecture) and Iwanuma City (Miyagi Prefecture) from the last part of March 2011. While the author engaged in such activities, the author saw the situation that corporate representatives engaged in various activities for the recovery of regional society as supplying materials and equipment that the corporation owns. For this reason, the author had started this research in that it might be possible to give an important suggestion to the community cooperation and resilience by focusing on the corporate contribution after the disaster.

4. "Gyo-Jyo": corporate contribution to community resilience

Corporations essentially have the pursuit of profit as their basic nature; fulfill their responsibilities to the society, earning satisfaction and profits as their reward; and establish their survival and development. Therefore, if the society encounters an emergency, it is thought that the corporate responsibility to be fulfilled includes the contribution to the solution of the emergency. Then, as a corporation performs business activities, it requires registering the location of the head office and establishes sales bases. So, corporate local areas exist. Therefore, corporations are considered to be in a position to carry out the corporate responsibility for the solution when the local area where their corporation is located is in an emergency situation. Based on the above statements, local contribution and social contribution to community cooperation as well as corporate self-help can be regarded as one of the actions that corporations can choose. In this section, the concept of "Gyo-jyo (corporate contribution to community resilience)" is presented [13], with a view on "the formation of community based on mutual-help centered on corporations" (**Table 2**). From the next section, the author will examine the structure of "Gyo-Jyo" through "mutual-help in a local community," "individual corporations,"

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Autor's concept (2018)	Gyo Jyo 業助 Corporate help Corporate Contribution to Community Resilience
Operating Actor	Regional Corporations

Table 2.
Concept of Gyo-Jyo.

"corporate network," and "case study" in Miyagi Prefecture which was devastated the worst by the Great East Japan Earthquake.

5. Characteristics of corporate contributions in community mutual-help

There are various actors in the local area; however, what kind of characteristics of corporate contribution are there in mutual-help relationships among those actors? The author obtained a memorial text collection "tomoni (together)" organized by Tamaura Junior High School, Iwanuma City, through carrying out restoration and reconstruction support activities since March 2011. This memorial text collection was written by hand in the theme of "what you think from looking back on the disaster" from December 2011 to January 2012, with 143 students attending the Tamaura Junior High School where the school district is included in the tsunami-affected area. It is a 120-page text collection, in which candid impressions of victims have been exposed shortly after the Great East Japan Earthquake and the situation at that time is described. The author converted student's sentences written by hand into text data and analyzed the description rate of each actor in Japanese original text. In addition, an analysis, after defining "conceptual word" (**Table 3**) which united the description showing each noun and verb, extracted the description about "who" and "what kind of help was received." And the author calculated the description rates of "support provider" and "support contents" [13].

5.1 Descriptive statistics value

The sentences written by the students were 143 writings, accounting for 96.6% of the 148 students enrolled. The total number of characters for all writings was 108,538 (Japanese), and the average number of characters per person was about 759 (standard deviation, 324.3). The student who wrote the longest sentence was 2176 characters, and the student who wrote the shortest sentence was 119 characters. 84.6% of the sentences in each student's sentence contained a description that could be read as "some support or help was received."

5.2 Descriptive rate of the support provider

Figure 2 shows the proportions in which each student's text contains the "description of the support provider," organized by each actor. "Neighbors

Conceptual word	Existent word
Corporation	Company, corporation, Corp. Enterprise, XX mart (name of the shop), carpenters, father's corporation, etc.

Table 3.
The example of a conceptual word.

(22.4%)" and "charity in Japan (21.0%)" are described in large numbers, then "unknown (19.6%)" and "charity overseas (14.7%)" are more frequently described, and "relatives" (12.6%), "Self-Defense Force (11.9%)," and "corporations (11.2%)" resulted in over 10%. Corporations were the sixth among the 21 entities, with a higher description rate than Iwanuma City and volunteers. At least from the viewpoint of elementary and junior high school students who have experience in affected areas, the corporate contribution is not small; it was suggested that the role of corporations in regional mutual-help relationships may exist as a reality.

5.3 Description rate of support contents

Next, **Figure 3** shows the proportions of "description of support contents" included in each student's text, regarding the content of what kind of support each body provided. The red part shows the corporate contribution.

Regarding the description rates of the support contents for mutual-help in local community, support contents which show "encouragement (28.0%)" are described the most. And then "human resources (26.6%)," "daily commodities (25.2%)," and "water and food (23.1%)" have a high description rate of more than 20%. In

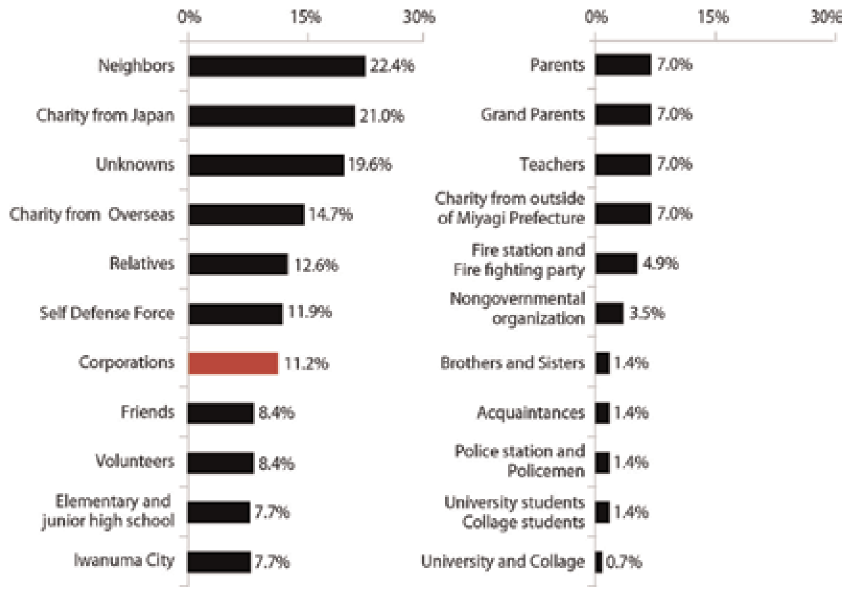

Figure 2.
Description rates of the support providers.

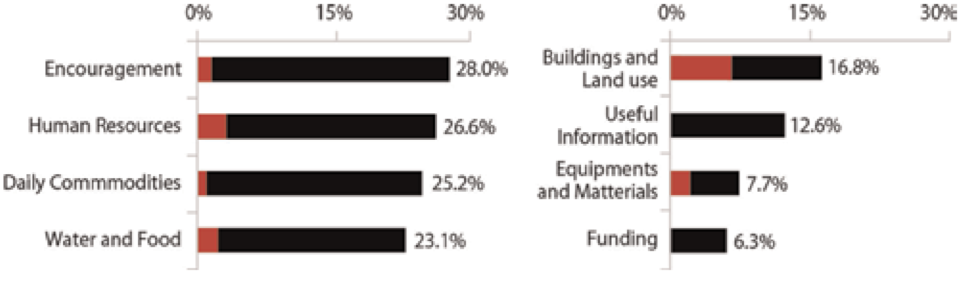

Figure 3.
Description rates of the support contents.

addition, the description rate of "temporary use of lands and buildings (16.8%)" and "useful information (12.6%)" was over 10%. On the other hand, the description rate of "equipment and materials (7.7%)" and "funds (6.3%)" was lower than the other support contents. The high contribution rates of corporations were "temporary use of lands and buildings," "equipment and materials," and "human resources." In addition, it was a surprising result for the author that "encouragement" was mentioned most frequently as support content in mutual-help relationships. According to the experiences of the affected people, it is implied that "encouragement" is an important support content as evidence has been obtained that "In the confuse situation, I was able to recover calm by having someone talked to me and concerned."

5.4 Characteristics of corporate contribution in regional mutual-help relationships

Based on the collection of sentences, it was identified that "temporary use of lands and buildings," "equipment and materials," and "human resource" were mentioned as the content of the description regarding the support with high corporate contribution in regional mutual-help relationships. Specific descriptions of these support contents were the following: (1) repair of houses and (2) temporary evacuation shelter. Regarding the repair of houses, the local constructors carried out the repair of the meeting place in response to a request from the local community, and the carpenter dispatched by a colleague or superior of the workplace of the parents carried out the floor replacement. The above descriptions were described by the junior high school students, and it is suggested that some support in local community after the disaster may be provided by having a "network" that can share issues of affected people. Regarding the temporary evacuation shelters, lands and buildings were provided by corporations and were not recognized as shelters before the disaster occurred; however, the descriptions were described in a context that was unexpectedly used after the earthquake. Therefore, it is suggested that one of the conditions is continuous locating and operating corporations in the regional society.

In this section, based on the analysis of the sentence collection, it was suggested that the corporation might take an important responsibility in the area through the characteristics of corporate contribution in the regional mutual-help relationship. Next, are these support contents often found in corporations located in the affected area? The next section will answer this question.

6. Characteristics of corporate contribution to the recovery of regional society

In this section, the author explains about "how many corporations did provide some support to recovery in the local community after the Great East Japan Earthquake" and "what the characteristics of corporations are that have contributed to recovery in the local community."

The author conducted a mail survey of 1020 companies (36.8% of the total 2941 corporations in the target area) located in Iwanuma City and Natori City, which were affected by the Great East Japan Earthquake and tsunami [14]. The location of the target corporations was shown in **Figure 4**. The target area was suitable for this investigation because corporations which were of various sizes and industry types were located around Sendai International Airport in the target area.

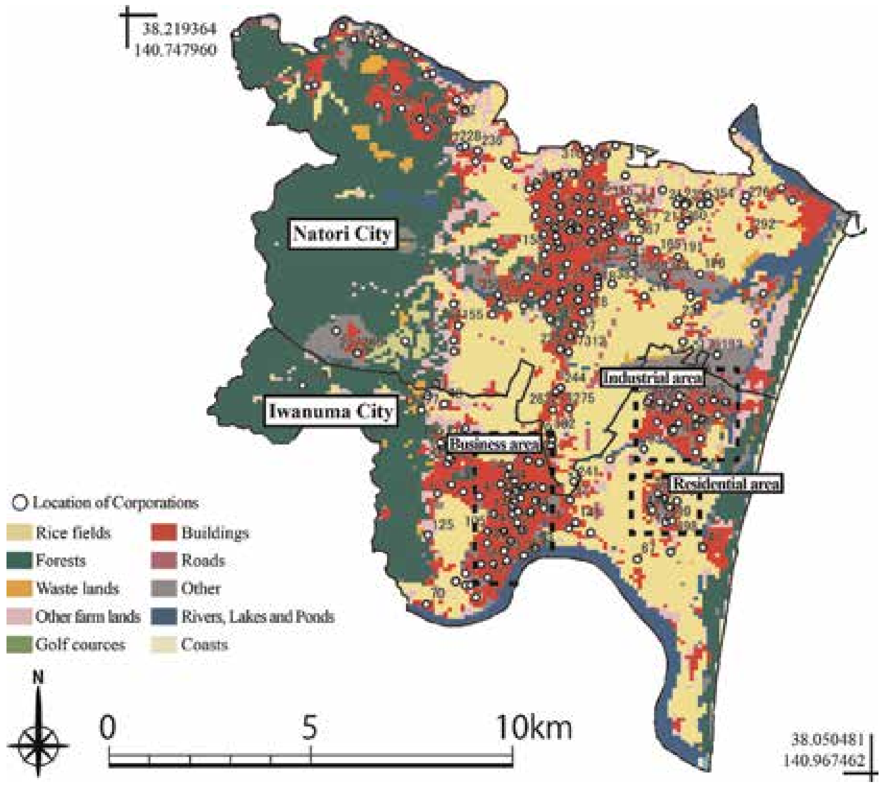

Figure 4.
Location of target corporations [13].

6.1 Attribute information of target corporations

6.1.1 Response rate

The author sent the questionnaire to 1020 corporations which were enrolled in Tokyo Teikoku Databank. Four hundred (39.2%) corporations responded to the questionnaire. The number of respondents by industry was high for "construction" (120 corporations), "wholesale and retail trade" (78 corporations), "manufacturing" (42 corporations), and "miscellaneous business services, n.e.c. (40 corporations)." **Table 4** shows the response rates by industry based on 1123 corporations including 103 corporations that were located in the target area and shut down from March 2011 to December 2014. Although the response rate for many industries exceeds 30.0%, it should be noted that the response rate for "finance and insurance" was 0%.

6.1.2 Percentage of companies by the number of employees of target companies

Figure 5 shows the ratio of the number of employees in the target corporations. The average number of employees was 32.2, with a median of 7, maximum of 3049, and minimum of 0. The target corporations were classified into the following categories based on the number of employees: "The number of employees is 0 (4.0%)," "micro corporation is more than 0 but fewer than 8 (46.5%)," "small corporation is more than 7 but fewer than 21 (29.5%)," "medium corporation is more than 20 but fewer than 101 (16.0%)," and "large corporation is more than

Industry type	Targets	Responded	RR (%)
Construction	351	120	34.2
Wholesale and retail trade	222	78	35.1
Miscellaneous business services, n.e.c.	120	40	36.7
Manufacturing	103	42	40.8
Medical, health care, and welfare	77	29	37.7
Transport and postal services	57	24	42.1
Real estate and goods rental and leasing	66	20	30.3
Living-related and personal services and amusement services	21	11	52.4
Electricity, gas, heat, and water supply	23	10	43.5
Accommodation, eating, and drinking services	23	8	34.8
Information and communications	11	4	36.4
Education, learning support	8	4	50.0
Scientific research, professional, and technical services	12	3	25.0
Agriculture, forestry, and fisheries	5	2	40.0
Mining and quarrying of stone	5	1	20.0
Finance and insurance	8	0	0.0

Table 4.
Response rate of each industry.

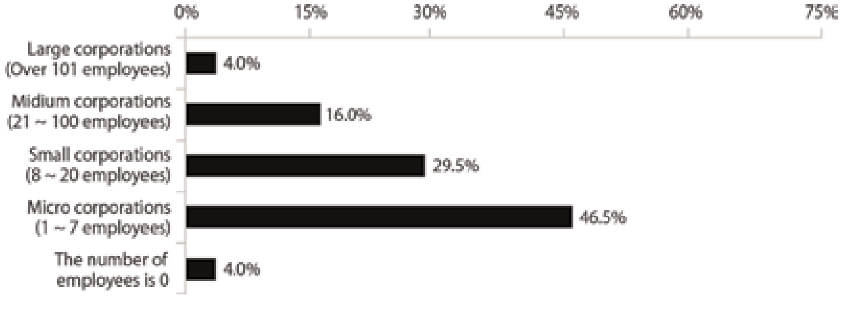

Figure 5.
Classification of the number of employees.

100 employees (4.0%).” Based on the economic census in Japan in 2009, the average number of employees of corporations located in the same target area is about 11, and the median is 7. The proportion of large enterprises in the target area was 1.1%, and the proportion of medium-sized enterprises was 10.1% based on the census, while the proportion of large enterprises in this survey was 4.0%, and the proportion of medium-sized enterprises was 16.0%. Therefore, it is judged that various corporations are included in the target corporations.

6.1.3 Damage suffered by target corporations

Figure 6 shows the ratio of damage to annual sales of target corporations. The average was 36.8%, the median was 29.4%, the maximum was 1500.0%, and the minimum was 0.0%. Only 6.3% of corporations responded that they did not suffer damage. Therefore, many of the target corporations are judged to have suffered some damage after the disaster.

Figure 7 shows the damage types that the target corporations received. Specifically, "equipment damage (59.3%)" was over half in the target corporations, and also "decreasing in sales (45.8%)," "decreasing in customers (29.8%)," and "inventory damage (26.5%)" had a relatively high proportion. "Increase in borrowing (16.0%)," "surging purchase (13.8%)," "surging outsourcing costs (13.3%)," and "surging personnel costs (9.5%)" had a relatively low proportion. In addition, 16.8% of the target corporations have an experience of temporarily stopping operations.

6.2 How many corporations contributed to the recovery of regional society after the disaster?

Based on the questionnaire survey, 32.8% of the target corporations provided some support for regional recovery after the disaster (**Figure 8**).

The contents of the support provided by the target corporations were shown in **Figure 9**. The contents were "human resources (59.5%)," "equipment and materials (45.8%)," "daily commodities (38.9%)," "useful information (15.3%)," "funding (13.7%)," and "temporary use of lands and buildings (11.5%)."

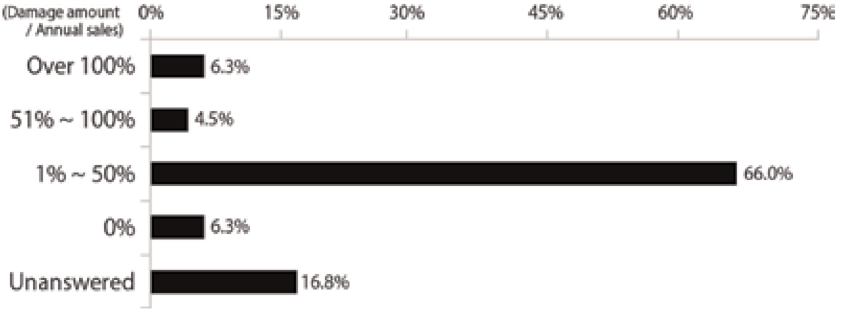

Figure 6.
Ratio of the damage amount to annual sales.

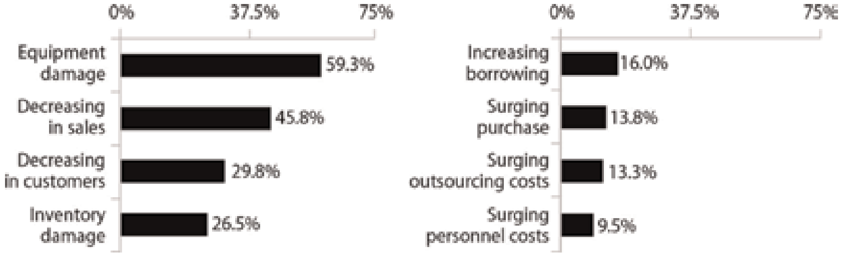

Figure 7.
Proportion of damage types.

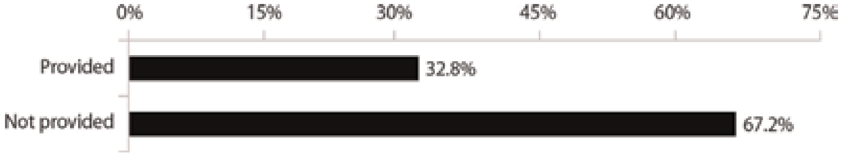

Figure 8.
Proportion of the type of damages.

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6.3 Reason for the providing support

74.5% of corporations that provided some support had a social relationship with the support recipient before the disaster occurred (**Figure 10**).

50.4% of the corporations that provided some support and had a social relationship with the support recipient did not conduct some particular activities (**Figure 11**). 49.7% of the corporations conducted some activities.

In addition, based on an interview survey, the author obtained the reasons and motivations why corporations provided the support to recovery of regional society, and these were the following: (1) leading to the continual and long-term benefits of the corporations, (2) having attachments to the hometown, (3) being present at the scene and providing, (4) searching direction of their action, and (5) receiving some support from others and having thought about providing some support to return the favor.

6.4 Differences of corporate contribution between groups classified by corporate consciousness

Next, are there any relationships between corporate contribution and corporate consciousness? The author tabulated corporate contribution of each group classified by corporate consciousness (**Figure 12**).

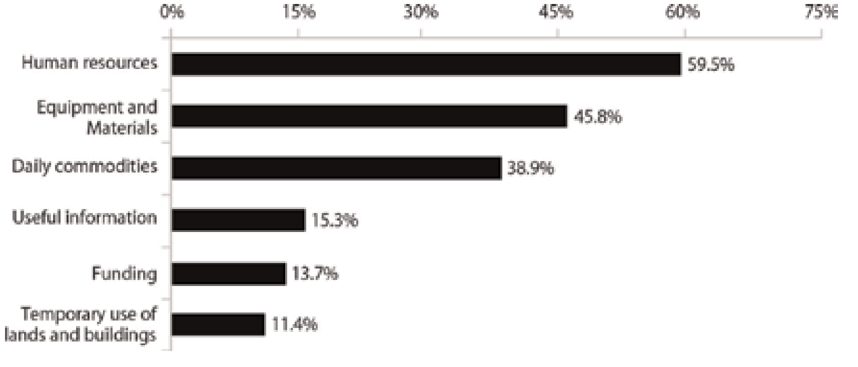

Figure 9.
The contents of the support provided by the target corporations.

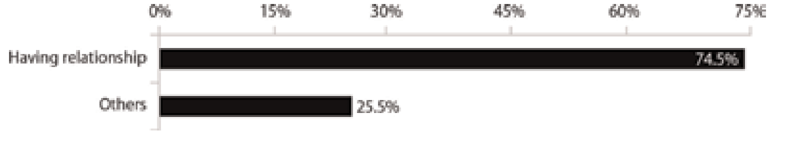

Figure 10.
Relationship between the corporation and the support recipient.

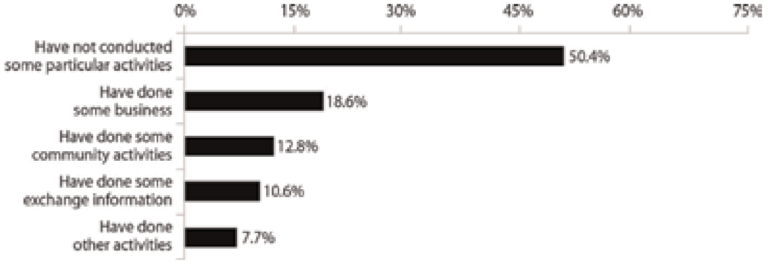

Figure 11.
Contents of social relationship between the corporation and the support recipient.

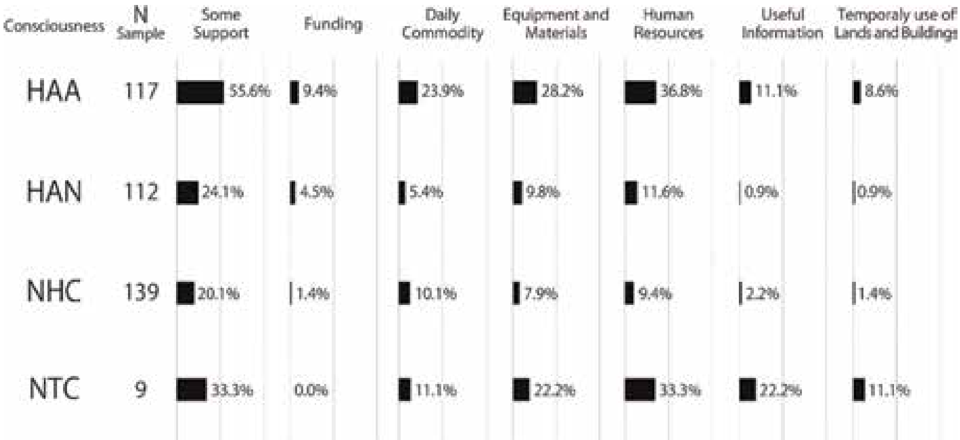

Figure 12.
Providing support between groups classified by corporate consciousness for contributions before the occurrence of the disaster [13]. HAA, having awareness of contributions to the recovery of regional society and having already conducted related activities; HAN, having awareness of contributions to the recovery of regional society but having conducted no related activities earlier; NHC, not having the capacity to contribute; NTC, having never thought about making contributions.

It obviously differed between "having awareness of contributions to the recovery of regional society and having already conducted related activities (HAA: 55.6%)" and the other answers.

And also, in 229 corporations (57.3%) that have a consciousness of the contributions, 92 corporations (40.2%) provided some supports.

It was important that not only having the awareness but also conducting related activities before the disaster for conducting the corporate contribution.

6.5 Characteristics of corporate contribution to recovery of regional society in Iwanuma City and Natori City after the Great East Japan Earthquake

Based on the analysis of the characteristics of corporations that contributed to the recovery of the regional society, it is identified that there are common characteristics of all support types and characteristics of each support. The results are shown in **Table 5** [14].

6.6 Common characteristics of all support types

As characteristics to increase the probability of providing some supports to recovery of regional society, it has identified that it is important the corporate consciousness to contribution to the recovery of regional society but also the having conducted related activities before the occurrence of the disaster.

6.7 Characteristics of each support

It was identified that the characteristics of each support type differ depending on the conditions such as the industry type, the location, and the number of employees. Specifically, "support for temporary use of land and buildings" and "located in a large-scale semi-destruction area" had an impact. Regarding "support for equipment and materials," "medium corporations" and "construction industry" had an impact. Regarding "support for daily commodities," the effects of "accommodation, eating, and drinking services" and "manufacturing" were significant.

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Support type	Consciousness	Number of employees	Industry type	Location of the main customers	Surrounding land use	Damage caused by the tsunami
Some of the support	HAA ***					
Funding	HAA **					
Daily commodities	HAA ***		ACCO*** MANU*	ISCL *		
Equipment and materials	HAA ***	Medium corporations*	CONS**		Rice-field area*	
Human resources	HAA ***			ISCL*	Building area**	TDND*
Useful information	HAA **		REAL***		Building area*	
Temporary use of lands and buildings	HAA **					LPDA*

****0 is not included in 99.9% Wald confidence interval.*

***0 is not included in 99% Wald confidence interval.*

**0 is not included in 95% Wald confidence interval.*
CONS, construction; MANU, manufacturing; ACCO, accommodation, eating, and drinking services; REAL, real estate and goods rental and leasing; HAA, having awareness of contributions to the recovery of regional society and having already conducted related activities before the occurrence of disaster; ISCL, inside the same city limits; TDND, districts without tsunami damage near the devastated area; LPDA, large-scale partially destroyed area.

Table 5.
Summary of the characteristics of the corporations that provided support [13].

Regarding “support for useful information,” the effect of “real estate and goods rental and leasing” had an impact.

In this section, the author explained about “how many corporations provided the support to the recovery of the regional society after the Great East Japan Earthquake” and “what the characteristics of the corporations are” through the case study in Iwanuma City and Natori City, Miyagi Prefecture, Japan, which had the highest damages from the Great East Japan Earthquake.

The target of the above explanation was a single corporation. However, in fact, there was a case that some supports were provided through a corporate network because some corporations could not afford to provide individual support. In the next section, the author is going to explain about the results of surveys and analyzes targeting corporate networks.

7. Characteristics of corporate network contribution to the recovery of regional society

In this section, the author tries to explain about the actual situation of the supports which were provided by some corporate network. The conditions of selecting the targets were the following: (1) corporate networks and organizations having bases in Iwanuma City, (2) the networks and organizations defining its contribution to regional society as their primary or secondary activities, (3) widely deployed nationwide, (4) composed of different industries, and (5) activities being recorded.

As a result of examining the above conditions, Iwanuma Chamber of Commerce and Industry, Iwanuma Rinku Industrial Park, Iwanuma Rotary Club, and Abukuma Youth Council were selected as survey targets. We collected and analyzed the records and documents of the activities in the corporate networks and organizations and grasped the actual situation through identifying the support types, support destinations, and collaboration partners that were addressed during the recovery period from the Great East Japan Earthquake. **Table 6** showed a list of collected data.

7.1 Actual situation of the project of contribution to recovery of the regional society from the disaster by corporate networks and organizations

Analyzing based on the data in **Table 6**, support project names, support destinations, support types, support content, and collaboration actors were identified. It can be understood that the support projects of each corporate network are diverse. There were a large amount of funding, human resources, and support for equipment and materials. In addition, there was a little funding support for the survey based on individual corporations in the previous section. It is thought that the single corporation could not afford to provide some supports; however, they could provide the supports through a corporate network (**Table 7**).

Regarding the actual situation of the project of contribution by corporate networks and organizations, it can be read that the number of the projects is small from March to May 2011 and the number of the projects is concentrated from June to December 2011. Of the projects related to regional restoration, 85.0% were

Literature material	Publisher	Period of time
NEWS LETTER Wing's	Cooperative Association with Natori City and Iwanuma City Chamber of Commerce	From Jan. 2011 to Oct. 2014
Annual report	Iwanuma City Chamber of Commerce	From Jan. 2012 to Dec. 2014
A list of members	Iwanuma City Chamber of Commerce	From Mar. 2011 to Dec. 2011
Weekly report	Iwanuma Rotary Club	From Mar. 2011 to Sep. 2014
Activity plan	Iwanuma Rotary Club	From Jan. 2011 to Jun. 2015
Inspection report of corporate preparation for disaster prevention	Iwanuma Industrial Park	From Sep. 2011 to Oct. 2011
Reconstruction of headquarters in response to the Great East Japan Earthquake in Iwanuma Industrial Park	Iwanuma Industrial Park	From Mar. 2011 to Sep. 2011
Inspection report of recovery in Iwanuma Industrial Park from the Great East Japan Earthquake	Iwanuma Industrial Park	Mar. 2011
Corporate report "Bridge"	Tohoku Electric Power Co., Inc.	Mar. 2012
Movie report of the festival "Ganbarou Miyagi" in Abukuma	Abukuma Junior Chamber	Sep. 2011

Table 6.
Material for survey analysis.

Network	Year/month	Project name	Support destination	Contents of support						Cooperate actors					
				EC	HR	FD	DC	UI	EM	LB	C	N	Np	Ed	Go
IRC	2011/3	Installation of shelter box	Disaster sufferers		○				○			○			
IRC	2011/5	Planting green near the temporary house	Residents who lived in temporary housing		○				○						
IRC	2011/6	Tomato for revitalization	Affected farmers		○			○			○		○	○	
IRC	2011/6	Providing cold patch	Affected farmers				○				○				
IRC	2011/6	Providing donation	Disaster sufferers			○						○			
ICC	2011/6	Consulting counter for emergency recovery	Affected corporations					○							
ICC	2011/6	Providing daily commodities	Disaster sufferers				○					○			
ICC	2011/6	Providing donation	Iwanuma City			○						○			
IRC	2011/7	Providing digital blackboard and PC	Affected junior high school						○						
IRC	2011/7	Providing fire vehicle pump (middle size)	Iwanuma City						○			○			
IRC	2011/7	Providing fire vehicle pump (small size)	Iwanuma City						○			○			
ICC	2011/8	Selling charity goods	Disaster sufferers			○						○			
ICC	2011/8	Organizing Iwanuma summer festival for revitalization	Disaster sufferers		○									○	
IIP	2011/8	Cleaning activities in Iwanuma Industrial Park	Local residents		○						○				
IRC	2011/9	Fund-raising campaign	Affected corporations			○									
IRC	2011/9	Providing project fund	Affected farmers			○						○			
IRC	2011/9	Providing temporary use of parking space	AJC							○	○				
AJC	2011/9	Organizing the festival Ganbarou Miyagi	Local residents		○	○			○			○			
IRC	2011/10	Providing quilt works	Affected elementary school	○											○
IRC	2011/10	Selling tomato for revitalization	IRC		○	○						○			
ICC	2011/11	Organizing marketplace for revitalization	Disaster sufferers		○						○				

Network	Year/month	Project name	Support destination	Contents of support							Cooperate actors				
				EC	HR	FD	DC	UI	EM	LB	C	N	Np	Ed	Go
IRC	2011/12	Providing fund for cultivating melon	Affected farmers			○						○			
IRC	2011/12	Providing donation for children	Affected kindergartens			○						○			
IRC	2011/12	Providing fund for constructing plastic greenhouse	Affected farmers			○						○			
IRC	2011/12	Providing boots	Disaster sufferers				○					○			
ICC	2012/1	Consulting grant application for the subsidy	Affected corporations		○	○		○							○
IRC	2012/4	Organizing charity concert	Local residents		○	○						○			
IRC	2012/4	Providing three small generators	Iwanuma City						○			○			
IRC	2012/5	Providing patient transfer vehicle	Affected hospital						○			○			
IRC	2012/6	Providing opportunity to participate in a summer camp	Affected junior high school		○	○						○			
IRC	2012/6	Supporting to make an application for “recovery of the tower clock”	Iwanuma City					○							
IRC	2012/6	Supporting to make an application for “recovery of the power tiller to cultivate cucumber”	Affected farmers					○							
ICC	2012/7	Establishing support project to revitalize the local community	Affected corporations			○									
IRC	2012/8	Providing machine for soil improvement	Affected farmers						○			○			
IRC	2012/12	Providing 600 books	Affected library				○					○			
IRC	2012/12	Providing UAV for “taking photos of recovery process by residents”	Disaster sufferers						○		○	○	○	○	
ICC	2013/1	Establishing support project to recovery of facilities for small and medium corporations	Affected corporations			○									○
ICC	2013/11	Conducting event “Iwanuma city shops stamp rally” to promote sales	Local residents			○					○				

IRC, Iwanuma Rotary Club; ICC, Iwanuma City Chamber of Commerce; AJC, Abukuma Junior Chamber; IIP, Iwanuma Industrial Park; EC, encouragement; HR, human resources; FD, funding; DC, daily commodities; UI, useful information; EM, equipment and materials; LB, temporary use of lands and buildings; C, a corporation; n, corporate networks; Np, nonprofit organizations; Ed, an educational institution; Go, government.

Table 7.
The recovery project provided by the corporate network based on the material analysis.

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implemented in cooperation with other corporations, corporate networks, and organizations.

7.2 Actual situations of corporate contribution by corporate networks and organizations to recovery of the regional society from the disaster

It was identified that the targeted corporate networks and organizations had provided some supports for the recovery of the regional society. First of all, the support provided by the Iwanuma Rotary Club varied in the type and destination of support and was based on a highly effective spillover effect that provided clear targets and details of support. The contents of these activities were mentioned in the sentence collection "tomoni (together)" of Iwanuma City Tamaura Junior High School, which was dealt with in the previous section, and gratitude was expressed. Therefore, these supports were considered to be an effective support in the regional mutual-help relationship. Second, the support provided by the Abukuma Junior Chamber was limited to one project as a group; however, the target was not clearly limited, and it was possible to brighten the awareness of the affected people widely from the mood that was not lively. The project was designed with the aim of brightening the atmosphere and was implemented as a support project that works directly on the area of Iwanuma City. Third, the support provided by the Iwanuma City Chamber of Commerce was also implemented for the recovery festival and projects aimed at helping the affected residents in Iwanuma City such as "Fukkou-ichi (market for affected people to be happy)." In addition, the Iwanuma City Chamber of Commerce also established and conducted the financial support for the continuation of corporations including corporations that contributed to recovery of regional society after the disaster. This support may be considered as the implementation of indirect support for the recovery of the regional society. Fourth, the Iwanuma Rinku Industrial Park Council did not provide specific support but only cleaned the entire industrial park with the affected people from the disaster. However, the recovery of distribution bases and maintenance/creation of employment were regarded as supporting the recovery of regional society in the medium to long term. In addition, they were contributed to recovery of the infrastructure for the destroyed electricity supply in 61 days after the disaster occurred. As mentioned above, "implementation of support based on high public interest ripple effects" by the corporate networks and organizations, "implementation of support projects that directly work on the area of Iwanuma city," "financial support for corporations that contribute to recovery of regional society from the disaster," and "recovery of infrastructure and maintenance and creation of long-term employment" were identified as different characters of corporate contribution by the corporate networks and organizations.

7.3 Characteristics of corporate networks and organizations that contributed to the recovery of the regional society

Through the support for recovery of the regional society after the disaster by corporate networks and organizations, it was implied that the characteristics of the contribution were the following: (1) implementing large-scale supports that each corporation and other actors had a difficulty to provide, (2) playing a role of intermediate support, and (3) continuously providing the support and the evidence of small visible recovery as a piece of revitalization from the disaster. Based on these points, the author considered the characteristics of corporate networks and organizations that have contributed to the recovery of regional society. First of all, based on "each corporation that achieved a difficult scale of support through cooperation with other actors" and "intermediate support role," it was considered that corporate networks and organizations played the role of the base where the support from all over the world could be collected. In actuality, in the case of Iwanuma Rotary Club, the structure of Rotary International's corporate network and organization was functioning, and "the fact that they regularly interact with various bases in the regional society and build trust relationships" provides access to the support destination. It is possible that it can be mentioned that "the network and organization with common philosophy being organized and interactive in Japan and abroad" is the fact that the support implementation system can be prepared. Second, based on "the evidence of small visible recovery that was gained continuously," the corporate networks and organizations steadily worked on projects with a view on medium- to long-term reconstruction and revitalization of the regional society, such as agricultural recovery support, involving various actors, and creating a forum and information transmission. In addition, one of the characteristics was providing occasions that have "overlap width for relationship building" in that new entrants can be involved. It is thought that the existence of the occasions has the potential to boost the reconstruction and revitalization of the entire regional society, as it is a content that arouses various people's sympathies and is easily taken up by the media.

8. Characteristics of corporate contribution based on continuous interview survey

The findings obtained up to the previous section are considered to have certain significance because the findings include the results obtained by the quantitative approach. However, due to the limited degree of freedom of responses through questionnaire surveys and limited material surveys, there may be a problem that essential findings may be discarded or reduced. In order to solve this problem, the author focuses on corporate behavior for corporations that have received continuous research cooperation from April 2012 to September 2018, examines the effects (phenomena) of corporate behavior, and understands the context (concepts) that leads to it; it will be a foothold of the argument on the structure of corporate contribution.

The corporation selected as the case study was based in Iwanuma City, a corporation whose main business was agriculture and affected by the tsunami caused by the Great East Japan Earthquake (hereinafter referred to as target farmers).

The behaviors of the target farmers had been selected "corporate recovery response (maximization of personal benefits)," "regional recovery response (maximization of public benefits)," and "leading regional reconstruction and revitalization (maximization of public benefits)" in time-sequentially.

"Corporate recovery response" is one of the preconditions for corporate behavior aimed at "regional recovery response" and "leading regional reconstruction and revitalization." Mr. F who was a managing director and center of the target farmers said in April 2012 that "No regional recovery is possible until corporate recovery is complete. Everything can be considered after the corporate recovery and living recovery." Target farmers achieved corporate recovery in September 2012 because the corporate recovery was promoted by the flow of public funds and external corporate funds into the area, such as East Japan grants, public funds of Miyagi Prefecture, and funds of major food manufacturing corporations.

The behavior of the target farmers who achieved the corporate recovery was changed from "corporate recovery response" to "undertaking of the affected farmland," "creating employment of affected farmers and victims," and "developing communities for affected farmers and residents." It has been changed into "behavior of maximizing public benefit" from "maximization of personal benefits."

The target farmer was entrusted with farmers who cannot restart the farmland for various reasons, the target farmer takes on the farmland which had not been resumed, and the scale of the cultivated area of the rice field was 20 ha before the earthquake and expanded to 177 ha as of September 2018. In addition, the target farmer hires affected farmers and victims who cannot reopen farmland for various reasons, contributes to the recovery of employment and life in the affected areas, and revitalizes the fields through agriculture. The target farmer made the occasion to connect with the affected farmers and victims.

Regarding "leading regional reconstruction and revitalization (maximization of public benefits)," it contributed to "preserving green landscape like an extensive rice field and prevention of the decline in regional agriculture" and recovery of 16.9% "affected farmland (rice field)" as a result of continuing the above "regional recovery response" for 6 years from September 2012 to September 2018. The estimated affected farmland of Iwanuma City is 1206 ha, of which 1068 ha is identified to be the affected rice fields. In September 2018, the target farmer has recovered 16.9% of the rice fields. In terms of planning theory, corporate recovery of the target farmers was the key to regional recovery, and it is thought that the target farmer contributed to the recovery of regional agriculture in the affected area and the preserving green landscape like an extensive rice field in Iwanuma City. In addition, one of the factors of the recovery was promoting the recovery caused by the flow of public and external funds from the support of corporations and corporate networks and organizations into the regional society. Therefore, corporate behaviors related to "applications of subsidies" that have brought "utility of the flow of public and external funds into the regional society" can be positioned as one of the factors of the recovery.

8.1 The context leading to the corporate behavior of the target farmer

In order to understand the context leading to a series of corporate behaviors that bring about the abovementioned effects, the author will focus on Mr. F's behaviors and consider it from the theoretical framework of social dilemma [16]. Social dilemmas are well-defined in various research fields; however, this research adopted the definition of "social situation that has to choose either maximization of personal benefits or maximization of public benefits" [17]. Regarding the behavior of corporations after the Great East Japan Earthquake dealt with in this research, any of the "corporate recovery response," "regional recovery response," and "leading regional reconstruction and revitalization" can be set as the purpose. Based on the definition [17], it is possible to consider corporate behaviors on two axes: escape behavior (maximizing personal benefits) and cooperative behavior (maximizing public benefits). Furthermore, the state of the corporation can be regarded as the result of repeatedly selecting any of the above actions. An approach to finding an answer that solves the social dilemma set up above is a "psychological strategy" [17]. A "psychological strategy" is defined as "inducing voluntary cooperative behavior by acting on psychological factors such as belief, attitude, and sense of responsibility, trust, morality, and knowledge that prescribes individual behavior" [17–20].

Based on these theoretical frameworks, the author tries to consider the corporate behavior of the target farmers.

Next, the author tries to consider understanding the context leading to the selection of corporate behavior of the target farmer shown in **Figure 13**, the

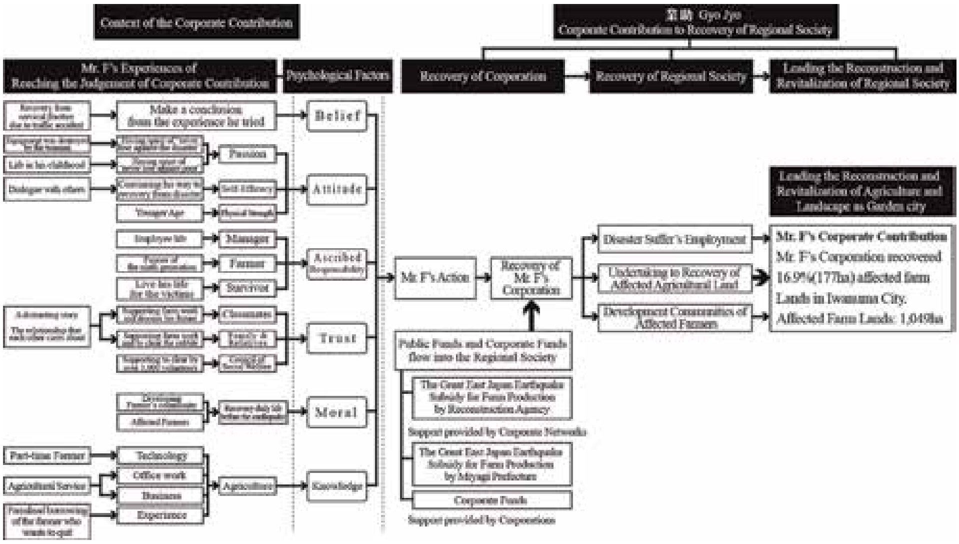

Figure 13.
The context leading to the corporate behavior of the target farmer.

corporation that maximizes the public benefit based on the narrative of Mr. F for each factor of the psychological strategy against social dilemmas.

Regarding "belief," the belief found in Mr. F's narrative was "concluding from the tried without giving up." The reason for the formation of this belief comes from the experience that Mr. F fractured the cervical spine in a traffic accident when he was a high school student, was hospitalized for 6 months, and recovered miraculously through rehabilitation.

Regarding "attitude," it is composed of a plurality of components such as "passion [21]," "action [21]," and "confidence [22]." Based on the above, it was defined in this research that the components that make up the attitude in this research were "passion," "self-efficacy," and "physical strength (required for action)." As for "passion," "having the spirit of never losing against the disaster" and "having the spirit of never losing against the poor" could be seen. The reason that these passions were formed was that the former was due to "the experience of the corporate equipment being completely destroyed by the tsunami" and the latter was because "when he was a child, he could not live a good life." Regarding "self-efficacy," the target farmer had obtained it through "self-identification of his own style in agricultural business."

The trigger of the formation of his self-efficacy was that "he has the confidence in his own agricultural style through various responses to agricultural efforts in dialogue with others."

Regarding "physical strength (required for action)," youngness was important. Mr. F said, "I think I could not continue farming if I were ten years older."

"Ascribed responsibility," based on Mr. F's narrative, can be raised from three perspectives: "manager," "farmer," and "survivor." According to Mr. F's narrative, it was confirmed that "It is necessary to maintain the employment of a trusted employee," as the ascribed responsibility in the view of the "manager." According to Mr. F's narrative, it was confirmed that "I want to revive affected farmland" and "Farmer is a farmer" as his testimony and "he is the ninth generation farmer." Therefore, it was considered that the above testimonies and facts were ascribed responsibility as the "farmer." According to Mr. F's narrative, it was confirmed that "I want to live and survive for the people who died in the disaster" as his testimony.

Therefore, it was considered that the above testimony was ascribed responsibility as the "survivor."

The "trust," based on Mr. F's narratives, includes the perspectives of "family, relatives," "classmates," and "social welfare council." As for "family, relatives," and "classmate friends," Mr. F said, "A relationship that we spend a long time. We know each other about pain, itching and tickling well." While farming, they remember the image of the daily scene before the disaster little by little, and they could confirm the trust in the recovery of daily life. About "social welfare meeting," approximately 3000 volunteer staff engaged in removal and cleaning work of rubble in the area of target farmer from April 2011 to November 2011 when the prospect of corporate recovery was not at a standstill. Mr. F testified to this fact, "I am really thankful for them," as a testimony showing trust.

The "moral," based on Mr. F's narrative, includes "recovery of daily life." Ka-chan Plaza (local market) was restarted by Mr. F for "farmers who shipped to Ka-chan Plaza (local market)" and "affected farmers who cannot restart on their own farmlands" as a place to support "face-to-face meeting opportunities, resumption of agriculture, and sales agricultural products."

The "knowledge," based on Mr. F's narrative, was about agriculture. The details of the knowledge were on "technology," "office work," "sales," and "experience."

As for "technology," Mr. F has been engaged in agriculture as a part-time farmer for a long time, and since the target farmer is a generation-long farmer, they have cultivated their own agricultural technology. As for "office work," Mr. F was familiar with the office work related to agricultural business because he was engaged in the preparation of documents related to agricultural business, office work, and support work when he was working in a nonprofit incorporated association related to the agricultural business. With regard to "sales," from the experience of Mr. F serving as a team leader for promoting the consumption of rice in Miyagi Prefecture nationwide while working for the association, he gained the knowledge of consumer behavior and sales methods regarding purchasing including personal relationships and public relations. As for "experience," Mr. F expanded the area of rice cultivation and took business difficulties when the tomato price collapsed caused by O-157 which occurred in 1996. At that time, they had experience of renting farmland and farming from a farmer who wanted to go out of business, and they were familiar with negotiations and procedures.

8.2 Understanding the context leading to corporate behavior that maximizes public interest based on Mr. F's narrative

It is suggested that each psychological factor mentioned above influenced Mr. F's behavior, and it can be understood as a context leading to the corporate behavior of the target farmer.

While the target farmer was aiming for their own corporate recovery, corporate networks, administrations, and volunteers provided support in response to the recovery, and that support promoted the recovery of the target farmers, and the large-scale public funds flew into the recovery of regional society.

After that, the target farmer has the prospect of restoration in mind; they decided to "undertake the recovery of affected farmlands" in the affected areas where there was a concern for the abandonment of cultivated land and continue to assume large-scale acreage by 2018.

"Small recovery" by target farmer was accumulated by "corporate recovery response" and "regional recovery response," creating an opportunity for the inflow of public funds, preventing the abandonment of cultivated land in the area, and driving the recovery of the agricultural industry in the area. One of the agricultural corporations could be organized and played a role of "preserving green landscape like an extensive rice field and prevention of the decline in regional agriculture" as "leading regional reconstruction and revitalization." Therefore, "Gyo-Jyo (corporate contribution to the recovery of regional society)" is extremely important after the disaster for the community resilience.

9. Conclusion: the role of "Gyo-Jyo"

In this chapter, in order to understand "Gyo-Jyo" advocated by the author, identifying characteristics of corporate contributions based on the study, the author focused on corporate behavior as the structure of "corporate contribution" and tried to understand its effect and the context leading to the behavior from the following viewpoints: (1) focusing on corporate behavior in the mutual-help relationship, (2) focusing on single corporate behavior of 1020 corporations located in the affected area, (3) focusing on the behavior of corporate networks and organizations located in the affected area, and (4) focusing on corporate behavior of corporations that have received continuous research cooperation from April 2012 to September 2018.

The structure of corporate contribution was considered to consist of "corporate recovery response," "regional recovery response," and "leading regional reconstruction and revitalization" In addition, after the corporate recovery was achieved, leading regional reconstruction and revitalization could be a small local recovery that was accumulated by the corporations and other actors and showed the flow which realizes the reconstruction of the area by having them cooperate with one flow.

About the flow in this chapter, in the case of an agricultural corporation, achievement the recovery of 16.9% of the affected farmlands in Iwanuma City by continuously repeating the practice of preventing the abandonment of local farming areas and involved the affected farmers.

It was implied that "Gyo-Jyo (corporate contribution to community resilience)" played a role of preserving the rich rural space and green landscape, playing a central role in the regional reconstruction and revitalization.

At the current stage, it is possible that the research will focus on individual small business owners closer to the residents and the effects of corporate contribution will differ depending on the industry types, and there will be issues to identify them. However, it is implied that the contribution of corporate contribution to the community resilience "Gyo-Jyo" was extremely large, and having presented the possibility and importance of that role, these findings make sense for the region to prepare for disasters in the future.

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Conflict of interest

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Chapter 10

The Role of Placemaking as a Tool for Resilience: Case Studies from Post-Earthquake Christchurch, New Zealand

Diane Brand, Hugh Nicholson and Natalie Allen

Abstract

In the aftermath of the 2010 and 2011 earthquakes in Christchurch, New Zealand, community-led temporary and adaptive urbanism filled a gap between the emergency response and recovery. In the space between response and recovery, the citizens of Christchurch showed their commitment to rethinking how they wanted to rebuild and then regenerate their city, leading to the embrace of collaborative processes, temporary and adaptive urbanism principles and a range of placemaking responses. In this chapter, the role of placemaking as a tool for post-disaster regeneration and resilience is considered by assessing three case study placemaking projects: the Re:START Mall, the Festival of Transitional Architecture (FESTA) and the placemaking programme at the Commons. Their development along with their success is considered within the context of the recovery of Christchurch and, in particular, how they align to the The Resilient Greater Christchurch Framework as it is set out in the Resilient Greater Christchurch Plan, in order to determine their role in building the resilience of Christchurch.

Keywords: placemaking, resilience, urban regeneration, adaptive urbanism, temporary urbanism, localism

1. Introduction

In an era of mass migration, growing iniquity, political tensions and climate change, modern cities are experiencing unprecedented challenges in the face of new or mounting pressures. As cities around the globe become more and more urbanised, the vulnerability of urban areas to these challenges is ever increasing. Add to this the uncertainty that comes when these challenges are also being faced in a post-disaster paradigm and we can begin to understand the complexity of moving from rebuilding to regenerating disaster-affected cities.

As outlined by the Intergovernmental Panel on Climate Change [1], it is anticipated that cities will continue to become increasingly prone to growing extremes in the frequency, duration and magnitude of natural disasters. Coupled with a plethora of additional socio-political pressures, the resilience of cities and the adaptive capacity of citizens to cope and manage in the face of crisis have become a central issue in urban planning discourse globally. How resilience is defined varies among disciples. However, a commonality among definitions is that they most frequently link resilience to the ability of a person, community, environment or system to maintain essential functions despite adverse events and phenomena [2]. This notion of resilience is affirmed by Pelling and Moench [3, 4] who define it as the ability to recover both quickly and effectively from catastrophes.

The continually growing vulnerability of cities to disasters is putting particular pressures on local communities. A city is only as resilient as its people, and therefore valuing local communities is paramount to a successful recovery during crisis [5]. However, the often-technocratic responses of governments post-disaster have been criticised for being both inefficient and ill-equipped to foster the sense of community required between the response and recovery phases in cities that need rebuilding following a disaster [6].

Subsequently, the role of civic action during this period has become increasingly important, with temporary urbanism and community-led placemaking initiatives often filling this vacuum and creating community support for the more macroscaled planning strategies as part of the rebuilding process. Unsurprisingly, these experiences became starkly evident in Christchurch, following the devastating earthquakes in 2010 and 2011.

Christchurch is New Zealand's second largest city, located on the east coast of the South Island in the Canterbury region (see **Figure 1**). The city is characterised by its flat alluvial landscape, surrounding hills and inland rivers and is known as New Zealand's 'garden city'. Christchurch has a rich history, with a number of different Māori rūnanga (indigenous governing groups) under the umbrella of the Ngāi Tahu iwi (wider indigenous tribe) living in the wider region before the arrival of Europeans.

Modern-day Christchurch emerged following the colonisation of New Zealand in 1840, initially planned as a small farming community on what once was a series of waterways and wetlands. The colonial and agricultural beginnings of what is now Greater Christchurch remain evident through the city's grid street layout, Victorian architecture (remnants left after the earthquake) and surrounding farmland. Since its origins, Christchurch continued to grow as a major New Zealand centre and the heart of the nation's South Island, with agricultural production and food processing still central to the city's economic base [7]. Until the earthquakes, the population of Christchurch had been steadily growing. However, by 2012 it had fallen by 20,000 people, not returning to its pre-earthquake level of 341,469 people until 2017 [8].

The first earthquake struck 40 km west of Christchurch City with a magnitude of 7.1 on September 4, 2010, causing predominantly localised damage to a small town called Darfield. The second and more devastating earthquake occurred the

Figure 1.
Location of New Zealand and Christchurch.

following year on February 22, 2011, within the Christchurch City Centre at a depth of just 5 kilometres and a magnitude of 6.3. The Christchurch earthquakes were some of the worst natural disasters experienced in New Zealand (see **Figure 2**), causing the destruction of 8000 households, damaging 90% of residential properties, killing 185 and injuring 7000. They also resulted in the demolition of 80% of the city's central business district [7].

Following the 2011 earthquake, a national state of emergency was declared, and it became quickly evident that the structures established to respond to the first earthquake would not be adequate. The government declared that a new agency, the Canterbury Earthquake Recovery Authority (CERA), would be put in place to coordinate the recovery in an effort to remedy the inefficiencies experienced post 2010.

The newly formed CERA was tasked with coordinating recovery efforts with local strategic partners, such as Te Rūnanga o Ngāi Tahu, Environment Canterbury and Christchurch City Council, and wider stakeholder groups including community groups, public service departments, crown- and council-controlled agencies and the private sector. The organisation was to facilitate and coordinate a shared effort among these organisations which each had their own mandate and role in the rebuild and recovery with the goal of ensuring the rebuilding of a vibrant city that embraced its shared cultural and natural heritage.

Over time the authority was given more of a mandate over areas of the city not initially considered to be within its remit—the most significant of these was the central city. A decision was made that CERA would prepare a Christchurch Central Recovery Plan (CCRP) for the central business district in 2012 [9], a move

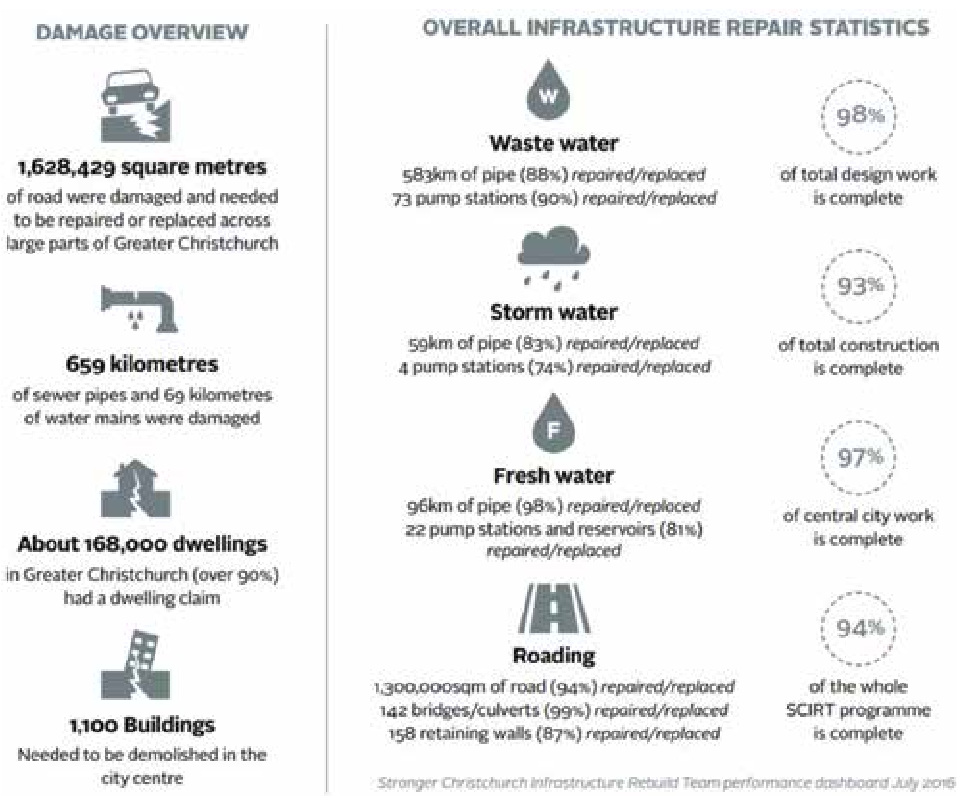

Figure 2.
Overview of the damage caused by the 2011 Christchurch earthquakes [7].

that was in large part a response to the ongoing co-ordination problems between CERA and local strategic partners. Christchurch City Council had commenced the *Share an Idea* campaign to consult with the public on the future of the central city and developed the Draft Central City Recovery Plan [10]. This work was subsequently absorbed by CERA to deliver the CCRP. The coordinated recovery effort was fraught with challenges, as clarity over who had what mandate, and who was responsible for funding which aspect, had to be negotiated between existing organisations. New structures and entities had to be created that were equipped to more effectively or more efficiently respond to a disaster of this scale. The establishment of new organisations to undertake the planning and delivery of the recovery created confusion over the role of the community and how its members could engage or participate. As the rebuild phase moved to a longer-term regeneration phase, there were further changes to the governance and management arrangements and distribution of responsibilities between agencies, the private sector and community. Ultimately, there were significant delays between what was being delivered as part of the official emergency response and the recovery phases of disaster management. In particular, there was a considerable time gap between the contracting of demolition occurred and the planning, designing, and ultimate delivery of government-led anchor projects. In response to this lag, Christchurch's citizens showed an enthusiastic and admirable commitment to regenerating their city, embracing collaborative projects and temporary urbanism initiatives within the vacuum created before a formal response became evident. This response from citizens initiated a significant phase in Christchurch's recovery efforts and has been a core component of the city's regeneration.

In essence, the grassroot response of citizens in Christchurch demonstrates the capacity of temporary urbanism and placemaking to effectively connect the community, provide a platform for citizen participation and build an ecosystem upon which a deeper understanding can emerge of varying views among the communities involved. Each of these is a fundamental aspect of the city's resilience. This chapter therefore investigates the response of Christchurch's citizens and the role that temporary urbanism and placemaking projects have played as a tool for the city's post-disaster regeneration. The impact of this on the resilience of Christchurch will be considered by assessing three case study projects: the Re:START Mall, the Festival of Transitional Architecture (FESTA) and the Commons. Each of these projects has been developed through grassroot initiatives to provide a physical place for connecting parts of the community, enabling a way for the community to participate in the city's recovery and acting as catalyst projects in understanding what the citizens wanted from their urban environment as they reimagined what the future of Christchurch could look like. The success of these projects and their contribution to enhancing Christchurch's resilience will be considered within local and international literature surrounding grassroot disaster recovery and the wider context of the city's regeneration, in particular the Resilient Greater Christchurch Plan [7].

2. The context of planning for resilience and temporary urbanism responses

A number of writers have researched specific issues related to urban, landscape and building design in the aftermath of the Canterbury earthquakes. Bennett et al. [11], for example, document and debate the recovery process after the Christchurch earthquakes. Swaffield [12] interrogates the kinds of places and cultures that have evolved in a rebuilt Christchurch as a result of the nexus between directive central government processes and spontaneous bottom-up community projects.

Wesener [13] has described in more detail the resulting transitional community-initiated open spaces in Christchurch. Jacques et al. [14] evaluated the performance of the Christchurch hospital system and developed a method which can predict the future performance of hospitals in terms of seismic preparedness strategies. However, a gap remains in the literature with respect to the potential contribution that urban design can make urban resilience planning, which this paper aims to address through a discussion of case study placemaking projects in post-earthquake Christchurch.

In order to investigate the development and success of the three case studies and their contribution to this, it is important to first understand the interconnections between temporary urbanism, placemaking and resilience. In this section, these core concepts and their role in disaster recovery will be drawn together by considering a range of international and local literature.

2.1 Resilience and urban regeneration post-disaster

The intersection of urban theory and resilience theory has been investigated by Godschalk [15] who discusses resilient cities in relation to both natural hazards and terrorism and Wu and Wu [16] who position classic urban design theory within resilience literature and posit areas of tension in future sustainable design practice around the dialectic of stasis and change.

Cities are complex systems and their resilience is tied to our human future. As Campanella [17] discusses, despite the growing prominence of natural disasters and humanity's continual ability to inflict havoc, since the early 1800s practically no city has been permanently lost. This is in spite of the unmatched catastrophes felt throughout Europe during the world wars, as well as the onslaught of natural disasters globally [18]. Evidently, despite profound devastation, cities are continually rebounding or in some case flourishing after crisis [17]. Not surprisingly therefore, the adaptive capacity of a city post-disaster and the factors contributing to this is an increasingly relevant field of research. Many authors attribute this adaptive capacity to resilience, a catchphrase that has become increasingly central in both academia and urban planning discourse [19]. Resilience is often defined as the ability of a system to return to a point of equilibrium after displacement or its capacity to adapt amidst adversity [20]. In the context of urban regeneration, resilience firstly infers the capacity of a city to absorb stresses and maintain basic functions during a disaster to offset the extent of devastation and ultimately the ability to bounce back and adapt from this devastation [6, 13].

There are many factors contributing to the resilience of cities; these are invariably unique from place to place [17]. Aldrich [20] breaks these into five core areas: citizens' psychological well-being, institutional and organisational restoration, economic and commercial productivity, infrastructural integrity and operational regularity. While immediate government response is undoubtedly essential, there are a number of complex and interacting elements that need to be employed during disaster relief to contribute to these spheres, extending far beyond reconstructing and repairing physical damage [6, 20]. This is because recovery is not only about services and the built form of a city but also is about a process of rebuilding communities [5]. As Campanella [17] and Aldrich [20] discuss, this is fundamental because social capital is a primary driver of resilience. Fostering a strong sense of civic engagement is therefore a core (and often overlooked) element to urban regeneration [20]. Subsequently, as Campanella [17] cautions, urban regeneration post-disaster can inherently conflict with a city's resilience. The top-down 'rebuild better' approach that has, in many cases, led to gentrification and displacement can undermine the communities pivotal to a city's resilience and therefore ironically its capacity to recover.

Christchurch exemplifies the power of social capital in post-disaster recovery and the need to facilitate a grassroot approach, with the community's resilience enormously tested in all spheres following the earthquakes. The loss of life, livelihoods and disruption of communities put a great strain on the city's social capital. There was unparalleled disruption to the industry, local business, institutions and infrastructure, all of which constricted local economic well-being; this included the relocation of 50,000 central city jobs and 6000 businesses [7]. Notwithstanding this, the response of citizens in coming together amidst adversity and their ability to convert dire situations and spaces into eccentric, inviting environments is a testament to the strength of the community, a factor that proved pivotal in the city's recovery.

2.2 Temporary and adaptive urbanism

Mannakkaram and Wilkinson's [6] discussion mirrors Christchurch's recovery experience, explaining that recovery is the least understood phase of disaster management and post-disaster responses are often slow and inefficient. As the response of many citizens globally has demonstrated, temporary urbanism has the potential to deliver genuine and effective recovery solutions within this vacuum created between a disaster and local evidence of a top-down bureaucratic response [13]. Equally, Wilson [21] and Wesener [13, 22] add that the ability of temporary urbanism to engage the community and generate social cohesion plays a fundamental role in fostering community resilience. With social capital understood as being paramount to a city's adaptive capacity, the role of temporary urbanism cannot be overlooked as a key component of disaster recovery. This can take a variety of forms, with post-disaster vacant sites or buildings providing spaces for events, performances and art. Not only does temporary urbanism provide the testing grounds for innovative solutions for regeneration initiatives, but it also encourages public participation, fosters community empowerment and facilitates positive interactions and experiences for communities in dire situations [13, 23, 24]. As Campanella [17] suggests, these elements are each vital to generate the social capital required for the efficient and effective recovery of a city.

Subsequently, a resilient city must foster and encourage community-led initiatives to increase the viability and effectiveness of temporary urbanism [13, 23]. However, this is a concept that has seen limited consideration in the literature and remains poorly understood [23]. Dionisio and Pawson [23] caution that the capacity of temporary urbanism to achieve this vital function is being narrowed and, in some cases, purposefully restricted in light of increasingly restrictive bureaucratic processes. In these cases, the top-down response to relief is arguably regressive, with inclusive grassroot responses required to heighten a city's ability to respond to disaster.

These broad themes experienced following disasters globally are indeed exemplified in Christchurch, where temporary urbanism played a core role in facilitating community cohesion and social capital following the earthquakes. The success of these projects has resulted in wider and longer-term benefits to the local community as a result of their contribution to placemaking within what was left of the city centre post-earthquakes.

2.3 Placemaking and sense of place

Placemaking is an overarching and broad initiative surrounding the recreation and activation of spaces into inviting and vibrant areas to re-establish a sense of place and reconnect people with their environment [25]. As examples of placemaking in Christchurch demonstrate, the successful implementation of temporary urbanism can result in wider community-building initiatives, where the benefits, social capital and grassroot community support of regeneration is able to solidify. In this sense, where temporary urbanism initiatives reclaim space in disaster-struck cities, the outcome of this and its contribution to a broader placemaking narrative is where the ultimate benefits occur.

As Jacobs ([26], p. 448) famously notes, 'lively, diverse, intense cities contain the seeds of their own regeneration, with energy enough to carry over for problems and needs outside themselves'. The process of placemaking seeks to reinvigorate the vibrancy of the public realm and restore the pride and connection of communities to the places they live [27, 28]. Coaffee [19] discusses that the notion of placemaking has arisen to become a central signifier in planning discourse, particularly as discussions surrounding resilience narrow to focus on smaller spatial scales. Heath, Rabinovich and Barreto [27] add that when placemaking is successful, placemaking experiments can cement development outcomes in the regeneration of disaster-struck cities. With temporary urbanism and placemaking providing a grassroots testing ground for future initiatives, instead of an imposed top-down response, community support and ultimately a successful recovery are much more likely [17, 27]. In turn, when recovery plans are sanctioned or initiated by the local population, they are much more likely to be successful.

In Christchurch, the Transitional City Projects Fund administered by Christchurch City Council was originally signalled in the Draft Christchurch Central Recovery Plan and responded to the spontaneous emergence of community grassroot initiatives ([11], p. 342). The purpose of the fund was to encourage and enable community placemaking initiatives through financial and technical support. This included establishing contestable funding rounds, helping with public liability insurance where needed and assisting with navigating planning regulations. The Life in Vacant Spaces Trust (LiVS) was formed during this process to assist in brokering access to and lease agreements for post-earthquake vacant sites. As a result of this initiative, 1500 commercial sites and 12,000 residential sites were able to be converted into sites for transitional urbanism where 325 community events could be hosted since 2010 [29]. One hundred vacant sites have been activated more than 450 times, with over 150 creative projects. Seventy new businesses have been established and 25 new business models, products and services have emerged from pop-up spaces since the programme began. This has resulted in a net influx of artists, entrepreneurs and visitors to the city as well as a three-to-one return on investment for every ratepayer dollar spent [29].

In writing about the long-term impacts of temporary urbanism in Christchurch, Sherow [30] links placemaking and sense of place by describing the importance of collaboration in the work of the Life in Vacant Spaces Trust, noting that 'the most well-used sites have been the result of multi-team efforts' ([29], p. 317). Similarly, Oliver [31] considers the need for collaboration in a healthy arts ecology and laments that 'despite (the) enthusiastic community participation and extensive local, national and international media coverage' ([31], p. 350) in placemaking following the earthquakes, the significance of such projects in creating a sense of place and their 'long-term impact have been largely overlooked in the recovery plan' ([31], p. 350) for Christchurch. This highlights that, while the relationship between placemaking and sense of place is established, how these in turn relate to the policy and planning contexts of regeneration is less commonplace and would benefit from additional scrutiny.

3. A methodology for considering the case studies

In order to consider the role of placemaking as a tool for post-disaster regeneration and resilience in Christchurch, relevant case studies and a Framework to assess their success were chosen. Therefore, the methodology developed in this chapter is divided into two parts. First, an overview is provided of the three case study projects chosen for analysis as well as an explanation as to why they are useful projects to consider in terms of their role in the post-disaster regeneration and resilience of Christchurch. Second, a framework for resilience, known as The Resilient Greater Christchurch Framework, is introduced and used to critique these projects. Criticising the Framework itself is beyond the scope of this paper; instead, the aim is to understand how the case study projects have emerged, what they represent in terms of contemporary urban design and urban art practice and how they can contribute to ongoing community resilience in Christchurch though a different delineation of the public realm as the city is rebuilt.

Each of the case studies was chosen partly because of its being delivered and widely engaged with by the residents of and visitors to Christchurch and partly because it represents a different type of transitional activity with different participants and outcomes. They all contributed to a greater level of connection, participation and understanding to support the Christchurch rebuild. The first case study, the Re:START Mall, was a single iconic temporary structure that allowed for continued central city retail activity. The second case study, the Festival of Transitional Architecture (FESTA), is an annual/biennial event which attracts tens of thousands of people and invites the public to reimagine what sort of city Christchurch could be. The third case study, the Commons, is a particular piece of land that became a hub for placemaking experiments where a wide range of engaged community groups, individuals and transitional projects have operated since the earthquakes.

3.1 Part 1: The case studies

The first case study, the Re:START Mall (see **Figure 3**), was a temporary container mall located in Cashel Mall, the central city's main retail street. The mall was initially established in 2011 by the Restart the Heart Trust and financially supported by the Christchurch Earthquake Appeal Trust and Auckland Savings Bank (ASB). It consisted of a number of converted shipping containers on vacant lots adjacent to Ballantynes, the surviving and much-loved traditional Christchurch department store, and within the Retail Precinct (an area of the city designated for retail development in the Christchurch Central Recovery Plan).

The container mall housed over 50 businesses, as well as food trucks, markets, artworks and street performers over its lifespan. Originally, the project was developed to encourage not only residents but also local retailers, to return to their central city. The container mall became an iconic cornerstone of the city centre during the rebuild phases, attracting significant numbers of tourists and locals in a highly successful example of placemaking.

The idea of a temporary or transitional shopping area after an earthquake was not new. After the Napier earthquake in 1931, when almost all of central Napier was destroyed, a temporary business centre constructed out of lightweight materials including corrugated iron and dubbed 'Tin Town' helped to support local businesses and retailers [33].

The case study demonstrates both the economic value of temporary urbanism in supporting central city retail and as a visitor attraction for tourists and locals. Beyond the initial impact of bringing people into the city centre, the success of

Figure 3.
The Re:START Mall [32].

Figure 4.
(Left) The Boxed Quarter. (Right) An exemplar of Christchurch's laneway network (images supplied by authors).

the container mall inspired a broader urban design response, with the small-scale laneway and courtyard retail model with anchor tenants subsequently being used in several of the permanent retail developments. It also inspired the Boxed Quarter (see **Figure 4**), a modular architecture based on the idea of making the shipping container model permanent with modular walls, windows and floor plates that can be interchanged as required. Built up to four or five storeys with retail, businesses and residential units around laneways and courtyards, the Boxed Quarter is the successor to the container mall.

The container mall has become a tool for successful regeneration, reinforcing many of the findings discussed across the literature. Notably, the initiative's contribution to placemaking and its ability to draw both residents and visitors back into the CBD demonstrates the project's capacity to reconnect the community with their city and contribute to the social capital required for successful recovery, an idea that is gaining increasing traction in the literature [13, 17, 20, 22, 23]. Likewise, the development of permanent retail and civic structures within and adjacent to the mall demonstrates the capacity of grassroot placemaking to act as a testing ground to shape permanent regeneration solutions (mirroring the discussions of Campenalla [17] and Heath, Rabinovich and Barreto [27]).

The second case study is FESTA, the Festival of Transitional Architecture (see **Figure 5**). FESTA is a festival which celebrates urban creativity. It provides an opportunity for the community to reimagine Christchurch. During the festival a series of events, such as workshops, live performances and tours, occur alongside interactive installations and pop-up stalls. The festival was held annually in 2012, 2013 and 2014 and has occurred biennially since, occurring every second Labour Weekend over a 4-day period. The project was originally initiated by creatives in the community through crowdfunding and local sponsorship. In addition to crowdfunding, the event is now also financially supported by a wide range of donors, seeking to contribute to Christchurch's ongoing regeneration.

Each festival has a different 'headline event' exploring urban ideas and inviting members of the public to reimagine what they want Christchurch to become. FESTA 2012—'Luxcity'—was a light festival that attracted more than 20,000 people back to part of the central city which had been cordoned off since the earthquakes in February 2011, inviting them to reclaim their city. FESTA 2013—'Canterbury Tales'—was headlined by a parade of giant puppets resembling local politicians, thus constructing a political allegory about the governance of the city which challenged the incumbent top-down approach. FESTA 2014—'The Future Will Be Live'—created an entire block of a futuristic city, inviting people to think about

Figure 5.
Events as part of FESTA 2018 (images supplied by Anna Wright at the University of Auckland).

what a rebuilt Christchurch might look like, while FESTA 2016—'We Have the Means'—addressed recycling and reuse as a demonstration of what a sustainable city means. FESTA 2018 invited the public to share in a celebration of communities and food and to consider the importance of these in Christchurch.

FESTA is an example of a temporal recurring event that is largely crowd and donor funded. It is participatory, attracts large numbers of people and seeks to encourage people to imagine and experience Christchurch differently. It celebrates the culture of creativity and active citizenship that has emerged in Christchurch since the earthquakes and encourages more people to understand and be involved in remaking their city.

This experience mirrors many learnings discussed by Heath, Rabinovich and Barreto [27] and Wesener [13], who emphasise that beyond having value in and of itself, temporary urbanism initiatives facilitate the experiencing of new, innovative ideas, generating wider and longer-term benefits to the community they are tested in. It enhances understanding and enables informed, wider strategic planning and decision-making by council and government authorities.

The final case study is the Commons, a prominent vacant site on Victoria Street in the central business district, made available by the Christchurch City Council for temporary interventions (see **Figure 6**). The Commons provides space for a diverse range of activities, collaborative work and community events. The initiative was established in 2012 to empower local communities to experiment in temporary urbanism and to co-locate with likeminded initiatives. It is a collaboration between Christchurch City Council, which owns the site; Life in Vacant Spaces, which administers it; and Gap Filler, which oversees everyday management.

Between 2012 and 2014, the Pallet Pavilion (constructed and managed by Gap Filler) operated on the Commons and was a temporary community event venue constructed out of 3000 pallets. Built by hundreds of volunteers, the Pavilion

Figure 6.
Various placemaking initiatives at the Commons [34]. (Top left) Catalyst project the Pallet Pavilion (December 2012–May 2014). (Top right) Grandstandium (October 2014–Current). (Bottom) The Arcades Project (June 2013–current).

hosted more than 250 events including live music, markets, outdoor cinema, yoga, book launches, film screenings, classes, lectures and associated mobile food caravans and trucks. While the Pallet Pavilion reclaimed the Commons for public use, the Arcades Project in 2012 reclaimed the diagonal alignment of Victoria Street which had been truncated by the Crowne Plaza Hotel that was formerly on the site. A crowdfunded architectural project, composed of a series of modular temporary structures in the form of an elongated archway, created a large open space with the capacity for caravans or marquees to join either side to form a dynamic market strip. The structure was initially displayed at FESTA 2012 and now provides space for special events at the Commons. Reopening the diagonal pedestrian route through the Arcades and Victoria Square has created a popular pedestrian and cycling route which has been supported by the Council and is also an excellent example of temporary uses influencing permanent city form which reclaimed an historic urban axis.

The Commons has hosted a wide range of projects and events, community groups and individuals in a collective space. Its facilities include water, power, temporary offices and meeting rooms, as well as public toilets. Perhaps, most importantly, it provides a welcoming space for participation, collaboration, support and interaction as part of a transitional community. As a result, the Commons has also hosted a number of start-up community organisations that have continued to develop and thrive both on-site and off-site. These include *RAD Bikes* (Recycle A Dunger), a community bike shed where people can recycle old bikes and learn how to fix and maintain them, and *Makercrate* (subsequently Fab Lab Christchurch) who provide a space, tools and technology for the community to come together, share ideas and make things and *Erica Austin Curation*—an event management organisation.

The significance of the Commons is twofold and lies in the way in which community groups and transitional activities have reclaimed a piece of the city for the public. Through the creation of a hub or centre for transitional activities, groups were able to establish a mandate to debate the importance of urban environments while encouraging and advocating for collaboration and sharing of ideas. They were also able to provide tangible opportunities for participation, by a wide range of groups, in redesigning and rebuilding narrative.

3.2 Part 2: Resilient Greater Christchurch Framework

The Resilient Greater Christchurch Framework [7] was developed by the Greater Christchurch Partnership Committee, a collaborative partnership between four councils in the Greater Christchurch area, Ngāi Tahu Iwi, and government organisations including the New Zealand Transport Agency, the Canterbury District Health Board, the Department of the Prime Minister and Cabinet and the city's regeneration agency, Regenerate Christchurch. It was developed to enhance the current and future resilience of Christchurch's citizens, the built environment and the economy. The plan establishes four key goals to foster resilience and build capacity in the people, places, organisations and systems of Greater Christchurch. These include:

- Connect: the need to connect the changing communities within Christchurch, including both communities disrupted by those leaving the city and new communities formed by those coming into the city to contribute to the rebuild

- Participate: to encourage and empower community engagement at the grassroot level and provide the opportunity for the community to actively engage with the decision-making process

- Prosper: to uphold and sustain Christchurch's environment and natural resources while supporting economic outputs, innovation and the attraction of people and capital
- Understand: to ensure that the community and agencies understand, manage and prepare for any future risks and hazards that Christchurch will face [7]

Figure 7 shows that each of these core goals is given effect to through a series of interconnected programmes, with each programme having a series of action areas outlining projects or initiatives to follow up. Interweaving and overarching each of these elements are two guiding principles, which must be given effect to at each stage, including a meaningful Treaty partnership with Ngāi Tahu (local indigenous tribe) and consistency and collaboration across all tiers of government.

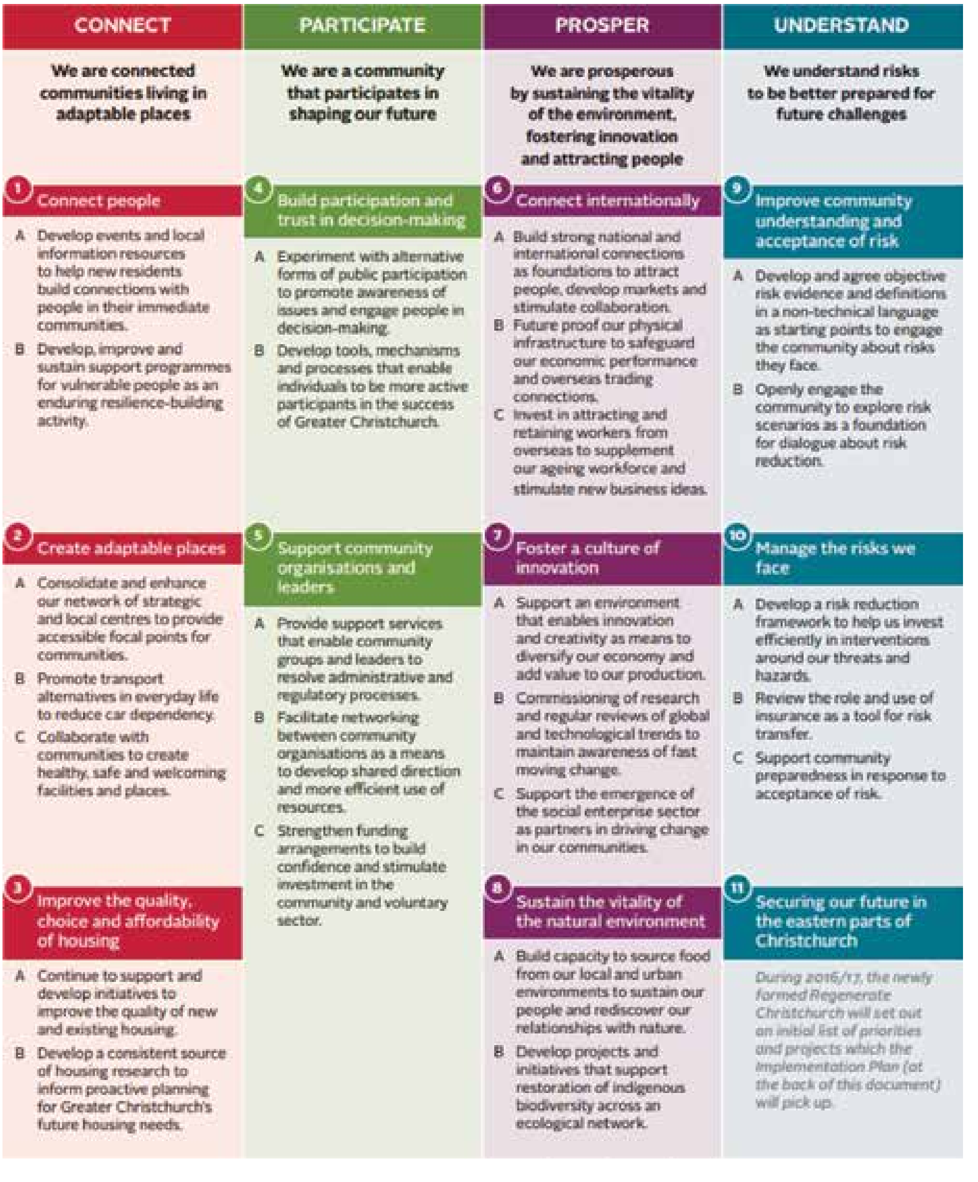

Figure 7.
An overview of the Resilient Greater Christchurch Framework [7].

This Framework is used to identify the various ways in which the case study projects meet the resilience criteria which are discussed in the Resilient Greater Christchurch Plan [7]. The process of considering how each of the three case studies aligned to the four goals of the Framework was intended to guide the review of these projects and is not an exhaustive evaluation process. Instead, the subsequent section is framed as a discussion to both present the projects as exemplars of important temporary urbanism within the context of resilience planning in Christchurch and to discuss the role of placemaking more generally as a tool for post-disaster regeneration and resilience.

4. A discussion of the relationship between placemaking projects and the resilience of Christchurch

The evaluation of the placemaking case studies against the four goals of the resilience criteria, as set out in the Resilient Greater Christchurch Framework, reveals that each of the case studies has made significant contributions to the resilience of Greater Christchurch. All three case studies contributed strongly to the criteria set out under the *Connect* and *Participate* goals. In particular, the Re:START Mall aligned strongly to the *Prosper* criteria, the FESTA case study rated highly against the *Understand* criteria and the Commons rated most highly against the *Participate* criteria. Rather than discussing each project individually, how they support resilience is examined by considering how they address the criteria set out within the four goals (Connect, Participate, Prosper and Understand) of the Framework.

4.1 'Connect'

Under the theme of *Connect*, *connecting people* to their communities is a fundamental tenet of the Resilient Greater Christchurch Framework [7]. The Re:START container mall was pivotal in providing a physical place for residents to connect with one another and to reconnect with the central city, which was one of the areas most affected by the earthquakes. Re:START provided eating and gathering areas to support the retail offering, acting as a new shopping centre in the CBD. Events including street performers and buskers, exhibitions, music, dance, theatre, fashion shows, art works and festivals activated the container mall, providing opportunities for residents to reinhabit the central city. In this way, Re:START provided a critical hub for connecting people through enabling retail activities in the central city for 5 years from 2011 until the permanent retail developments in the Bank of New Zealand (BNZ) and Australia and New Zealand Banking Group (ANZ) Centres and the Crossing were opened in 2016/2017. Today, many of the businesses from the container mall have successfully relocated into permanent retail buildings. The container mall remains one of the most recognised symbols of Christchurch's recovery and a strong symbol of community connectedness with each other and with the city. While the overall economic impact of the container mall has not been assessed, it maintained the central city as a retail destination through the 5-year gap between emergency response and recovery.

Additionally, FESTA was created as an event to build connections with people in their communities. It was set up to celebrate the transitional and placemaking initiatives that have emerged in Christchurch since the earthquakes and to encourage more people to get involved in remaking their city through a positive collective experience. Attendance at FESTA has been significant for a city of 374,000, with numbers totalling as follows:

- Luxcity (2012)—20, 000 people
- Lean Means (2016)—16,000 people
- FEASTA (2018)—12–14,000 people

FESTA was purposely developed and has evolved to offer opportunities for the public at large to experience a reimagined Christchurch, comprising imaginative architectural installations, workshops, talks, pop-up projects, family events, tours, live performance and artworks—the festival supports learning about cities and improved community connections.

Often feeding in to events at FESTA, the Commons similarly facilitated many connections between the various community organisations and individuals involved in the site and the wider community. It actively built connections with neighbours and the general public who walked through the Commons to Victoria Square or attended one of the many events held at the site; there were more than 250 events held at the Pallet Pavilion project during the 2 years that it was on the Commons. The space continued to be used for events over the following years, including markets, Holi Festival of Colours, music concerts, Speakers' Corner, retro-sports events, a bicycle-powered cinema, exhibitions, performances, a cardboard shelter workshop and pop-up dining events.

Continuing under the category of *connecting people*, resilience thinking is seen to align with developing, improving and sustaining support programmes for vulnerable people as an enduring resilience-building activity [7]. How each project may have addressed this criterion depends largely on how vulnerable people are defined. In the aftermath of the earthquakes as these projects were being developed, they each arguably assisted a wide range of Christchurch residents, through their community-building events and activations, who were dealing with the impacts of the earthquakes in different ways. The true extent and exact impact of the combined efforts of these case studies on improving and sustaining support programmes for vulnerable people are unclear. For example, over the years the Commons attracted homeless people looking for shelter, toilets and food. This started with the Pallet Pavilion project at the site, and since this time, Gap Filler and other partner organisations at the Commons have adopted a supportive approach by befriending the individuals, offering them small jobs in exchange for food and working with local wardens to establish boundaries.

Creating adaptable places follows *connecting people* as a second significant category within the theme of *Connect* in the Resilient Greater Christchurch Framework. This is firstly focused on consolidating and enhancing the available network of strategic and local centres across the city, to provide accessible focal points for communities [7]. While the case study projects were deliberately and predominantly focused on bringing life back into the CBD, considering this as a key strategic local centre, it is evident in considering this criterion that each of the projects contributed strongly to resilience of post-earthquake Christchurch by activating this central node of the city. Re:START, for example, was a key part of the primary hub of activity in the central city for 5 years after the second earthquake in 2011. The project acted as a lynchpin, maintaining the central city in the network of strategic and local centres by providing an accessible focal point for Christchurch residents and visitors while planning for the permanent rebuild was being implemented. The not-for-profit model allowed new businesses to test and establish themselves before transitioning into permanent developments, and the temporary retail spaces kept central city retailing alive after the earthquakes.

FESTA has involved some of the largest events in the central city since the earthquakes and was instrumental in attracting people back to the central city once the earthquake cordon was removed, notably from 2012 and 2013. The event has fostered an ongoing dialogue through workshops and guest speakers and encouraged the public to reimagine what Christchurch could become.

In between the relative longevity of Re:START (7 years) and the temporary nature of FESTA sits the placemaking programme at the Commons. The Commons was established on a site that had effectively been privatised for 25 years by a hotel development which truncated Victoria Street and the diagonal access to the centrally located Victoria Square. The Commons turned this land into a public space and invited the public to reclaim it and recreate the diagonal route. In doing so, it has formed a much stronger connection between Victoria Street and the Town Hall and Victoria Square and the central city. The programme of placemaking to encourage this transformation was delivered by multiple organisations over multiple years, through revolving temporary projects of differing timeframes at the same site. Through its inclusivity and adaptability, the Commons became a focal point for the transitional movement in Christchurch—the HQ of temporary urbanism. Creating a highly visible physical space with various transitional projects happening on it, this has been an important part of the identity of the transitional movement in Christchurch and has undoubtedly provided an accessible focal point for both locals and visitors to connect with the central city as an important strategic centre.

Building on the notion of consolidating and enhancing strategic and local centres across the city, collaborating with communities to create healthy, safe and welcoming facilities and places is a second key criterion within the *creating adaptable places* category of the *Connect* theme [7]. All three of the case studies clearly align to this criterion. Re:START was created through a collaboration between businesses and government organisations and managed via the Re:START the Heart Trust which had representatives from various community groups and organisations involved. Additionally, a wide range of stakeholders contributed to the viability and success of the Re:START case study, including land owners who provided land for the mall at nil or nominal cost, the Central City Business Association, which supported the original proposal, and a number of professionals who provided design services pro bono or at reduced rates.

The project provided an opportunity to create healthy, safe and welcoming facilities in the area of the central city which was known as the CBD Red Zone, a civil defence cordon and public exclusion zone implemented due to the damage caused by the 2011 earthquake. Despite government agencies renaming the area to the CBD Rebuild Zone, the stigma of the Red Zone and the danger associated with it were initial deterrents for many residents to reoccupy the central city. The significance of opening retail facilities in this area was therefore about more than providing important urban amenities for residents; the project became symbolic of the rebuilding and resilience of Christchurch.

FESTA was similarly created through an extensive network of collaborations with a wide range of groups and individuals. The festival is run by a charitable trust—Te Pūtahi: Christchurch Centre for Architecture and City-Making. Other organisations such as Greening the Rubble, Creative Junk, Gap Filler and Rekindle are involved in specific parts of the festivals as well as at the Commons site. The professional institutes of architects and landscape architects participate in the festivals alongside a number of other artists, community groups, youth groups, cultural performance groups and local businesses.

In turn, the Commons is a collaboration between Christchurch City Council, which owns the site; the Life in Vacant Spaces Trust, which administers it; and Gap Filler, which oversees everyday management. The Commons was governed by a set of principles, and decisions about its future were made by a group composed of the various site members. A range of other community organisations, social enterprises, businesses and individuals have been a part of the collaborative approach to the Commons, becoming a part of the Commons community and contributing their ideas and projects.

The final criteria in the *Connect* theme fall less clearly under the mandate and scope of the case study projects. For example, the relationship between resilience and mobility is addressed under the criterion of 'promoting transport alternatives in everyday life to reduce car dependency' [7]. While FESTA has included workshops and bike tours promoting alternative modes of transport and launched initiatives such as the Food Resilience Network Canterbury to reduce dependence on vehicular transport, and the Commons has encouraged people to walk through the central city, in general these placemaking activities have not targeted the promotion of transport alternatives. Successively, the criterion to 'improve the quality, choice and affordability of housing' [7] as a signifier of resilience is beyond the scope of the case study projects.

4.2 'Participate'

The theme of *Participate* in the context of rebuilding and regenerating Christchurch centres around enabling a way for the community voice to be heard and for people to feel empowered and responsible for the future of their city within a top-down government-led recovery process. Considering the case studies within this theme aligns to both the global trend towards increasing citizen-centric participatory planning and citizen-led self-determination in shaping the future identity of post-disaster cities such as Christchurch.

Building participation and trust in decision-making, by experimenting with alternative forms of public participation, is a significant process identified in the Resilient Greater Christchurch Framework for promoting awareness about key issues and subsequently to engage people in decision-making [7]. Re:START provided an alternative retail model where the container mall was established and managed by a not-for-profit community trust. The trust was able to successfully run Re:START for 5 years where a market model would not have been economic and external agencies would have struggled to raise funding from such a wide variety of sources. While there was a level of public distrust of the various local and national government agencies involved in the rebuild, there was a high degree of support for the Restart the Heart Trust.

FESTA is an experimental form of public participation and promotes awareness of current urban issues (predominantly associated with the rebuild) in a way that engages people through architecture, design creativity and food. Through this participation people feel, they are contributing to the discussion about the future of the city and that they are creating a place for themselves in the future Christchurch. Such a well-supported event also signals the need for further investment in arts and culture. FESTA is organised by Te Putahi (Centre for Architecture and City-Making), a charitable trust. Te Putahi, in collaboration with the Christchurch City Council, also runs the Christchurch Conversations Series which hosts national and international speakers talking about city-making as another way to promote awareness about key urban issues.

Over time, there have been significant changes to the projects on the Commons site, the people involved and the public usage of the site. While the three core members have been consistent, many other people and groups have been involved. The Commons has therefore been an ongoing experiment in self-governance where the groups involved in temporary urbanism and placemaking collaborate and make decisions about what happens on the site.

Furthermore, each of the three projects has also established innovative ways to develop tools, mechanisms and processes that enable individuals to be more active participants in the success of Christchurch. Re:START, for example, enabled more than 50 small retail businesses to operate successfully in the container mall and to support other remaining central city retailers. The success of the container mall in maintaining the central city as a retail destination in turn supported the success of Greater Christchurch. FESTA is specifically aimed at getting more people to be involved in remaking their city and to stimulate long-term change in how and who makes Christchurch. Through a combination of learning and participation in a positive collective experience, the festival encourages people to become more active and involved citizens. At its core, FESTA is conceived as an event that seeks new ways to create meaningful connections between and within communities and urban places in a co-operative and open way. Likewise, the Commons has been a testing ground for the evolution of a number of different tools, mechanisms and processes. The Pallet Pavilion was designed so that it could be constructed by unskilled volunteers under the supervision of a builder. The project Makercrate was initially developed in a shipping container on the Commons before it was moved to activate other sites. The Food Truck Collective started gathering at the Commons on Friday nights before graduating to Cathedral Square as the event became more popular. The Space Academy pop-up café started life at the Commons before moving into an old commercial building on St. Asaph Street in a permanent form. The Commons has been a safe place to try new ideas and new ways of doing things before moving onto other spaces.

Supporting community organisations and leaders has been spearheaded by the Commons case study. The partnership with Christchurch City Council at the Commons has helped to resolve some regulatory issues. The Pallet Pavilion, for example, was one of the early transitional projects requiring a building consent. It quickly became obvious that transitional projects would be hamstrung by the bureaucratic business-as-usual consenting process and that the people involved did not have the skills or resources to navigate the process. In order to resolve this, the Transitional Team at the Council provided expert technical assistance and worked with a couple of building consent officers to develop a more supportive solution-focused process for transitional projects. Subsequently, the success of the approach culminated in the Arcades Project at the Commons (a modular series of 6-metre archways) being classified as a 'garden pergola' not requiring a building consent (noting that the structure was designed and supervised by structural engineers).

The Commons has also provided shared space and governance arrangements that facilitate networking between community organisations. Shared resources, including available land, power, water, meeting rooms and public toilets, have made it easier and more efficient for transitional projects to be delivered at the site. The day-to-day management by Gap Filler and the governance group composed of the various groups on-site have all provided points of contact for networking with other community organisations.

Arguably, the Christchurch City Council transitional programme has been pivotal in enabling community groups and social enterprises to operate effectively in transitional activities and spaces. There are three key components to the Council's transitional programmes:

1. **Core funding for key groups** including Gap Filler, Greening the Rubble and Life in Vacant Spaces. This funding has allowed the people involved to have some security of income, so they can work in the transitional space without worrying about where their next meal is coming from. However, this funding only covers a limited part of the total operating budget.

2. **Technical expertise** to support transitional groups. Council established the Life in Vacant Spaces Trust to find and lease vacant sites and protect landowners by providing public liability insurance for community groups. Council also supported the provision of key infrastructure and services to sites. Life in Vacant Spaces was therefore able to resolve many of the technical and legal risks for the transitional groups, letting them focus on the placemaking.

3. **Contestable project funding** for transitional projects provided a potential source of funding for them. Given the broad range and evolution of transitional projects, one of the difficulties in administering the funding has been developing a useful scope and set of criteria against which to evaluate them. This is an area where a framework, such as the Resilient Greater Christchurch Framework, provides a useful initial guide from which a more specific evaluation process could be developed.

Strengthening funding arrangements to build confidence and stimulate investment in the community and voluntary sector has also been demonstrated at Re:START where successful partnerships were established between a community trust, local and national government and the private sector. Initial funding came through a grant from the Christchurch Earthquake Appeal Trust ($3,368,523.00) and sponsorship from ASB ($300,000). Private landowners provided the land at nil or nominal cost, and the business operations covered marketing and operational costs. The success of the container mall and the broad-based funding model helped to build confidence and stimulate further investment in the community and voluntary sector.

Similarly, the joint funding arrangements for FESTA demonstrate a high level of collaboration and support for temporary urbanism in Christchurch. The key funder is Christchurch City Council with additional grants from national groups including the Creative New Zealand, the Warren Trust and the Lion Foundation. Crowdfunding, as well as individual donations and support, has provided a successful stream of income for later festivals. There has been significant sponsorship by local businesses including pro bono time and expertise and the pro bono use of equipment and materials. For example, the cranes and heavy machinery used to construct and support the architectural installations in Luxcity (2012) was provided pro bono by demolition companies working in the central city.

4.3 'Prosper'

The third of the four themes is *Prosper.* Within the category of *connecting internationally*, all three case studies have built strong national and international connections to attract people, develop markets and stimulate collaboration in line with the Resilient Greater Christchurch Framework [7].

For example, as an innovative shopping precinct made from shipping containers, Re:START brought shoppers back to the Christchurch CBD and drew attention from around the world. Re:START has been used as a great example of successful placemaking and assisted in elevating the importance of placemaking in both the local and international discourses. It has been included in current placemaking and adaptive urbanism literature (e.g. Bennett, Wesener, Swaffield, Brand et al.) and was included in global publications such as Lonely Planet [35]. It demonstrated the value of leading international trends and adapting to change in our urban environments. It also achieved significant recognition nationally with awards including:

- Property Council NZ RCG Retail Property Award 2012—Merit
- New Zealand Institute of Architects New Zealand Architecture Award 2013—Planning and Urban Design
- New Zealand Institute of Landscape Architects Pride of Place Community Design Award 2015

FESTA has also built strong national and international connections with design, architecture and landscape architecture schools to produce the installations as part of the festival. Nationally, these collaborators include the University of Auckland, Victoria University of Wellington, the ARA Institute, Lincoln University, Unitec and Massey University. Australian-built environment schools involved include programmes from the University of Adelaide, the University of New South Wales, the University of South Australia and the University of Technology, Sydney.

At the Commons, the Pallet Pavilion was a finalist in the International Award for Public Art (IAPA) in 2014, and the presence of the Gap Filler office at the Commons has attracted significant numbers of national and international visitors, becoming one of the must-see sites for visitors coming to Christchurch to see temporary urbanism in action.

Each of the projects similarly contributed to *fostering a culture of innovation* in post-earthquake Christchurch. While shipping containers, like those used in the Re:START mall, have been used to construct shopping malls in other places, including London and Kyrgyzstan, and temporary shopping areas have been created after other disasters, the use of shipping containers to create a post-disaster temporary shopping mall is an innovative typology. This innovative funding and ownership model used is arguably as significant as the built form, sidestepping the conventional land ownership and profit drivers that would make this kind of development less viable under a 'business as usual' scenario. Aforementioned governance models behind FESTA and the Commons were similarly enabling of innovative urban outcomes.

The purpose of this innovative approach was often to 'support the emergence of the social enterprise sector as partners in driving change' [7] in the community. Re:START was one of a number of highly successful social enterprises in Christchurch after the earthquakes. Others included the Arts Centre Trust, the Isaac Theatre Royal Trust and the Christchurch Stadium Trust. The speed and effectiveness of these trusts in driving changes in the city have been considered; hosting the Social Enterprise World Forum in Christchurch in 2016 suggests that social enterprise promoting environmental and social sustainability alongside financial imperatives has become an accepted part of doing business in Christchurch. FESTA itself is an emerging social enterprise. It is run by a charitable trust with the aim of supporting and celebrating active citizenship. The wide-ranging collaboration with agencies, businesses, community groups, universities and other social enterprises is evidence of its success in supporting the emergence of the social enterprise sector to support the wider resilience of Christchurch.

The final category within the *Prosper* theme is '*sustain the vitality of the natural environment*' [7]. FESTA in 2018, named FEASTA, explored the interconnections between food and urbanism and the capacity of food to shape and enrich our urban environments. It explored a whole range of options for producing food in our local and urban environments, improving resilience and public health. At The Commons, the Food Truck Collective established itself and was then able to move to other sites as its popularity grew. This initiative provided a place for food businesses to source products from local and urban environments and promote urban agriculture.

An example is the *Plant Exchange* run by the social enterprise group *Greening the Rubble*, where people bring plants, crops and trees, to swap them for other varieties. Each year, hops are planted and grown over the Arcades Project at the Commons before being harvested and brewed into a Commons beer.

4.4 'Understand'

Lastly, the theme of *Understand*, in the context of the case study projects, focuses on creating community support for the more macroscaled planning strategies and the way in which these exemplars of temporary urbanism are conduits which have helped to facilitate the transition from the rebuild and recovery phases into the ongoing regeneration and placemaking of Christchurch. Their continuation also stands as a reminder of what Christchurch was, where it has been and where it is going and demonstrates the resilience that temporary projects can help to develop its post-disaster cities.

A willingness to openly engage the community to explore risk scenarios [7] was demonstrated by FESTA through its forums for open engagement and participation about various aspects of city-making and the risks and trade-offs associated with different choices. The wider FESTA programme includes a range of workshops, international guest speakers, book launches, guided tours and exhibitions which address issues such as food resilience, recycling and reuse and the exploration of alternative building techniques. Previous workshops at the event, for example, have included constructing adobe bricks, rammed earth, straw-bale and cob buildings, assembling 3D printed wikihouses and building green roofs.

Perhaps, the most significant way in which the projects represent this theme is the way in which they act as testing grounds for prototyping ideas. By testing new ideas, at a relatively low cost, short-term placemaking initiatives at these case studies created buy-in from residents. This invariably led to investment into their development, such as the now-permanent marketplace on the site of the Re:START mall and wider value for the city, both economically and socially.

5. Conclusion

Temporary and adaptive urbanism projects were particularly significant in the period between the Canterbury earthquakes in 2010 and 2011 and the opening of the first major permanent developments in Christchurch (the Christchurch Bus Interchange and Margaret Mahy Family Playground in 2015 and the BNZ Retail Centre in 2016). During this period, they represented limited signs of tangible recovery on the ground.

The three case studies considered in this chapter demonstrate the range of significant placemaking that occurred in Christchurch. These projects were significant in reconnecting residents with the city centre, fostering a culture of innovation as the city recovered, supporting community organisations to flourish, building participation in decision-making and, ultimately, creating resilient urban spaces through their adaptability and broad inclusion of residents. In this context, temporary and adaptive urban projects have contributed in a major way to the recovery of Christchurch communities and to building and supporting the resilience of the city. An evaluation of three case studies suggests that placemaking projects rate highly against resilience criteria and that different types of projects contribute in different ways.

The use of temporary or adaptive urbanism or placemaking as a disaster recovery strategy is of critical importance, particularly in the period between the end of the emergency response and before permanent rebuilding is completed. This chapter demonstrates that placemaking projects have a central role in empowering communities and enhancing community resilience in post-disaster scenarios.

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Section 5

Risk Assessment

Chapter 11

Multi-Hazard Assessment of Seismic and Scour Effects on Rural Bridges with Unknown Foundations

Xuan Guo, Zhaohua Dai and ZhiQiang Chen

Abstract

This chapter proposes a probabilistic framework for assessing seismic and scour effects on existing river-crossing bridge structures. The emphasis is on bridge structures in rural areas, for which it has been recognized that a large number of rural bridges have unknown foundation types and further are subject to both flooding-induced scour and seismic damage. With a review of the US-based rural bridges, this chapter presents a probabilistic framework for bridge performance assessment. Using a representative rural bridge model, the fragility results for the bridge reveal that scour tends to be beneficial in reducing structural damage at slight to moderate seismic intensities and to be detrimental in increasing collapse potential at high-level intensities. The demand hazard curves further quantify probabilistically the occurrence of local damage and global collapse, and systematically reveal the complex effects of scour as a hydraulic hazard on bridge structures.

Keywords: bridge, unknown foundation, flood-induced scour, multi-hazard, resilience

1. Introduction

There are over 484,500 highway bridges built over river channels in the U.S., among which over 20,904 are regarded scour-critical [1]. A distinct feature of flood-induced scour is that once it starts forming around a foundation, it may accumulate or vary over the bridge's service life. Hence it is intuitive that a potentially more severe risk is that scour is combined with other extreme hazards, such as earthquakes, which may threaten bridges serving in both earthquake and flooding active regions, such as Alaska, Oregon, and California in the U.S. On the other hand, it is recognized that a large number of bridges that are in service for tens of years have unknown foundation, in the meantime, been suffering from flooding induced scour.

In a recent National Cooperative Highway Research Program (NCHRP) report published in 2006 [2], it was identified that a very large proportion of the bridges built in 1950 and 1980 had unknown foundations, although it was surprising that even 69 bridges built during 2000–2005 were concluded with the label of bridges with unknown foundation types. Based on this report, we further extract the proportion of bridge structures with unknown foundations in different function categories under two primary groups: rural and urban. Two characteristics are observed (**Figure 1**). First, the bridges with unknown foundations in rural areas outnumber significantly those in urban areas (50,743 vs. 8151). Second of all, among the bridges of different functions, the local bridges are the majority with unknown foundations. Particularly, in rural areas in the US, 34,478 bridges (out of 50,743 or about 68%) have unknown foundations; whereas in the urban areas, this number is 3948 (out of 8151 or about 48%). One significant feature of these local bridges is that they are usually structurally simple, short-span with one or two bents. When seismically active regions are concerned, in the aforementioned states of Oregon and California, 801 and 993 local rural bridges with unknown foundations are identified, respectively. Two arguments are raised herein. First, the seismic performance of these simple bridges imposes a great challenge to the stakeholders when duly considering the fact that these bridges have unknown foundation type, and in the meantime, they are subject to flooding induced scour. Second, a rapid and quantitative multi-hazard assessment methodology is demanded.

To evaluate the risk and to provide decision-making for managing these bridges, a methodological and practical procedure has been proposed in [2]; and **Figure 2** recreates part of the workflow. In this workflow, empirical methods are proposed to infer the foundation types and basic geometric parameters. If the foundation types can be determined, then a standard failure analysis is followed. Two additional steps are proposed if the foundation types are not inferable. If the bridge is of high priority, then field reconnaissance is needed to determine the foundation type and configuration. If not, simple risk calculation procedures are used to evaluate if the bridge's minimum performance levels are met (in terms of the annual probability of failure) are proposed. If further not, again the field reconnaissance is recommended to carry out followed by a rigorous and quantitative performance assessment procedure. With this state-of-the-practice methodological framework, however, two limitations are recognized. First, no quantitative procedure that considers the source of uncertainties (e.g., materials or scour) is found, which in nature demands a probabilistic procedure. Second, in light of the bridges that serve in seismically active areas, a multi-hazard approach is further necessary. These limitations imply the necessity of developing a quantitative and multi-hazard assessment procedure.

Besides the need for a quantitative multi-hazard framework, we further state that a rapid approach is favorable for the bridges with unknown foundations in

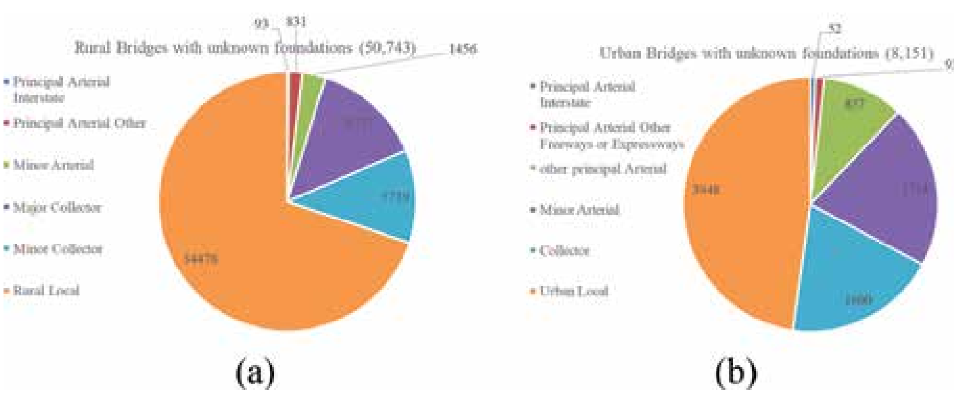

Figure 1.
Bridges with unknown foundations in the US: (a) rural areas and (b) urban areas.

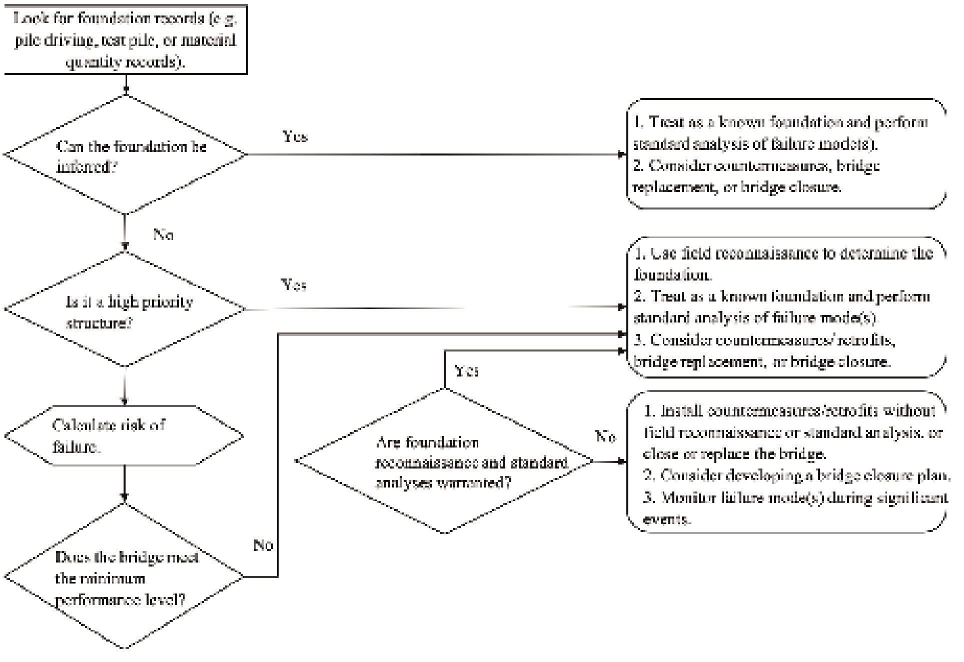

Figure 2.
Risk management workflow (part) proposed in [2].

rural and remote areas. This is a resourcefulness measure to increase the resilience of a bridge system [3, 4], and bridges are critical links with interdependence with other infrastructure systems. Indirectly, if a decision is made regarding that the scour countermeasure be added, this would build the structural redundancy to the bridge system hence reducing the possible bridge loss, increasing the robustness property of the bridge resilience against both the potential flooding, scour, and seismic hazards. Last and above all, rural areas lack technology resources when compared with urban areas; at least due to the geospatial remoteness, any technical measure when being deployed would take a longer time. Therefore, a rapid and quantitative assessment procedure is essentially necessary.

With this motivation, this book chapter is organized as follows. First, Section presents systematically the proposed methodology framework for multi-hazard seismic and scour assessment. Second, a numerical experiment is proposed with a known shallow foundation type. Last, this chapter concludes with a number of remarks for practical application and future research work.

2. Probabilistic methodology

2.1 Related work

Towards a multi-hazard approach to assessing the conjunct effects of earthquakes and flooding-induced scour on the vulnerability of bridges, a probabilistic approach to bridge scour analysis is required due to its inherent uncertainties in the first place. In two recent papers, a general approach to probabilistic scour hazard modeling was reported, which starts with the deterministic scour estimation equation then incorporates model bias and random errors [5]. Furthermore, Briaud et al. [6] concluded that for shallow foundations supporting bridge structures, the design scour depth needs to be 2.0–2.5 times of the HEC-18 estimates to ensure that the probability of exceeding the estimated scour depth be less than 0.001, even that both HEC-18 (Sand and Clay) methods are considerably conservative compared with measured bridge scour data. Besides probabilistic scour assessment for bridge foundations, however, these two efforts did not address the multi-hazard effects on a bridge as a system if earthquakes are involved.

For a system-level multi-hazard assessment of seismic and scour effects (termed seismic-scour effects hereafter), a number of efforts are found. Wang et al. investigate the vulnerability of scoured pile-foundation supported bridges through probabilistic fragility surface analysis [7]. However, in their work, scour was treated deterministically. Dong et al. proposed a multi-hazard assessment approach to studying bridge performance considering time-variant structural deterioration; however, scour uncertainty was not considered either [8]. Prasad and Banerjee investigated the seismic risk of four example bridges considering scour variations [9, 10]. While studying the characteristics of seismic fragility curves, however, only system-level displacement-based demands (i.e., drift demands at the deck level) were used, which led to the conclusion that scour always increases seismic fragility. Several recent efforts are found on probabilistic calibration of load-resistance factors that are used to combine scour condition with seismic and other design forces [11–13]. No quantitative and probabilistic framework is found to date that is able to comprehensively assess the conjunct seismic-scour effects on river-crossing bridge's vulnerability. In the following, a probabilistic framework is proposed that aims to output seismic-scour integrated fragility and probabilistic demand hazard. The focus is then on the experimental results and observations based on a simple shallow-foundation supported bridge model, followed by the conclusions in the last section.

For assessing performance and vulnerability of structures considering seismic hazards, two probabilistic analysis tools are usually employed, which are probabilistic seismic fragility analysis (PSFA) and probabilistic seismic demand analysis (PSDA). PSFA can be applied to identify the probability of a defined limit-state (e.g., structural damage or collapse) conditional on one or multiple measures of seismic intensity [14–17]. PSDA is used to assess structural vulnerability by estimating the annual probability of a structural demand exceeding a varying demand parameter without conditioning on the input hazard [18, 19]. The output of the PSDA model is a demand hazard curve that is analogous to a seismic hazard curve (from probabilistic seismic hazard analysis, PSHA). Since the demand hazard curve is an essential component of the probabilistic performance-based seismic design framework [20], PSDA has been frequently used for assessing building structures [21, 22] and bridge structures [23, 24].

Different from general multi-hazard analysis wherein two or more hazards appear as a joint occurrence of two independent events that may be generalized as external forces applied to structures (but independent to structures), earthquake and scour should be treated distinctly. Different from loading-based hazards, scour primarily leads to modification of the geometric boundary condition of the soil-foundation-structure (SFS) bridge system. This boundary modification further results in reduction in foundation stiffness, and nonlinear foundation bearing and lateral capacities as demonstrated previously. To account for such changes, a system-level modeling approach needs to be adopted considering SFSI subjected to dynamic loadings (e.g., earthquakes). This in turn leads to an unfavorable situation, wherein the SFS bridge system is not invariant; rather, it is subject to significant modification in terms of foundation impedance and nonlinear capacities due to the varying scour (treated as a hazard).

2.2 Mean-scour seismic fragility modeling

The seismic fragility or the probability of structural damage given a seismic *IM* can be modeled as a conditional probability, $P(Z > z^* \mid IM)$, where z^* is a specifically defined value of the demand variable. The expression $Z > z^*$ defines a limit state that indicates occurrence of a certain level of damage or even collapse. For measuring the seismic intensity, a sufficient *IM* should be chosen. Peak ground acceleration (PGA) is often used as an objective scalar measure of seismic intensity. When a structure is considered, the spectral displacement (Sd) and spectral acceleration (Sa) defined at the structure's modal period (Tn) are two commonly used measures. In this chapter, Sa is adopted; particularly, Sa measured at the fixed-base first-mode period of the bridge model is used When the sample values of *IM* and *Z* are available, a fitting function in terms of $IM = x$ is usually used to fit the conditional probability $P(Z > z^* \mid IM)$, denoted by $\Psi(x)$. The most popular approach is to enforce a monotonically increasing function bounded by [0, 1], such as the Lognormal cumulative distribution function $\Psi(x)$ [15], to fit the data set of $\{(Z > z^*)_i, IM_i \mid i = 1 \ldots N\}$:

$$\Psi(x) = P(Z > z^* | IM = x) \approx \Phi\left(\frac{\ln x - \mu}{\beta}\right) \tag{1}$$

where μ and β are the mean and standard deviation parameters of the Lognormal cumulative function, respectively. Based on the sample data, a general approach to parameter estimation is the maximum likelihood estimation (MLE) method [25]. This method is adopted in this chapter and formulation details are found in [25].

When scour depth (SD) is considered in seismic fragility analysis, an easy treatment is to compute seismic demands using the SFS bridge model that incorporates a designated scour condition in terms of a deterministic *SD* value, y^*:

$$\Psi(x) = P(Z > z^* | IM = x, SD = y^*) \approx \Phi_{y^*}\left(\frac{\ln x - \mu}{\beta}\right) \tag{2}$$

The expression in Eq. 2 represents the seismic fragility considering a deterministic scour depth, wherein the uncertainties come from external seismic inputs and possibly from structural materials.

If one considers scour as a type of hazard and then treats scour depth as a random variable, a bivariate fragility model becomes of interest:

$$\Psi(x, y) = P(Z > z^* | IM = x, SD = y) \tag{3}$$

If the conditional probability model in Eq. 3 is fitted by a bivariate Lognormal function, a fragility surface model is achieved. A fragility surface model has its merit in expressing the true fragility of a structure when multiple hazards are affecting the structure [26] or multiple parameters are used to describe one hazardous effect [27]. As implied in Eq. 6, one may consider fitting the conditional probability by a bivariate function in terms of both seismic intensity and scour depth as independent variables and then study the resulting seismic-scour fragility surface. However, a significant difference of scour effects from seismic effects as illustrated previously is that scour may cause beneficial effects (i.e., reduction of force demands). This implies that the fragility when partially conditional on scour may decrease as the scour depth increases. With the fragility partially depending on seismic measure *IM* (which often designates a monotonic increasing relation), the resulting fragility surface from Eq. 3 may be nonmonotonic, which causes difficulty in interpreting such a surface. To retain the traditional simplicity in a fragility curve, it is more straightforward to marginalize out the scour depth as a random variable. Based on the law of total probability, one has

$$\begin{aligned} &\mathrm{P}(\mathrm{Z} > \mathrm{z}^* | \mathrm{IM} = \mathrm{x}) = \\ &= \int P(Z > z^* | IM = x, SD = y) f_{SD}(y) \mathrm{d}y \\ &= \mathrm{E}_{SD}[\Psi(x, y)] \end{aligned} \tag{4}$$

$$P(Z > z^* | IM = x) \approx \Phi_{MS}\left(\frac{\ln x - \mu}{\beta}\right) \tag{5}$$

where $f_{SD}(y)$ is the probability density function for the scour depth as a random variable and E[] defines the mathematical expectation operator. In Eq. 4, the seismic fragility is defined by integrating out scour depth as a random variable, which is equivalent to the mathematical mean of the bivariate fragility upon the scour depth distribution. Due to this analytical meaning, a notion of *mean-scour* (MS) fragility is proposed in this chapter. In the meantime, the analytical expression of the mean-scour fragility $P(Z > z^* | IM = x)$ means that the fragility model can be directly estimated by fitting the simulated data set using the Lognormal model in Eq. 5.

2.3 Seismic-scour integrated demand modeling

Traditional PSDA assesses the performance of a structure by probabilistically predicting the seismic response in terms of the probability of exceedance for a limit state defined by $Z > z$, where z is a varying demand value. The resulting function, $H_z(z) = P(Z > z)$, is termed probabilistic demand hazard model. In the original efforts [e.g., [18]], a probabilistic demand hazard model (or strictly speaking the mean annual frequency of the exceedance event for a response demand) is evaluated based on the summation over seismic sources described by magnitudes and site distance. In more recent literature, a probabilistic demand hazard model for evaluating the seismic performance of a structure has been defined in a continuous form [19]:

$$H_Z(z) = \int P(Z > z | IM = x) |\mathrm{d}H_{IM}(x)| \tag{6}$$

where $P(Z > z | IM = x)$ defines the likelihood that the structural demand Z exceeds a post-elastic demand value z, and $\mathrm{d}H_{\mathrm{IM}}(x)$ defines the derivative of the seismic hazard model (the absolute sign is necessary since the derivative is negative).

It is noted that Eq. 6 considers one (seismic) hazard. If flooding-induced scour as a hazardous condition is considered, the integrated seismic-scour demand hazard, denoted by $H_{SS}(z)$, is proposed, which is based on a simple extension of Eq. 6:

$$H_{SS}(z) = \int\int P(Z > z | IM = x, SD = y) \mathrm{d}H_{IM}(x) \mathrm{d}H_{SD}(y) \tag{7}$$

where $H_{IM}(x)$ and $H_{SD}(y)$ are the probabilistic seismic hazard and scour hazard models, respectively. The demand hazard model in Eq. 7 involves probabilistic models of seismic and scour hazards. The two hazard models are introduced below.

2.4 Probabilistic seismic hazard analysis

The probabilistic seismic hazard analysis (PSHA) attempts to define the probability of exceedance (POE) for an IM variable x that is exceeded annually, denoted by $H_{IM}(x)$. In practice, PSHA can be analytically conducted for a given site [28].

In addition, seismic hazard models can be obtained from the web portal of the United States Geological Survey (USGS) for a given site in the United States [29]. One key step in PSHA is to select an appropriate seismic *IM* type. Traditionally, peak ground acceleration (PGA) and spectral acceleration (Sa) at a certain natural period (T_n) are commonly used [30]. In this chapter, the USGS' seismic hazard model in terms of SAs is adopted.

2.5 Probabilistic scour hazard analysis

For local bridge scour (scour around bridge foundation), two primary estimation methods exist as described in Hydraulic Engineering Circular No. 18 [31], which is termed the HEC-18 Sand and HEC-18 Clay. The HEC-18 Clay method was developed at the Texas A&M University, which was designed to predict scour depths in cohesive fine-grained soils (e.g., clay) and was once termed the SRICOS-EFA method [32]. Using the HEC-18 Clay method, the scour depth is the function of time over the period of the hydrograph. First, this method predicts the maximum scour $\hat{y}_{max}$ as:

$$\hat{y}_{max} = 0.18R^{0.635} \tag{8}$$

where R is Reynolds number equal to $\nu D_p/\upsilon$, v is the upstream velocity, D_p is the diameter of the pier, and υ is the water viscosity (10^{-6} s/m^2 at 20°C). The time-dependent scour depth, denoted by $\hat{y}_t$, is defined by linking the maximum scour depth in Eq. 1, the time at which a given velocity is applied, and the initial rate of scour:

$$\hat{y}_t = \frac{t}{\frac{1}{\dot{y}_i} + \frac{t}{\hat{y}_{max}}} \tag{9}$$

where t with a unit of year is the time over which a given velocity is applied and $\dot{y}_i$ denotes the initial rate of scour.

Based on the deterministic estimation described in Eqs. 8 and 9, multiplicative correction factors are considered to account for the bias and random errors inherent in the deterministic models, which leads to the probabilistic scour modeling [5] and is termed probabilistic scour hazard analysis in this chapter (PScHA to be different from PSHA).

In Bolduc et al. [5], by adopting a Lognormal distribution for scour depth, the probabilistic scour depth is formulated in a Logarithm expression:

$$Log\left[y_t\right] = Log\left[\theta_y\right] + Log\left[\hat{y}_t\right] + \sigma_y \mathbf{N}(0;1) \tag{10}$$

where θ_y is a parameter accounting for the model bias; $\hat{y}_t$is the deterministic and time-dependent scour estimation from Eq. 9; $\mathbf{N}(0;1)$ represents a Normal random variable with zero mean and unit variance; σ_y is therefore the standard deviation of the Lognormal variable y_t. This implies that when these deterministic parameters, θ_y, $\hat{y}_t$ and σ_y are available, a probability density function for the distribution of the scour depth can be defined using a Lognormal distribution, denoted by $f_{SD}(y_t)$ in this chapter. Given $f_{SD}(y)$, the scour hazard can be analytically expressed as $H_{SD}(y_t) = 1 - \int_0^{y_t} f_{SD}(y)dy$. Similar to the seismic hazard curve, this model when depicted as a curve quantifies the probability of exceeding a scour-depth value at a bridge site; the only distinction is that different from the annual POEs as used in a seismic hazard model, a scour hazard model defined above is calculated at a certain year of service.

3. Experimental results

3.1 Simple bridge model

The bridge chosen in this chapter has a shallow foundation system with a full embedment depth that is constructed in a hard-soil (e.g., cohesive clay) river bed. The bridge has three spans of concrete decks supported by two concrete columns. Such a bridge is commonly used in practice for short-span river passing when the foundation soil is relatively hard (e.g., clay) [33]. In addition, by analyzing a shallow foundation-supported bridge model, the probabilistic assessment can be readily conducted. It is noted, nevertheless, the framework developed and demonstrated in this chapter can be easily adapted for assessing existing bridges with deep foundation systems (e.g., piles) in soft-soil river bed provided a finite-element (FE) based SFS model is provided. **Figure 3** illustrates a simple bridge model, which is considered as a representative rural local river-crossing bridge. The bridge is a three-span (27 m + 36 m + 27 m) continuous structure supported by two piers on two separate shallow foundations. This bridge model was used in the author's previous work [34].

The height of the circular piers is 9.0 m with a diameter of 1.4 m. The steel ratio of the column is about 1.3%. The foundation is constructed on hard clay with a density of 1700 kg/m^3 and with a small-strain shear wave velocity of 260 m/s. The thickness of the foundation is 2.4 m, with the transverse width being 2.8 m and the longitudinal length being 3.3 m, respectively. In this experiment, the embedment depth of foundations is 4.0 m. For bridges with unknown foundation, such full embedment depth can be determined through field inspection methods (for example, for shallow foundations, one can use a drilling device to drill through the footing to determine the elevation of the footing bottom). The simplified configuration of the bridge is shown in **Figure 3**. A three-dimensional finite-element (FE) model for the bridge is developed to simulate the bridge using the OpenSees framework [35]. The FE modeling and the details about beam-column elements, footing elements, material uncertainties, sampling scheme, and the nonlinear time-history analysis details are found in this work as well. Particularly, we consider a target service period of 50 years among its 75-year design life. The purpose is to mimic the situation of an existing bridge that is subject to progressive scour after 50 years of service.

3.2 Demand variables

A variety of response demand parameters can be extracted. In this chapter two demand variables are considered in the following fragility and demand modeling.

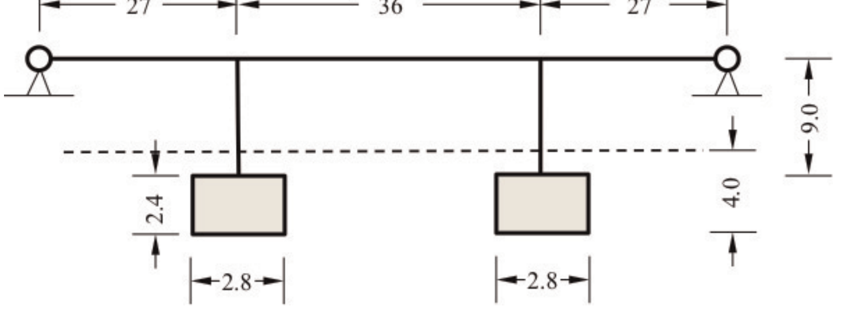

Figure 3.
Bridge configuration (unit: m).

1. Local strain ductility: defined as the ratio of the strain demand ($|\epsilon_{max}|$) at the base of the concrete pier to the compressive yielding strain (ϵ_y) of the concrete, $\mu_s = |\epsilon_{max}|/\epsilon_y$. Since the local strain at the surface is proportional to the curvature, $\epsilon = \rho\, r$, where r is the diameter of the circular column, one can define an equivalent local curvature ductility demand. Hereinafter, local strain ductility demand (μ_s) is used.

2. System drift ductility: defined as the ratio of the transverse system drift demand at the mid-span of the bridge deck ($|u_{max}|$) to the bridge's yielding drift (u_y) at the fixed-end boundary condition, $\mu_d = |u_{max}|/u_y$. For the bridge model considered herein, the yielding drift is about 6.1 cm.

The local strain ductility demand μ_s reflects the degree of local inelasticity occurred to the bridge's concrete piers. For bridge structures, the ranges for using local strain ductility demand to characterize different damage levels are well defined (e.g., [36]). In general, when given a limit state of $\mu_s > 1$, it implies the onset of local damage or indication of slight damage. A larger threshold may be used to define higher-level structural damage, such as $2 < \mu_s < 4$ for moderate damage or $\mu_s > 4$ for extensive damage. Fragility models resulting from these higher-level damage limit-states are not reported in this chapter. The system drift ductility demand indicates the degree of global displacement, which in general consists of structural deformation and foundation-induced rigid-body motion (e.g., sliding and rocking) as a SFS system. In this chapter, if μ_d is larger than seven ($\mu_d > 7$), the onset of system collapse limit-state is defined (usually a drift ductility of 5–10 is used to define bridge collapse in the literature; herein a median value of 7 is used) [37, 38]. We particularly note that for a scoured SFS bridge, it may be biased to define a limit-state using the system-level ductility demand to indicate structural damage in local members. Especially when considering an extreme scour, a limit-state in the range of $2 < \mu_d < 3$ may be dominated by the rigid-body displacement from the substructure with linear-elastic or insignificant inelastic structural deformation; in this case, structural damage may not reach to the expected level (e.g., $\mu_s < 1$).

3.3 Fragility analysis results

Based on the limit states defined previously, **Figure 4(a)** shows the probability of local damage defined by $\mu_s > 1$ considering four designated scour-depth values (No scour; Scour S1 with z = 2.8 m; S2 with z = 4.0 m; S3 with z = 4.2 m). In addition, the mean-scour (MS) fragility curve according to Eq. 5 is shown as well. **Figure 4(b)** uses the same configuration for plotting the fragility curves in terms of the defined collapse limit-state ($\mu_d > 7$). It is noted that material uncertainties are not considered in the two fragility illustrations in **Figure 4**.

Figure 4(a) indicates that the probability of damage is insignificant (less than 10%) if Sa (T1) < 0.33 g (equivalently corresponding to an annual POE of 9.2×10^{-3}, which is the Expected Earthquake design level). In addition, at the NS (i.e., z = 0 m) and the S1 level of scour depth (i.e., z = 2.8 m), the probability of damage quickly approaches to a high probability (>50%) when the spectral acceleration becomes larger than 0.5 g (or an equivalent 0.38% annual POE). The general trend is that if the scour depth increases when the *IM* is greater than 0.33 g, the probability of damage decreases significantly. Especially, when the scour reaches the full-depth of the foundation (S2), the probability of damage dramatically reduces; for example, at Sa (T1) = 1.19 g (about 4.1×10^{-4} annual POE or subject to the MCE-level earthquake), the probability of damage is around 5%, whereas it is 95% compared with the N1 case (z = 2.8 m). This observation is consistent with the

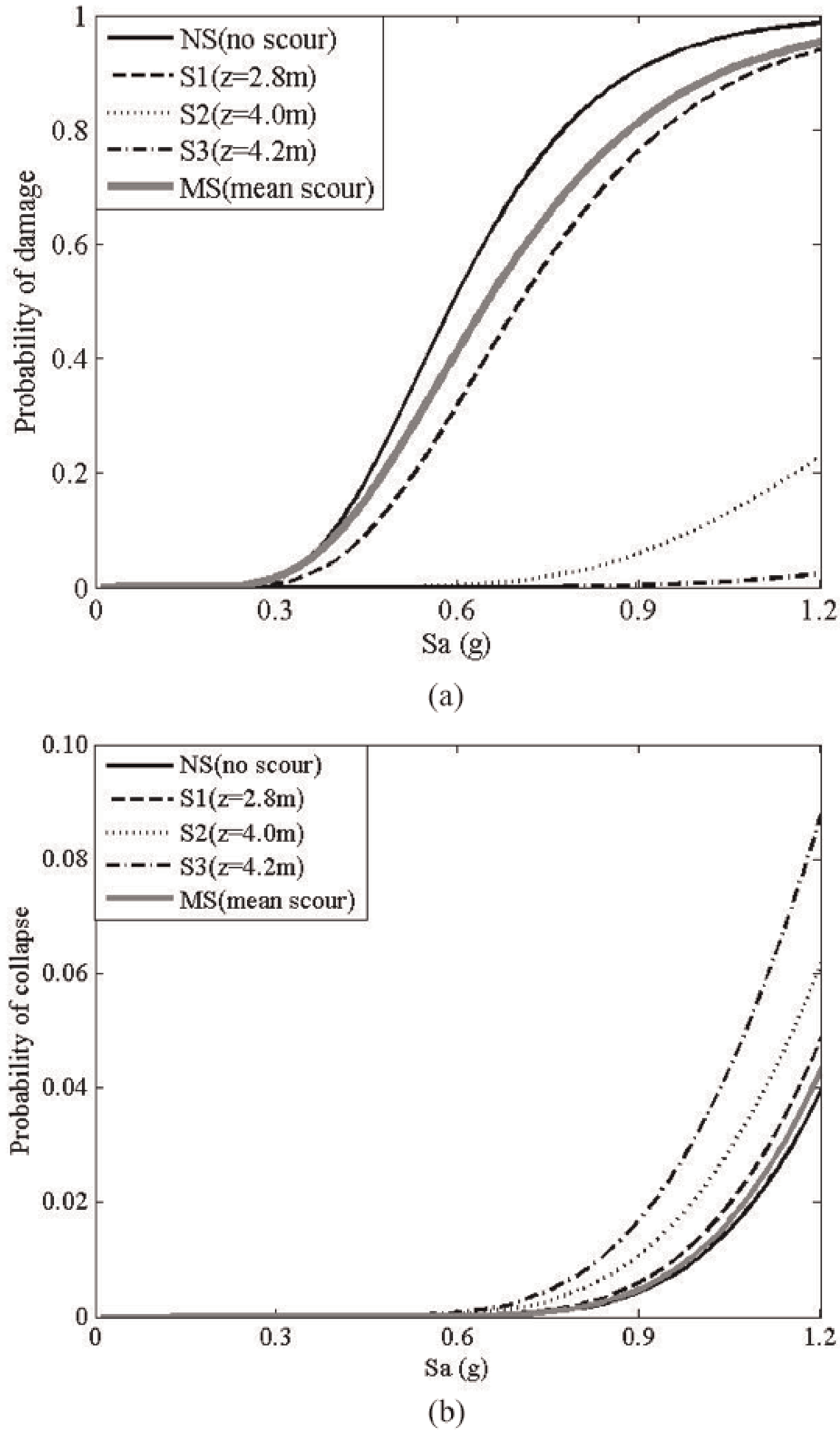

Figure 4.
Fragility model at different scour depths without considering material uncertainties: (a) probability of structural damage at the column base and (b) probability of system collapse.

aforementioned literature that softened foundations in the context of seismic soil-structure interaction tend to lead to less structural damage or smaller base-shear force demands [11]. However, it should be pointed out that when the bridge is subjected to high-intensity earthquakes and greater scout depths, the potential threat is system collapse. Therefore, it is rational to state that increasing scour depth is only beneficial when subjected to weak to moderate-intensity earthquakes (e.g., in the case of the bridge model herein, Sa(T1) < 0.8 g).

Figure 4(b) shows the probability of collapse defined based on the drift ductility demand at the bridge deck. This figure indicates that the probability of collapse increases as the scour depth and the seismic intensity levels increase. Specifically, the conditional probability of collapse is close to zero when Sa (T1) < 0.7 g. Nonetheless, the probability of collapse rises for each scour condition when Sa (T1) > 0.7 g. For a NS system, the probability of collapse is 4% if Sa (T1) = 1.19 g or considering a MCE level earthquake. By contrast, the corresponding probability for a scour system with the scour depth of 4.2 m is about 9%, which is about 2.25 times of that for the NS system. Accordingly, scour is detrimental by increasing the probability of collapse at all levels of ground motions, but much significantly when the seismic intensity approaches to the MCE level.

The above fragility curves are constructed at designated scour conditions (NS, S1, S2, and S3). However, for an in-service bridge, its scour depth may be completely unknown; therefore, one may not be able to designate a scour depth. Based on Eq. 5, **Figure 4(a)** and **(b)** also report the resulting MS fragility curves. First, one can observe that the MS fragility curve at either of the limit states lies between the fragility curve at the S1 condition (z = 2.8 m) and the one at the NS condition (no scour or z = 0 m), although it is worthy to mention that this observation depends on the probabilistic scour hazard modeling at a specific site.

Second, similar observations in the trend of the MS curves as *IM* increases are still seen compared with the curves at the designated scour depths. Considering the smaller difference of the MS fragility curves from the curves at the S1 condition yet significant difference from the curves at the S2 and S3 conditions, one may assert that scour survey is critical in terms of the potential high risk resulting from a possibly greater scour depth. Nonetheless, if an accurate scour depth is not available, the proposed probabilistic MS fragility modeling becomes instrumental to quantitatively assess the seismic-scour effects.

3.4 Demand analysis results

The seismic-scour integrated demand hazard curves can be approximated as expressed in Eq. 7. With the two ductility demand measures, **Figure 5** reports the demand hazard curves, wherein the vertical axis indicates the probability of exceeding a demand variable that is marked in the horizontal axis (which is either μ_s or μ_d). The two illustrations in **Figure 5** provide a comparison between the cases of considering scour vs. not considering scour (in both cases, material uncertainties, denoted by "mu," are considered). Among them, **Figure 5(a)** illustrates the demand hazard curves in terms of the local strain ductility variable; whereas **Figure 5(b)** presents the system drift-ductility hazard curves.

First of all, the demand hazard curves in **Figure 5** reveal the effects of scour as a source of hazard on the bridge structure. In terms of the local strain ductility μ_s in **Figure 5(a)**, the POEs in the range of $\mu_s < 2.1$ indicates that scour lowers the probability of structural damage in bridge piers, which is consistent with the previous fragility study. However, in the range of $2.1 < \mu_s < 4.1$, scour increases the probability of damage, which is not revealed in the fragility study since such limit-state of $2 < \mu_s < 4$ is not defined. It is noted that in both ranges, scour effect is insignificant due to the fact that scour-depth (*SD*) as a random variable has been integrated out numerically; therefore, it should be roughly regarded as a "mean"

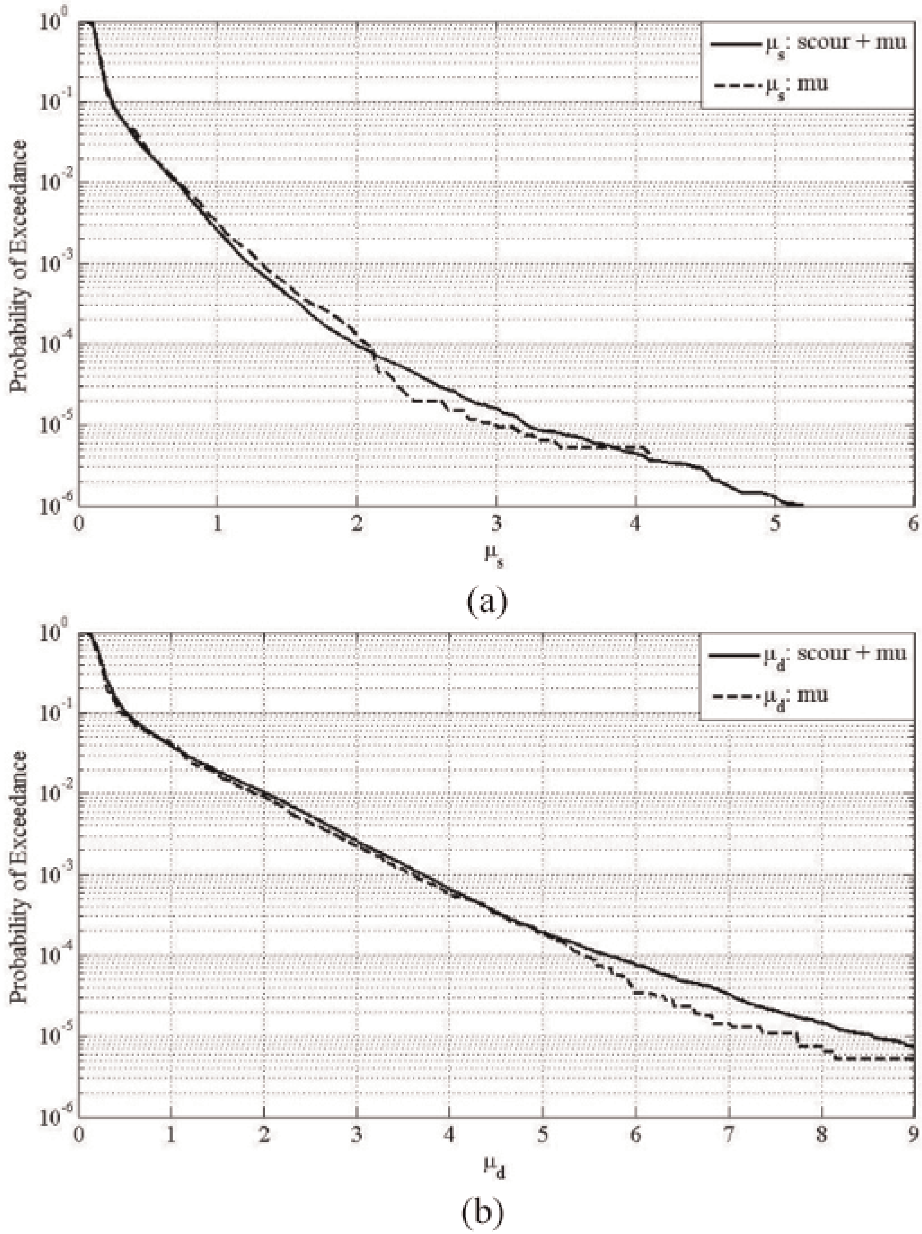

Figure 5.
Probabilistic demand hazard curves considering scour and material uncertainties (denoted by "mu") vs. considering "mu" only: (a) strain ductility demand hazard curves and (b) drift ductility demand hazard curves.

effect of the scour. In terms of the system drift ductility μ_d in **Figure 4(b)**, the overall trend is that the probability of exceeding any specified μ_d increases due to the consideration of scour. This is especially evident when μ_d is greater than 5. This implies that at larger drift ductility levels, wherein the likelihood of system collapse is defined, scour tends to increase the probability of system collapse. Due to these observations, we state that the probabilistic demand hazard modeling provides a more comprehensive approach to evaluating the effects of scour on the seismic response and the vulnerability of bridge structures.

4. Conclusions

This chapter begins with a review of studying bridges with unknown foundations, which can be impacted by both flooding induced scour and earthquakes. Using the data from the United States (US), it is recognized that a large number of bridges have foundation types not identified in the database; in the meantime, many of these bridges serve in rural areas. With this fact, this chapter states that is essential to develop a probabilistic and multi-hazard framework to assess these bridges, although they are often simple in configuration. Such methodological framework can be treated as a resourcefulness measure to improve the resilience of rural bridges, hence local civil infrastructure systems in general (as bridges are interconnected with the functions of other infrastructure systems), and communities. With this motivation, this chapter presents a comprehensive probabilistic framework for assessing the effects of scour on the seismic response of existing bridge structures. Through a case-based assessment using a representative bridge model, several important observations are quantitatively revealed. These include:

- The fragility curves at designated scour depths or the proposed mean-scour seismic fragility curves indicate that scour tends to be beneficial in reducing structural damage at slight to moderate seismic intensities. However, the concern should be raised at strong seismic intensities, wherein even with a lowered probability of structural damage, the collapse potential is significantly increased due to scour.

- The demand hazard curves systematically reveal the complex effects of seismic attacks and scour conditions on exceeding any local structural deformation or system drift demands. These effects include that scour can lower the probability of exceeding a local strain ductility demand at small values compared to the case where scour is not considered; nonetheless, scour can increase the probability of exceedance at larger demand values. In the meantime, scour systematically increases the probability of exceedance at any system drift ductility level, and more significantly at a larger demand level; or equivalently, scour in general increases the likelihood of system collapse when compared with the case of no consideration of bridge scour.

    - Material uncertainties can be ignored if solely for evaluating the effects of scour. If ignored, the proposed framework provides a computationally efficient approach to performing an integrated seismic-scour assessment for bridge structures. However, if material uncertainties considered, the computational cost is much increased since more parametric finite-element models are included, which results in excessive nonlinear static pushover analysis in the framework. To mitigate this, one may choose a small and unique set of ground motions (e.g., only one motion is used in this chapter) at different seismic intensity levels.

To this end, we envision that the proposed probabilistic framework and the associated numerical implementation in this chapter may provide a rapid means for assessing the conjunct seismic and scour effects on existing river-crossing bridges, particularly the simple bridges in the rural areas. We further note that the proposed probabilistic framework can be adapted when it is used to assess the effects of flood-induced scour on other bridge types (e.g., deep-foundation supported bridges in soft soils), provided that a finite-element based nonlinear model for the bridge is available.

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Chapter 12

Earthquake-Generated Landslides and Tsunamis

Jonas Eliasson

Abstract

Large earthquakes generate tsunamis, but when it also triggers a landslide, the tsunami may become enormous. Slide scars on the continental shelf of the North Atlantic Ocean show this. For estimating the tsunami, a translatory wave theory has been suggested. Slide data are used to estimate the amplitude of the displacement wave. The amplitudes are used to obtain wave heights at a reference point outside the breaker zone. Energy transmission formulas are used to find the wave height transfer coefficients from the source area to a reference point. Tsunami risk from several sources at a reference point is quantified using stochastic processes, and estimations of a hazard curve for the probability of landslide occurrence are carried out. The sensitivity of the hazard curve to uncertainties in determining the wave height from the individual sources turns can be evaluated. In two case studies, the Tohoku tsunami and earthquake in 2011 in Japan is found to be caused by a coseismic slip and a landslide in combination, and a hazard curve for a reference point south of Iceland is found for tsunamis in the North Atlantic Ocean.

Keywords: earthquake, tsunami, landslide, hazard

1. Introduction

The main difficulty in tsunami hazard assessment is to estimate the generation of wave energy at the source. In many cases, this is simply solved by running a CFD model and estimating the ocean surface amplitude at the source [1] from it. This estimate of the amplitudes involves many problems and can be very uncertain, when the measured amplitudes are small, but a better method is still to be found.

Sometimes it is better to estimate the initial wave itself, and when that is done, the energy transmission from the source to the point of impact can be quite accurately modeled in CFD models [2–4], if the shallow water wave equations are in the numerically stable domain.

Strong earthquakes cause large deformations of the surface of the earth, so tsunamis are more often than not strengthened by landslides triggered by the earthquake. Often the triggering earthquake does not contribute any significant amount of energy to the tsunami wave, and this seems to be the general case in the North Atlantic, where few dangerous tsunamis are reported.

There have also been speculations in the scientific community about the danger of tsunamis in the North Atlantic from gigantic glacial flood waves of volcanic origin, (jökulhlaups), emerging on the south coast of Iceland. In this case, there is a well-defined probability of occurrence [5] and clear geological evidence of the

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volcanic events [6] but practically no historical evidence of tsunamis. For the landslide tsunamis, we introduce a translatory wave model to estimate the initial disturbance [7]. Block slide models are popular for this purpose [8]; in them the blocks must reach very high velocities to create a serious tsunami. The translatory wave model assumes that sliding blocks break up and become debris flows when the velocity is high enough.

When the wave crest of the tsunami approaches a beach, instability of the wave fronts, wave breaking, and reflection set in. There may be little reflection on a flat beach but large energy dissipation due to wave breaking.

Few authors discuss how this problem is to be handled in practical hazard assessment, and most often this is simply done by making all coasts completely reflecting. This is on the safe side in run-up estimation. But how the correct boundary conditions should be formulated in terms of reflection and energy dissipation in the various models reported is an open question.

The following treatment on tsunamis has the emphasis on the estimation of initial disturbance and energy formation in the tsunami. The underlying theories are formulated in [8, 9] and the case studies in Chapter 7. The theory of CFD modeling of a tsunami and the associated procedures of preparing tsunami warnings are left out, as they can be found in various internet resources of the government institutions that make them.

2. Properties of a tsunami wave

Tsunamis are ocean waves that are considerably different from the best known types of ocean waves, storm waves, and ocean tides. There is much less periodicity in tsunamis, and they can run over dry land in a more or less unpredictable way. On dry land, large tsunami waves have a devastating power that resembles flood waves of the type "translatory waves" [6], such waves knock down most everything in their way. Out in the oceans (deep water), it is normally like a long wave and can be modeled using the shallow water wave theory. In this, it resembles the tidal wave.

However, there are several snags in the numerical modeling of tsunamis. Ordinary storm waves create steep wave crests that break in the shore line, but tsunamis are more like a bore, or a moving hydraulic jump; **Figure 1** illustrates this difference.

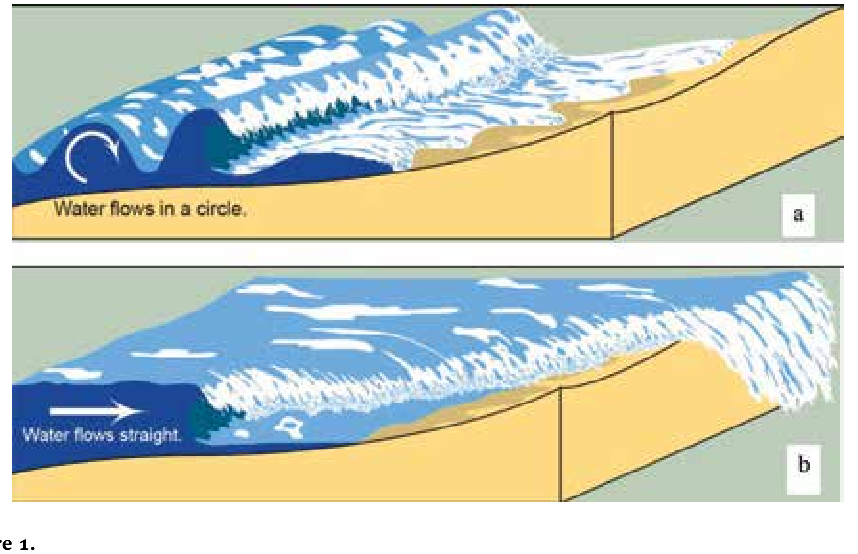

Figure 1.
Difference between storm waves (a) and tsunamis (b) [9].

Figure 2.
Nearshore breakup of a tsunami wave in Phi Phi Island 2004.

How the final inundation height is affected is unclear. Energy is lost in the jump as the bore moves inland, but with water behind has not, so it keeps moving. Then there is the role of the bathymetry; it has an influence on the dispersion and reflection of the wave fronts that is sometimes significant and sometimes not.

In short, the mathematics and numerical schemes are well developed in tsunami modeling, but there are pitfalls that can be difficult to avoid. Even models that have been through a scrutineer's process of calibration and validation can fail. Still, the initial conditions in the source area are the biggest uncertainty. It has therefore been concluded that verification and validation are necessary for each case, even for models that have been through this process before [10].

There are several numerical methods available to treat such waves using, for example, the well-known St. Venant's equations, see [11], to take an example. But the names used here, St. Venant's equations and translatory waves, are usually not mentioned. Analytical solutions are possible for stationary flows using a wave progressing with constant velocity down an inclined plane, or in a funnel, as the translatory wave in [7]. In there it is also demonstrated that numerical solutions of the St. Venant's equations can produce exactly this kind of flow without presuming a constant velocity wave.

However, when a wave runs upwards a mild slope with constant celerity c, as a translatory wave, c will inevitably reach the shallow water wave celerity, $c = \sqrt{gD}$ (g acceleration of gravity and D the water depth) somewhere, and then the surface profile may become unstable, which can result in a breaking wave (bore) or a series of braking waves if the wave is very long. **Figure 2** shows a nearshore breakup of this kind. The successive waves, resulting from the breakup, ride upon each other making the ultimate tsunami run-up very difficult to predict, even when the deep-water wave is well known. This difficulty is discussed further in Sections 5 and 7.

3. Propagation of tsunami waves

3.1 Deep water

It sounds like a misconception, but in deep waters outside the continental shelfs, tsunamis propagate as shallow water waves. The mathematics of shallow water waves has been investigated by many; the analytical description is well known from [12] and similar works. The equations are a system of partial differential equations of the hyperbolic type, and the solution propagates along the characteristics.

Tsunamis originate in a source area, unlike the tidal wave that propagates in the same manner in deep water but originates from a gravity potential created by the moon and the sun (astronomical tide). In a point, well away from the source area, a tsunami wave front propagates along the line drawn from the source area through the point with the phase velocity $c = \sqrt{gD}$, called the wave orthogonal. The actual water velocity is much lower than c. How much lower depends on the wave amplitude H in the point and the usual shallow water formulae for local energy, $E = \frac{1}{8}\rho g H^2$, and transported energy, $E_{tr} = E\, c$, applied for a wave train, if there is one.

The full set of the partial differential equation system for tsunami propagation is nonlinear and includes terms for Coriolis forces and shear stress at the bottom and wind stress at the surface of the ocean. However out on deep water, the shear stress terms are not dominating so the equation system is only weakly nonlinear. This means that the nonlinear interaction with the local astronomical tide will be small, so its amplitude and velocity can be added without damaging errors, while the wave stays in deep water. This is not the case in shallow water.

The wave celerity c of a tsunami is the velocity of propagation of both the surface disturbance and the transported energy. This velocity is very high when the water depth is counted in kilometers, comparable to the travel speed of a passenger jet. This has a great impact on the danger of the tsunami. The tsunami attack comes swiftly, few hours after the onset of the wave from the source area.

Prediction of tsunamis is very important in disaster prevention, and a large warning system is maintained all over the world, see, for example, https://www.tsunami.gov/. A simulation model that solves the partial differential system numerically is the heart of every warning system. The model usually simulates the real wave quite well in deep water, so the estimate for the arriving time of the attacking wave may be quite accurate even when the amplitude of it is less accurately predicted. Waves that originate from the continental shelf and run over deep water regions to their place of attack are a special problem. They usually start out as displacement waves, i.e., waves without characteristic periodicity, but change to an oscillatory wave train in deep water, and the periodicity of the wave train may be difficult to model.

Numerical simulations of tsunami waves are an invaluable part of the tsunami warning system, but the uncertainty about initial wave heights and total wave energy generation is a problem.

3.2 Shallow water

Shortly after the tsunami wave hits the continental shelf, it reaches shallow water where the processes of wave refraction and diffraction take over the propagation. The wave becomes highly nonlinear as these processes, called the shoaling, set in. The wave fronts turn toward the coast, so the angle of attack is different from the deep-water direction. An example of wave fronts curved by shoaling may be seen in **Figure 2**.

When the wave hits the shoreline, the shoaling process is finished and is followed by the run-up. Approaching the coast from a reference point, the tsunami wave runs into a new near-field process of breaking and run-up of the tsunami wave and inundation of the land. In the run-up, large tsunami waves travel ashore as spilling breakers; this is a nonlinear process. The methods to predict such processes are extremely complex; depend on the incoming wave height and natural and manmade landscape; and are very difficult to model. The run-up wave height must be estimated for each place individually. Several mathematical solutions exist for the shoaling process, both analytical and numerical from CFD. The analytical methods mostly utilize conservation of momentum or transported energy, but they are for two-dimensional waves only. Run-up heights and attenuation are very difficult to control in numerical calculation, because of difficulties in modeling the breaking of water waves, influence of obstacles on the beach, and the amount of energy dissipated in this process [13].

In finding some expressions for shoaling and run-up of two-dimensional waves, two kinds of waves will be considered: Firstly, a displacement wave, which is translatory in nature. Secondly, an oscillatory wave is considered; it has different properties than the displacement wave. When we have big tsunamis, it will be the displacement wave that hits the nearby coasts but may become an oscillatory wave farther away from the source.

3.2.1 Displacement wave

A bore, H meters high above still water level, will be formed as the water particles cannot overtake the wave front. A bore that inundates the land travels ashore as a breaking wave. Bore is formed when the water velocity u = c. According to first-order wave theory, this leads to H = D (D is the breaking depth of the wave), but from higher-order theories and practical experience, H = 0.7 D is closer to the true value for long waves breaking on a beach. If the beach slope is only slight (e.g., river estuaries), traditional long wave mild slope equations in [13] are valid. We will have an inundation, or run-up, to a level of R = H above still water level. If the slope is steep, full or partial reflection sets in, but for steep and mild slopes, R will not exceed:

$$R = H + \frac{u^2}{2g} = H + \frac{H^2\left(\sqrt{g(H/0.7)}\right)^2}{(H/0.7)^2 2g} = 1.35H \qquad (1)$$

3.2.2 Oscillatory wave

The shoaling process is assumed to be near linear for tsunami waves of a very small steepness. Linear theory for shoaling means keeping the energy flux constant until the point of breaking. Then we find:

$$\frac{H_b(r)}{H} = a = \left(\frac{0.7D}{H}\right)^{1/5} \qquad (2)$$

The amplification factor due to shoaling of the radial wave is denoted as a. $H_b(r)$ is the breaker height of the incoming radial wave. For waves of around 1 m coming in from the deep regions of the ocean, it can become a = 2–5. For waves of a few centimeters, it can become a = 5–10. When $H_b(r)$ is found, the run-up will be the same as in the case of the displacement wave, 1.0–1.35 times the breaking wave height.

This investigation shows that the run-up process depends very heavily on the far field wave height. But if a reference point is selected in water that is deep enough to exclude the effect of breaking on the wave height estimation, then we will have a quasi-linear transfer process from the source area to the reference point. This means that a fixed coefficient, independent of source area wave height, can be used as a wave height transfer coefficient from the source area to the reference point. This method is utilized in Chapter 6.

4. Causes of tsunamis

Large earthquakes usually start a tsunami. The earthquake deforms the bottom landscape and creates a surface disturbance in the source area and the associated transfer of energy to the water mass. This energy is transmitted from the source area by the tsunami wave.

An earthquake of magnitude 7 or larger on the Richter scale usually starts a tsunami. However, this is a rule of thumb only; smaller earthquakes can trigger a tsunami by starting a submarine landslide on bottom slopes. If it does, the magnitude of the tsunami depends on the size of the landslide, so the tsunami can be enormous even though the earthquake is small. Some years ago, it was discovered that huge submarine landslides on the continental shelf of the North Atlantic Ocean have caused large tsunamis. In Table 7.1 in [14], 11 submarine landslides with slide volumes 20–20,000 km^3 are listed. Submarine landslides of that magnitude run as translatory waves. The deadliest tsunami attacks in the recent years have struck Indonesia and the Indian Ocean coasts; the most recent one is the Anak Krakatau volcano, where a submarine landslide of type Case 1a (see Section 5.1) caused a tsunami December 22, 2018.

If a landslide is triggered or not, it can be stated that a movement on the sea bottom creates a surface disturbance with a certain potential energy, deduced by the common methods of wave mechanics. Some kinetic energy will also be created in the boundary layer around the moving object; this is mechanical energy and can thus be converted in wave energy in the tsunami wave. But as a rule, the kinetic energy will be converted to turbulent energy that cannot be converted into wave energy and is dissipated. Thus, the total potential energy of a mass that flows from land and into the sea is not converted into wave energy; only the potential energy of the initial disturbance it causes on the sea surface contributes to the tsunami.

5. Initial disturbance and the tsunami wave energy

In estimating the mechanical wave energy generated in the source area of a tsunami, three types must be considered and separate estimates devised for each one. The different types are landslides down mountain slopes and in the water where $V > c$ (Case 1). Totally submerged submarine landslides where $V < c$ at least in for a part of the slide (Case 2) and bottom landscape features are moving vertically and horizontally (Case 3). The initial tsunami wave height is estimated. The energy transmitted to the water by the movement of the landslide is estimated from the moving mass. The total wave energy is estimated as the potential energy in the water mass the slide displaces from the still water surface, using the assumption that turbulent energy transmitted to the water cannot be regenerated as mechanical energy in the tsunami wave.

The wave energy transmission away from the source area can be translatory or by a solitary group of oscillatory waves. The wave transmission can be estimated in numerical models, and the shoaling also until either the point of breaking or where the numerical stability is lost in the model. In the following we will therefore estimate the wave energy generation in the source area and the corresponding wave amplitudes. In the following, the expressions for the wave energy and amplitude h depend on the variables listed here.

B: The width of the submarine landslide	V: Velocity of the front
y_0: The frontal height of the landslide	L_h: The length under water
x_v: Distance from the shoreline to c = V	x_w: Distance to slide front
C_m: Average wave celerity in $x_w - x_v$	$L_{hb} = L_s + (x_w - x_v)C_m/V$
L_s: Effective length of a submerged slide	ρ: Density of water

For further discussion and estimation of slide dimensions, see Section 7 and [6, 9, 15].

5.1 Case 1

In this case the surface disturbance, or the water wave, cannot run away from the translatory wave, i.e., the submarine landslide that causes it because $c < V$. The water volume above the still water level will therefore simply be equal to the displacing volume, of the submerged part of the slide. The estimates for the energy of the initial wave are for the two sub-cases: Case 1a, a slide that originates from land, and Case 1b, a slide that originates at the sea bottom.

5.1.1 Case 1a

The displaced water volume will be equal to the total submerged volume of the slide. The slide will hit the water with a great splash and run on the bottom until it stops. The water will be lifted the distance y_0 from the bottom, and this will be the resulting height of the water wave when the slide suddenly stops. In that situation, the energy added to the water will be.

$$E_{W1a} = ½y_0\rho\, gy_0 B\, L_h = ½\rho g{y_0}^2 B\, L_h \quad (3)$$

The wave progresses in the x direction with the shallow water velocity c. In a numerical model, the initial condition for the tsunami wave height h will be zero everywhere, except in the source area where $h = y_0$ in an area of size B L_h.

5.1.2 Case 1b

Now the slide will leave a scar, or a hole L_s long, in the seabed of volume $L_s B\, y_0$. An equal part of the slide will be outside the scar and leave a heap at the slide front. The hole and the heap have the same volume. We will find.

$$E_{W1b} = ½\, y_0\rho g\, L_s B\, {y_0}^2 = \rho g{y_0}^2 B\, L_s \quad (4)$$

In a numerical model, the initial condition for the tsunami wave height h will be zero everywhere, except in the source area where $h = -y_0$ in the hole area of size B L_s and $h = +y_0$ in the heap area.

5.2 Case 2

In this case, the slide passes the point where V = c, or the depth $D = V^2/g$, and the water wave will run away from the front of the translatory slide wave. When the slide front stops, the water wave front will be at a distance $L_{ha} = x_v + (x_w - x_v)C_m/V$

away from the shoreline. In estimating the energy, we still have to distinguish between the two schemes (a) and (b) as before.

5.2.1 Case 2a

In a point x_v from the shoreline, we have c = V, the velocity of the slide, but the slide stops at the position x_w from the shoreline. With C_m denoting the average shallow water wave velocity in $x_w - x_v$, we will have $L_{ha} = x_v + (x_w - x_v)C_m/V$ for the distance from the shoreline to the water wave front. Now we have a wave height slightly less than before.

$$h_{2a} = y_0 x_w / L_{ha} \quad (5)$$

The energy of the water wave becomes

$$E_{W2a} = ½\, h_{2a}{}^2 \rho\, gB\, L_{ha} \quad (6)$$

In a numerical model, the initial condition for the tsunami wave height h will be zero everywhere, except in the source area; we will have $h = h_{2a}$ in a square of size B L_{ha}.

5.2.2 Case 2b

Assuming the slide will start where $c < V$, we now have $L_{hb} = L_s + (x_w - x_v)$ C_m/V. The slide will leave a scar in the seabed of size L_sB. A part of the slide, $\kappa\, L_s(\kappa < 1)$ long, will be outside the scar and leave a hole in the scar of area of volume $\kappa y_0 L_s B$. At = 0 there will be a through in the water table approximately corresponding to this volume, but in the front of the slide, we have an initial wave L_{hb} long and h_{2b} high with the same volume as the through. Then we have.

$$E_{W2a} = ½\left(y_0{}^2\, \kappa L_s + h_{2b}{}^2\, L_{hb}\right)\rho\, gB \quad (7)$$

In a numerical model, the initial condition for the tsunami wave height h will be zero everywhere, except in the source area; we will have a through y_0 deep and a wave h_{2b} high at time t = 0.

5.2.3 Sudden increase in depth

In both Case 1 and Case 2, the slide is very likely to be in shallow water. A sudden increase in depth is therefore possible as soon as the tsunami wave sets out from the source area. A translatory wave with the velocity V, in a place where the wave celerity is c_1, will in theory continue to flow until the bottom slope I_0 is zero, but in practice it will stop sooner. The water wave will therefore run into deeper water with higher wave velocity c_2, and that affects the wave height. When the slope where the slide is running downhill fades out to a flat bottom, there is no problem in the numerical model, but in the rare occasions when there is a sudden increase in the ocean depth just in front of that point, it may provide better results to find the height h_2 of the initial wave in the deeper water:

$$h_2 = h_1 (c_1/c_2)^{1/2} = h_1 (D_1/D_2)^{1/4} \quad (8)$$

Here index 1 refers to the shallower source area and 2 to deeper water. The energy flow Eq. (8) assumes the translatory wave motion to be preserved. The translatory wave may be transformed into a group of oscillatory waves; the details of that wave group are unclear.

Similarly, it is not quite clear what will happen in the case when the slide starts at a depth where $c > V$. In this case, the distance x_v is not defined, but if the run time of the slide can be estimated, the water wave height can easily be found.

5.3 Case 3

A movement of the ocean bottom by an earthquake usually happens fast. The movement will leave an uplift of the ocean surface where the bottom is lifted and a sink where the bottom sinks down. Both the lift and the sink contribute to the potential energy of the disturbance.

There are two possibilities to model this: Firstly, to find the Fourier transform of the surface disturbance and, secondly, to use linear wave theory to radiate it away from the source. Analytic models can be used for this if the boundary configuration can be coped with. Otherwise, a numerical model with an initial surface disturbance of the same configuration as the bottom disturbance is the only chance.

6. Studies of individual tsunamis and regional risk assessment

6.1 Tohoku tsunami in Japan

The earthquake event and the devastation caused by this tsunami is very well documented; it is the most famous tsunami event of recent years. It took place off the Pacific coast of Tohoku, Japan, on Friday, March 11, 2011 at 05:46 UTC. It was caused by a M_w 9.0 (magnitude moment) undersea megathrust earthquake with the epicenter approximately 70 km east of the Oshika Peninsula of Tohoku with the hypocenter in approximately 30 km deep water (see **Figure 3** gray arrow).

From the data obtained in the exploratory drilling at the site shown in **Figure 3**, it was concluded in [16] that the tsunami was caused by the mass movement shown in **Figure 4**.

The details of the bottom deformation are estimated and pictured in **Figure 3b** in [18]. This picture resembles a 150 km long slide scar with L_s and B about 110 km and y_0 about 8 m using the symbols in Chapter 5.2. This would be a Case 2b slide, stopping 25–75 km from the trench, see **Figure 4**; here the average bottom slope is about 4/50 or 8–9%. It is interesting to note that layers of fine sediments on such a slope can easily liquify, slide down the slope, and cause a bottom deformation like the one pictured in [18] and indicated by black arrows in **Figure 4**. No evidence has been found in [16] to support this suggested slide event, but the information on the bottom deformation given in [18] is considered reliable, and it is supported by a coseismic slip model in **Figure 4** in [17]. The suggested slide would have characteristics that can be calculated using the equations for the Case 2b slide. If the slide is due to liquefaction, the movement will start at the onset of the strong motion and stop when it stops. According to graphs in [18], this time is about 30 seconds; this is an information additional to what we have in Sections 5.2.2 and 5.2.3.

$V = 2$ m/s corresponds to the 9% slope and $y_0 = 8$ m. Together with the time 30 s, this gives a horizontal flow path of 60 m. This corresponds well to **Figure 4**, giving 56 m as maximum horizontal deformation.

The water depth gives $c = 250$ m/s so we get $L_{bh} = 250 \times 30 = 7500$ m $= 7.5$ km for the initial disturbance. As the flow path is short the $\kappa \sim 0$. Now we get.

$L_{bh} = L_s + 7.5 = 110 + 7.5 = 117.5$ km.

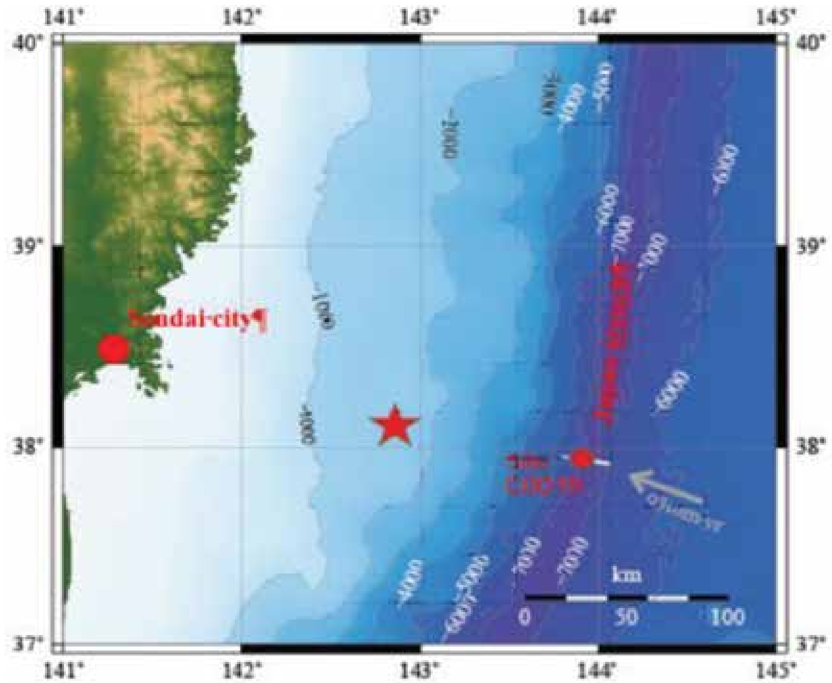

Figure 3.
Location chart of the tsunami site with the epicenter (red star) and an exploration well, drilled at site C00 19, [16].

The uplift caused by the coseismic movement means that there will be just a small hole in the scar area. The volume of the heap caused by the slide will be.

$W_{T2b} = By_0L_s = 1 \times 110000 \times 8 \times 110000 = 9.68 \times 10^{10}\ m^3 = 96.8\ km^3$.

The height of the wave with same volume as in Section 5.2:

$h_{2b} = W_{T2b}/(L_{hb}\ B) = 8 \times 110/117.5 = 7.5$ m.

Eq. (7) must be modified due to the uplift and the small scar hole; this is done by putting $\kappa \sim 0$ as before, and then we have for the energy in the source area:

$E_{W2a} = ½h_{2b}^2\ L_{hb}\rho\ g\ B = ½\ 7.5^2 \times 117500 \times 1025 \times 9.81 \times 110000 = 3.6\ 10^{15}$ Nm.

This result can be checked against the simulation results published by NOAA [19]; it is on **Figure 5** and shows the spread of the tsunami very well. Comparing this with a ring wave spreading in an effective 90° conical channel gives a resulting average wave height 2–3 feet 900 km from the source. According to C = 250 m/s (800 km/h), this should occur after little more than 1 hour. This checks well against **Figure 5**.

The bottom deformations that caused the very strong Tohoku tsunami in the Pacific Ocean, simulated numerically by the Japanese and USA scientists, [17, 19], can be explained by a submarine landslide. This suggests that the coseismic slip of the earthquake triggers a sliding of the surface sediments. In combination they cause the bottom deformation. Finally, it can thus be concluded that the coseismic slip and the landslide are both responsible for the Tohoku tsunami in March 2011, not the coseismic slip alone.

This shows that in assessing the tsunami risk in the Pacific coastal regions of Japan, the landslide risk must be considered. This fact may result in that considerably larger events than the Tohoku tsunami are possible if a larger slide than this 8 m thick slide is released. This landslide is not very high compared to what has happened elsewhere. The assessment of this possibility of larger slides can be

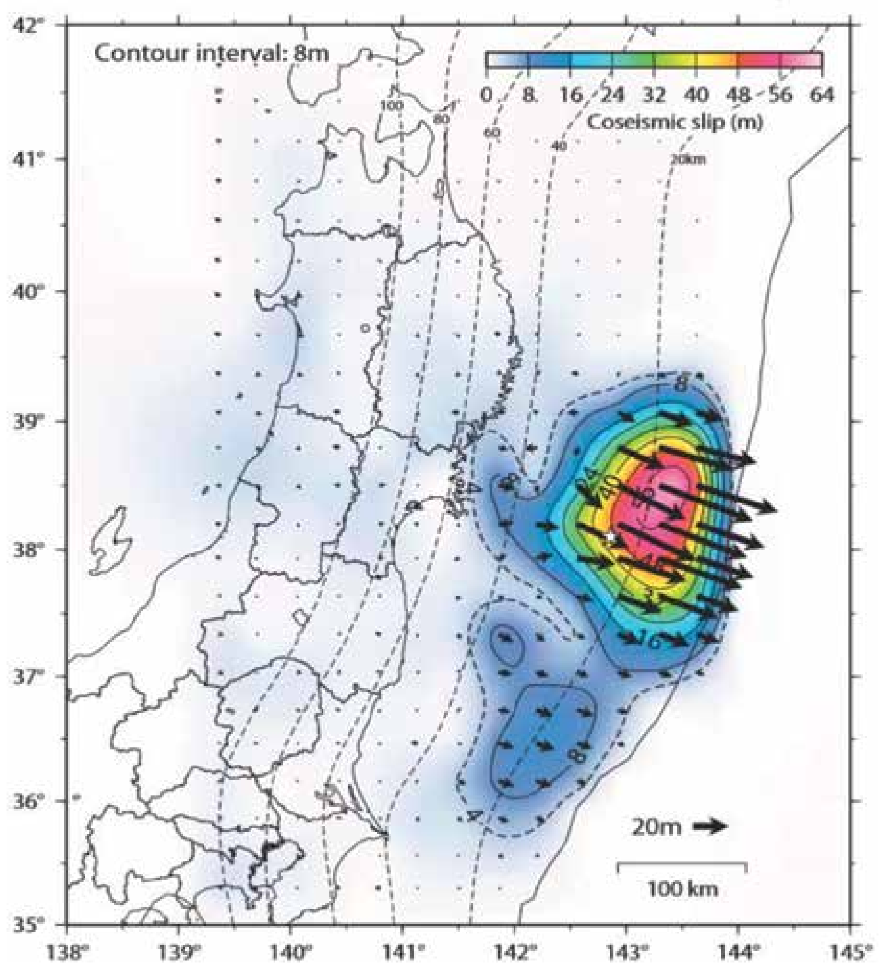

Figure 4.
The 2011 Tohoku earthquake: Coseismic slip distribution model, from [17].

difficult; there is considerable uncertainty in estimating the height (y_0) of possible landslides.

6.2 Tsunami risks in the North Atlantic Ocean

There are many tsunami sources in the Atlantic Ocean, but in the northern regions, the tsunami risk is less than in many other places, and the source of the main threat may be unknown, both location and magnitude. A good method is presented in [9], to estimate the hazard curves for a reference point in south Iceland. This involves estimating initial wave heights at the source and their frequencies. Then the transfer functions must be applied, and the hazard curves are found by numerical integration.

6.2.1 Risk assessment methods

To assess the risk, we have to estimate event return periods for the various event magnitudes and the correlation structure of the event history. This correlation may be between time length between events and event magnitude and autocorrelation (positive or negative) in the time history.

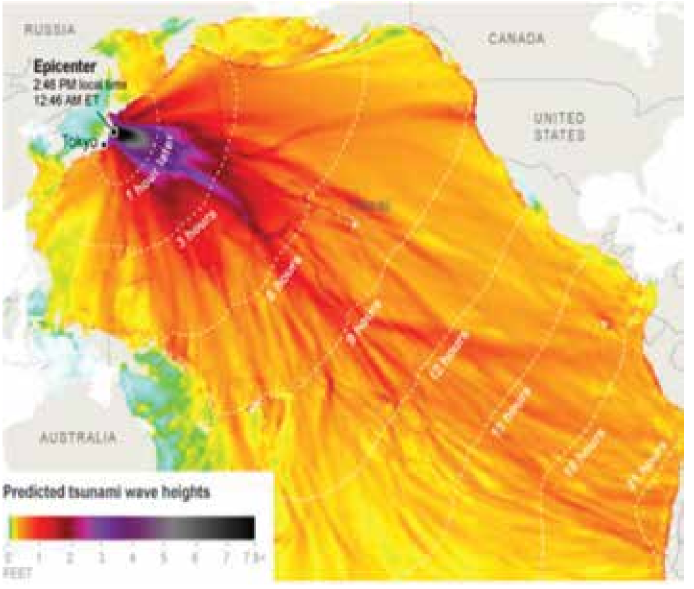

Figure 5.
Spreading of the Tohoku tsunami in the Pacific Ocean March 11, 2011. (NOAA Center for tsunami research, Pacific marine environmental laboratory; NOAA. 2011. Printed in the N.Y. Times).

The very long records necessary for a complete picture of the event statistics are normally not available. Certain assumptions are necessary, but we must estimate the basic statistics such as average time between events, t_a, the standard deviation associated to it, t_s and the correlation between magnitude and event interval ρ (note the different meaning of ρ in chapter 5). Now the following formula can be derived for the interval between tectonic events, it being earthquakes, submarine slides, or volcanic events:

$$g_k(i) = \rho\, h_k(i) + \sqrt{(1-\rho^2)}\, e_k(i) \tag{9}$$

i	Number of event occurring at time t(i)
$g_k(i) = ((t(i+1) - t(i) - t_a)/t_s$	Dimensionless relative time between events
$h_k(i) = \rho(H_k(i) - H_a)/H_s$	Relative magnitude, e.g., wave height
$\rho = E\{g_k(i)h_k(i)\}$	Magnitude time correlation (E denotes average)
$e_k(i)$	Random function $e_k(0.1)$
k	Series number

The time between the tectonic events i and i + 1 is known when $g_k(i)$ is known so series for the occurrence of events in time can be simulated when $h_k(i)$ is known. If the simulation period is a limited number of years into the future, it is necessary to simulate sufficiently many series (the number k) so the statistical distribution of H is represented.

If this statistical distribution is not known, some classification that fits available observations of H has to be assumed. Three classes, small, medium, and large events, should be considered as minimum. Then the Monte Carlo method is used to simulate the k series, and they are used to determine the statistics of interest empirically. These are various hazard curves and event probabilities for fixed periods to come, e.g., economical lifetime of structures and so on. It must be noted that the probability of a specified event of a given class happening in the next year is not a constant. This probability will increase with time.

6.2.2 Example from South Iceland

There are several methods to estimate the distribution functions we have to use as building blocks in Eq. (9) recommended in the literature. The log-normal distribution is often usable for g_k, especially when ρ is low [5].

When there is more than one source, the procedure has to be repeated for all significant sources. Then the transfer functions have to be applied and H_a and H_s calculated for the chosen reference point. H_s is much more difficult to estimate from observations than H_a, but sometimes it is possible to estimate the coefficient of variation $C^v = H_a/H_s$. If not it has to be included as a parameter in order to estimate the accuracy of calculated probabilities and risks.

In [9], all this is done for a reference point south of Iceland. There are eight possible sources for tsunamis in the North Atlantic, six of these are found significant for the reference point chosen. For clarification the reference point is shown and the resulting risk curve.

The only significant Icelandic source contributing to the calculated tsunami height in the reference point on **Figure 6** is the Katla volcano [6]. The hazard curves for these points are in **Figure 7**. Here all the risk curves follow the Gumbel distribution $P(H > x) = \exp(-\exp(-y))$ where $y = 3.91 + 1.12\ x$ rather closely. Here the probability P does not denote the next event, but the maximum to be expected in the next year (annual maximum); it will be $x = (y - 3.91)/1.11$ in each point in **Figure 7**.

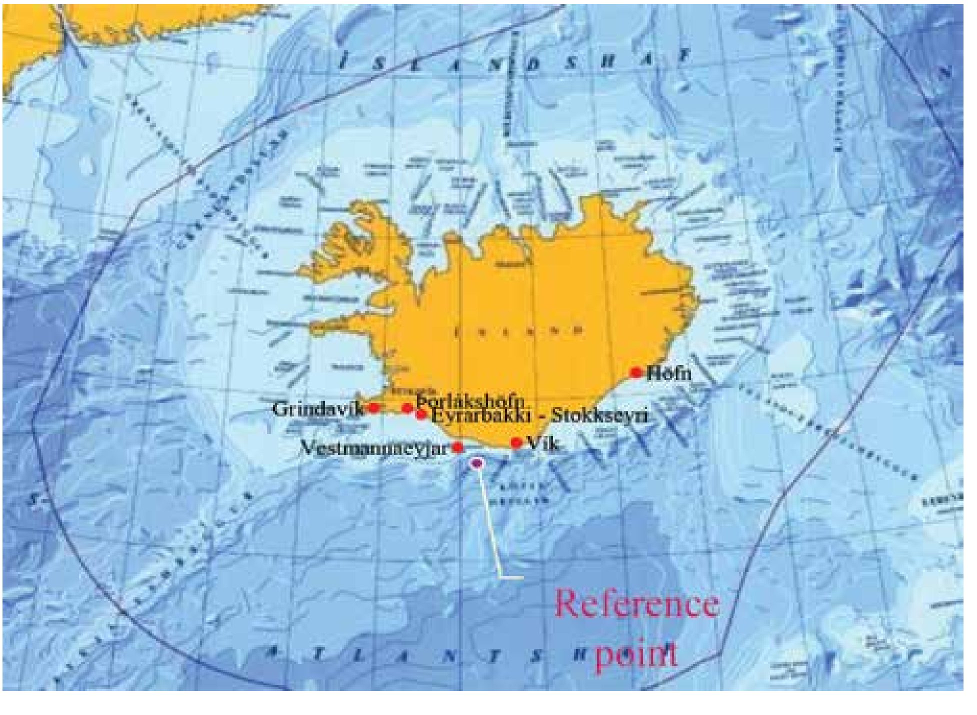

Figure 6.
Icelandic coastal waters, depth scale by deeper blue for each 200 m. Population centers in red [9].

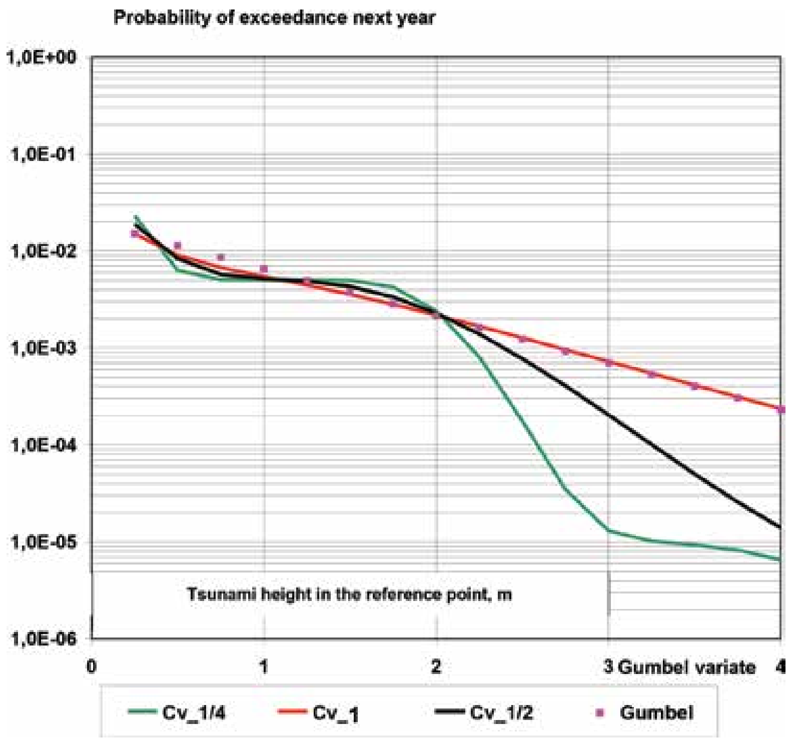

Figure 7.
Hazard curves for the reference point with three different C^v values. The abscissa is the Gumbel variate [9].

The probability is for the maximum to be expected in the next year (annual maximum). To take an example, the maximum to be expected in the very next year with probability P = 1% or 0.01 has the Gumbel variate 0.4, corresponding to a wave height of x = 0.1 m which is rather insignificant, but for P = 0.1%, the Gumbel variate is 2.8 giving seven times larger wave height.

7. Discussions

Tsunami attack is very difficult to predict, even though the models that simulate the propagation of the tsunami wave over deep water are very good and in most cases reliable. The mathematics of these models is very difficult, but effective, as long as the wave stays in deep water [20]. The difficulty in modeling is to predict the shoaling and the run-up. And then there is the uncertainty about the initial wave height and wave energy formation in the source area.

The importance in such analysis is to identify the sources that cause the largest tsunami threats. The methods devised in Chapter 5 can be used to estimate the initial wave and energy in the source area when the bottom deformation is known. This is demonstrated in the case study of the Tohoku tsunami, in Section 6.1; in [21] is a detailed description of this huge event and its consequences.

The cause of the bottom deformation is directly or indirectly an earthquake. It can start a submarine landslide, or the earthquake wave itself can deform the bottom so much that a large tsunami is produced, especially earthquakes above 7 in magnitude. But this very information tells us that the variability in tsunami properties will be very great in the source area. The magnitude of the average event may be possible to estimate from existing observations and geophysical data, but their standard deviation will always be difficult to estimate; usually there are not enough observations of serious tsunami events to establish a reliable value for this coefficient.

In the example taken in Section 6.2, there are eight identified tsunami sources in the North Atlantic Ocean, six of these contribute significantly to the hazard curve in the danger zone on **Figure 7**. This is the zone above 2 m, meaning that the tsunami has to be 2 m or higher to pose any significant threat alone, i.e., without being accompanied by a flood of different origin [9] or attacking upon a spring tide flood.

The effect of the coefficient of variation on the hazard curve **Figure 7** is quiet surprising. The estimation of its value is very difficult. However, to leave it out corresponds to estimating its value to be zero, and that is totally unsatisfactory. In **Figure 7** the effect of three different values, common in geophysical data, is demonstrated, and the difference is quite striking. The difference in frequency of occurrence is of one decade, up or down, from the C^v = 1/2 value.

8. Conclusion

The translatory wave theory is used to estimate the expressions for energy and wave height in the source area, and it can be used for the initial conditions in wave models.

Earthquakes, of too small a magnitude to produce dangerous tsunamis themselves, can do so by triggering submarine landslides.

Approximate analytical methods can give good results as a first approximation for the transfer functions that link the wave heights in the source area to wave heights in a reference point selected in the wave propagation path. The best position for such a point is offshore, outside the zone of nonlinear shoaling and wave breaking, but near the places where the attack of the tsunami is expected. Then a hazard assessment may produce a wave height-frequency curve for this point.

It is clearly demonstrated that it is very important to include the C^v factor for the event magnitude in the hazard assessment. Otherwise the tsunami wave heights for a given frequency may be seriously underestimated.

For high C^v values the hazard curves may be expected to follow the Gumbel distribution or possibly another distribution of the extreme value distribution family because the hazard curve is the maximum expected frequency for a given wave height.

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Conflict of interest

The author declares that there are no conflict of interests regarding the publication of this chapter.

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Chapter 13

Kinematics of Slow-Slip Events

Chi-Yu King

Abstract

Large earthquakes are often preceded or followed by slow-slip events, which when better understood may help better understand the mechanisms of the earthquakes and the possibility of their prediction. This chapter summarizes kinematic values of large slow-slip events observed in Circum-Pacific subduction zones and creep events observed along strike-slip faults in California. The kinematic parameters include maximum slip S, duration T, rupture length L, rupture width, magnitude M, slip velocity V_S, rupture velocity V_R, and maximum slip/rupture length ratio S/L. For a large surface and subsurface creep event in California: S = 0.9–2.5 cm, T = 2–5 day, L = 6–8 km, W = 3–4 km, M = 4.7–4.8, V_S = 0.4–0.5 cm/d, V_R = 1.6–3.0 km/d, and S/L = 0.3–1.5 × 10^{-6}. For a large short-term slow-slip event in Circum-Pacific subduction zones: S = 1–20 cm, T = 2–50 day, L = 20–260 km, W = 10–90 km, M = 5.6–7.0, V_S = 0.1–0.8 cm/d, V_R = 2–20 km/d, and S/L = 0.3–1.5 × 10^{-6}. The latter kind of events have larger sizes in slip, duration, rupture length/width, and magnitude than the former, but are comparable in slip velocity, rupture velocity, and S/L ratio. The kinematic behaviors of both are similar, despite their large difference in temperature, pressure, and composition of the fault-zone materials. The larger size of the latter is probably due to their larger inertia caused by their larger overburden. Compared with normal earthquakes, the slip and rupture velocities of both are smaller by many orders of magnitude. But their S/L values, and thus stress drops, are smaller by only one or two orders of magnitude. For a large long-term slow-slip event in the subduction zones: S = 1–50 cm, T = 50–2500 day, L = 40–1000 km, W = 30–750 km, M = 6.0–7.7, V_S = 0.01–0.10 cm/d, V_R = 0.1–2 km/d, and S/L = 0.1–2 × 10^{-6}. The estimated slip, duration, rupture length, and magnitude values are larger than the short-term events, but the average slip and rupture velocities are much smaller. This difference suggests that the long-term events may have commonly encountered stronger asperities, which can slow down or even break them into smaller short-term events.

Keywords: slow-slip, events, earthquake, tremor, fault zone, strike-slip, downdip, updip, plate interface, seismic, geodetic, Circum-Pacific, subduction zone, asperity, fault gouge, friction

1. Introduction

Tectonic faults may rupture rapidly (seismically) to generate earthquakes or slowly (aseismically) without doing so. During the last two decades, many slow-slip events have been discovered, especially in the subduction zones around the Pacific Ocean [1–4]. Some of them preceded or followed major earthquakes [5–15]. This chapter summarizes kinematic parameters of these slow-slip events reported in the literature and compares them with creep events and shallow slow-slip events

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observed along the strike-slip faults in California. By such comparison, I hope to better understand not only the physical mechanisms of the different kinds of fault-slip behaviors but also the mechanisms of the related hydrological, geochemical, and geophysical changes often accompanying them [16, 17]. Such understanding, in turn, may help us to explore the possibility of short-term prediction of some earthquakes.

2. Creep events in California

The fact that a tectonic fault may slip slowly was first found on a surface trace of a strike-slip fault in central California [18]. Early measurements by creepmeters showed that the slow-slip motion can occur not only steadily but also episodically in small steps of several millimeters in short durations of a few days with no slip in between [19]. Subsequent measurements by widely distributed networks of creepmeters showed that the occurrence of creep events was quite common along many fault segments in central California, and elsewhere [20–22].

By studying creep events recorded at neighboring sites, Nason [20] noticed that they often began at different times, suggesting that a creep event is a rupture propagation process with a velocity of about 1–10 km/day. King et al. [23] estimated the maximum slip velocity to be about 0.01–1 cm/day. By analyzing creep data recorded at many network sites (**Figure 1**) and by fitting the creep data to a faulting model [24], King et al. [25] found that a large creep event might have a rupture length of

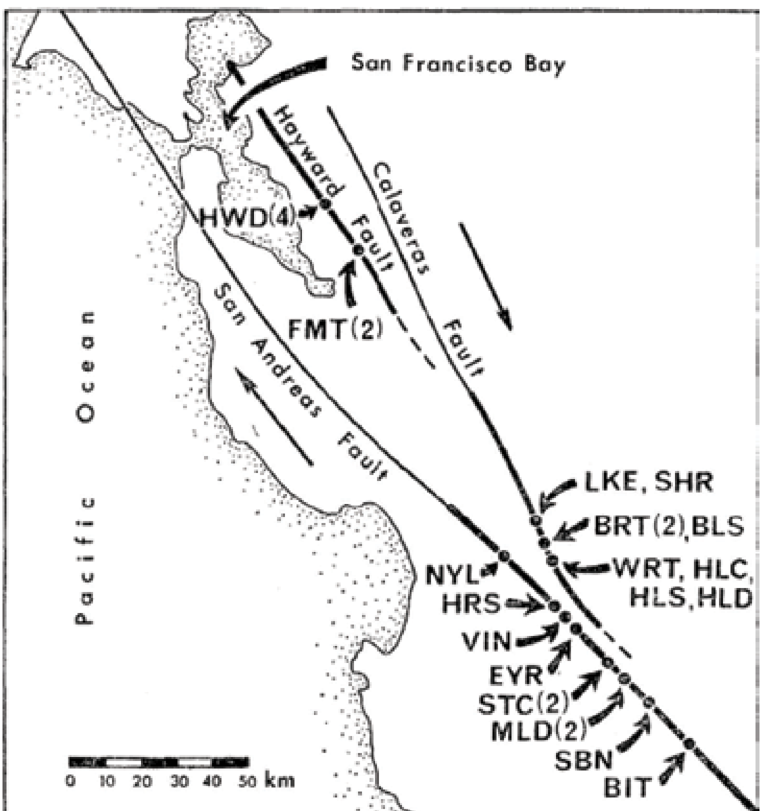

Figure 1.
Distribution of creepmeters along San Andreas, Calaveras, and Hayward faults in central California. The long-term fault motion in this region is right-lateral strike slip, ranging from 0 to 3 cm/year (after King et al. [25]).

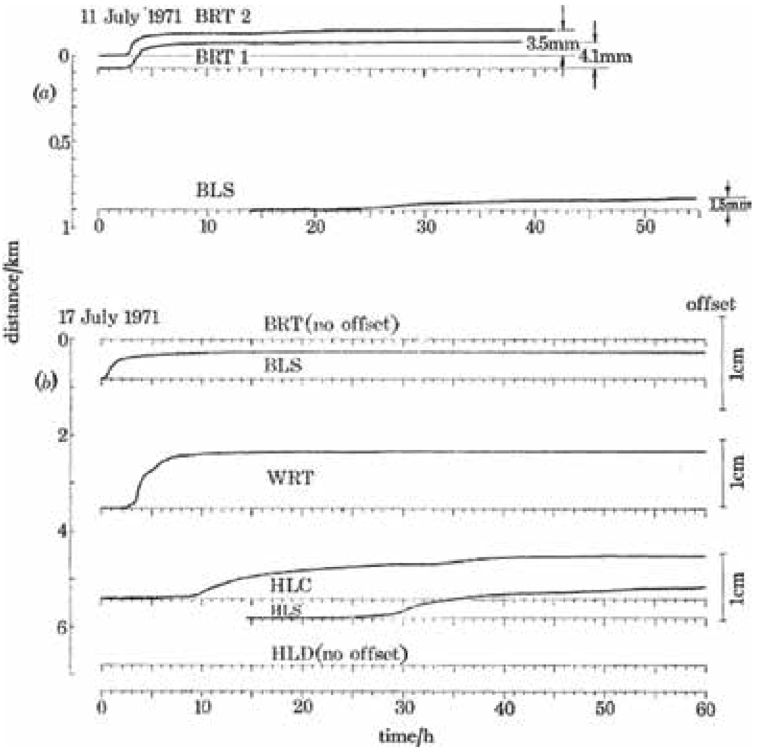

Figure 2.
Two creep events that occurred within a dense array of creepmeters on Hayward-Calaveras fault (a and b). The records are arranged properly in both time and space, except for BRT2 where the timer was out of order (after King et al. [25]).

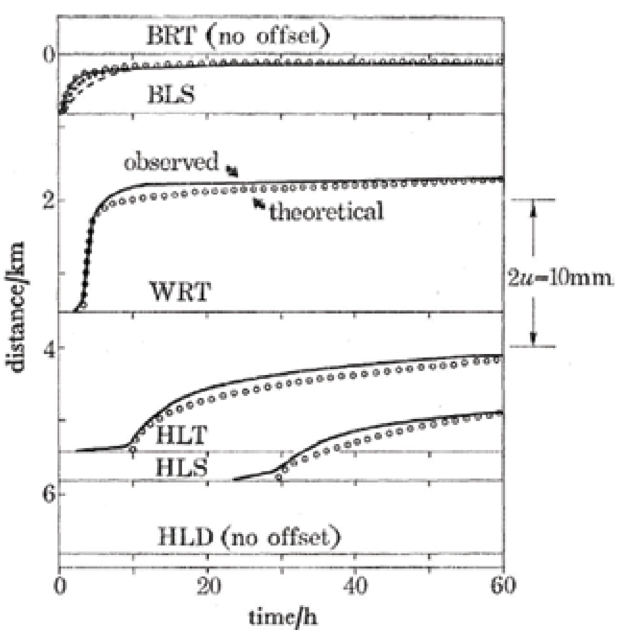

Figure 3.
Fit of the observed creep curves for the 17 July 1971 event with a theoretical model with three different guiding-center depths: 0 km (open circle), 0.5 km (dot), and 1.0 km (dashed line). The model curves are significantly different only at BLS. 2u is the amount of slip (after King et al. [25]).

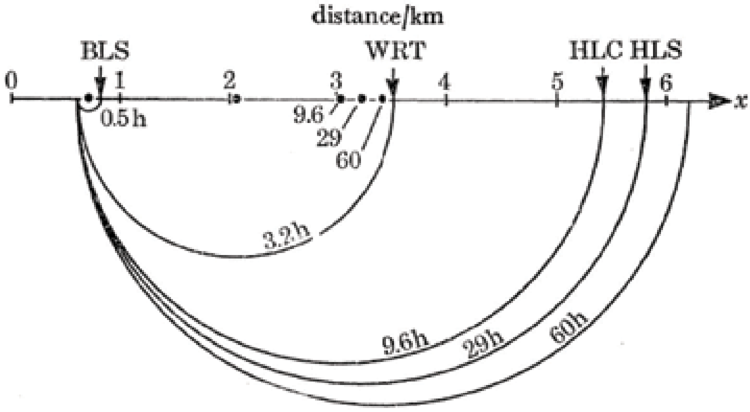

Figure 4.
*Fault-plane view of a theoretical faulting model that can reasonably fit the creep data of the 17 July 1971 event (case of 0 km depth in **Figure 3**). The fault trace is along the x-axis, below which is the fault plane. The rupture expands with a circular boundary whose positions are shown for several specified times (after King et al. [25]).*

several kilometers, an offset of about 1 cm. They also concluded that a creep event was kinematically similar to seismic faulting, but with rates that are five or more orders of magnitude smaller. **Figures 2–4** show the records of two creep events and the model fitting of the larger (**Figure 2b**) by King et al. [25], who found the following kinematic values: maximum slip S = 0.9 cm, duration T = 2 days, rupture length L = 6 km, rupture width W = 3 km, magnitude M = 4.7, average slip velocity V_S = S/T = 0.45 cm/day, average rupture velocity V_R = L/T = 3 km/d, and slip/rupture length ratio S/L = 1.5×10^{-6}. The S/L ratio, which is a measure of stress drop, is an order of magnitude smaller than that of seismic faulting.

3. Subsurface slow-slip events in California

Subsurface slow-slip event was first observed at San Juan Bautista (SJB) in central California, by using two continuously recording borehole strainmeters [24]. The recorded slip curves showed some kinks, which are probably caused by some higher-resistance patches, for similar kinks were found in a theoretical faulting model by barriers [25]. This event reached an estimated depth of 4 km and lasted about 5 days with an estimated maximum slip of 2.5 cm, a rupture length of 8 km, and a magnitude of 4.8. The kinematic values are comparable to those of the surface creep event described above.

In Parkfield area of California, Guilhem and Nadeau [26] studied 52 tremor episodes, which may be related to slow-slip events about 25 km deep. They estimated that a typical event has a duration of about 10 days, maximum slip of about 7.8 mm, rupture length of about 25 km, width of 15 km, and equivalent magnitude of 5.0–5.4. Excepting the slip value, it is larger than the surface and subsurface events described above. Similar slow-slip events have been detected along other inland faults also [7, 13].

4. Slow-slip events in Circum-Pacific subduction zones

Since about the beginning of the twenty-first century, with the deployment of an increasing number of geodetic instruments, many below-surface slow-slip events have been detected, especially along plate boundaries in the subduction zones around the Pacific Ocean, where megathrust earthquakes often occur [1, 4, 27–30]. Most slow-slip events occurred offshore and were relatively far away from onland instruments. In areas where such events were continuously detected by dense networks of geodetic and seismic instruments, the resultant data have been analyzed to estimate their kinematic values [2, 31–33].

In the Circum-Pacific subduction zones, most observed slow-slip events occur in transition areas downdip the seismogenic areas (asperities) and updip the stable-sliding areas of the plate interfaces (e.g., **Figure 5**). Except in New Zealand and Costa Rica, they are mostly located quite far from onland instruments, including strainmeters, tiltmeters, and GPS stations [27–28, 34]. To delineate the kinematic parameters of a slip event, data have to be recorded continuously at multiple sites and inverted with the help of some elastic dislocation models, such as that by Okada [35]. Thus, the estimated kinematic values are rather uncertain. Some slow-slip events occurred in transition areas of plate interfaces updip the seismic asperities also. They have been detected more frequently as more instruments are deployed further offshore [9, 36].

Some slow-slip events were found to be accompanied by seismic tremors and low-frequency/regular earthquakes in/near the same areas of the plate interface [29, 37–40]. This suggested that these tremors and earthquakes were generated at small asperities swept over by the rupture front of the slow-slip events. Since then, additional information about the slow-slip kinematics has been obtained from the distribution and migration of these events recorded by seismic instruments.

The depths of the observed slow-slip events usually range from 25 to 60 km; the durations in some zones show bimodal distribution of long term (of months to years) and short term (days to weeks). Short-term events in most subduction zones occurred closer to the deeper stable-sliding zone, while long-term events closer to the shallower seismogenic zone (**Figure 5**) [4]. The situation is somewhat different in New Zealand and Costa Rica, however [41].

The estimated kinematic parameters are given in the following order: maximum slip S, duration T, rupture length L, width W, magnitude M, average slip velocity Vs = S/T, average rupture velocity V_R = L/T, maximum slip/rupture length ratio = S/L.

In *Northeast Japan*, where the Pacific plate subducts west-northwestward beneath the North American or Okhotsk plate along the Northeast Japan Arc and the M 9.0 Tohoku-Oki megathrust earthquake occurred in 2011, a 9-year-long geodetic transient was detected that can be attributed to a very-long-term slow-slip event (possibly consisting of a serious of short-term subevents) with S = 40 cm,

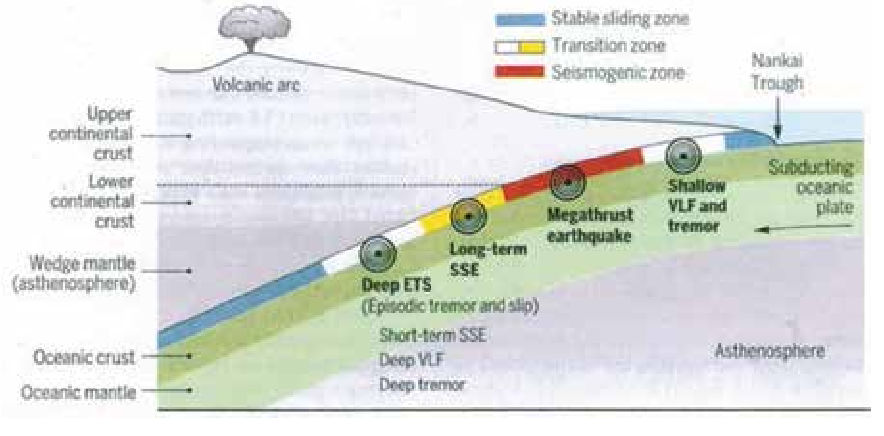

Figure 5.
A cross-sectional sketch of the Nankai subduction zone in Japan (after Obara and Kato [4]).

T = 3000 days, L = 250 km, W = 150 km, and M = 7.7. Also short-term slow-slip events here have the following kinematic values: S = 2–20 cm, T = 7– 35 days, L = 30–80 km, W = 30–50 km, and M = 6.8–7.0 [8–9, 42–44].

Boso Peninsula is in a complicated tectonic setting, where the Philippine Sea plate subducts northwestward beneath the Okhotsk plate at the Sagami trough, and the Pacific plate subducting westward beneath the Philippine Sea plate. Slow-slip events occur here roughly every 5–7 years on the interface between the Philippine Sea plate and the Okhotsk plate at a shallow depth of about 13 km. Short-term large events have the following kinematic values: S = 1.6–20 cm, T = 2–50 days, L = 40–100 km, W = 30–50 km, M = 6.0–6.7 [11, 45–50].

In the tectonically more complicated Southwest Japan including Tokai region and Kii and Bungo Channels, where quite a few great earthquakes occurred in history, the Pacific plate in the east subducts westward beneath the Philippine Sea plate, which in turn subducts northwestward beneath the Eurasian plate along the Nankai trough and northeastward beneath the Okhotsk plate along the Sagami trough. Many "long-term" and "short-term" slow-slip events at depths of 30–40 km have been observed since 1997.

In *Tokai region* near the Suruga trough, where the Philippine Sea plate subducts northwestward beneath the Eurasian plate at an annual rate of 2–3 cm/year, large long-term events have the following kinematic values: S = 7–30 cm, T = 2000–2500 days, L = 80–100 km, W = 60–70 km, and M = 6.6–7.1. Large short-term events have the following kinematic values: S = 0.7–1.8 cm, T = 2–5 days, L = 20–90 km, W = 20–40 km, and M = 5.6–6.2 [38, 50–53].

In/near *Kii channel*, long-term slow-slip events have the following kinematic values: T = 398 days and M = 6.7 [54]. Short-term slow-slip events have the following kinematic values: S = 1–2 cm, T = 2–5 days, L = 20–90 km, W = 20–30 km, and M = 5.3–6.1 [36, 38, 55].

In/near *Bungo Channel*, large long-term events have the following kinematic values: S = 1–50 cm, T = 90–700 days, L = 40–200 km, W = 40–100 km, and M = 6.0–7.3. Some of them were found to possibly consist of multiple short-term events. Large short-term events have the following kinematic values: S = 1–4 cm, T = 4–10 days, L = 20–100 km, W = 20–50 km, and M = 5.8–6.3 [27, 38, 56–64].

In *Gisborne/Raukumara Peninsula*, *New Zealand*, where the Pacific plate subducts westward beneath the eastern North Island at the Hikurangi subduction zone, long-term events downdip the seismogenic interface area at the depth of 25–60 km in the southern margin have the following kinematic values: S = 4–56 cm, T = 50-550 days, L = 60–200 km, W = 30–150 km, and M = 6.5–7.2. Short-term events updip the seismogenic area (5–15 km deep) along northern Hikurangi margin have the following kinematic values: S = 1.2–24 cm, T = 5–36 days, L = 50–180 km, W = 50–90 km, and M = 5.8–7.0 [41, 65–75].

In *Alaska* subduction zone, where the great Mw = 9.21964 Prince William Sound earthquake ruptured a large portion of the shallow plate interface above 30 km depth at the eastern end, several long-term slow-slip events were detected just below the seismogenic zone at depths between 25 and 45 km with the following kinematic values: S = 2–40 cm, T = 620–1600 days, L = 150–1000 km, W = 140–750 km, and M = 6.9–7.5 [76–78].

In *Cascadia* subduction zone, where the Juan de Fuca plate subducts beneath the North American plate, geodetic measurements show that the plate interface along an entire 1000 km segment between British Columbia and northern California is locked from near the surface to a depth of about 20 km [84]. No long-term slow-slip event has been detected here. Large short-term slow-slip events at depths of 30–55 km in this segment have the following kinematic values: S = 1–8 cm, T = 7–50 days, L = 25–400 km, W = 25–70 km, and M = 6.1–6.9 [2, 28, 79–86].

In *Mexico*, where the Cocos plate subducts beneath the North American plate along the Middle American Trench and great earthquakes occurred every 30–100 years, several long-term slow-slip events were detected below the seismogenic depth of 15–40 km with the following kinematic values: S = 9–30 cm, T = 90–400 days, L = 200–500 km, and W = 150–230 km. Short-term events have the following kinematic values: S = 2–10 cm, T = 30–45 days, L = 200–260 km, W = 50–130 km, and M = 6.3–7.2 [10, 87–96].

In northwestern *Costa Rica*, the Nicoya Peninsula is located along the Middle America Trench where the Cocos plate subducts beneath the Caribbean plate at about 8 cm/yr. The subduction segment has ruptured repeatedly in the past. The peninsula lies directly over the seismogenic zone, and several slow-slip events possibly updip the seismic interface were detected with the following kinematic values: S = 1.5–15 cm, T = 20–180 days, L = 30–120 km, W = 20–40 km, and M = 6.6–7.2 [97–103].

Events	S (cm)	T (day)	L (km)	W (km)	M	S/T (cm/d)	L/T (km/d)	S/L
California surface creep	0.9	2	6	3	4.7	0.45	3	1.5
SJB subsurface slow slip	2.5	5	8	4	4.8	0.5	1.6	0.31
Parkfield deep slow slip	0.8	10	25	15	5.0–5.4	0.08	2.5	0.03
Circum-Pacific short term								
Northeast Japan	2–20	7–35	30–80	30–50	6.8–7.0	0.29–0.57	2.3–4.3	0.67–2.50
Boso Peninsula	1.6–2.0	2–50	40–100	30–50	6.0–6.7	0.04–0.80	2–20	0.20–0.40
Tokai region	0.7–1.8	2–5	20–90	20–40	5.6–6.2	0.35–0.36	10–18	0.20–0.35
Kii Channel	1–2	2–5	20–90	20–30	5.3–6.1	0.40–0.50	10–18	0.22–0.50
Bungo Channel	1–4	4–10	20–100	20–50	5.8–6.3	0.25–0.40	5–10	0.40–0.50
Hikurangi, New Zealand	1.2–24	5–36	50–180	50–90	5.8–7.0	0.24–0.67	5–10	0.24–1.33
Cascadia	1–8	7–50	25–400	25–70	6.1–6.9	0.14–0.16	3.6–8.0	0.20–0.40
Mexico	2–10	30–45	200–260	50–130	6.3–7.2	0.07–0.22	5.8–6.7	0.10–0.38
Northwestern Costa Rica	1.5–15	20–180	30–120	20–40	6.6–6.7	0.07–0.08	0.7–1.5	0.50–1.25
Central Ecuador	8–40	4–40	30–80	10–60	6.0–6.8	1.00–2.00	2.0–7.5	2.67–5.00
Chile	1.3–8	2–15	20–60	20–30	6.5–6.7	0.53–0.65	4–10	0.65–1.33
Circum-Pacific long term								
Northeast Japan	40	3000	250	150	7.7	0.013	0.08	1.60
Tokai region	7–30	2000–2500	80–100	60–70	6.6–7.1	0.004–0.012	0.04	0.86–3.00
Bungo Channel	1–50	90–700	40–200	40–100	6.0–7.3	0.01–0.07	0.29–0.44	0.25–2.50
Hikurangi, New Zealand	4–56	50–550	60–200	30–150	6.5–7.2	0.08–0.10	0.36–1.20	0.67–2.80
Alaska	2–40	620–1600	150–1000	140–750	6.9–7.5	0.003–0.025	0.24–0.63	0.13–0.04
Mexico	9–30	90–400	200–500	150–230	6.5–7.6	0.08–0.10	1.25–2.22	0.45–0.60
Chile	50–80	240	70–150	20–30	6.5–6.9	0.21–0.33	0.29–0.63	5.33–7.14

Table 1.
Kinematic values.

In the Central *Ecuador* subduction zone, short-term slow-slip events along this segment of the North Andean subduction zone, where the Nazca plate subducts beneath South America plate, are estimated to have the following kinematic values: S = 8–40 cm, T = 4–40 days, L = 30–80 km, W = 10–60 km, and M = 6.0–6.8 [42, 104–105].

In *Chile*, along a megathrust fault off northernmost Chile, where the Nazca plate subducts beneath the South American plate, a long-term slow-slip event occurred in a transition zone at depth of 40–60 km with the following kinematic values: S = 50–80 cm, T = 240, L = 70–150 km, W = 20–30 km, and M = 6.5–6.9. Also a short-term event indicated by earthquake migration occurred with S = 1.3–8 cm, T = 2–15 days, L = 20–60 km, W = 20–30 km, and M = 6.5–6.7 [11, 106–108].

Table 1 gives a summary of the estimated kinematic values of slip S, duration T, rupture length L, rupture width W, and magnitude M, as well as calculated values of slip velocity V_S = S/T, rupture velocity V_R = L/T, and S/L, which is a measure of stress drop. In this table, a factor of 10^{-6} is omitted from the S/L values.

5. Discussion

Among the short-term slow-slip events included in **Table 1**, those in New Zealand and Costa Rica occurred updip the seismogenic area of the subduction interface. Yet the estimated kinematic values are comparable to those downdip the seismogenic interface areas in other subduction zones. On the other hand, the kinematic values for central Ecuador are quite different, due to the unusually large slips reported. The same is true with Chile in the case of long-term events, and the opposite is true for the Parkfield events, when compared with two other cases in California. In the following discussion, we shall exclude these three cases from further consideration.

It may be seen that most short-term slow-slip events in the various Circum-Pacific subduction zones have comparable kinematic values: a slip of about 1–20 cm, duration of 2–50 days, rupture length of 20–260 km, width of 10–90 km, magnitude of 5.6–7.0, slip velocity of 0.1–0.8 cm/d, rupture velocity of 2–20 km/d, and an S/L value of 0.1–1.3. Compared with creep and shallow slow-slip events in California, they have larger values in slip, duration, rupture length/width, and magnitude, but comparable values in slip velocity, rupture velocity, and S/L ratio. This result indicates that kinematics of slow-slip events are basically similar, independent of temperature, pressure, and composition of the fault-zone materials, as long as they are mostly velocity-strengthening fault-gouge type; the larger sizes of the subduction events are probably due to their larger inertia associated with larger overburden at greater depth. Compared with normal earthquakes, the slip and rupture velocities of the slow-slip events are all smaller by many orders of magnitude, and the estimated S/L values are smaller by one or two orders of magnitude. Since S/L is proportional to stress drop, this result shows that the stress drops for the slow-slip events are one or two orders of magnitude smaller than normal earthquakes.

The long-term events have large variations in their kinematic values: slip of about 1–50 cm, duration of 50–2500 days, rupture length of 40–1000 km, width of 30–750 km, magnitude of 6.0–7.7, slip velocity of 0.01–0.10 cm/d, rupture velocity of 0.1–2 km/d, and S/L of 0.2–3. Compared with the short-term events, they have larger values in slip, duration, rupture length, and magnitude, comparable values in slip/rupture length ratios (thus stress drops) and smaller values in average slip and rupture velocities. This feature arose may be because they occurred closer to the seismogenic area of the plate interface [4], which has more asperities to hinder the rupture process or even to break them into smaller events, as shown in the cases of northeast Japan and Bungo Channel. Being more remote from the instruments, they are less distinguishable, thus giving an appearance of slower propagation. This possibility is further supported by some recent analysis of long-term events [109, 110].

The reason why slow-slip events and seismic tremors occur in the transition areas, both downdip and updip the seismogenic area, of a subduction interface (e.g., **Figure 5**) is not well known, but may possibly be understood by the following consideration of a five-stage evolution of a subducting seafloor, which consists of seamounts of different heights and strengths embedded in sediments at its surface. At the initial stage of subduction, while under the front edge of the accretionary wedge where the temperature and confining pressure are low, the effect of heterogeneity of sliding friction is small, and thus fault slip caused by crustal convergence proceeds in the form of aseismic stable sliding. When the same seafloor subducts further down and encounter larger confining pressure but still relatively low temperature, the friction at the stronger patches (seamounts) begins to show its stick-slip (velocity weakening) feature in sliding, while the sedimentary parts acts like (velocity strengthening) fault gouge. As a relatively strong asperity breaks under increasing shear stress, the rupture propagates slowly into a larger area of interface consists of weaker asperities embedded in compliant gouge materials, thus causing slow-slip events and small earthquakes in the transition zone updip the seismogenic area of the plate interface. When the same seafloor subducts further down to the seismogenic depth, where the confining pressure becomes sufficiently large while the temperature is not, the heterogeneity contrast becomes very sharp, and thus when a strong patch (asperity) breaks, it may cause a rupture to propagate rapidly into a large area of the interface, sweeping through smaller asperities embedded in compliant gouge materials and resulting in a large or even megathrust earthquake in the seismogenic area of the interface. When the seafloor subducts further down and encounter still larger confining pressure and higher temperature, the large asperities may have been worn down by now and become softened, while the surrounding fault-gouge materials further cumulated in volume and strength. When such a weaker asperity breaks, it encounters stronger resistance and thus may cause only a slowly rupturing event in the transition zone of the downdip area; as the rupture sweeps through some even smaller asperities, it may cause seismic tremors and perhaps small earthquakes. When the seafloor subducts further down and encounters still higher confining pressure and temperature at the deepest level of subduction, the asperities may have become sufficiently worn and softened and the gouge materials further cumulated; the frictional heterogeneity may finally become insignificant and thus the sliding becomes stable again.

What further directions should be pursued? Besides acquiring additional high-quality data through more continuous monitoring efforts closer to the events, it is important to analyze the data with appropriate faulting models to better understand the mechanics of slow-slip events and their role as a silent agent in stress adjustment along fault zones. Such knowledge should help us to better understand the occurrence pattern of earthquakes, such as foreshocks, main shocks, aftershocks, earthquake swarm, and earthquake migration [111], as well as crustal deformation without earthquakes [112]. It may also help us better understand the mechanisms of various earthquake-related hydrological, geochemical, and geophysical changes [16]. Together with better monitoring efforts of such changes, especially those that precede earthquakes [14, 15], it may finally be possible to predict some destructive earthquakes and aftershocks.

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