2024 Noto Peninsula Earthquake

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PRELIMINARY VIRTUAL RECONNAISSANCE REPORT (PVRR)

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DEDICATION

This report is dedicated to the memory of all those who lost their lives in the January 1, 2024 earthquake in Japan and in solidarity with those who were injured or displaced by this event. We also wish to honor those who labored tirelessly to rescue as many as possible under extremely challenging conditions. This report is a symbol of our ongoing commitment to learn from this disaster and work with colleagues in the region to build more resilient communities in the future.

PREFACE

The National Science Foundation (NSF) awarded an EAGER grant (CMMI 1841667) to a consortium of universities to form the Structural Extreme Events Reconnaissance (StEER) Network (see https://www.steer.network for more details). StEER was renewed through a second award (CMMI 2103550) to further enhance its operational model and develop new capabilities for more efficient and impactful post-event reconnaissance. StEER builds societal resilience by generating new knowledge on the performance of the built environment through impactful post-disaster reconnaissance disseminated to affected communities. StEER achieves this vision by: (1) deepening structural engineers' capacity for post-event reconnaissance by promoting community-driven standards, best practices, and training, as well as their understanding of the effect of natural hazards on society; (2) coordination leveraging its distributed network of members and partners for early, efficient and impactful responses to disasters; and (3) collaboration that broadly engages communities of research, practice and policy to accelerate learning from disasters.

Under the banner of the Natural Hazards Engineering Research Infrastructure (NHERI) CONVERGE node, StEER works closely with the wider Extreme Events Reconnaissance consortium to promote interdisciplinary disaster reconnaissance and research. The consortium includes the Geotechnical Extreme Events Reconnaissance (GEER) Association and the networks for Interdisciplinary Science and Engineering Extreme Events Research (ISEEER), Nearshore Extreme Event Reconnaissance (NEER), Operations and Systems Engineering Extreme Events Research (OSEEER), Social Science Extreme Events Research (SSEER), and Sustainable Material Management Extreme Events Reconnaissance (SUMMEER), as well as the NHERI RAPID equipment facility, the NHERI Network Coordination Office (NCO), and NHERI DesignSafe CI, curation site for all StEER products.

While the StEER network currently consists of the three primary nodes located at the University of Notre Dame (Coordinating Node), University of Florida (Southeast Regional Node), and the University of California, Berkeley (Pacific Regional Node), StEER is currently expanding its network of regional nodes worldwide to enable swift and high-quality responses to major disasters globally.

StEER's founding organizational structure includes a governance layer comprised of core leadership with Associate Directors for each of the primary hazards as well as cross-cutting areas of Assessment Technologies and Data Standards, led by the following individuals:

- **Tracy Kijewski-Correa (PI),** University of Notre Dame, serves as StEER Director responsible for overseeing the design and operationalization of the network and representing StEER in the NHERI Converge Leadership Corps.
- **Khalid Mosalam (co-PI),** University of California, Berkeley, serves as StEER Associate Director for Seismic Hazards, serving as the primary liaison to the Earthquake Engineering community.
- **David O. Prevatt (co-PI),** University of Florida, serves as StEER Associate Director for Wind Hazards, serving as the primary liaison to the Wind Engineering community.
- **Ian Robertson (co-PI),** University of Hawai'i at Manoa, serves as StEER Associate Director for Coastal Hazards, serving as a primary liaison to the coastal engineering community and ensuring a robust capacity for multi-hazard assessments.
- **David Roueche (co-PI),** Auburn University, serves as StEER Associate Director for Data Standards, ensuring StEER processes deliver reliable and standardized reconnaissance data suitable for re-use by the community.

This core leadership team works closely with StEER Research Associates, Data Librarians, and its Student Administrator in event responses, in consultation with its Advisory Boards for Coastal, Seismic, and Wind Hazards.

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ATTRIBUTION GUIDANCE

Reference to PVRR Analyses, Discussions or Recommendations

Reference to the analyses, discussions, or recommendations within this report should be cited using the full citation information and DOI from DesignSafe (these are available at https://www.steer.network/responses).

Citing Images from this PVRR

Images in this report are taken from public sources or were acquired by DPRI members. Each figure caption specifies the source; re-use of the image should cite that source directly. Note that public sources might still have copyright issues and depending on the use case, the user may need to secure additional permissions/rights from the original copyright owner.

ACKNOWLEDGMENTS

Conducting post-earthquake reconnaissance is critically important to observe, document, and analyze the seismic performance of built and natural environments. While experimental work in the laboratory and analytical modeling is extremely valuable, we will continue to rely on post-earthquake reconnaissance for many years to come to learn about and understand the effects of earthquakes on full-scale three-dimensional structures in the field, which provides the ultimate test of our progress in mitigating the effects of earthquakes on society. Hence, post-earthquake reconnaissance is at the very core of the mission of the Structural Extreme Events Reconnaissance (StEER) Network.

This report is the result of collaborative work and contributions by participants from the Disaster Prevention Research Institute (DPRI) and Graduate School of Global Environmental Studies (GSGES) of Kyoto University, the StEER Network, and the Pacific Earthquake Engineering Research (PEER) Center. All authors and editors listed on the cover page participate as volunteer professionals. Thus, any opinions, findings, conclusions, or recommendations expressed herein are those of the individual contributors and do not necessarily reflect the views of their employer or other institutions and organizations with which they affiliate.

The authors also thank Keegan Wolohan, StEER Program Manager, for his assistance in formatting and publishing this report.

The field and virtual surveys in Japan were supported by JSPS KAKENHI Grant Numbers 21H04598 and 23KK0080. Special thanks to Nishino Tomoaki from DPRI for his contribution to Section 7.2 about the fire that occurred in the coastal city of Wajima.

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Common Terms & Acronyms

Acronym	General Terms	Brief Description
--	DesignSafe	Data Repository
--	DesignSafe-CI	Academic Organization within NHERI
ASCE	American Society of Civil Engineers	Professional Organization
ASTM	American Society for Testing and Materials (now ASTM International)	Standards Body
ATC	Applied Technology Council	Professional Organization
BOCA	Building Officials and Code Administrators	Code Body
CC-BY	Creative Commons Attribution License	Code/Standard
CESMD	Center for Engineering Strong Motion Data	Governmental Agency
CI	Cyberinfrastructure	Research Asset
CLPE	Critical Load Path Elements	StEER Term
CMU	Concrete Masonry Unit	Building Material
DBE	Design Basis Earthquake	Design Terminology
DEQC	Data Enrichment and Quality Control	StEER Term
DOI	Digital Object Identifier	Common Term
EARR	Early Access Reconnaissance Report	StEER Term
EERI	Earthquake Engineering Research Institute	Professional Organization
EEFIT	Earthquake Engineering Field Investigation Team	Professional Organization
EF	Enhanced Fujita Scale	Hazard Intensity Scale
EF	Equipment Facility	Academic Organization within NHERI
EIFS	Exterior Insulation Finish System	Building Component
FAA	Federal Aviation Administration	Governmental Agency
FAQ	Frequently Asked Questions	Common Term
FAST	Field Assessment Structural Team	StEER Term
FEMA	Federal Emergency Management Agency	Governmental Agency
GEER	Geotechnical Extreme Events Reconnaissance	Academic Organization within NHERI
GPS	Global Positioning System	Measurement Technology

GSA	Government Services Administration	Governmental Agency
HVAC	Heating, ventilation, and air conditioning	Building System
HWM	High Water Mark	Intensity Measure
IBC	International Building Code	Code/Standard
ICC	International Code Council	Code Body
IRC	International Residential Code	Code/Standard
ISEEER	Interdisciplinary Science and Engineering Extreme Events Research	Academic Organization within NHERI
LiDAR	Light Detection and Ranging	Measurement Technology
MCE	Maximum Considered Earthquake	Design Terminology
ME&P	Mechanical, electrical, and plumbing	Building System
MMI	Modified Mercalli Intensity	Hazard Intensity Scale
NBC	National Building Code	Code/Standard
NEER	Nearshore Extreme Event Reconnaissance	Academic Organization within NHERI
NFIP	National Flood Insurance Program	Government Program
NHERI	Natural Hazards Engineering Research Infrastructure	Academic Organization within NHERI
NIST	National Institute of Standards and Technology	Governmental Agency
NOAA	National Oceanic and Atmospheric Administration	Governmental Agency
NSF	National Science Foundation	Governmental Agency
NWS	National Weather Service	Governmental Agency
OSB	Oriented strand board	Construction Material
OSEEER	Operations and Systems Engineering Extreme Events Research	Academic Organization within NHERI
PEER	Pacific Earthquake Engineering Research Center	Academic Organization (Earthquakes)
PGA	Peak Ground Acceleration	Intensity Measure
PHEER	Public Health Extreme Events Research	Academic Organization within NHERI
PVRR	Preliminary Virtual Reconnaissance Report	StEER Term
QC	Quality Control	Oversight process
RAPID	RAPID Grant	Funding Mechanism

RAPID-EF	RAPID Experimental Facility	Academic Organization within NHERI
RC	Reinforced Concrete	Building Material
SAR	Search and Rescue	Standard Hazards Terminology
SGI	Special Government Interest	FAA Process
SLP	Surface-Level Panoramas	Measurement Technology
SMS	Short Message Service	Communication Modality
SPC	Storm Prediction Center	Governmental Agency
SSEER	Social Science Extreme Events Research	Academic Organization within NHERI
StEER	Structural Extreme Events Reconnaissance network	Academic Organization within NHERI
SUMMEER	SUstainable Material Management Extreme Events Reconnaissance	Academic Organization within NHERI
TAS	Testing Application Standard	Technical Standard
UAS/V	Unmanned Aerial Survey/System/Vehicle	Measurement Technology
USD	US Dollar	Standard Currency
USGS	United States Geological Survey	Governmental Agency
VAST	Virtual Assessment Structural Team	StEER Term
WS	Windshield Survey	Measurement Technology

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EXECUTIVE SUMMARY

On January 1, 2024, a powerful earthquake with a magnitude of Mj 7.6 (Mw 7.5) struck the Noto Peninsula in Japan, at a focal depth of 10 km. This seismic event was characterized by a significant under-ocean fault rupture over 100 km, leading to major crustal deformation, strong ground motion, and a tsunami, with a notable 4.0 m uplift of the ocean floor.

The Japan Meteorological Agency (JMA) recorded a maximum intensity of 7 on their scale in Sika Town and Wajima City, with substantial impacts felt up to 300 km away. Ground motion parameters such as Peak Ground Acceleration (PGA) and Peak Ground Velocity (PGV) exceeded 1,000 cm/s² and 100 cm/s, respectively, suggesting potential structural damage beyond the design basis for extremely rare seismic events. Acceleration and displacement spectra at the sites with extensive building and lifeline damage show high response in the 1.0-2.0 sec range, likely due to relatively soft soil conditions.

The earthquake severely impacted Ishikawa Prefecture, damaging at least 96,000 structures, including traditional timber houses, historical temples, and shrines. Damage was exacerbated by soft soil conditions, particularly affecting aged timber housing and low-rise non-ductile reinforced concrete (RC) buildings. Steel buildings generally survived the shaking unless they had poor welding details. Significant damage to steel structures also included buckling of braces in parking structures and damage to cladding materials.

The region's infrastructure suffered extensive damage. Roads and tunnels were compromised by slope failures and landslides, and 60 of the 69 fishing ports in Ishikawa were damaged, affecting local industries. Due to Japan's stringent 1995 earthquake design and retrofit regulations, school and public buildings, including those with seismic retrofits, generally withstood the earthquake. However, some RC buildings experienced damage, such as diagonal shear cracking and joint region damage. Meanwhile, medical facilities faced significant challenges, particularly from water supply disruptions that affected critical services like dialysis. The need for external medical assistance persisted for over two months due to the deteriorated functionality of local hospitals.

The tsunami caused by the earthquake led to extensive inundation in several towns, with a maximum inundation height of over 4 meters. It resulted in at least 26 fatalities in the affected areas, with tsunami fires complicating emergency responses in places like Wajima.

The early warning system managed to issue alerts within seconds of the initial P-wave. While the warning was less effective near the epicenter due to the rapid onset of S-wave shaking, the alert was issued at the start of the S-wave, which still gave advance notice of strong shaking.

This **Preliminary Virtual Reconnaissance Report (PVRR)** represents a collaboration between StEER and the Disaster Prevention Research Institute (DPRI) at Kyoto University to study the 2024 Noto Peninsula Earthquake. As DPRI had direct access to the affected areas, the PVRR uses both third party and DPRI-field-collected data to:

1. Provide an overview of the earthquake's intensity and tectonic setting to characterize the strong motion impacts to the built environment.
2. Overview the regulatory environment and construction practices in the affected area.
3. Synthesize preliminary reports of damage to buildings and other infrastructure.
4. Provide societal lessons learned and recommendations for continued study of this event by StEER and the wider engineering reconnaissance community.

1. Introduction

On January 1, 2024, at 4:10 pm local time, a magnitude Mw 7.5 earthquake occurred, with a focal depth of 10 km and epicenter coordinates of 37.498°N 137.242°E (Figure 1.1), at the Noto Peninsula of Japan (USGS, 2024). The earthquake was followed by aftershocks, including one larger than 6.0, and more than 10 larger than 5.0 (CNN, 2024). The earthquake resulted in very high strong shaking and led to the collapse of several buildings, interruptions to power and water, and disruptions to the community.

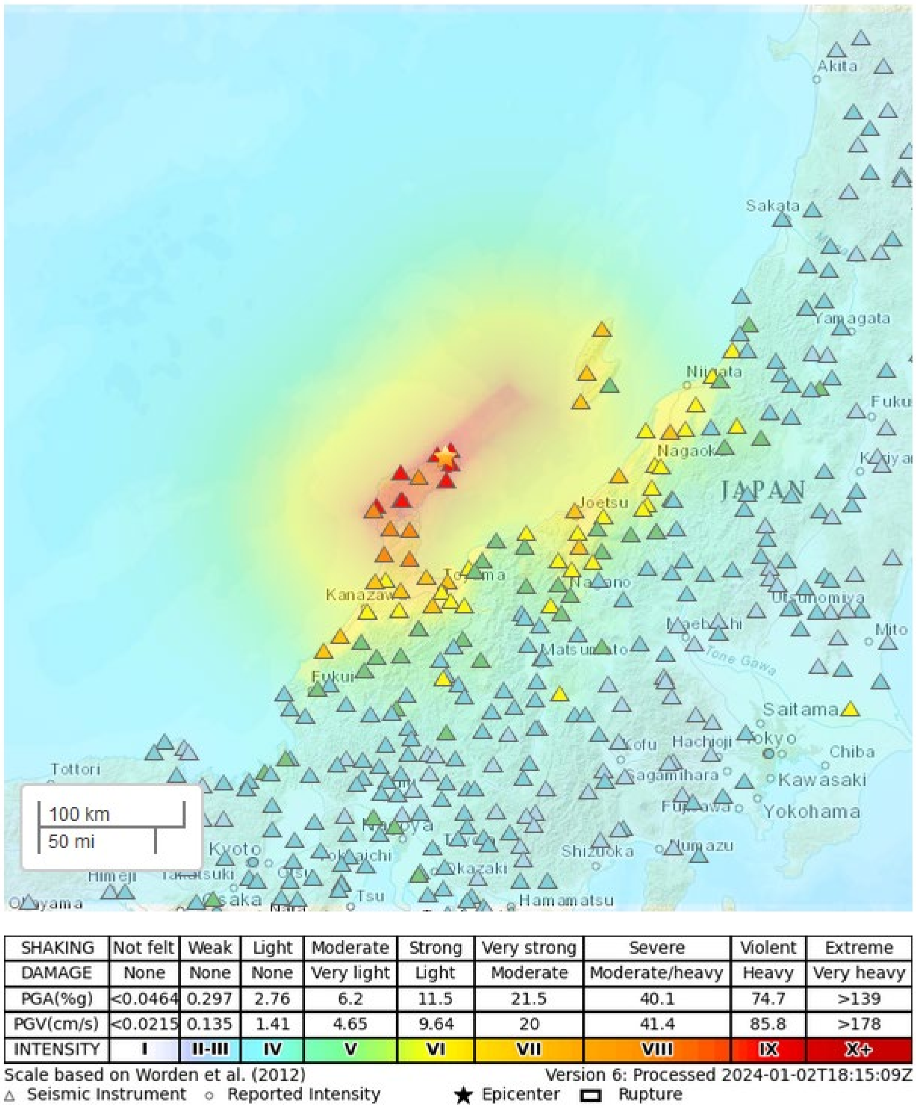


Figure 1.1. Location of the earthquake epicenter and estimated shaking intensity in the earthquake-impacted region (USGS, 2024).

1.1. Casualties and Injuries

As of April 12, 2024, 230 direct deaths and 15 disaster-related deaths were reported in the seven cities and towns of Nanao, Wajima, Suzu, Hakui, Shiga, Anamizu, and Noto in Ishikawa Prefecture following the 2024 Noto Peninsula earthquake (Ishikawa, 2024). Ishikawa Prefecture has been releasing the cause of death from this earthquake if the families of the victims agree. As of April 2024, two people were reported to have died due to the tsunami. However, reports in the press (NHK, 2024) indicate that at least 26 people died in the tsunami inundation zone, according to some investigative reports. The remaining majority of the deaths were attributed to collapsed buildings, with several due to landslides. USGS PAGER (USGS, 2024) estimated the fatalities to be from 1 to 10, 10 to 100, 100 to 1,000, and 1,000 to 10,000, with probabilities of 7%, 36%, 44%, and 13%, respectively (Figure 1.2).

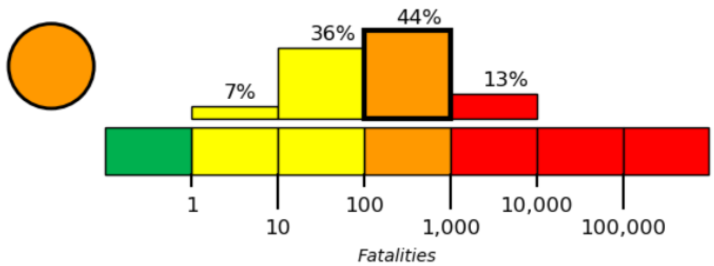


Figure 1.2. The number of fatalities estimated by PAGER for the earthquake (Source: USGS).

Aging population may have been a contributing factor. Wajima City and Suzu City suffered the most significant human casualties, and the Okunoto region, which includes these two cities, has a declining and aging population. According to Wajima City (2022), the population in 2022, the year before the earthquake, was 23,575, and the aging rate, which indicates the percentage of the population over 65 years old, was 47.6%. The city had a population of 30,508 in 2012, which means the population has decreased by 7,000 over the past ten years. Vacant houses are a problem in an aging society, and Wajima City (2018) reported that 19.1% of its houses were vacant in a survey conducted in 2018.

A similar situation was found in Suzu City, located at the tip of the Noto Peninsula near the epicenter. According to the statistics of Suzu City (2023), the population in 2022 is 12,947, and the aging rate is 51.1%, which is as high as that of Wajima City. Also, ten years ago, in 2012, the population was 16,643, and the aging rate was 40.6%, indicating that the population has decreased by more than 3,500 people and the aging population has rapidly increased over the past ten years. According to a vacant house survey conducted in 2020 (Suzu City, 2022), there were 1,490 vacant houses out of a total of 7,170 houses in the city, accounting for 20.7%.

The 2024 Noto Peninsula earthquake occurred in a region that can be seen as a microcosm of the various issues facing Japan, as the overall Japanese population has been declining since 2011, the aging of the population is approaching 30%, and vacant houses that are not well managed are becoming a problem in many areas.

1.2. Economic Losses

For the Mw 7.5 earthquake, PAGER estimated economic losses in USD from $10 to $100 million, $100 to $1,000 million, $1,000 to $10,000 million, $10,000 to $100,000 million, and greater than

100,000 million with probabilities of 8%, 27%, 38%, 21% and 5%, respectively, as shown in Figure 1.3 (USGS, 2024).

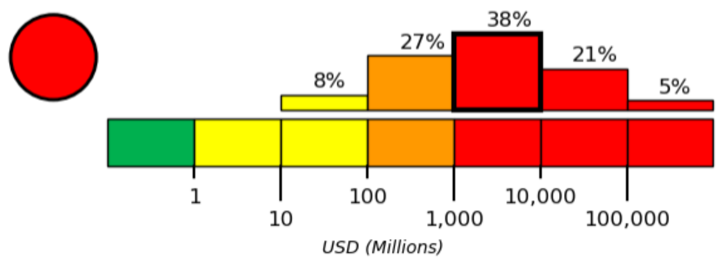


Figure 1.3. Estimated economic losses by PAGER for the earthquake (Source: USGS).

1.3. Official Response

The Japan Meteorological Agency (2024) issued an earthquake early warning at 16:10 and a tsunami warning for Niigata, Toyama, and Ishikawa prefectures at 16:12, approximately two minutes after the earthquake. At 16:22, the tsunami warning for Noto, Ishikawa Prefecture, was raised to a major tsunami warning.

The evacuation rate of residents at the time of the tsunami and tsunami warnings is not known. Still, there are reports of post-quake population movements based on smartphone location data. According to this report, for example, in the Iida and Nao areas of Suzu City, five minutes after the earthquake, the population was found to be moving from residential areas located along the coast toward Iida High School located on higher ground (i.e., evacuation behavior was considered to have taken place) (Yomiuri Shimbun, 2024a). In the Shimode district of Teraya, Misaki-cho, Suzu City, evacuation drills have been conducted continuously for more than ten years under the community slogan of gathering at a meeting place on high ground in case of emergency. As a result, about 40 households and all 80 people were saved (Mainichi Shimbun, 2024).

Overall, the communities succeeded in tsunami evacuation. However, some communities failed to confirm nearby residents' safety and evacuation status because community association members had evacuated to different locations. These communities established voluntary disaster prevention associations and regularly inspected their equipment but could not conduct sufficient evacuation drills due to the recent COVID-19 pandemic. As the earthquake occurred on January 1, the New Year's holiday, many households had young people returning home, and their families gathered, which is said to have allowed for the prompt evacuation of older people.

1.3.1 Evacuation Shelters

As of 10:00 on January 4, three days after the earthquake, Ishikawa Prefecture reported that there were 364 evacuation centers in the prefecture, sheltering 34,173 people (Ishikawa, 2024b). What was also noticeable in this disaster were evacuations to designated evacuation centers and voluntary evacuation centers, where people took refuge in so-called community meeting halls or agricultural greenhouses. About half of all evacuation centers are voluntary evacuation centers. It is believed that people are not moving to designated evacuation centers because "designated evacuation centers are flooded with people," "access to designated evacuation centers is difficult in mountainous areas due to roads being cut off," or "people want to stay in evacuation centers with their neighbors who they know well”. However, it is difficult for the government to assess the situation and understand the needs of voluntary evacuation centers, and as a result, relief supplies are sometimes not delivered.

As in previous disasters, issues such as privacy, nutritious food, water, toilets, bathing, and isolation of persons with fever have been observed in evacuation centers. In addition, a small number of young evacuees were taking care of a large number of older evacuees at evacuation centers in various areas, and people began to voice their concerns several days after the disaster, saying that it was difficult to continue taking care of a large number of older people.

The number of administrative staff in each town and village is limited; they are also victims of the disaster. The burden on local staff is heavy, and they continue to be exhausted. The city of Kobe and other cities that have experienced similar challenges providing disaster support for their administrative staff.

Attention is now shifting to temporary housing units. According to media reports on February 3, Wajima City plans to have 1,300 units completed and occupied by the end of March. Still, the supply has not kept pace with the 9,000-unit demand. The city now struggles to secure land for emergency temporary housing due to the vast area affected and the lack of flat land (Nihon Keizai Shimbun, 2024).

1.3.2 Wide-Area Evacuation

In the 2016 Kumamoto earthquake, there were 218 earthquake-related deaths compared to 50 direct deaths. In the 2024 Noto Peninsula earthquake, the risk of earthquake-related deaths due to poor shelter conditions was considered high. However, the number of related deaths reported so far is not as high as during the Kumamoto earthquake. Future research is needed to determine the extent to which wide-area evacuation (secondary evacuation), which was prominent in the recent disaster, contributed to reducing earthquake-related deaths.

There were two major patterns of wide-area evacuation. The first were cases where the evacuees had family members or relatives in Kanazawa City or outside of the prefecture in urban areas unaffected by the earthquake and took shelter there. The other was a wide-area evacuation supported by the government. At its peak in early February, more than 5,000 people were evacuated to 246 secondary evacuation centers (inns, hotels, etc.) (Ishikawa Prefecture, 2024c). In addition, more than 1,000 facilities were prepared to receive more than 30,000 evacuees as secondary shelter capacity.

Not all evacuees necessarily requested secondary evacuation, as evidenced by the available capacity of secondary evacuation centers. Some older people did not wish to seek secondary evacuation due to their connection to the land and the local community. According to a survey using smartphone location data, as of January 22, more than 30% of Wajima, Suzu City, and Noto Town residents are believed to have evacuated in a wide area (Yomiuri Shimbun, 2024b).

While wide-area evacuation is believed to have effectively prevented disaster-related deaths, it has also created challenges in the affected areas. The consent of owners is essential for the demolition and removal of collapsed houses and the use of various support systems. However, many people cannot contact the owners due to the wide-area evacuation, slowing down the recovery and reconstruction process.

1.4. Report Scope

StEER coordinated with colleagues in the Disaster Prevention Research Institute (DPRI) at Kyoto University to support their local response to this event. Deferring to DPRI colleagues, StEER did not activate the traditional Level 1 response to the 2024 Noto Peninsula Earthquake, but rather played a supporting role as DPRI began documenting the event. An official response page was instituted at the StEER website to house any products generated by this collaboration. Given DPRI's access to the affected area, this enabled a unique form of **Preliminary Virtual Reconnaissance Report (PVRR)** that included both third party and DPRI-field-collected data. The report is intended to:

1. provide an overview of the earthquake's intensity and tectonic setting to characterize the strong motion impacts to the built environment,
2. overview the regulatory environment and construction practices in the affected area,
3. synthesize preliminary reports of damage to buildings and other infrastructure,
4. provide societal lessons learned and recommendations for continued study of this event by StEER and the wider engineering reconnaissance community.

2. Hazard Characteristics

The seismic activity of Japan can be classified as moderate, driven by the underlying tectonic conditions described herein.

2.1. Tectonic Setting of Japan

The Japanese Islands belong to four tectonic plates, that is, the Okhotsk (or North America), the Eurasia (or Amurian), the Pacific, and the Philippine Sea plates (Figure 2.1). The former two continental plates are colliding in Honshu, the largest island of Japan. The Pacific Plate moves towards the WNW at a rate of about 8 cm/year and is subducted beneath the Kuril Arc and the Izu-Bonin (or Izu-Ogasawara) Arc (Wei and Seno, 1998). The Kuril, Japan, and Izu-Bonin Trenches are deeper than 6000 m in the region where the Pacific Plate is subducted. The Quaternary volcanoes lie parallel to these trenches and form a "volcanic front". In the north, subduction of the Pacific Plate is oblique to the Kuril Trench, causing a strike-slip movement along the Kuril Arc, which results in a local collision zone within the Okhotsk Plate in central Hokkaido.

While the oceanic plate boundary is located in the Pacific Ocean, earthquake activities are active also along the Japan sea coastline. MLIT (the Ministry of Land, Infrastructure, Transportation, and Tourism) held a survey committee for large-scale earthquakes in the Japan sea from 2013 to 2014. Using the under ocean fault tracing data, the committee set groupings of faults as shown in Figure 2.2 (MLIT 2014). Note that F43 to F46 surround the Noto Peninsula. Damaging earthquakes in recent years include the 1964 Niigata earthquake (Mw 7.5), 1983 Sea of Japan earthquake (Mw 7.7), 1993 Okushiri earthquake (Mw 7.8), 2004 and 2007 Niigata earthquakes (Mw 6.8) on the east side and on the west side, 1948 Fukui earthquake (Mw 7.1), and 2005 Fukuoka earthquake (Mj 7.0, Mw 6.6) (Figure 2.3).

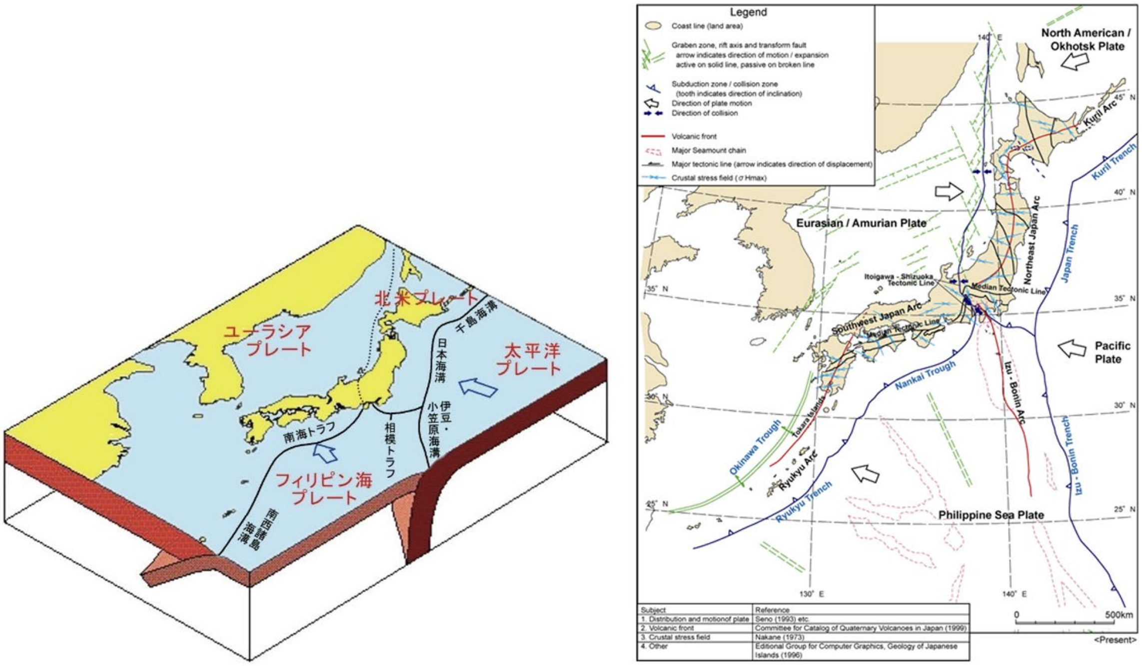


Figure 2.1. Current tectonic setting of Japan (HERP, 2024; NUMO, 2004).

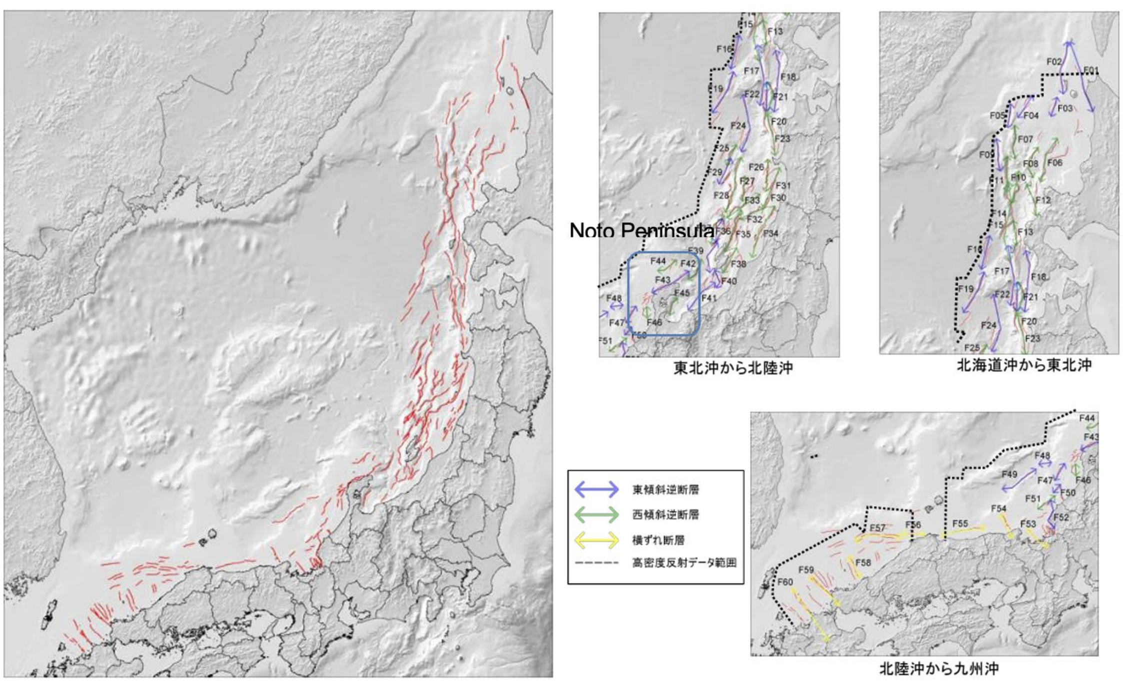


Figure 2.2. Under ocean faults along Japan sea coastline (MLIT, 2014).

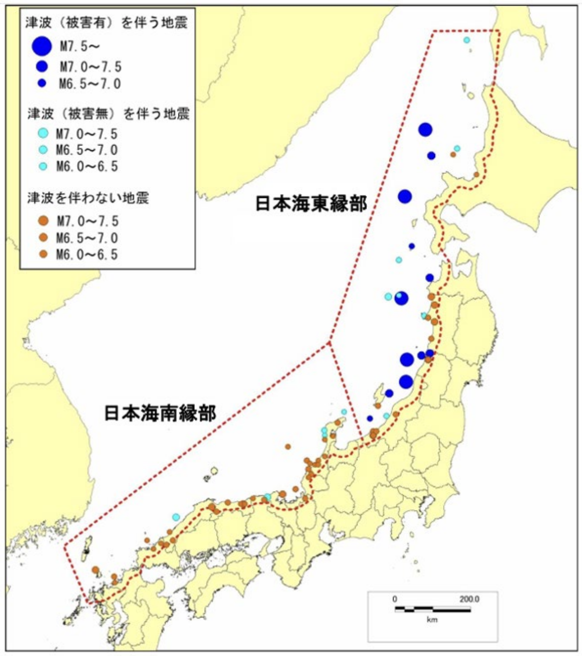


Figure 2.3. Distribution of historic earthquakes (M≥6) along Japan sea coastline (MLIT, 2014).

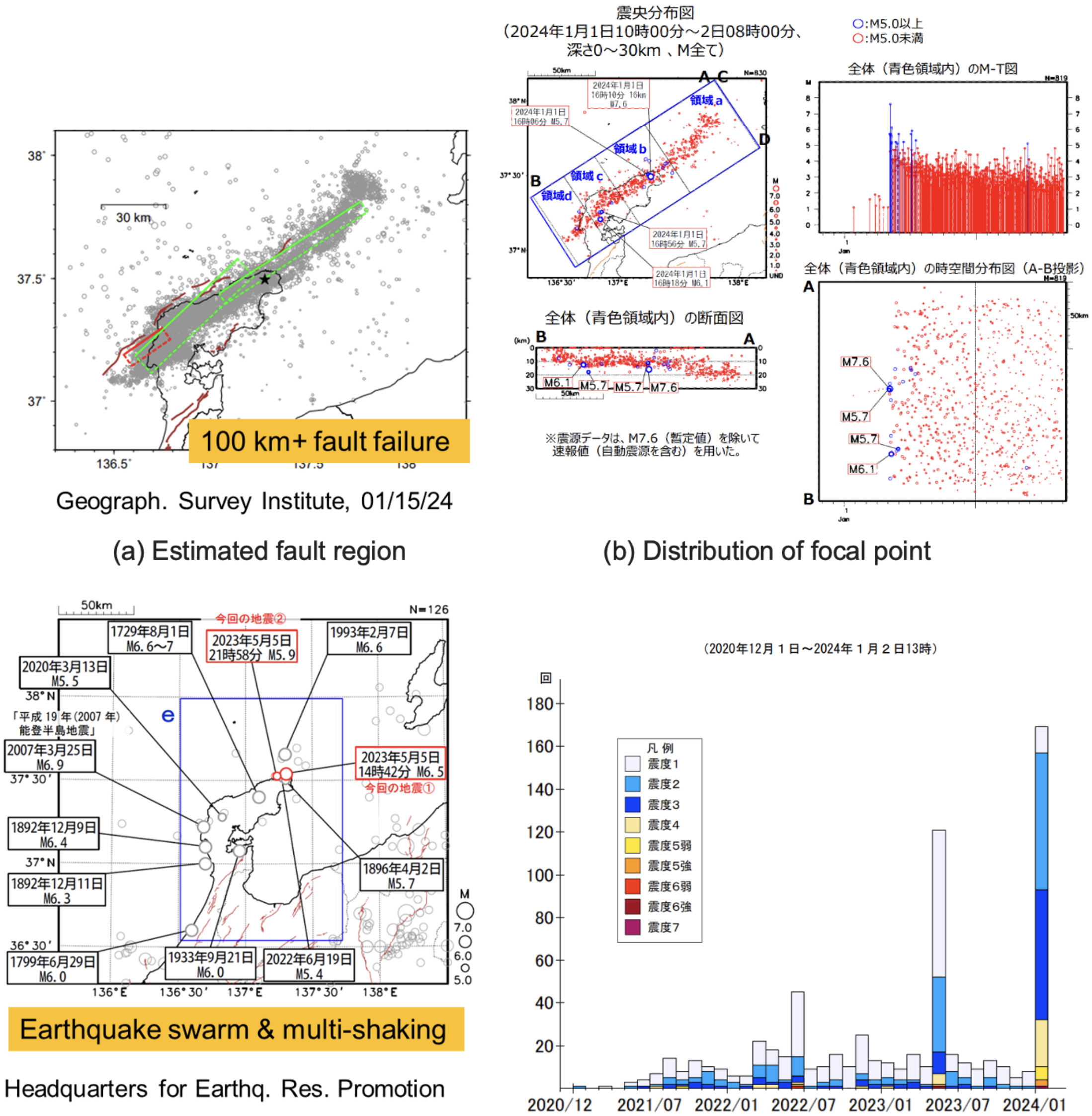
2.2. Earthquake Overview

At 16:10 on January 1, 2024, an earthquake of M7.6 (provisional value) occurred at a depth of about 15 km in the Noto region of Ishikawa Prefecture. Figure 2.4(a) shows the estimated fault region and aftershock distribution (GSI, 2024). Later, several researchers made source process estimations. One report suggests that the event was composed of two earthquake events of Mw 7.3 in 13 sec intervals (Asano, 2024). At the initial estimate, a fault with a length of over 100 km under the ocean failed and triggered crustal deformation, strong ground motion, and a tsunami. The focal mechanism was a reverse fault type with a northwest-southeast oriented pressure axis and occurred in the upper crust (Earthquake Headquarters, 2024). In the early investigation, the active fault known as F43, identified by past under-ocean exploration a dozen years ago or so, has been suspected as a potential fault. Later, by under ocean investigation, about 4 m uplift of the ocean floor was confirmed along the active fault.

The region has been known to produce earthquake swarms and multiple shaking. Figure 2.4(b) shows the past earthquake activity at the Noto peninsula depicting a recent earthquake in May 2023 (Earthquake Headquarters, 2023). The event in 2007 with Mj 6.9 resulted in severe damage to old traditional-style timber houses and some historical structures. More recently in 2023, two events took place at the location close to the estimated fault region of the 2024 earthquake. These events again damaged old traditional-style timber houses in the region.

Figure 2.5 shows the seismic intensity map published immediately after the event using ground motion records (Earthquake Headquarters, 2024). The Japan Meteorological Agency initially announced that the maximum intensity of 7 on the JMA intensity scale was observed at Sika town. On January 25, JMA modified the intensity of Wajima city to 7, with three ground motion records obtained later. The regions with a seismic intensity of 6+ include Suzu City, Nanao City, and

Anamizu Town. These cities and towns are located along the coastline. The population of the Noto region was approximately 166K in October 2023, which was 17% smaller than the population in October 2013. The affected area intensity extended 300 km in width, including areas with intensity of 5 or more in Ishikawa, Fukui, Toyama, and Niigata prefectures (Figure 2.5(b), Table 2.1). The ground motion becomes severe at some sites with relatively large site amplifications reaching seismic intensity of over 5. The sites with intensities of 5+ include several large cities at the coastline, which suffered from building damage, tsunami impacts, and liquefaction. For comparison, the area affected by the 2017 Osaka Hokubu earthquake with Mj 6.1 is provided as an inset to Figure 2.5. The earthquake in 2017 paralyzed the Osaka metropolitan area with a population of 2.6 million, inducing tremendous economic loss.



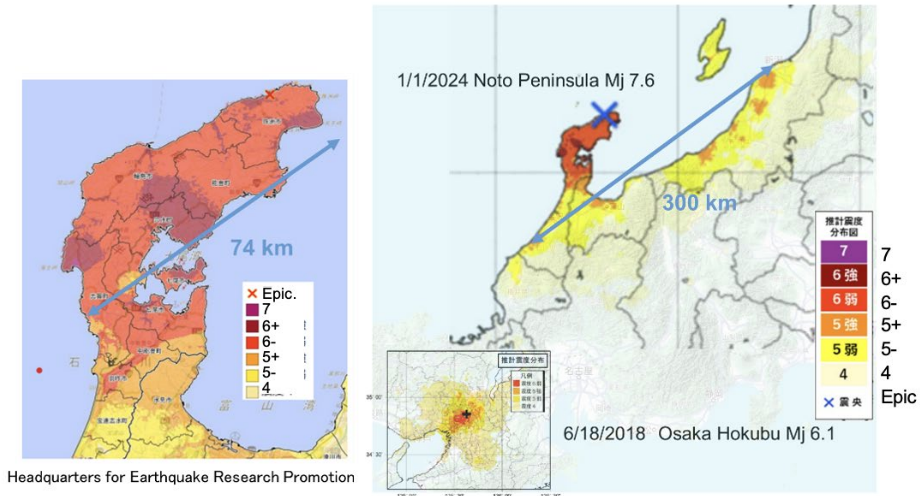
(a) Estimated fault region

(b) Distribution of focal point

(c) Past EQ activity at the peninsula

(d) Recent EQ activities at Noto peninsula

Figure 2.4. Fault failure and epicenter (Earthquake Headquarters, 2023 and 2024; JMA, 2024).



(a) Noto peninsula, Ishikawa prefecture (b) Affected prefectures

Figure 2.5. Seismic intensity map (Earthquake Headquarters, 2024).

Table 2.1. Intensity by municipality.

Prefecture	Intensity	Municipality
Ishikawa	7	Shika Town, Wajima City
	6+	Nanao City, Suzu City, Anamizu Town, Noto Town
	6-	Naka-Noto Town
	5+	Kanazawa City, Komatsu City, Kaga City, Hakui City, Kahoku City, Nomi City, Hodatsu-Shimizu Town,
Niiagata	6-	Nagaoka City
	5+	Niigata-Chuo Ward, Niigata-Minami Ward, Niigata-Nishi Ward, Niigata-Nishiura Ward, Sanjo City, Kashiwaazaki City, Mituke City, Tsubame City, Itoigawa City, Myoko City, Joetsu City, Sado City, Minami-Uonuma City, Aga Town, Kariwa Village
Toyama	5+	Toyam City, Takaoka City, Himi City, Oyabe City, Nanto City, Isui City, Funahashi Village
Fukui	5+	Awara City

2.3. Recorded Ground Motion

Figure 2.6 shows the estimated peak ground acceleration (PGA) and peak ground velocity (PGV) using K-NET and Kik-net strong motion records of the National Research Institute for Earth Science and Disaster Resilience (NIED) (NIED, 2024). At some sites, PGA and PGV exceeded

1000 cm/s^2 and 100 cm/s, respectively, indicating probable damage to buildings and infrastructure. Figure 2.7 shows the locations of the K-NET ground motion stations in Ishikawa prefecture and the original ground motion records. The ground motions lasted around 40 sec.

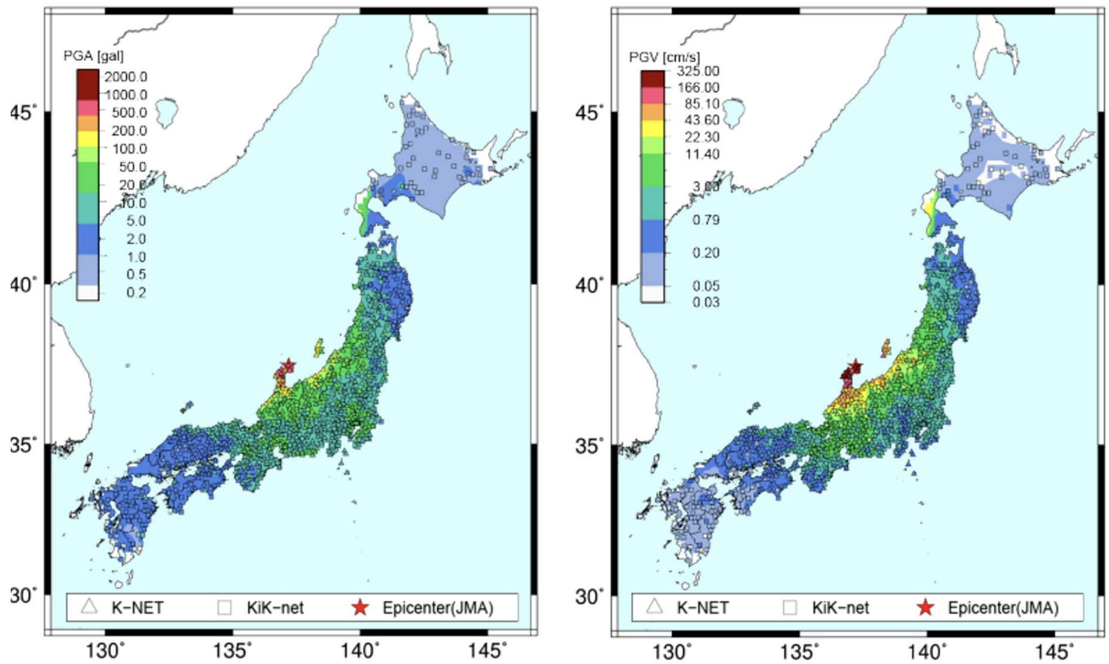
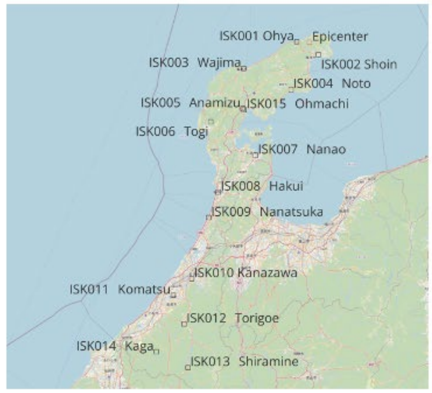
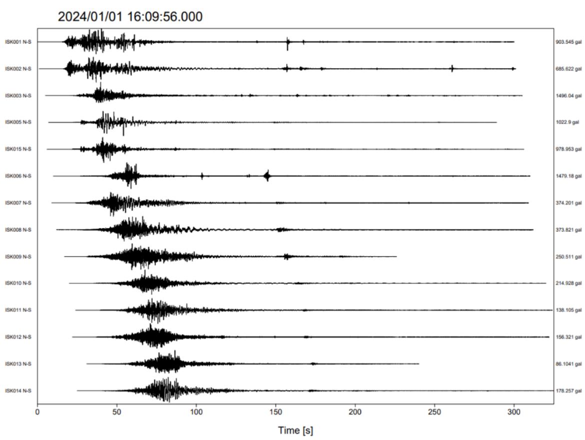


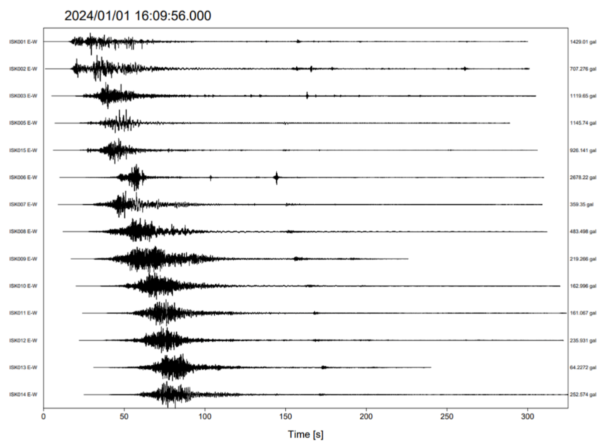
Figure 2.6. PGA and PGV estimated with K-NET and Kik-net strong motion records (NIED, 2024).



(a) K-NET strong motion stations



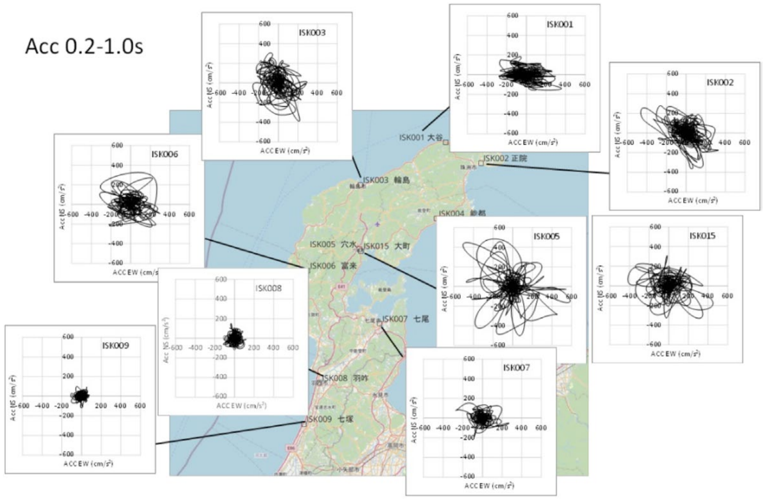
(b) NS direction



(c) EW direction

Figure 2.7. K-NET strong motion stations and ground motion records (Credit: M. Kurata).

The acceleration trajectory after applying the ground motion with a 0.1-2.0 sec bandpass filter is plotted in Figure 2.8. The EW components govern in the northeast areas close to the epicenter, while the dominant direction varies by location. Figure 2.9 shows the Pseudo acceleration-displacement spectra relationship. Suzu (ISK001), Wajima (ISK003), Anamizu (ISK005), and Nanao (ISK007) suffered extensive building damage. The ground motions at these stations contain significant energy in the 1.0-2.0 sec range. For reference, site characteristics are shown in Figure 2.10. Note that the regions with severe structural damage have relatively soft soil conditions.



Acceleration trajectory (0.2-1.0s bandpass filtered)

Figure 2.8. Acceleration trajectories at multiple stations (Kurata, 2024).

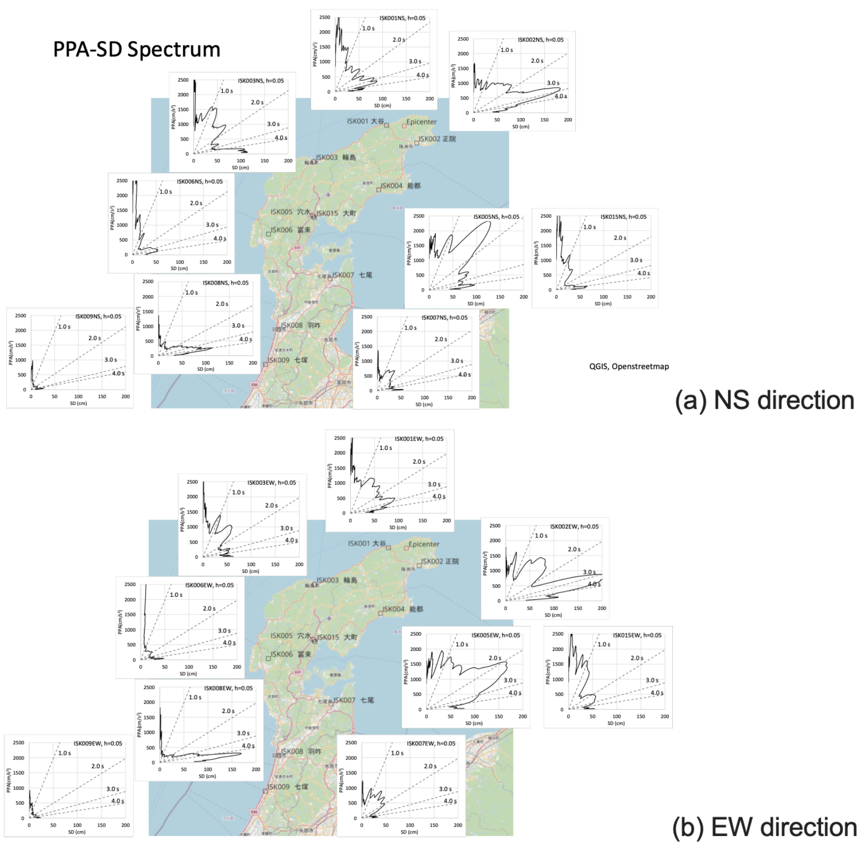


Figure 2.9. Pseudo acceleration vs displacement spectra at multiple stations (Credit: M. Kurata).

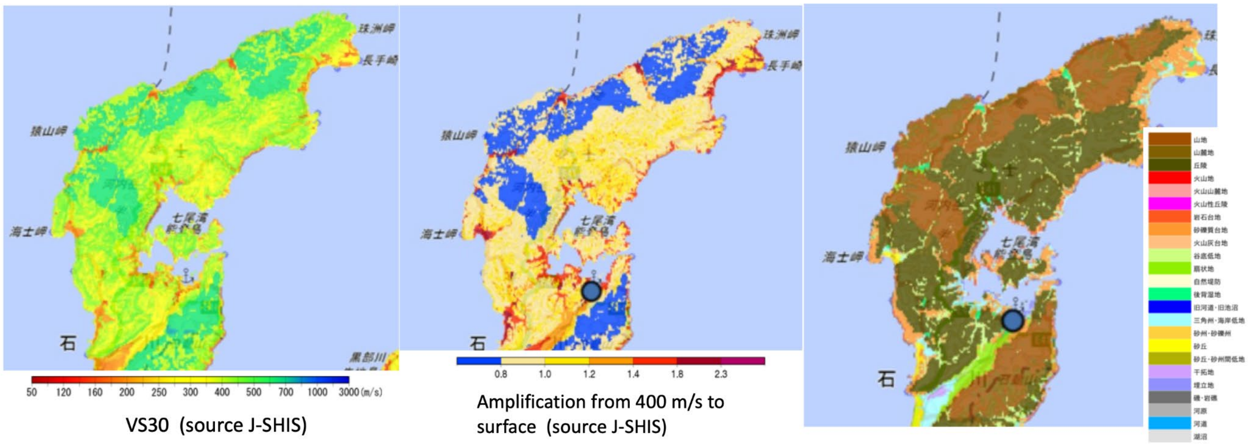


Figure 2.10. Site characteristics (J-SHIS, 2024).

2.4. Crustal Deformation

The earthquake caused extensive crustal deformation. Figure 2.11 shows the measured deformation by the Global Navigation Satellite System (GSI, 2024). In the area near Wajima City, the observed uplift reached 4.0 m.

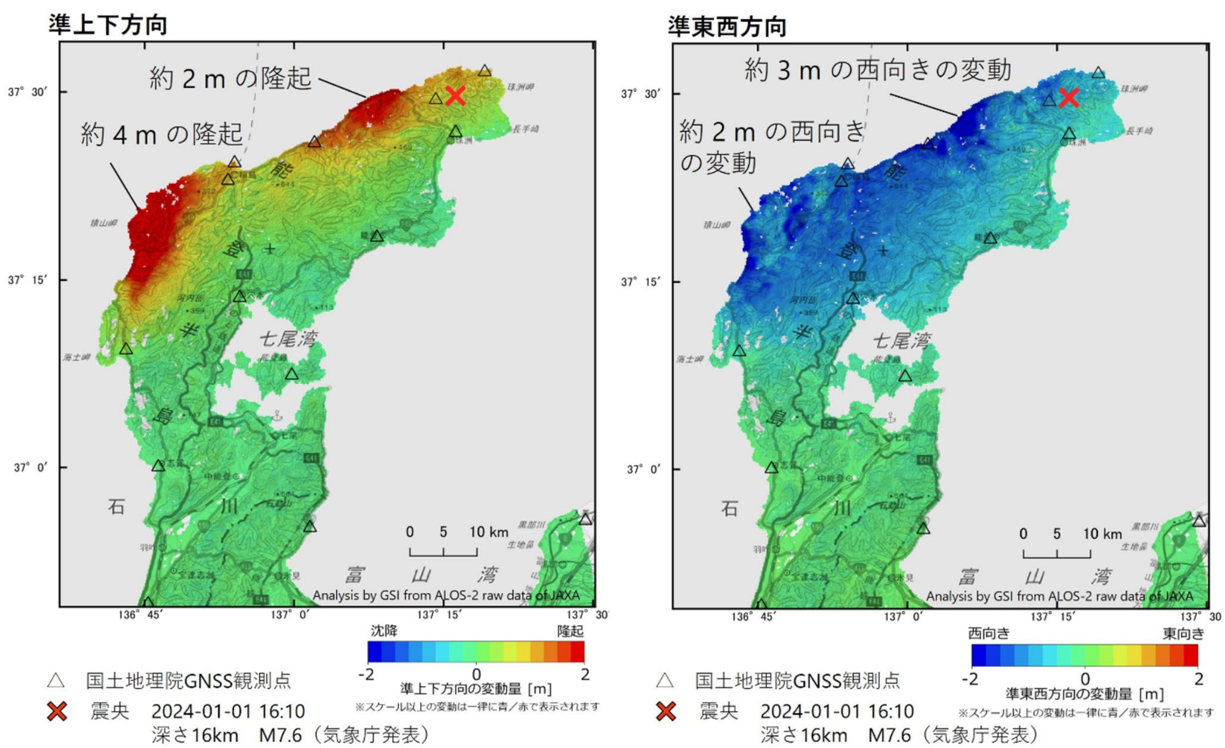


Figure 2.11. GNSS by Daichi 2 (Geographical Survey Institute, 2024).

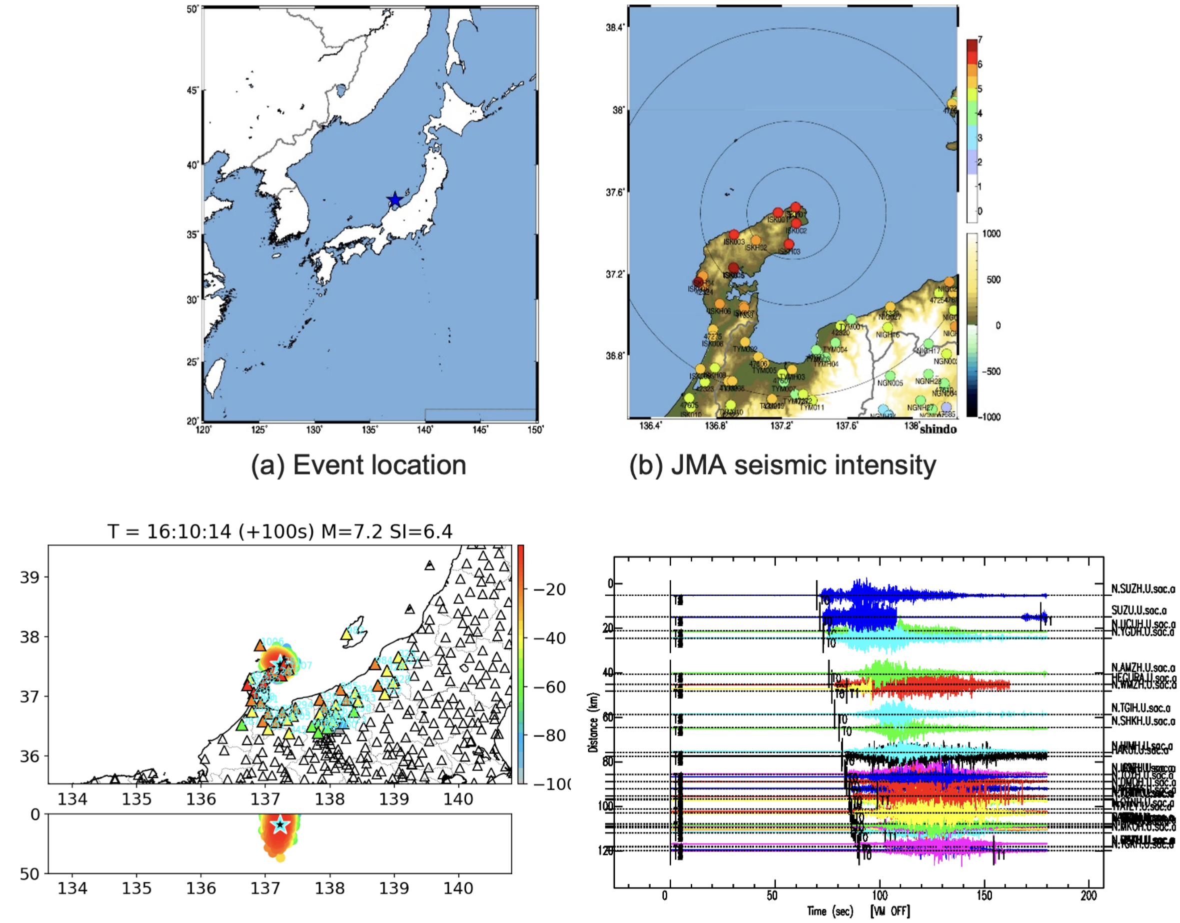
2.5. Early Warning

The earthquake early warning for the general public was sent out to the Noto region 6 seconds after the first P-wave was observed and seven seconds after the earthquake occurred. According to the JMA's warning history (Table 2.2), the earthquake early warning did not arrive before the S-wave in the 20-30 km range near the epicenter. However, considering that the shaking lasted for several minutes, the fact that the warning was issued at the beginning of the S-wave still provided ample notice to prepare for strong shakings.

In Japan, an earthquake early warning is issued when a seismic intensity of 5- or higher is expected. To specific users, an earthquake early warning forecast is issued when a seismic intensity of 3 or higher is expected, or when the amplitude of P- or S-waves measures more than 100 gals. The earthquake early warning forecast is also shown on the JMA website, which also reports the performance of the earthquake early warning for the 2024 Noto peninsula earthquake (see JMA website). Yamada (2024) computed the location and shaking intensity from the continuous seismic record by using the IPFx method (Yamada et al., 2021). Figure 2.12 shows the event location and shaking intensity at the stations used for the simulation. The simulation results of the IPFx method illustrate the time history of source parameter estimates. The warning time and estimation accuracy are similar to the JMA earthquake early warning system.

Table 2.2. Earthquake early-warning reports

Info ID	**Origin Time**	**Maximum Intensity**	**JMA Magnitude**	**Epicentral Coordinates**		**Depth**	**Time to issue Report**
01	24/01/01-16:10:08	5+	M5.5	37.5N	137.2E	010 km	24/01/01-16:10:16
20	24/01/01-16:10:08	07	M6.6	37.5N	137.2E	010 km	24/01/01-16:10:43
30	24/01/01-16:10:08	07	M7.4	37.6N	137.2E	010 km	24/01/01-16:11:07
Source: The Committee of Earthquake Observation and Research in the Kansai Area							



(a) Event location (b) JMA seismic intensity

(c) Estimated location by the IPFx method (d) Seismic waveforms and P-wave arrivals

Figure 2.12. Earthquake early warning simulation by the IPFx method (Yamada, 2024).

3. Local Codes and Construction Practices

3.1. Local Codes and Acts

Seismic design was first included in building standards in Japan in 1924, after the Great Kanto Earthquake of 1923. Structural provisions include a seismic coefficient of 0.1, added to the Urban Building Law 1919. Since then, building standards have been revised in response to building damage in major earthquakes. In 1959, the Building Standards Law was introduced to replace Urban Building Law, and the standard value of the seismic coefficient was increased to 0.2 but did not change essential seismic design requirements, as a comparable increase in allowable stresses for various materials accompanies an increase in seismic loading. The latest major revision of building standards occurred in 1981 and incorporated a new seismic design method. Accordingly, buildings that are built after 1981 are deemed earthquake-resistant, but those built before 1981 need to have their seismic capacity evaluated based on the 1981 standards. Figure 3.1 summarizes the basic concept and new trends in Japanese structural design.

The new seismic design method was adopted in an amendment to the Buildings Standard Law. The old standard required buildings to minimize earthquake damage to minor ones in smaller and more frequent earthquakes. The new standard also required buildings not to collapse and to secure the safety of the people inside in rare and severe earthquakes, even if buildings may become deformed and not repairable. This methodology is called two-level design, where both strength and ductility indicators are considered, considering the ultimate lateral load-resisting capacity in the second level.

The 1995 Kobe Earthquake highlighted the vulnerability of buildings designed before the 1981 revision. The 1995 Act on Promotion of the Earthquake-proof Retrofit of Buildings (Okada et al., 2000) was prepared in response. This ACT has played a key role in the nationwide campaign for the seismic diagnosis and retrofit program targeting buildings built before 1981. The 1995 Kobe Earthquake also showed the need for a new generation of seismic design. New technical specifications were issued in 2000, including the definition of the performance objective: life safety and damage limitation of a building at two corresponding levels of earthquake motion (Midorikawa et al., 2003).

The 2011 Tohoku Earthquake highlighted some shaking-induced damage to nonstructural elements, including falling ceiling materials. In 2013, the Building Standards Law Enforcement Order was revised to include seismic considerations on the design and construction of nonstructural components. Also in 2013, the Act on Promotion of the Earthquake-proof Retrofit of Buildings was revised to obligate owners of certain buildings—including large-scale buildings such as hotels and buildings built alongside designated major roads that serve as access roads for emergency service vehicles—to undertake earthquake-resistant building inspections (Cabinet Office, 2015a).

The Building Standards Law specifies design loadings and allowable stresses for each material, along with minimum requirements for the detailing of members. Further details of structural design are specified in design standards issued by the Architectural Institute of Japan (AIJ) and "Commentary on the Structural Calculation based on the Revised Enforcement Order, Building Standards Law, (1981)" by MLIT and the Japan Conference of Building Administration.

The 2016 Kumamoto Earthquake highlighted the functional continuity of key facilities after earthquakes. In 2018, the Functional Continuity Guideline for Disaster Response Bases was issued by MLIT to enhance building design for government offices, hospitals, shelters, schools, etc., with higher performance in earthquake-resistant structures and foundations and lifeline resilience.

- New Building Law（1981）
  - Rare EQ (return period of appx. 50 yrs) → Level 1 Design: Serviceability Limit
  - Very rare EQ (return period of appx. 500 yrs) → Level 2 Design: Safety Limit
- Promotion of Seismic Retrofit（1995, 2006）: Diagnosis, Upgrading
  - Hospitals・Shops・Hotels（unspecified large #), Schools・Elderly care homes （Evacuation vulnerable）
  - Regional disaster response bases, Evacuation route
- Functional Continuity Guideline for Disaster Response Bases（2018）
  - Government offices, hospitals, Shelters, Schools, etc.
  - Higher performance with earthquake-resistant structures and foundations, lifeline resilience

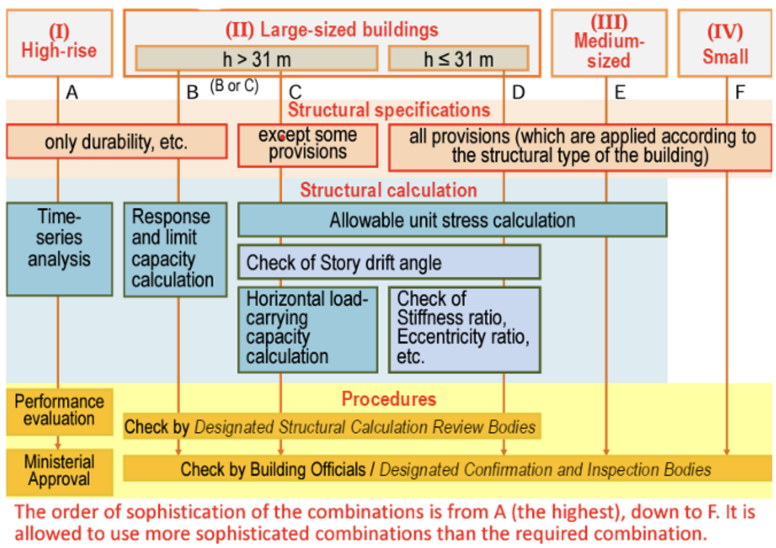
Figure 3.1. Basic concept and new trends in Japanese structural design.

3.2. Construction Practice and Structural Design Flow

The building category and the associated structural design are illustrated in Figure 3.2 (BCJ, 2013). Buildings are classified into four categories by height and scale, and further into wood and non-wood structures. The design flow varies with the building categories. Wood buildings damaged severely by the 2024 Noto Peninsula earthquake belong to category IV, while most severely damaged traditional-style timber houses do not comply with modern seismic codes. Structural designers select the design method of the structures following the design route shown in Figure 3.2(c).

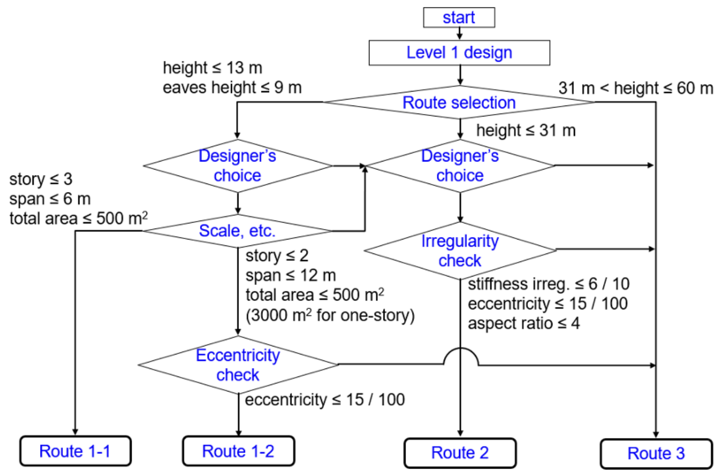
Categories (share)	Structure, height, and size of building: Wooden buildings	Structure, height, and size of building: Buildings other than wooden buildings
(I) High-rise buildings (0.1 %)	Building height ＞ 60 m	
(II) Large-sized Buildings (2.5%)	- Building height ＞ 13m, or - Eave height ＞ 9m, other than (I)	Any of the buildings below other than (I): - Steel buildings with 4 or more stories (excluding basement); - RC or SRC buildings of 20m or more in height, and - Buildings stipulated by the Cabinet Order, such as steel buildings more than 13 m in height or more than 9 m in eave height,
(III) Medium-sized buildings (25%)	- Number of stories ＞3, or - Total floor area ＞500 m² other than (I) and (II)	- Number of stories ＞2, or Total floor area ＞ 200 m², and - Masonry structure, etc. that are more than 13m in height and that have eaves of more than 9m in height. other than (I) and (II)
(IV) Small buildings (over 70%)	Buildings other than (I), (II) and (III). It means wooden buildings that conform to: - Number of stories ≦2; - Total floor area ≦500 m²; - Building height ≦13 m; and - Eave height ≦9 m.	Buildings other than (I), (II) and (III). 76

(a) Building category (BIJ, 2013)



(b) Check flow (BIJ, 2013)

Figure 3.2. Structural checks: (a) specification of building category.



(c) Design route

Figure 3.2. (con't) Structural checks: (b) check flow, and (c) design route used in Japanese codes.

3.3. Basic Structural Design

Allowable stress design (Level 1 design)

The story shear force in level 1 design is calculated using the following equation:

$$V = C_i W = Z R_t A_i C_0 W$$

The regional factor, Z, is obtained from Figure 3.3. Note that a hazard map based on seismological study is not used in the current Japanese design practice. The regional factor is under debate for potential updates in response to the 2016 Kumamoto and 2024 Noto Peninsula earthquakes that occurred in the zone with a regional factor of 0.9.

The dynamic factor, R_t, accounts for the relationship between site amplification and the structure's natural period. The corner period, T_c, is defined for each site category, as shown in Table 3.1.

$$R_t = \begin{cases} 1 & T < T_c \\ 1 - 0.2\left(\dfrac{T}{T_c} - 1\right)^2 & T_c \le T < 2T_c \\ 1.6T_c/t & 2T_c \le T \end{cases}$$

The following equation estimates the natural period of buildings.

$$T = \begin{cases} 0.02h & \text{for steel structures} \\ 0.03h & \text{for steel structures} \end{cases} \text{, where } h \text{ is the height of a building}$$

The ground period, T_c, is defined for each soil type as shown in Table 3.1. The coefficient A_i gives the vertical distribution of the story shear coefficient by the following equation.

$$A_i = 1 + \left(\frac{1}{\sqrt{\alpha_i}} - \sqrt{\alpha_i}\right)\frac{2T}{1+3T}$$

$\alpha_i = \sum_{j=i}^{N} w_j \,/\, \sum_{j=1}^{N} w_j$, where w_j is the weight of *j*-th floor

The standard base shear coefficient, C_0, is taken as 0.2 (if a two-level design is selected with Route 3) or 0.3 for Route 1 and 2. *W* is the total weight of the structure.

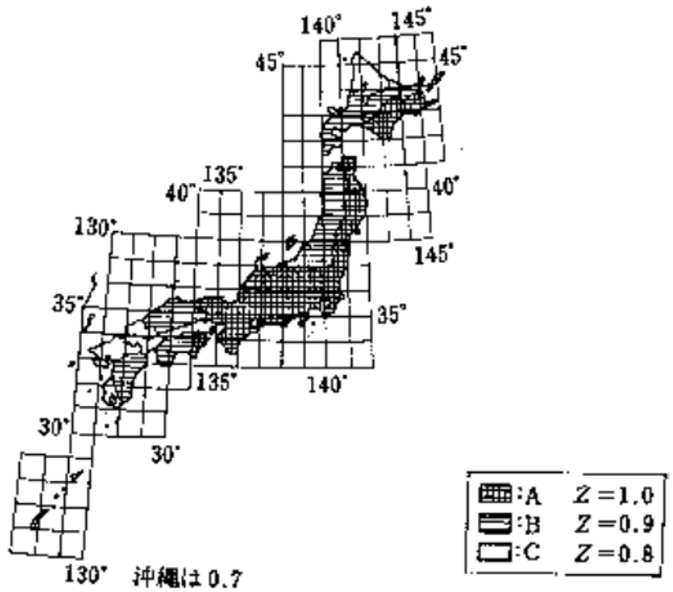


Figure 3.3. Regional factor (MLIT, 1980)

Table 3.1. Site category and ground period.

Site category	T_c
I	0.4
II	0.6
III	0.8

Horizontal load-carrying strength design (Level 2 design)

The horizontal load-carrying strength is calculated using the following equation:

$$Q_{un} = D_s F_{es} Q_{ud}$$

The structural characteristic coefficient, D_s, is selected by the structural type and shape. For reinforced concrete structures, D_s varies from 0.3 to 0.55, and for steel structures, it ranges from

0.25 to 0.5. The shape factor, F_{es} computed as the product of the stiffness continuity factor R_s and the eccentricity factor R_e. For buildings without ill-shaped stiffness distribution and eccentricity, F_{es} becomes 1.0.

The story shear force for large earthquakes, Q_{ud} , is calculated by the following equation.

$$Q_{ud} = C_i W_i = Z R_t A_i C_0 W_i$$

where W_i is the floor weight and the standard base shear coefficient C_0 is taken as 1.0.

Performance-Based Seismic Design Provisions (2000) (Midorikawa et al., 2004)

The seismic design provisions of buildings in Japan were revised toward a performance-based structural engineering framework in 2000. The provisions provide two performance objectives: life safety and damage limitation of a building at two corresponding levels of earthquake motion. The design earthquake motions are defined in terms of the acceleration response spectra specified at engineering bedrock (Figure 3.4) to consider the effects of soil conditions and soil-structure interaction as correctly as possible. The seismic performance shall be verified by comparing the predicted response values with the estimated limit values of a building. The verification procedures apply the equivalent linearization technique using an equivalent single-degree-of-freedom (ESDOF) system and the response spectrum analysis. The site amplification factors for site class I are reported in Table 3.2, while the site amplification factor can be computed from local site conditions and earthquake response analysis alternatively.

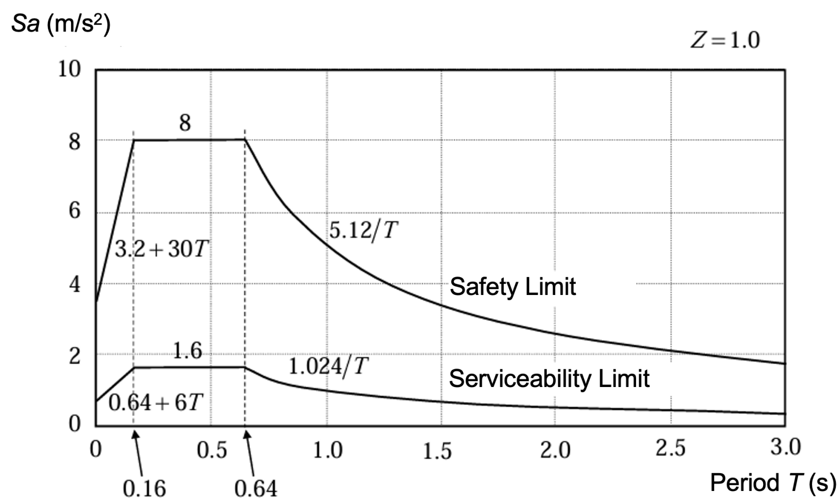


Figure 3.4. Acceleration Spectra at Engineering Bedrock in *Performance-Based Seismic Design Provisions* (*Z*=1.0).

Table 3.2. Site amplification factor (for site class I).

Period of building	G_s
$T < 0.576$	1.5
$0.576 \le T < 0.64$	$0.864/T$
$0.64 \le T$	1.35

4. Building Performance

At least 96,000 structures, including 74,000 houses, 190 public buildings, and 22,000 unspecified uses, were damaged across Ishikawa Prefecture (Ishikawa Prefecture, 2024). Included were 24,000, which were partially or completely destroyed. Many historical buildings, temples, shrines, and important cultural properties were also destroyed. Building damage rates were reported by the city council of Wajima on February 4 as: (1) Destructive = 2,218, (2) Very Severe and Severe = 1,446, and (3) Moderate and Slight = 2,809, out of 6,497 buildings surveyed buildings. For Suzu city, damage was reported as: (1) Destructive = 2,937, (2) Very Severe and Severe = 1,737, and (3) Moderate and Slight = 2,259, out of 7,612 buildings surveyed. These damage categories are based on inspections of the roof, walls, with component damage rated as Destructive for 50% or more, Very Severe for 40-50%, Severe for 20-40%, Moderate for 10-20%, and Slight for 10% or less. The following sections illustrate the performance of specific building subclasses.

4.1. Field Surveys

The DPRI team conducted a preliminary reconnaissance survey on January 13-14, followed on January 21-22 by a joint survey conducted with the collaborators at Nagoya and Tokyo Universities. The survey aimed to collect information on damage patterns around ground motion stations, behavior of non-wood structures, ground deformations, functionality of disaster response bases, and performance of other large buildings.

During the survey, the StEER Unified App in Fulcrum was used to record the surveyed building locations and collect media. Note that the damage ratings assigned were determined by rapid visual inspection and sole judgment of the researcher. GIS was used to aid post-survey analysis, merging building locations with other data on soil conditions, ground motion intensity, etc. Table 4.1 summarizes the individuals who participated in the survey. Figure 4.1 shows the surveyed area in Wajima city and the records as an example.

Table 4.1. Team collecting preliminary reconnaissance data.

Dates	Team Members
1/13-14/2024	Hiroyuki GOTO, Kimiyuki ASANO, Masumi YAMADA (DPRI)
1/21-22/2024	Takuya NAGAE (Nagoya U.)，Tatsuya ASAI (Tokyo U.)，Norihide TAKADA (Local constructor), Kazumori Ohta（Nagoya U., Grad. Student)

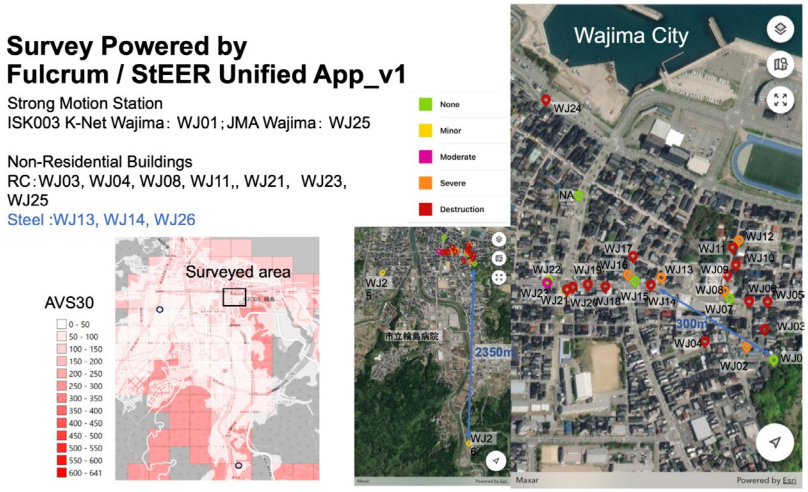


Figure 4.1. Sampling of records collected in Wajima City.

4.2. Design strength vs GM intensity

Figure 4.2 shows the acceleration spectra of the recorded motions and design strength for the 0.2-2.0 range period. The recorded motions exceeded the Level 1 strength at all the sites. In Wajima, Suzu, Anamizun, and Togi, the recorded motions' spectra exceeded or reached the Level 2 design strength. This provides important context for the interpretation of damage in the following sections.

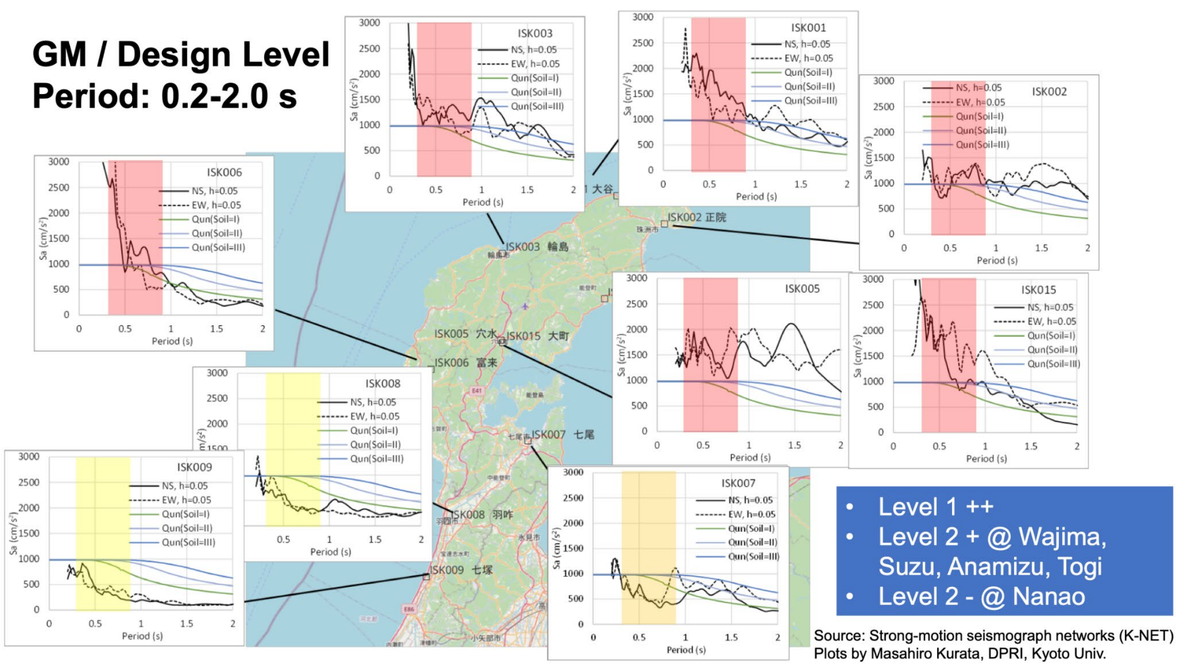


Figure 4.2. Acceleration response spectra against design spectra.

4.3. Residential Buildings

Figure 4.3 shows the drastically changed scenery in Ishikawa prefecture. The extremely high severe-to-collapse ratio for aged, traditional timber housing was notable at the sites with soft soil conditions. The road access to the affected site was quite limited due to landslides and pavement failure.

According to previous studies (e.g., Sakai, 2013), the 1-2 second components in ground motions correlate with damage to houses and low-rise buildings whose equivalent period after yielding corresponds to this period range. When these structures are subjected to severe damage, response amplification by resonance does not occur since hysteretic damping becomes large, and the maximum responses are known to occur with one pulse input. Figure 4.4 shows an illustration of a typical traditional timber house in a rural area of Japan. The traditional construction does not use hole-down anchors at the base and metal joints at the connections. As a result, the connections are semi-rigid, and the period of the building elongates significantly after the initial yield, reaching the 1-2 second period range.

Figure 4.3. Traditional building damage at the affected sites (Credit: Kurata and Yamada).

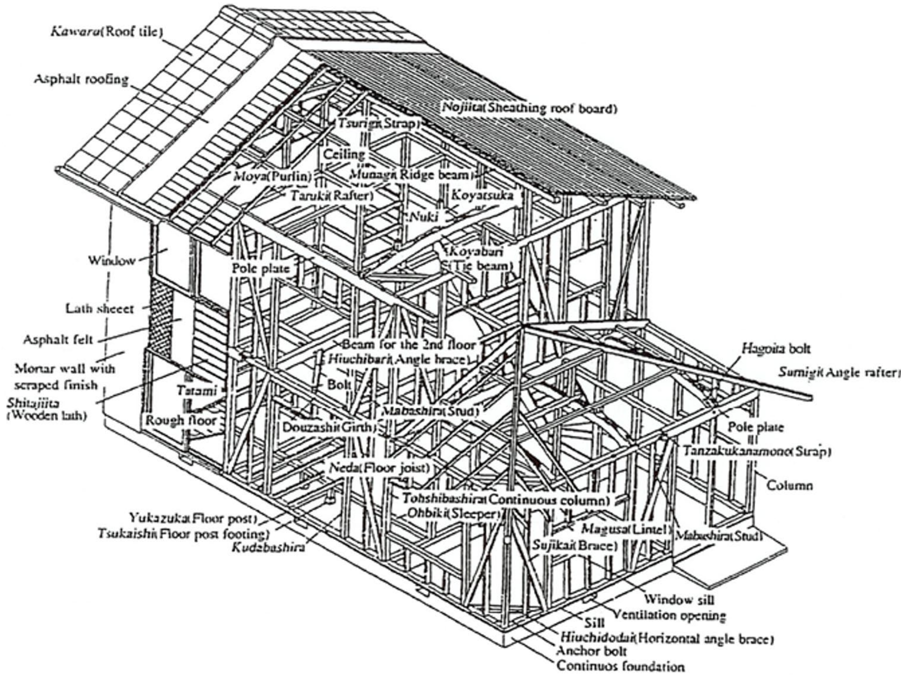


Figure 4.4. Traditional timber house in Japan (AIJ, 1995).

4.4. Concrete Buildings

Most reinforced concrete (RC) buildings in the affected area of the Noto peninsula are low-rise buildings with four or fewer stories. These RC buildings behaved well with limited damage except for a few with shear failures in their columns resulting in the collapse of the first story. However, as shown in Figure 4.5, ground deformation around the buildings and uneven settlement, primarily due to soft soil conditions, was typical at sites along the coasts. The overturned mid-rise building in Figure 4.5 is one exceptional case, and the cause of the collapse is still under investigation. These RC structures have pile foundations, but the piles of old buildings are not designed or well-designed against earthquakes and soft soils. Seismic diagnosis has been widely applied after the 1995 Kobe earthquake, but upgrades are typically only undertaken on superstructures.

Wakura-onsen town features a number of mid-to-high-rise buildings overlooking the hot springs and incredible scenery at the coastline. Since these buildings house a large number of occupants, seismic diagnoses are mandatory. Figure 4.6 shows the damage to such RC buildings. Due to soft soil conditions, many older RC buildings were tilted with uneven settlement. The ground motions likely reached close to the second-level design seismic force at the period of these structures. Some buildings also suffered from nonstructural wall damage, but severe damage to columns and beams was not observed.

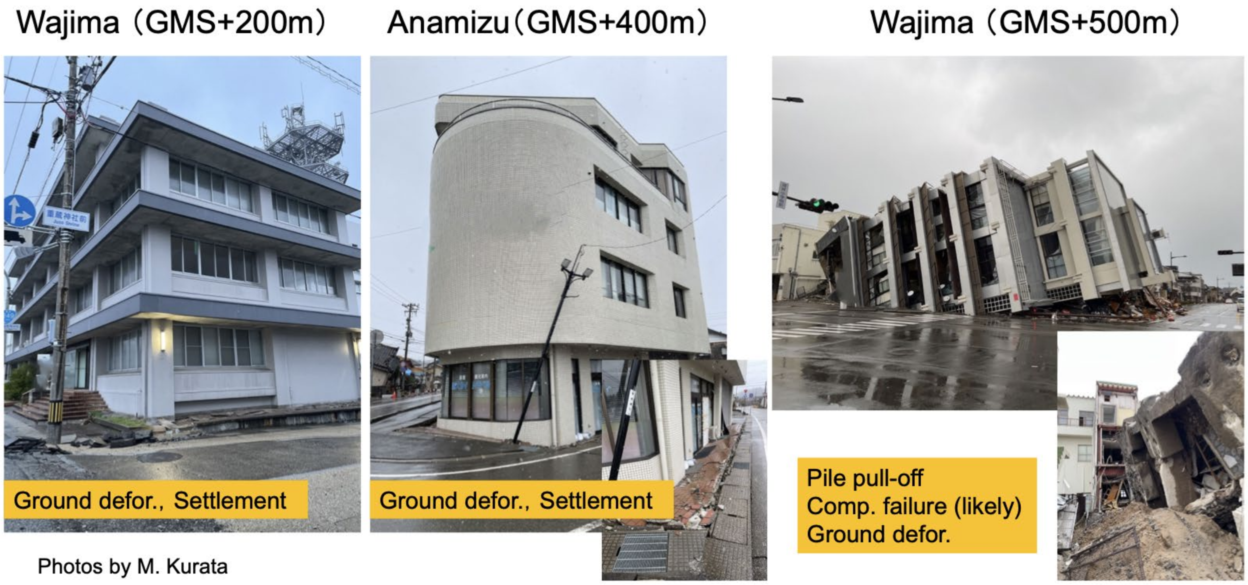


Figure 4.5. Damage to low-mid-rise RC buildings (Credit: M. Kurata).

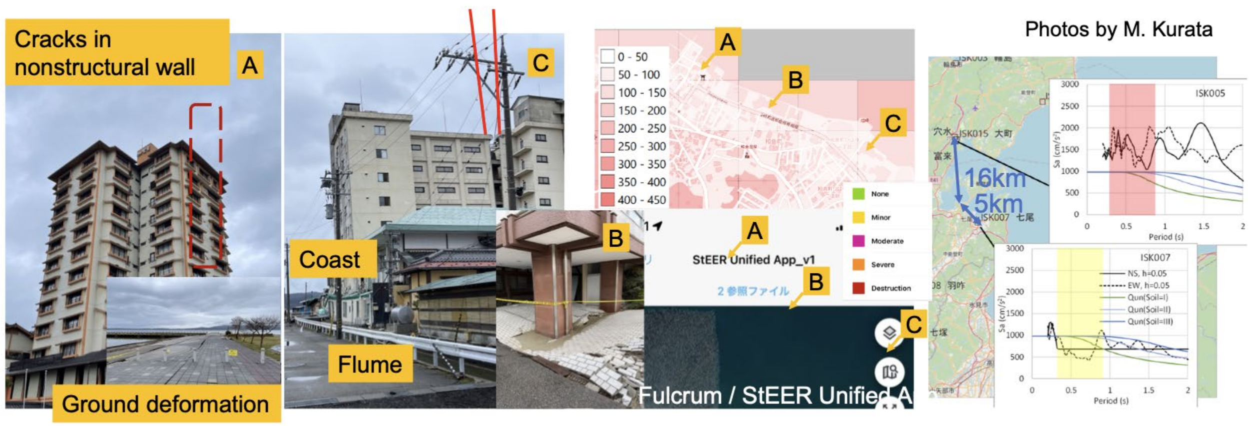


Figure 4.6. Damage to mid-high-rise RC buildings in Wakura-onsen town (Credit: M. Kurata).

4.5. Steel Buildings

Steel frame structures used as shops, office buildings, school buildings, gymnasiums, parking structures, and amusement facilities were also investigated. Figure 4.7 shows the typical damage observed in Wajima City, Anamizu Town, and the severely shaken area in Nanao City. The damage to the cladding made of light-gauge steel or timber grid and mortar finishing on metal lath was notable. The collapse of steel buildings was limited to those with significantly small sections or ill-conditioned welding details. Buckling of braces and column base failure of exposed type were typical for mid-rise parking structures and industrial facilities. Notably, corrosion of steel members and metal lath was severe at the hot spring site along a coastline (Fig 4.8). Cladding damage due to the collision of two adjacent structures was suspected in one mid-rise building.

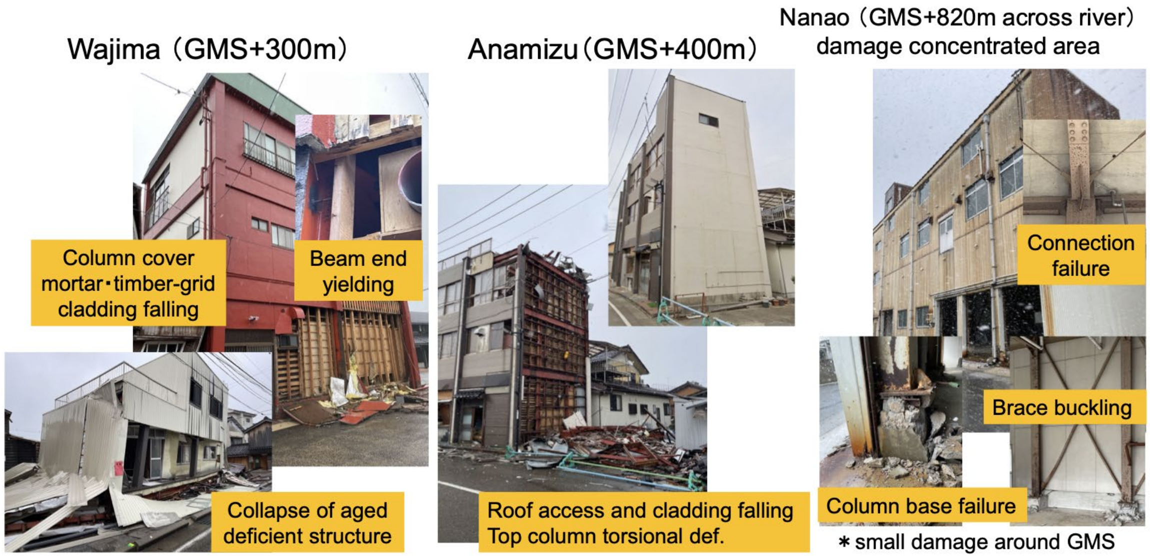


Figure 4.7. Damage to low-mid-rise steel buildings (Credit: M. Kurata).

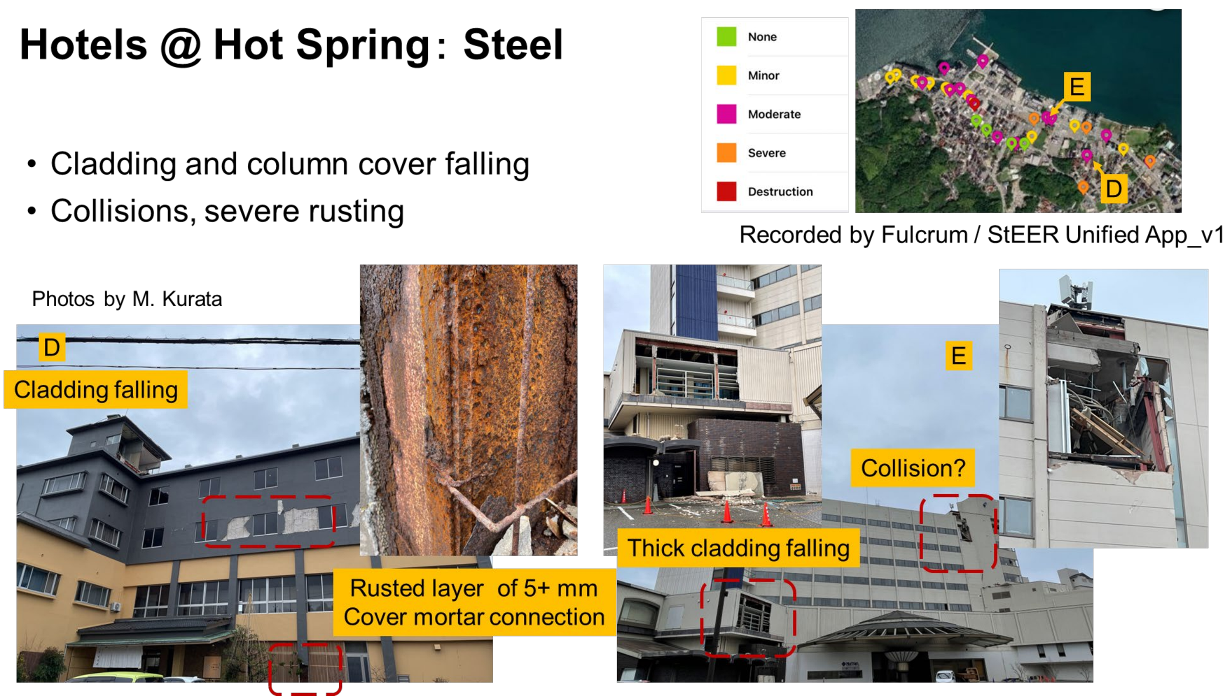
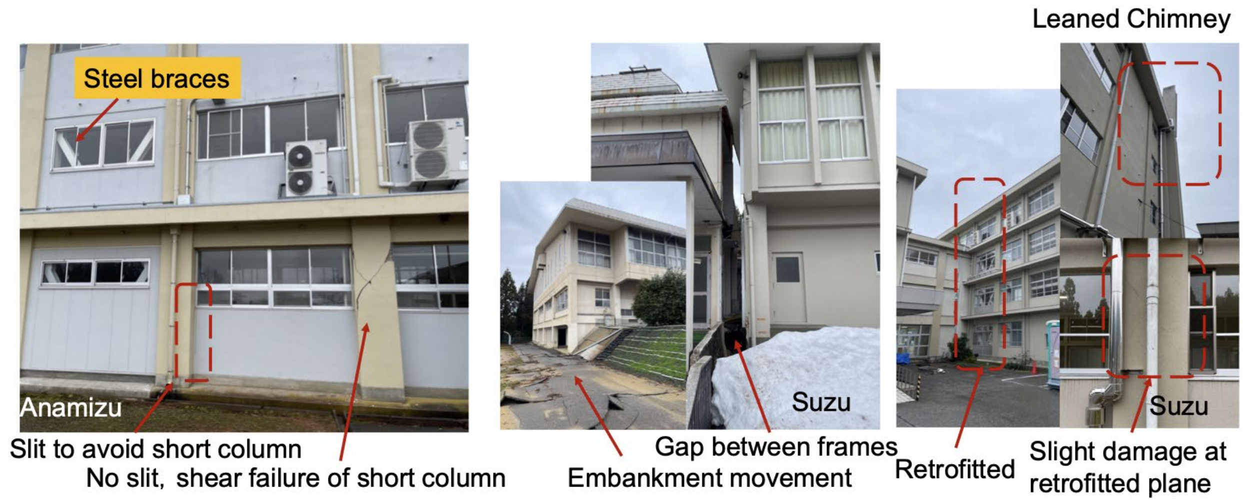


Figure 4.8. Damage to mid-rise steel buildings (Credit: M. Kurata).

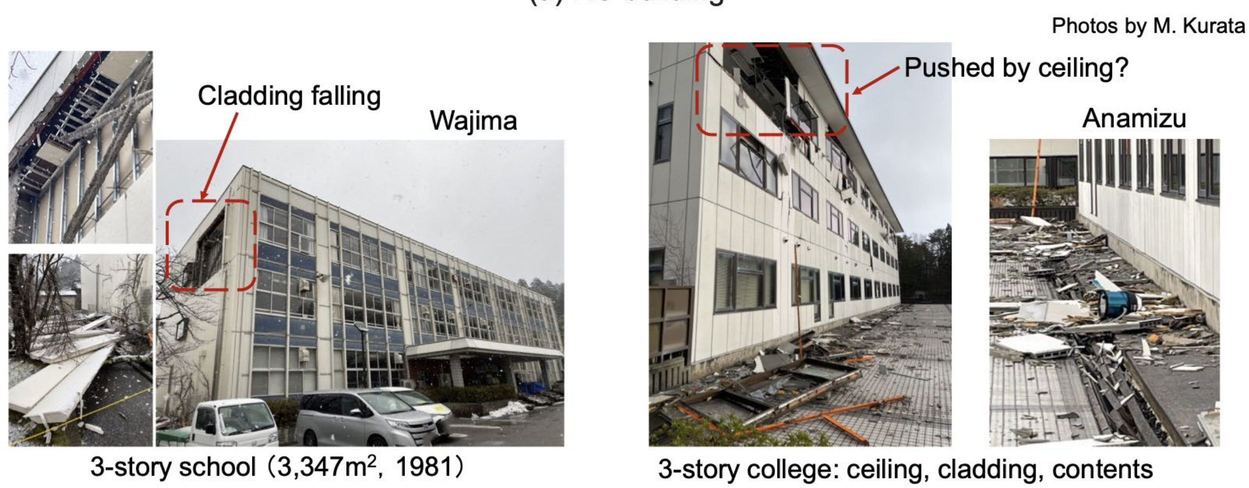
4.6. School Buildings

As mentioned in Section 3.1, a nationwide campaign for school buildings started in the late 1990s. Thanks to the 1995 Act on Promotion of the Earthquake-proof Retrofit of Buildings (Okada et al., 2000) and subsidies, most schools in Japan are retrofitted and conform to the new seismic design introduced in 1981. These structures are classified as "earthquake-resistant". In Ishikawa prefecture, the ratio of earthquake-resistant to non-earthquake-resistant school buildings is 100% (MEXT, 2022).

During the on-site survey, no collapsed school buildings were observed. In fact, most RC school buildings had some structural sections with steel brace retrofit systems (Figure 4.9). Some columns sustained shear failure due to poor detailing and damage to the expansion joint/joint region, which were notable for many buildings. Still, structural integrity was sustained. Landfill deformation around the foundation and embankment failure were severe at the surveyed sites, which had loose soil and poor landfill.



(a) RC building



(b) Steel building

Figure 4.9. Damage to school buildings (Credit: M. Kurata).

There were a few steel school buildings. Notable damage to steel was caused by cladding failure of an Autoclaved Lightweight Concrete (ALC) panel or extruded cement panel. While the structure had been retrofitted, the seismic-resistance ratio for nonstructural components remained around 70% in Ishikawa prefecture. Although the nationwide campaign for nonstructural components was initiated after the 2011 Tohoku earthquake, seismically deficient nonstructural components remain.

4.7. Government Buildings and Welfare Facilities

Government buildings and welfare facilities made of reinforced concrete were mostly earthquake-resistant (Figure 4.10). There was no damage to structural members, but ground deformation was significant at some sites. Sliding of rigid RC frames was suspected for those with a flat foundation. Welfare facilities were registered and used as a shelter, but damage to the ceiling and some secondary structural members was documented at some sites.

Some government buildings had steel parking lot facilities. Damages such as beam-end yielding, column base failure, and buckled braces were found at aged facilities. Gymnasiums attached to welfare facilities typically have steel-trussed roofs and supporting structures. These structures sit either on steel or concrete columns. A ceiling with an area of more than 200 m^2 is classified as a specified ceiling (Tokutei tenjo). It requires earthquake-resistance or retrofit (Figure 4.11). In one facility, the ceiling with a light-formed panel suffered damage, and steel wire meshes and bracing failed.

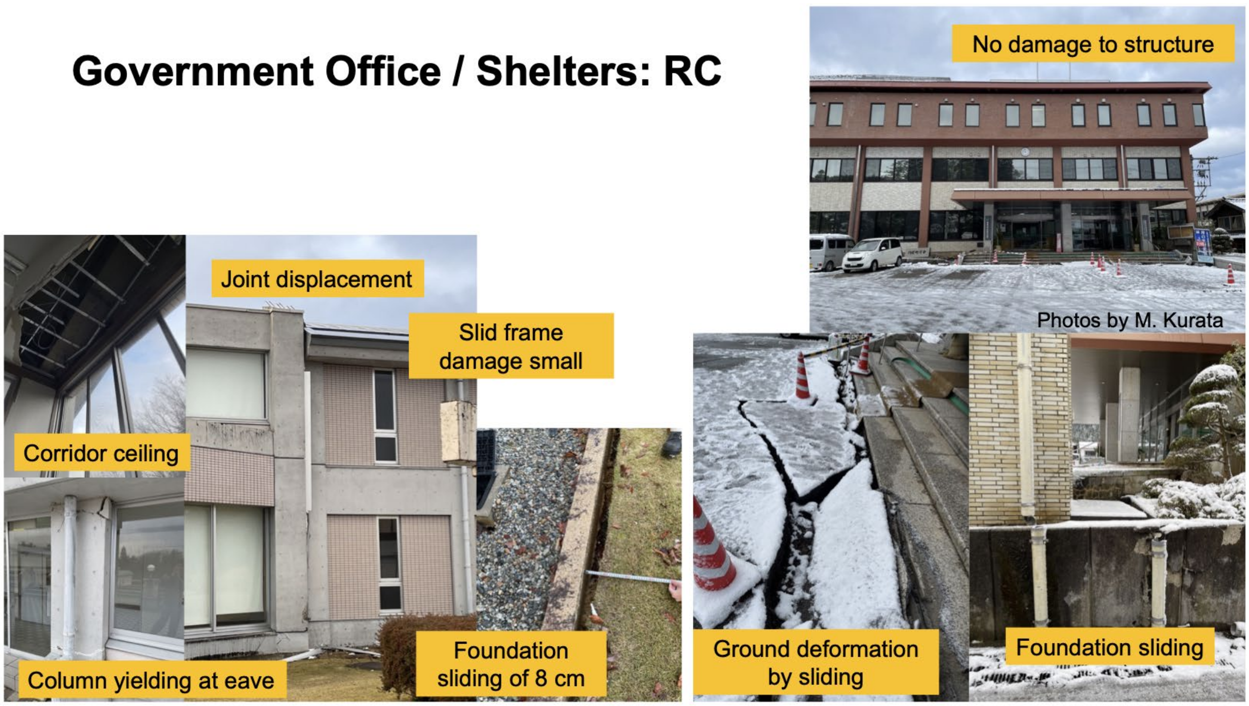


Figure 4.10. Government building and welfare facility (Credit: M. Kurata).

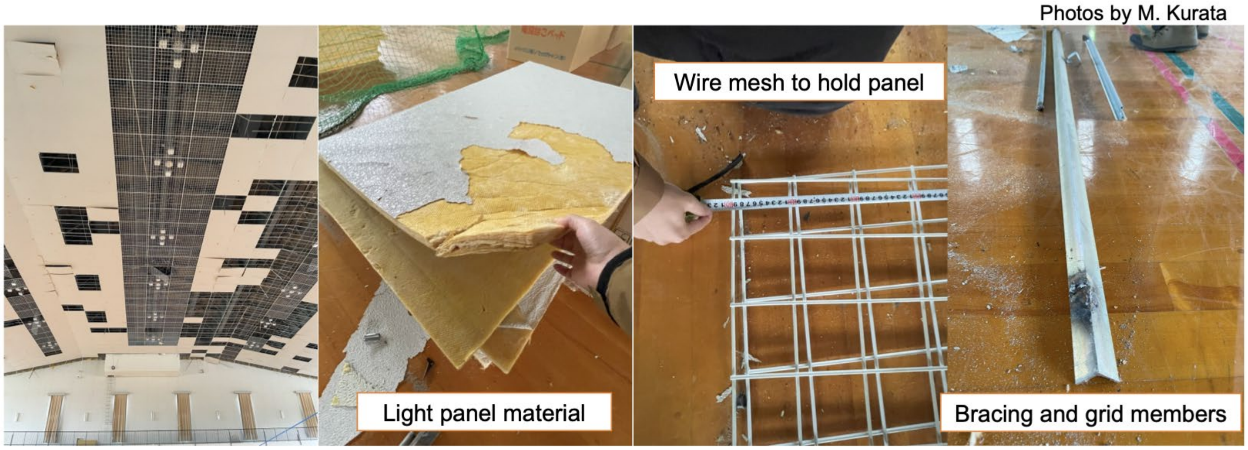


Figure 4.11. Gymnasium at a welfare facility (Credit: M. Kurata).

4.8. Hospitals

Hospitals and nursing homes were also negatively impacted by the earthquake. The most severe problem was the lack of water due to significant damage to water lifelines. The damage to structural members was limited as all the facilities were earthquake-resistant (Table 4.1). Still, nonstructural damage, including water leaks from piping and hot-water supply systems, deteriorated the functionality of some facilities. One entrance was closed due to severe ground deformation around buildings (Figure 4.12). Damage to façade design structures and ceiling damage were also documented.

Dialysis services were temporarily disrupted due to regional water stoppages, power outages, and partial damage to facilities and equipment (continued by well water). Hospitalized patients, seriously injured patients, and febrile patients were transported out of the area. The strong shaking caused disorder inside the building due to displaced contents.

The need for acute treatment decreased a few weeks after the earthquake, yet, the Disaster Medical Assistance Team (DMAT) continued to work for more than two months because of staff fatigue in affected areas and the need for transport outside the region due to infrastructure damage (Figure 4.13).

Table 4.1. Earthquake resistance ratio of hospitals.

Prefecture	Total #	EQ resistance	Base isolated	Ratio
Ishikawa	91	74	12	81.3%
Nation	8085	6425	639	79.5%
Ministry of Health: Seismic Upgrading Survey (2023)				

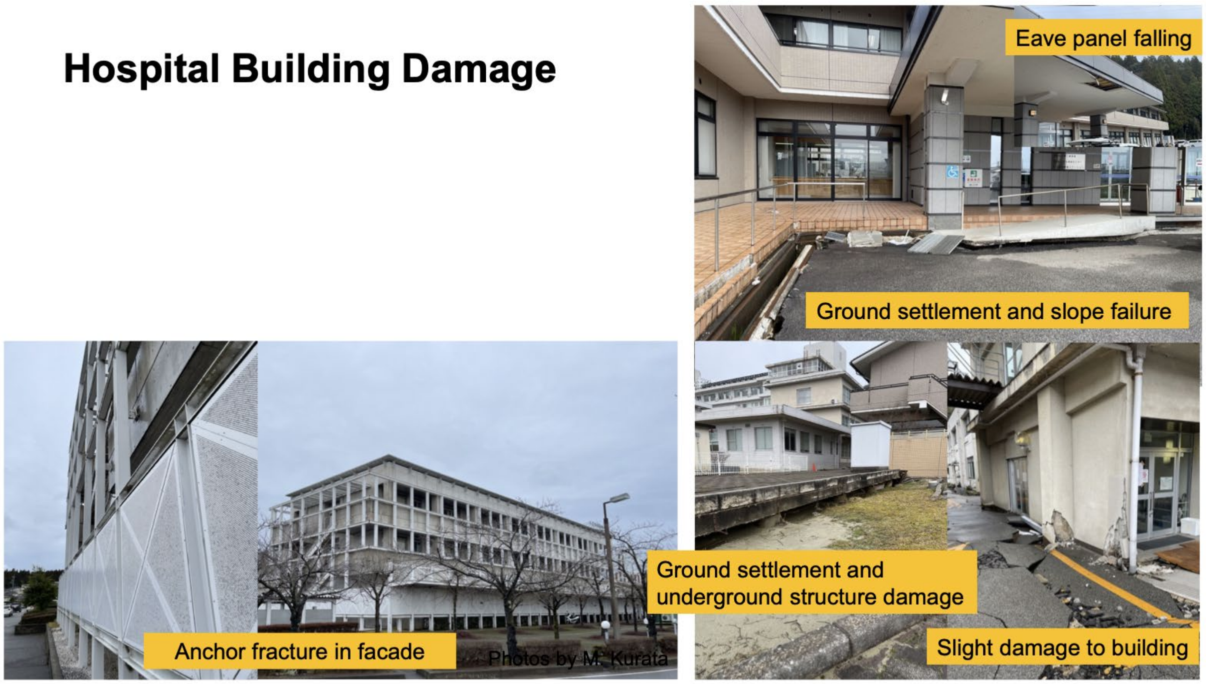


Figure 4.12. Visual survey of hospitals (Credit: M. Kurata).

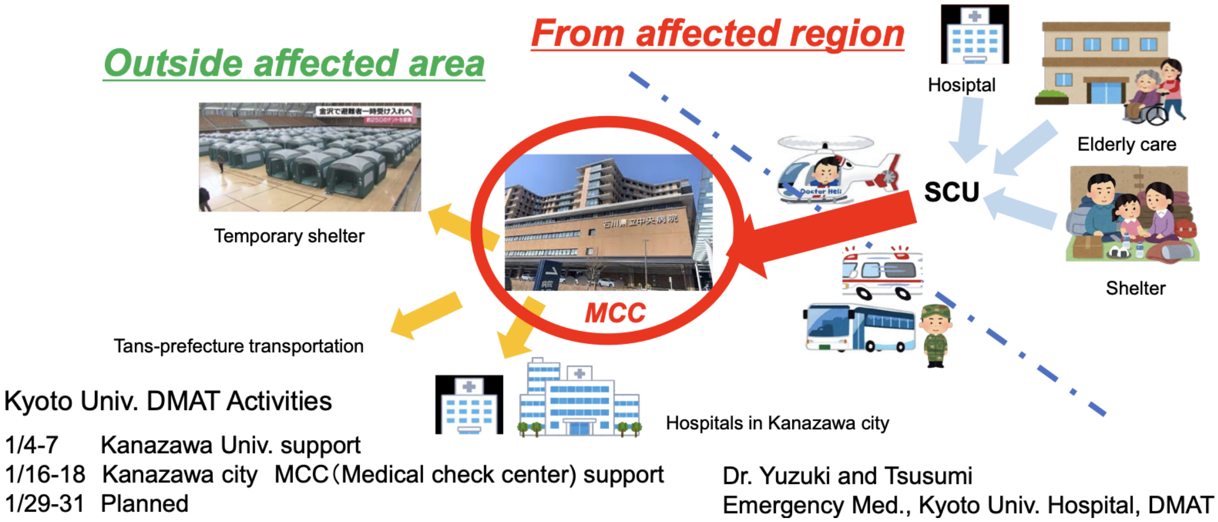


Figure 4.13. Kyoto University DMAT activities (Credit: T. Yuzuki and T. Tsusumi).

5. Infrastructure Performance

5.1. Road Access

Figure 5.1 shows the damage and emergency restoration of major access roads to the severely affected areas in the Noto Peninsula (MLIT, 2024a). The Noetsu Express highway was damaged severely, and the southbound flow has been closed for months. The national routes were closed at 40 locations, with 80% restored as of April 5. The prefectural routes were closed at 145 locations in Ishikawa, Niigata, and Toyama, while 70% were restored as of April 5. The railway system also suffered from damage. The Nanao line of JR West was closed until February 15, and the Noto railway was closed until April 6. The facilities and runway of the Noto airport were also severely damaged. The runway was reopened to the defense force on January 12 and opened to the public on January 27.

Figure 5.1. Road failure by landslides and tsunami (Road Bureau, MLIT, 2024a).

5.2. Bridge, Road, and Tunnels (MLIT, 2024c and 2024d)

The National Institute for Land and Infrastructure Management (NILIM) of MLIT and the Public Works Research Institute (PWRI) of the National Institute for Research Advancement (NIRA) conducted a survey of road structures damaged in the 2024 Noto Peninsula earthquake.

The main bodies of bridges designed after the 1995 Hyogo-ken Nanbu (Kobe) Earthquake, which significantly changed the seismic design standards, have generally sustained only minor damage and have demonstrated the expected performance. Figure 5.2 shows the damage of bridges in Ishikawa Prefecture conforming to 1996 specifications (Anamizu Kokakyo, Anamizu Town and Noto-Satoyama Airport IC Hashi, Wajima City), retrofitted (Uemachi Kokakyo, Noto Town and Notojima Oh-hashi, Notojima Town) and unretrofitted (Ukai Oh-hashi, Suzu City and Oomachi Oh-hashi, Anamizu Town). Road bridges that had undergone seismic retrofit, such as pier reinforcement and bridge fall prevention measures, avoided catastrophic damage and contributed to the speedy restoration of bridges. On the other hand, some road bridges designed based on old standards did not collapse or overturn, but still show serious damage, and it is necessary to take urgent measures for those bridges that have not yet been reinforced.

The 1996 specifications for road bridges stipulate that it is desirable to install step slabs, and the 2012 specifications for road bridges stipulate requirements for the structure of the rear abutment approach. The effects of these regulations were observed (Figure 5.3): emergency restoration of 10-50 cm step slabs in Nanao City and Anamizu Town; confirmed effectiveness of step slabs in Nanao City and Wajima City. On the other hand, there is a bridge in Kanazawa City that suffered from the liquefaction-induced ground subsidence of 1.5 m.

(a) New code conforming bridges (b) Seismically-retrofitted bridges (c) Unretrofitted bridges

Figure 5.2. Bridge damage in piers and supports in Ishikawa Prefecture (MLIT, 2024c).

(a) Emergency restoration (b) Step slabs effective (c) Large step by liquefaction

Figure 5.3. Bridge damage with step slab in Ishikawa Prefecture (MLIT, 2024c).

Many sections of roadways were disrupted due to slope failures and landslides. There is a possibility that the slope behind the collapsed soil may become unstable, and the collapsed soil itself may become unstable when the soil is removed for restoration. The landslide occurred at the cut slope of the loop in the Ootani area (Karasugawa Bridge attachment area).

Many embankments were found to be damaged, mainly in the stream-filled high embankments (Figure 5.4). In the Noto-satoyama Kaido, five embankment failures in a four-lane section (approx. 6 km) and 16 embankment failures in a two-lane section (approx. 21 km) were observed. In the section with four lanes, there were no collapses that caused loss of traffic function. However, in the two lane section, traffic function was lost at nine locations. Many of the restored sections, whose embankment was stabilized with drainage measures after the large-scale collapse caused by the Noto Peninsula earthquake in 2007, were slightly damaged. The Wajima Road (opened in 2023), conforming to the compaction standards for embankments were raised in 2013, suffered no damage to the embankment that would have led to the collapse.

(a) four lane section

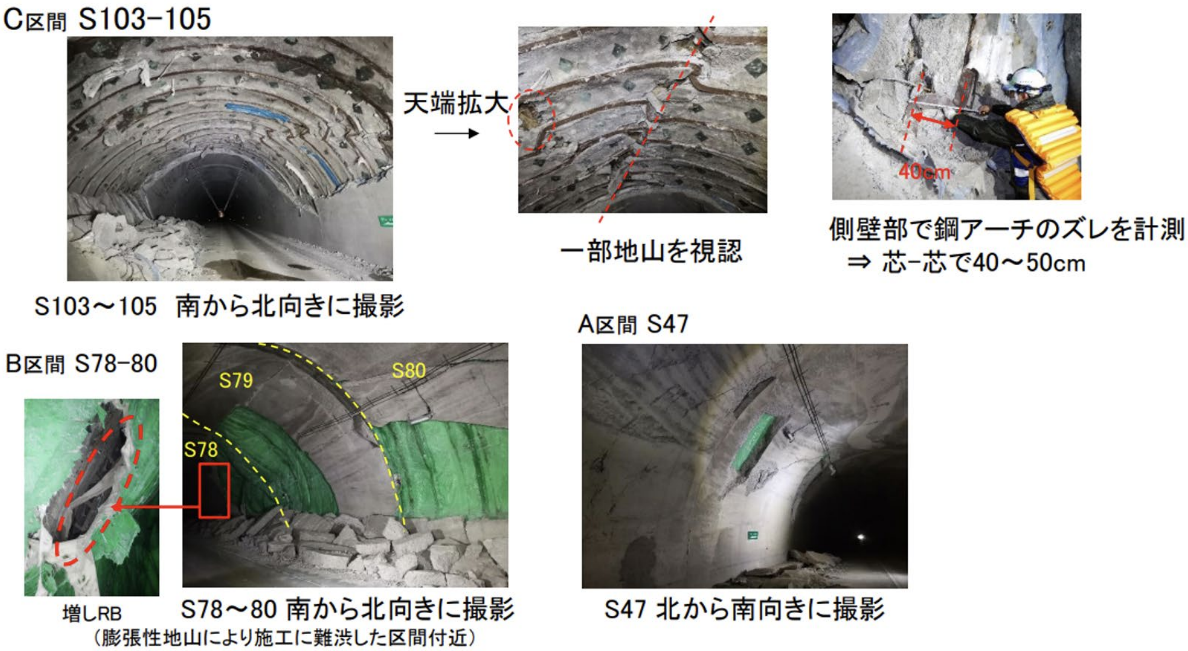
(b) two lane section

(c) Restored section after the 2007 earthquake and new failure

Figure 5.4. Embankment failure in Noto-satoyama Kaido (MLIT, 2024c).

In a wide area between Suzu City and Wajima City, several road tunnels were found to have deformations presumably caused by the earthquake. The most extensive were the Oya and Nakaya tunnels (both constructed by NATM), where the tunnel lining collapsed. However, the ground itself did not collapse, and the tunnel space was not blocked. The mechanism of the damage needs further analysis, but it is assumed that one of the factors is that the earthquake caused large-scale ground deformations.

(a) Oya Tunnel



(b) Nakaya Tunnel

Figure 5.5. Damage to tunnels between Suzu City and Wajima City (MLIT, 2024d).

5.3. Inland Waterways and Dams

Inspections were completed on 17 rivers in 12 water systems in five prefectures (Niigata, Toyama, Ishikawa, Fukui, and Nagano) (MLIT, 2024a). In government-administered rivers, sixteen locations in four rivers and four water systems were checked for bank subsidence, cracks in levee crowns, etc. Emergency measures have been taken, including completing emergency restoration work on the Shinanogawa River in the Shinano River system. In prefecture-administered rivers, inspection was completed on 554 rivers in 122 water systems managed by six prefectures (Niigata, Toyama, Ishikawa, Fukui, Nagano, Gifu); damage to revetments, levee crowns, etc. were confirmed on 113 rivers in 66 water systems managed by four prefectures (Niigata, Toyama, Ishikawa, Fukui); emergency measures being implemented (ongoing in northern Ishikawa, already implemented in other prefectures). In the Kawarada River and Yamada River systems administered by Ishikawa Prefecture, houses, and other structures were inundated due to river channel blockage caused by landslides.

Inspections were completed at all 96 dams. 94 of the 96 dams were inspected and found to be in good condition. Both damaged dams are managed by Ishikawa Prefecture. Experts at NRI provided technical support by helicopter on January 11, in addition to measurement data and images. Emergency measures have been taken.

5.4. Coasts and Ports

On the directly controlled coastline, abnormalities were observed in one of the four coasts in Ishikawa prefecture, but access was restricted (MLIT, 2024a). On the auxiliary coast, ten coasts out of 124 coasts in Ishikawa prefecture had anomalies, with damage to levee revetments, detached breakwaters, water-hammer damage, etc.

According to a prefectural survey, crustal deformation caused damage to 60 of the 69 fishing ports in Ishikawa Prefecture (86.9%), including ground uplift, breakwaters, quays, and port roads. Many of the prefecture's 12 ports, used by cargo carriers and work vessels in addition to fishing vessels, were also damaged. Figure 5.6 shows photos of the Kuroshima port south of Wajima. The port structure remains without structural damage, but no water exists inside the port. The ocean front line receded around 200 m from the original coastline.

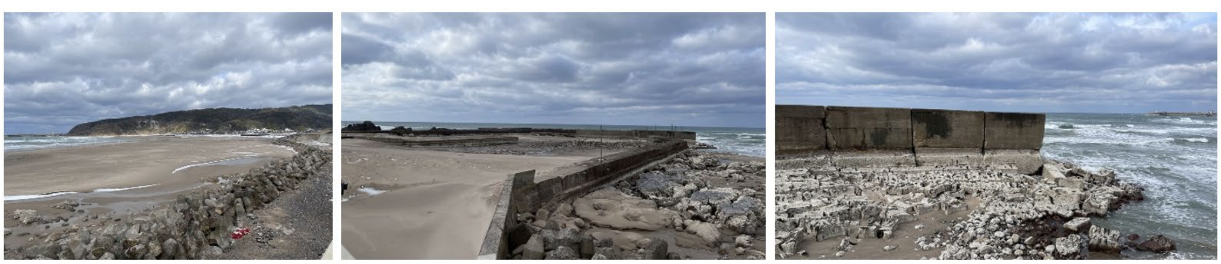


Figure 5.6. Kuroshima port south of Wajima (Credit: M. Kurata).

5.5. Lifelines

The earthquake caused damage to some facilities at Shiga Nuclear Power Station, but important functions such as external power supply and cooling facilities have been maintained (HEPC, 2024). There were no reports that the reactor facilities were compromised. However, at least 36,000 households and 19 medical facilities lost power following the earthquake, and more than 110,000 households were left without water immediately after the quake. The disruptions in nearby prefectures (Toyama and Niigata) were also significant (MLIT, 2024a). A number of sewage treatment plants were damaged but restored in Ishikawa prefecture (25 out of 57), Niigata prefecture (4 out of 83), and Toyama prefecture (4 out of 29). In Ishikawa prefecture, 14 out of 52 pump facilities were also damaged, but restored. Water and sewage pipelines and facilities were severely damaged in large areas of these prefectures.

6. Geotechnical Performance

6.1. Landslides

Landslides occurred at 409, 18, and 13 locations in Ishikawa, Niigata, and Toyama prefectures, respectively. Landslides caused Destructive damage to 64 houses, Very Severe or Severe damage to 33 houses, and Moderate or Slight damage to 18 houses. Landslides also resulted in river channel blockage (sediment dam) at 14 locations in 6 rivers (MLIT, 2024b). Erosion Control Facilities had no damage.

6.2. Liquefaction

Liquefaction was observed over a vast area during the earthquake, as shown in Figure 6.1, including Ishikawa Prefecture (Nanao City; Kahoku City; and Uchinada Town, Kawakita County), Toyama Prefecture (Takaoka City; Himi City; and Imizu City), and Niigata Prefecture (particularly Nishi Ward, Niigata City). While not directly confirmed, available public documents and media reports suggest that liquefaction also likely occurred to varying degrees in other areas of Ishikawa Prefecture, central and southern Toyama Prefecture, and a broad region along the Sea of Japan in Niigata Prefecture west of Niigata City. Reclaimed land and old river channels are especially prone to liquefaction. The locations where extensive liquefaction damage occurred in this earthquake are believed to have been influenced by three main factors: relatively loose sand deposits, a shallow groundwater table, and seismic intensity (JMA intensity) of 5 or higher. Typical types of liquefaction damage commonly observed in the horizontal and sloping ground during the earthquake include cracks and sand boiling, tilting and settlement of buildings and utility poles, and uplift of buried underground structures. In sloping terrain (e.g., Uchinada Town, Ishikawa Prefecture) and behind quay walls (e.g., Nanao Port and Wakura Port in Nanao City, Ishikawa Prefecture), lateral spreading associated with liquefaction may have increased damage, including deformation and uplift of roads near slopes, horizontal displacement of quay walls, and settlement of the ground behind them.

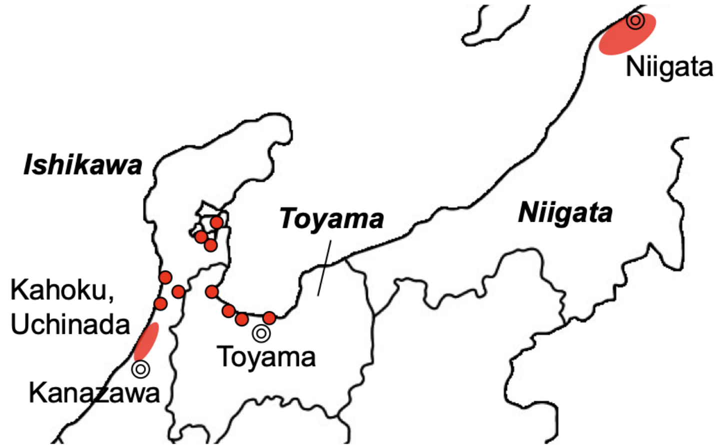
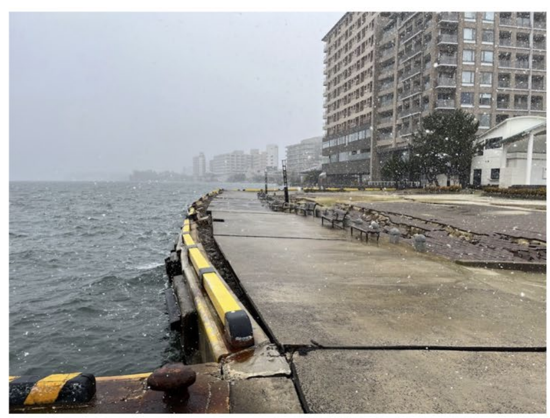


Figure 6.1. Locations where liquefaction damage occurred during the 2024 Noto Peninsula earthquake.

Figure 6.2 illustrates liquefaction damage at Wakura Port in Nanao City, Ishikawa Prefecture. According to the strong-motion seismograph network of the NIED, a maximum acceleration of 374 gal was recorded at an observation station located in Nanao City (K-NET ISK007). As depicted in Figure 6.2(a), cracks and sand boiling were observed in the ground behind the quay wall due to this intense shaking. Additionally, lateral spreading in the ground caused the quay wall to bulge towards the sea, leading to ground settlement, as illustrated in Figure 6.2(b). Wakura Port also experienced liquefaction damage during the 2007 Noto Peninsula earthquake (with a maximum acceleration of 202 gal recorded at K-NET ISK007), and the extent of damage shown in Figure 6.2 from the 2024 earthquake surpassed that of 2007. The recurrence of liquefaction at the same location 17 years later highlights a significant issue when considering liquefaction mitigation measures for future earthquakes. In the 2024 earthquake, similar damage due to reliquefaction was also observed at Nanao Port in Nanao City, Ishikawa Prefecture, and Himi Fishing Port in Himi City, Toyama Prefecture.

(a) Sand boiling and cracks in the ground



(b) Horizontal displacement of the quay wall

Figure 6.2. Liquefaction damage at Wakura Port in Nanao City, Ishikawa Prefecture (Credit: K. Ueda).

In Kahoku City and Uchinada Town, Ishikawa Prefecture, liquefaction damage such as sand boiling, tilting of utility poles and residential walls, and road deformation occurred on gently sloping ground from the foot of dunes in the west to tidal flats in the east. Several meters of lateral spreading occurred in some places due to liquefaction, and the roads on the lower elevation side were significantly deformed and uplifted due to this ground deformation. Figure 6.3 shows the liquefaction-induced damage in the Nishiaraya area of Uchinada Town (refer to Ueda et al. (2024) for liquefaction damage in other areas). Many areas where lateral spreading occurred in Kahoku City and Uchinada Town are topographically characterized by sand dunes on the west side and lagoons on the east side. It is thought that gently sloping ground was created by cutting the foot of the dunes and filling the tidal flats. Although the dune itself is not susceptible to liquefaction, groundwater is easily supplied from the base of the dune toward the gently sloping ground, likely contributing to liquefaction. The gently sloping ground is also composed of sand with a relatively uniform grain size, which may have contributed to increased liquefaction damage. However, considering that the JMA seismic intensity levels in Kahoku City and Uchinada Town are 5 upper and 5 lower, respectively, and that the ground formed by cutting sand dunes is relatively firm against seismic shaking, the detailed mechanism of lateral spreading on the scale of several meters is not fully understood at this time.

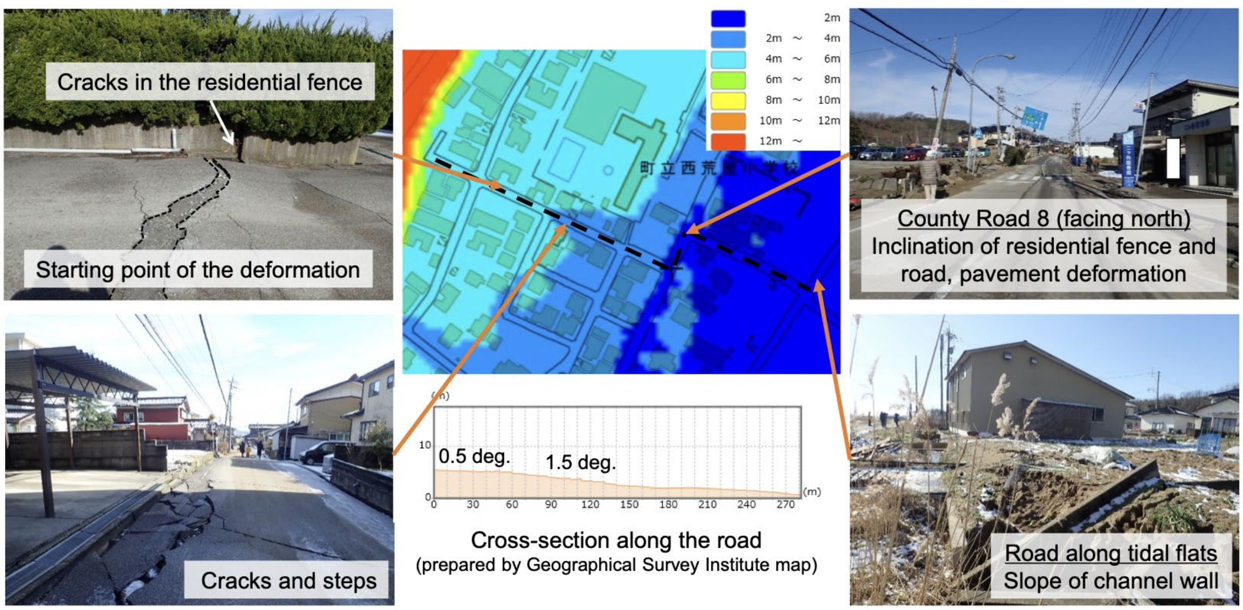


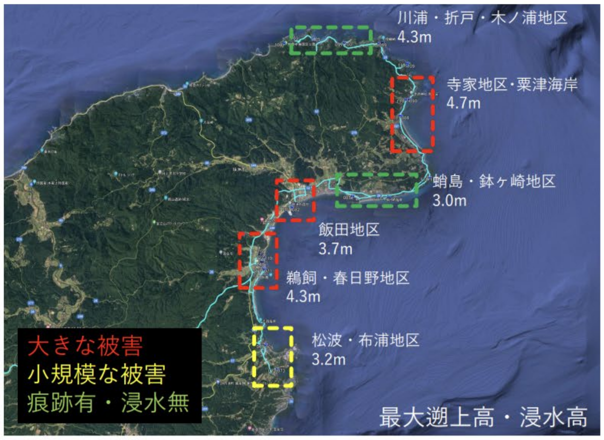
Figure 6.3. Ground deformation along the road (black dashed line) from the dune foot (west side) to the tidal flat (east side) in Nishiaraya, Uchinada Town, Ishikawa Prefecture.

7. Cascading Hazards

7.1. Tsunami

The tsunami triggered by the 2024 Noto Peninsula earthquake reached an inundation height of more than 4 meters in Suzu and Noto in Ishikawa prefecture, causing extensive damage. Approximately 190 hectares were inundated by the tsunami in Suzu City, Noto Town, and Shiga Town in Ishikawa prefecture (MLIT, 2024a). In addition, approximately 4 ha of land was inundated by the tsunami in Joetsu City, Niigata Prefecture. Inundation depth is estimated to be up to 1 m. The number of tsunami victims announced by Ishikawa Prefecture is two. However, at least 26 people were killed in the areas inundated by the tsunami, and the number of tsunami victims may be even higher (NHK, 2024).

Figure 7.1 shows the locations of Tsunami inundation areas in the Noto Peninsula, reported by a joint team of the Japan Society of Civil Engineers and the Architectural Institute of Japan (Mori, 2024). The reconnaissance team conducted tsunami surveys along the east and west coasts of the Noto Peninsula. Run-up height of more than 4 m was measured along the east and west coasts (Figure 7.1). Maximum water levels in the calculation results are consistent with the observed height (Figure 7.2). The level of protection (vulnerability) and distribution of buildings and population (exposure) contributed to the magnitude of damage caused by the combination of strong ground motion, fire, and tsunami. However, uplift by crustal deformation significantly reduced the impact of tsunamis.



(a) Suzu City and Noto Town (left)

(b) Wajima City and Shika Town

(c) Damage

Figure 7.1. Tsunami inundation area with maximum run-up height / Inundation height (red: severe, yellow: slight, green: confirmed) (Mori et al., 2024).

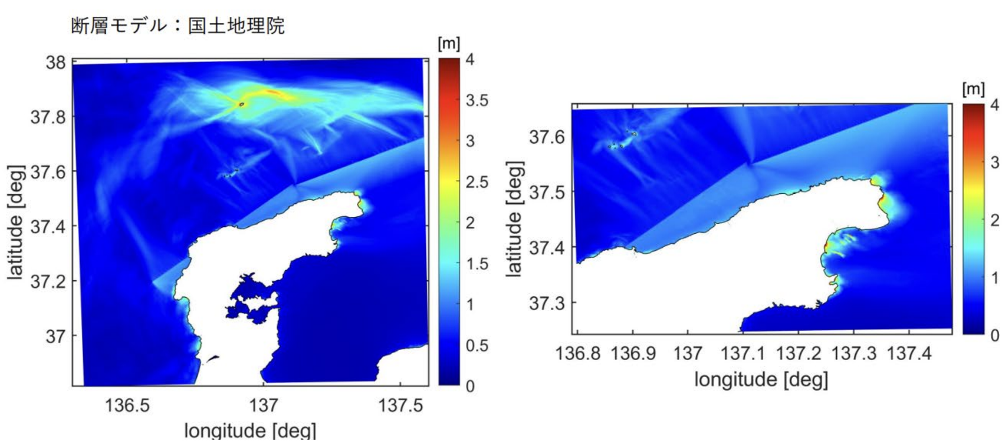


Figure 7.2. Estimated water height by simulations with earthquake fault model (Mori et al., 2024).

7.2. Fire

Based on the report by Nishino (2024), there were 17 fire cases, including 15 earthquake-induced fires and 2 tsunami-induced fires. Notably, the possibility of tsunami inundation coincided with the occurrence of earthquake fires in the coastal city of Wajima, which may have uniquely hindered the initial firefighting by residents and the fire brigade's response. However, the phenomena was similar to the 1995 Hyogo-ken Nanbu (Kobe) Earthquake and the 2011 Tohoku Tsunami Fire, though the impact was smaller scale[1].

In the case of earthquake-induced fires, fires in coastal urban areas consisted mainly of bare wooden buildings that were at high risk of being affected by the tsunami (Figure 7.3(a)). The confirmed timeline was as follows: i) earthquake motion, ii) tsunami warning, iii) fire outbreak, iv) fire spread, v) tsunami warning, vi) tsunami warning, and vii) suppression (no flooding). The fire occurred in an almost windless condition (weak southerly winds), and there was nothing unique about the direction of the fire spread (spread in all directions except west of the river) or speed (about 30 m/h). Even if the building was of noncombustible construction (RC or S), there is a possibility that openings in the exterior walls did not prevent the fire spread and that propane gas from household LPG cylinders may have contributed to the spread of the fire. The fact that a tsunami warning was issued and both residents and firefighters had to respond to the tsunami may have contributed to the delay in the discovery of the fire. In addition, it was challenging to make decisions on firefighting activities along the coast, and it is assumed that it was difficult to take water from natural water resources such as rivers and the sea due to the tsunami. Although the firefighters were outnumbered, they were able to prevent the fire from spreading to Iemon and Umabashi Lanes despite the difficult conditions under the tsunami warning (and tsunami warning), which may have contributed to the final reduction of the damage.

It should be pointed out repeatedly that it is essential to install and increase the use of earthquake-sensitive breakers as a fire prevention measure[2], because of the possibility of multiple fires coinciding and the limited firefighting capability of fire departments.

In the case of tsunami-induced fires, the buildings a short distance away from the area of the fire, near the sea and rivers, were washed away by the tsunami (Figure 7.3(b)). The area of the fire and its vicinity were likely inundated above floor level, and it is likely that the original buildings in the area of the fire were not washed away and remained intact. The buildings in the area of the fire were mainly bare wood, and the role of accumulated driftwood cannot be determined. Still, the nature of the fire appears to have been similar to a normal spreading fire, and it is estimated that 10 to 20 buildings were destroyed. A fire truck was stationed next to Hensho-ji Temple, north of the burned area, with a water bucket and hose to extinguish the fire.

The preventative measures are still missing from the disaster prevention plan. In particular, there were several cases in Tohoku 2011 where tsunami fires affected tsunami evacuation buildings (e.g., Kadowaki Elementary School, Kesennuma City Shikaori Senior Citizens Home, Kesennuma Central Community Center, and Otsuchi Elementary School). In one case, tsunami evacuees were forced to stay in one room despite the fire spreading inside the building. It is necessary to

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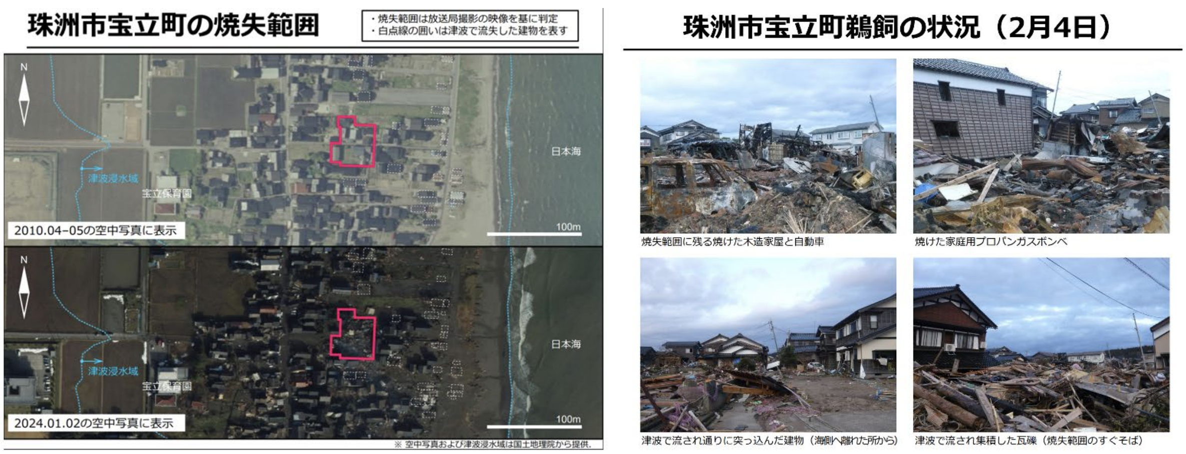
[1] More than 200 earthquake fires occurred and burned an area of over 46 ha in the 1995 Hyogo-ken Nanbu Earthquake; more than 100 tsunami fires occurred and burned an area of over 61 ha in 2011 Tohoku Earthquake.

[2] Based on the fact that many fires start from electrical appliances and wiring.

check the fire safety measures in designated tsunami evacuation buildings and ensure these structures are not vulnerable to fire.

(a) Earthquake-triggered fire in Wajima city



(b) Tsunami-triggered fire in Suzu city

Figure 7.3. Fire damage in Wajima and Suzu cities (Source: Nishino, 2024).

8. Recommended Response Strategy

The 2024 Noto Peninsula earthquake underscored the critical need for robust, multi-hazard disaster preparedness and response strategies. While Japan's investment in earthquake-resistant design and early warning systems has proven beneficial, this event highlighted areas needing further improvement, such as enhancing the resilience of healthcare facilities and integrating response plans for concurrent disasters like tsunamis and fires. Future efforts should focus on refining building codes, improving the effectiveness of early warning systems across all areas in close proximity to the epicenter, and fostering community resilience, particularly in coastal and seismically active regions, with careful attention to support for Japan's aging population.

Based on the information gathered by this Preliminary Virtual Reconnaissance Report (PVRR), the authors offer the following recommendations for future study:

TOPIC 1: Seismic Activity and Fault Dynamics: The Mj 7.6 earthquake on January 1, 2024, originated from an under-ocean fault over 100 km long, with a focal depth of 10 km, highlighting research needs on surveying under-ocean faults and their evaluating risk in triggering large-scale seismic events, including tsunamis and extensive crustal deformation to coastline communities.

TOPIC 2: Liquefaction and Landslide Risks: The widespread occurrence of liquefaction and landslides, with severe effects on structures and roads, indicates the critical need for geological and risk assessments in earthquake-prone areas. Comparisons between liquefaction and landslide hazard maps and observed damage should be undertaken to improve these maps.

TOPIC 3: Ground Motion and Building Response: In regions with soft soil conditions, the earthquake caused ground motions exceeding design standards for very rare earthquakes, resulting in substantial damage to buildings and infrastructure. Notably, aged, traditional timber housing showed a high proportion of severe damage to collapse; other building types with relatively long periods showed amplified damage due to a large input in the period range of 1-2 sec. These failures warrant further investigation.

TOPIC 4: Structural Damage: Most low-rise reinforced concrete (RC) buildings withstood the earthquake with limited damage, whereas specific shear failures and differential settlement were observed mainly due to soft soil conditions. Steel buildings suffered from nonstructural damage to cladding and ceilings, which prevented the safe usage of the damaged buildings. Rapid inspection of falling hazards for the remaining cladding is a challenge. The effects of soft soil conditions and deterioration by harsh coastal environments on the observed building damage and the implications for continuity/recovery needs further investigation.

TOPIC 5: Impact on Road and Port Infrastructure: Extensive damage to roads, slopes, and ports underscores the need for robust design and maintenance strategies that consider potential large-scale deformations and the specific challenges posed by seismic activity.

While beyond the scope of typical engineering research, other lessons learned and areas requiring further attention are as follows:

TOPIC A: School and Government Buildings: Retrofitting efforts under Japan's seismic reinforcement policies have been effective, as demonstrated by the absence of school building collapses and minimal damage to earthquake-resistant government buildings. However, some nonstructural damage and deformation in landfill areas were noted.

TOPIC B: Medical and Welfare Facilities: Significant disruptions occurred in medical services due to water lifeline damage and structural issues, highlighting the need for enhanced resilience in healthcare infrastructure, especially in water supply systems.

TOPIC C: Early Warning System Effectiveness: The earthquake early warning system, which issued alerts 6 seconds after the initial P-wave, was instrumental in mitigating some impacts, although improvements could be sought in the timing to cover areas closer to the epicenter.

TOPIC D: Community and Emergency Response: The response to the earthquake revealed strengths in community evacuation practices but also pointed out areas for improvement in disaster preparedness, especially in light of aging demographics and recent social constraints like the pandemic.

TOPIC E: Tsunami Impact and Response: The severe impact of the tsunami, with significant loss of life and property, stresses the importance of tsunami preparedness and the effectiveness of community-based evacuation strategies.

TOPIC F: Integrated Disaster Response for Tsunami-Induced Fires: The occurrence of fires in tsunami-affected areas, particularly noted in Wajima City, highlights the need for comprehensive disaster response strategies that simultaneously address fire hazards and flooding risks. Effective planning should incorporate fire brigade protocols tailored to scenarios where fires and tsunamis intersect, ensuring rapid response capabilities despite challenging conditions.

As DPRI and other Japanese colleagues are continuing to gather data and learn from the 2024 Noto Peninsula earthquake, **StEER's response to this event will remain at Level 1 with no activation of a Field Assessment Structural Team (FAST).** As a result, this PVRR represents the extent of StEER's official response. However, StEER will continue to support its Japanese colleagues in the continued study of this event to encourage consideration of the above recommendations and will monitor their assessments. Should these ongoing efforts reveal new information that would necessitate StEER deploying a FAST, this decision will be revisited and the opportunity announced through our standard channels.

References

AIJ. (1995) *Structural Engineering Textbook*. Architectural Institute of Japan.

AIJ. (1995) *Illustration Collection of Japanese Architecture*. Architectural Institute of Japan.

Asano, K. (2024) "Tentative Source Process of the 2024 Noto Peninsula Earthquake Based on Strong-Motion Seismic Waveform Records." January 15, 2024. https://sms.dpri.kyoto-u.ac.jp/topics/2024noto_source_20240115.pdf.

BCJ. (2013) *Introduction to the Building Standard Law-Building Regulation in Japan (Ver. July 2013)*. Building Center of Japan. https://www.bcj.or.jp/upload/international/baseline/BSLIntroduction201307_e.pdf.

CNN. (2024) "January 1, 2024 Japan Earthquake." January 23. https://www.cnn.com/asia/live-news/japan-ishikawa-earthquake-01-01-24/index.html.

Earthquake Headquarters (2023) *Evaluation of seismic activity in the Noto region of Ishikawa Prefecture* (published June 9, 2023) https://www.static.jishin.go.jp/resource/monthly/2023/2023_ishikawa_2.pdf

Earthquake Headquarters (2024) *Evaluation of the 2024 Noto Peninsula Earthquake* (3rd, published February 9, 2024) https://www.static.jishin.go.jp/resource/monthly/2024/20240101_noto_3.pdf

Geographical Survey Institute. (2024) *2024 Noto Peninsula Earthquake: Results of Emergency Survey*. Geographical Survey Institute. https://www.gsi.go.jp/sokuchikijun/R6-notopeninsula-earthquake-EmergencyObservation.html.

HERP (2024) "Plate tectonics." *Headquarter of Earthquake Research Promotions, Japan*. https://www.jishin.go.jp/main/yogo/e.htm [Accessed: 2024.4].

HEPC (2024) *Current Status of Shika Nuclear Power Station after the 2024 Noto Peninsula Earthquake*. (https://www.rikuden.co.jp/eng_shika/attach/current%20status_%20SHIKA.pdf)

Ishikawa Prefecture (2024a) *Situation of Damage, etc. (121st report) [as of 14:00, April 12, 2024]*. (https://www.pref.ishikawa.lg.jp/saigai/documents/higaihou_121_0412_1400.pdf) [Accessed: April 14, 2024].

Ishikawa Prefecture (2024b) *Situation of Damages (10th Report)*. (https://www.pref.ishikawa.lg.jp/saigai/documents/202401040930higaihou-2.pdf) [Accessed: April 14, 2024].

Ishikawa Prefecture (2024c) Situation of Damages (78th report). (https://www.pref.ishikawa.lg.jp/saigai/documents/higaihou_78_0202_1400.pdf) [Accessed: April 14, 2024].

JMA: Japan Meteorological Agency (2023) May *2023 Earthquake and Volcanoes Monthly Report (Disaster Prevention Edition): Special Feature: Earthquake Activity in Noto District, Ishikawa Prefecture.*

JMA: Japan Meteorological Agency (2024) *Evaluation of the 2024 Noto Peninsula Earthquake*. (https://www.static.jishin.go.jp/resource/monthly/2024/20240101_noto_2.pdf) [Accessed: April 14, 2024].

J-SHIS (2024) "Japan Seismic Hazard Information Station." https://www.j-shis.bosai.go.jp/en/.

Kurata M. (2024) *2024 Noto Peninsula Earthquake: Damage and Functional Continuity of Non-Timber Buildings*. DPRI Noto Peninsula Earthquake Report. (in Japanese) (https://www.dpri.kyoto-u.ac.jp/contents/wp-content/uploads/2024/01/cb1ade720c857810fd77192e8336b400.pdf)

Mainichi Shimbun (2024) "No tsunami fatalities in a village in Suzu, Ishikawa, Japan: A watchword that saved residents' lives." *Mainichi Shimbun*. https://mainichi.jp/articles/20240211/k00/00m/040/065000c [Accessed: April 14, 2024].

MHLW (2023) *Results of a survey on the status of seismic retrofitting of hospitals*. Ministry of Health, Labor and Welfare. (https://www.mhlw.go.jp/content/10800000/001155408.pdf)

Midorikawa M., Okawa I., IIBA M., Teshigawara M. (2004) "Performance-based Seismic Design Provisions Newly Introduced to the Building Standard Law of JAPAN," *Journal of Japan Association for Earthquake Engineering*, Volume 4 (Issue 3), Pages 162-173. https://doi.org/10.5610/jaee.4.3_162

MLIT (1980) *Ministry of Construction Notification*, No. 1793 (November 27, 1980)

MLIT (2014) *Report of the Survey Committee on Large-Scale Earthquakes in the Sea of Japan Charts and Figures*. (http://www.mlit.go.jp/river/shinngikai_blog/daikibojishinchousa/houkoku/Data.pdf)

MLIT (2024a), Damage, and Response to the 2024 Noto Peninsula Earthquake (Report 89), the Ministry of Land, Infrastructure, Transportation and Tourism, 2024.4 https://www.mlit.go.jp/common/001736865.pdf

MLIT (2024b), Reference: Locations of river channel blockages, etc. and status of countermeasures, the Ministry of Land, Infrastructure, and Transportation, 2024.1.23 https://www.mlit.go.jp/report/press/content/001719306.pdf

MLIT (2024c) *Press release: Results of the 2024 Noto Peninsula Earthquake Specialist Survey (Interim Report)*. National Highway and Engineering Division, the Ministry of Land, Infrastructure, Transport and Tourism. (https://www.hrr.mlit.go.jp/press/2023/2/240221dourobu.pdf)

MLIT (2024d) *Reference report: 2024 Noto Peninsula Earthquake Damage analysis of road structures (bridges, earthworks, tunnels)*. National Highway and Engineering Division, Highway Department, the Ministry of Land, Infrastructure, Transport and Tourism. (https://www.mlit.go.jp/policy/shingikai/content/001733619.pdf)

MEXT (2022) "Results of Survey on Aging Condition of Public School Facilities and Follow-up Survey on Status of Seismic Retrofitting." *Ministry of Education, Culture, Sports, Science and Technology*. https://www.mext.go.jp/b_menu/houdou/2022/attach/1419963_00001.html.

Mori, M., Miyashita, T., Yasuda, T., Fukui, N. (2024) *Notohanto EQ Report*. DPRI Noto Peninsula Earthquake Report. (in Japanese) (https://www.coast.dpri.kyoto-u.ac.jp/files/disaster/20240101_notots_report_v2.pdf)

NHK (2024) "26 people died in the tsunami inundation zone, and some testified that they heard voices from collapsed houses. Noto Earthquake." *NHK News*, 2024.4.1. https://www3.nhk.or.jp/news/html/20240401/k10014408981000.html

Nishino, T. (2024) *Nishino_20240122_Fire-following-earthquake* (in Japanese). (https://www.dpri.kyoto-u.ac.jp/contents/wp-content/uploads/2024/01/Nishino_20240122_Fire-following-earthquake-aspects-of-the-2024-Noto-Peninsula-earthquake.pdf)

NIED (2024) *Strong ground motion caused by the 2024 Noto Peninsula earthquake*. The National Research Institute for Earth Science and Disaster Resilience. (https://www.kyoshin.bosai.go.jp/kyoshin/topics/html20240101160813/main_20240101160813.html)

NUMO-TR-04-04 (2004) *Evaluating Site Suitability for a HLW Repository - Scientific Background and Practical Application of NUMO's Siting Factors*.

Sakai, Y. (2013) "Correspondence of strong ground motions and damage to houses and buildings in the 2011 Tohoku-Chiho Taiheiyo-oki earthquake: Seismic intensity measure to evaluate heavy structural damage to houses and buildings more accurately," *Journal of Structural and Construction Engineering*, 78(683), pp. 35–40. doi:10.3130/aijs.78.35

Suzu City (2023) Statistics Suzu 2023. (https://www.city.suzu.lg.jp/uploaded/attachment/5300.pdf) [Accessed: April 14, 2024].

Suzu City (2022) Suzu City Vacant House Countermeasure Plan. (https://www.city.suzu.lg.jp/uploaded/attachment/3738.pdf) [Accessed: April 14, 2024].

The World Bank (2016) *Making Schools Resilient at Scale: The Case of Japan.* (https://gpss.worldbank.org/sites/gpss/files/knowledge_products/2019/Japan_MakingSchoolsResilientatScale.pdf)

Ueda, K., Uzuoka, R., Jayakody, S., Tanaka, N. (2024) *2024 Noto Peninsula Earthquake. Field Survey Report: Liquefaction Damage in Ishikawa and Toyama Prefectures* (in Japanese). DPRI Noto Peninsula Earthquake Report. (in Japanese)

(https://www.dpri.kyoto-u.ac.jp/contents/disaster_report/files/20240101NotoEQ_GeohazardReport.pdf)

US Geological Survey (USGS) (2024a) “M 7.5 - 2024 Noto Peninsula, Japan Earthquake.” January 23. https://earthquake.usgs.gov/earthquakes/eventpage/us6000m0xl/executive

Wajima City (2022) *Population Tally of Wajima City, Ishikawa Prefecture, FY2022*. (https://www.city.wajima.ishikawa.jp/docs/2017050900011/file_contents/R541.pdf) [Accessed: April 14, 2024].

Wajima City (2018) Wajima City Vacant House Countermeasure Plan. (https://www.city.wajima.ishikawa.jp/docs/2019011100027/file_contents/akiya_keikaku.pdf) [Accessed: April 14, 2024].

Wei, D. and T. Seno (1998) “Determination of the Amurian plate motion.” In M. Flower, S. L. Chung, C. H. Lo, & T. Y. Lee (Eds.), *Mantle Dynamics and Plate Interaction in East Asia*. Geodynamics Series, 27, 337-346.

Yamada, M. (2024) “Earthquake Early Warning for January 1, 2024 Noto Peninsula Earthquake (M7.6)” (in Japanese). http://www.eqh.dpri.kyoto-u.ac.jp/~masumi/ecastweb/240101/index.htm

Yamada, M., Tamaribuchi, K., & Wu, S. (2021) “IPFx: Extended integrated particle filter method for achieving high-performance earthquake early warning system,” *Bulletin of the Seismological Society of America*, 111(3), pp. 1263-1272. https://doi.org/10.1785/0120210008

Yomiuri Shimbun (2024a) “Five minutes after the Noto earthquake, people move to higher ground... Living lessons from tsunami evacuation.” Yomiuri Shimbun. https://www.yomiuri.co.jp/science/20240304-OYT1T50053/ [Accessed: April 14, 2024].

Yomiuri Shimbun (2024b) “More than 30% of residents in Wajima, Suzu, and Noto evacuated outside the cities and towns...estimated from smartphone location data.” Yomiuri Shimbun. https://www.yomiuri.co.jp/national/20240128-OYT1T50166/ [Accessed: April 14, 2024].