Published by JScE as Proceedings of 4th International Conference on Earthquake Engineering and Post-Disaster Reconstruction Planning (ICEE-PDRP), 19-21 Jan. 2026, Bhaktapur, Nepal

CULTURAL HERITAGE DAMAGE AND POST-DISASTER RECOVERY UNDER COMPOUND HAZARDS: THE NOTO PENINSULA EARTHQUAKE OF JANUARY 1, 2024 FOLLOWED BY EXTREME RAINFALL

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Abstract

A devastating earthquake hit the Noto Peninsula in Japan on the first day of 2024, a region rich in history, culture and nature, caused serious damage to those heritages. The present paper introduces the earthquake damage to cultural heritages together with the damage related to outlines of the major earthquake. Recovery of the damaged cultural heritages started on the basis of the disaster prevention measures that had been developed since the Kobe Earthquake in 1995. However, during the process of recovery phase, the earthquake-affected areas in the Noto Peninsula suffered further damage from the disastrous rainfall in September, 2024. In the present paper, the earthquake damage to the cultural heritages are reviewed with being followed by the further damage caused by the heavy rainfall in order to share our experience internationally.

Keywords: Cultural heritages, Heritage structures, Earthquake damage, Heavy rainfall, Compound disaster

1. Introduction

On the New Year's Day of 2024, a major earthquake occurred with its epicenter in the Noto Peninsula, one of the historic rural areas in Japan. The devastating earthquake caused serious damage to cultural heritages. In the present report, after introducing outlines of the earthquake and the disaster, the damages to the cultural heritages are overviewed, as well as, the recovery state is briefly described. Furthermore, the present report shows a new issue that the extremely heavy rainfall in September 2024 affected seriously the earthquake-damaged heritages. This report is given by the special committee for support of damaged cultural heritage, ICOMOS Japan.

2. Outlines of Earthquake

The Noto Peninsula is a local area located in the center of the mainland, Honshu, on the side of Japan Sea. No major earthquakes have been recorded in the past 100 years, but a large earthquake of 6.9 (M_{JMA}) occurred in 2007, which caused severe damage to a number of traditional wooden buildings and public lifelines. Seismic activity has increased since 2018, with a magnitude 6.5 (M_{JMA}) earthquake occurring in May 2023 and the devastating earthquake of magnitude 7.6 (MJMA), described in the present report, occurred on the New Year's Day, 2024. The map of the epicenter and the estimated fault of the mainshock that caused the major earthquake is shown in Figure 1. The present near-field earthquake was followed by a series of aftershocks of magnitude 6 (M_{JMA}). The representative acceleration time histories of the strong motions recorded at K-NET and KIK-net provided by NIED are described in Figure 2. Table 1 summarizes the peak acceleration and the peak velocity of the ground motions recorded by that system. The peak acceleration level ranged from 0.8 to 2.6G, while the peak velocity level ranged from 0.6 to 1.4m/s. Figure 3 shows the acceleration spectra of those recorded ground motions, compared with the spectra recorded by the Kobe Earthquake of 1995 and given by Japan Building Code. It should be noticed that the intensity of the recorded ground motions was comparable to the Kobe Earthquake,

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https://doi.org/10.3126/jsce.v13i1.89638

and was so strong that it would exceed the intensity of Japan Building Code. Table 2 summarizes the human impact and the damage to the buildings caused by the Noto Peninsula Earthquake as of October 1, 2024.

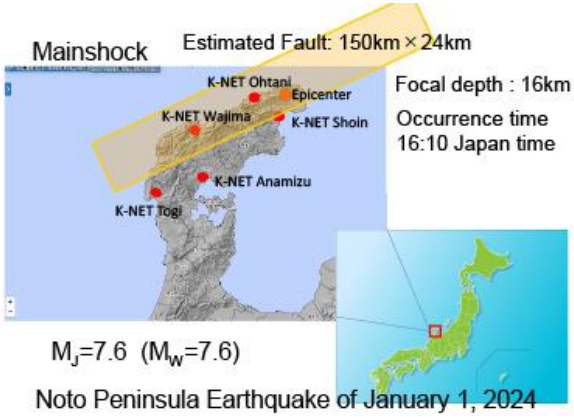


Figure 1: Epicentre and estimated fault with seismograph network observation points

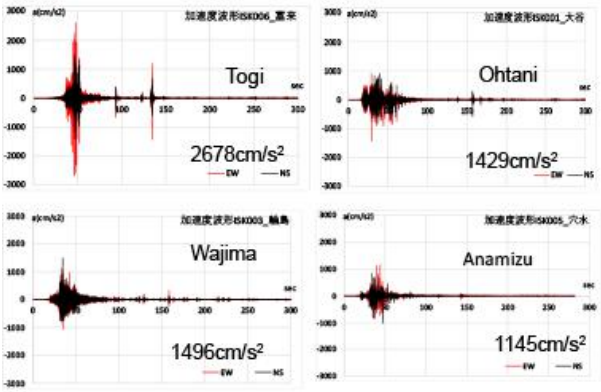


Figure 2: Wave forms of acceleration recorded in the epicentral area

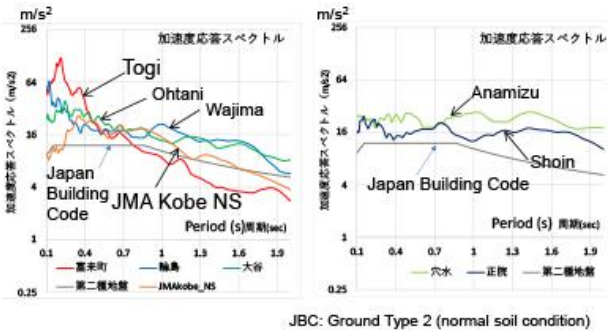


Figure 3: Response spectre of recorded strong motions compared with Japan Building Code & Kobe EQ

3. Overview of Earthquake Damage to Cultural Properties

The Noto Peninsula is a rural area characterized by a rather complex topography consisting of coastal and mountainous areas. Under such topographical conditions, it has a long history with many cultural heritages and historic sites. In particular, a number of wooden traditional houses were seriously affected by the extremely strong ground motions. Furthermore, the earthquake caused numerous landslides in the mountain areas and the tsunami along the coasts. Due to the numerous landslides, the traffic disruption was seriously caused, having made it difficult to rescue disaster-affected people and recover damaged lifelines. As for the cultural heritages, from designated to undesignated cultural properties, collapsed or severely damaged. Table 3 summarizes the damage to cultural properties designated at national or local government level.

Incidentally, some of the heritage structures were reinforced after they were damaged by the 2007 Earthquake of (M_{JMA})=6.9. Those reinforced structures were affected again by the 2024 Earthquake of (M_{JMA})=7.6, which would give significant knowledge from an earthquake engineering point of view.

As described later, some damaged cultural heritages were hit by the floods and debris flow by the extreme rainfall in September, 2024. Those heritages suffered seriously the compound disaster caused by the major earthquake and the post-earthquake meteorological disaster.

4. Earthquake Damage to Cultural Heritages

4.1. Architectural Heritages Damaged by the Strong Ground Motions

In the Noto Peninsula, most of the houses were of traditional wooden construction characterized by frame structures with roof tiles. Most of those traditional wooden construction houses might be vulnerable to earthquake-induced strong ground motions, therefore, they were severely damaged or collapsed by the Noto Peninsula Earthquake of 2024, exampled in Figure 4.

In the Noto Peninsula, there are several traditional construction houses designated as national important cultural properties. Kamitokikuni family house constructed in 1831, one of the important cultural properties, totally collapsed, shown in Figure 5. While survey and discussion were performed for restoration after the disaster, the destructed house and its surrounding historic site were buried by the mudslides caused by extreme rainfall in September, described in Chapter 6.

Table 1: Peak ground acceleration, peak ground velocity, and JMA intensity at selected locations

Location	PGA (m/s^2)			PGV (m/s)			JMA
	NS	EW	UD	NS	EW	UD	Intensity
Togi	14.8	26.8	11.4	0.61	0.69	0.36	6.6
Wajima	15.0	11.2	11.1	0.84	0.62	0.51	6.2
Anamizu	10.2	11.5	10.4	0.96	1.43	0.41	6.5
Shoin	6.9	7.1	7.7	1.06	1.17	0.46	6.2

Table 2: Summary of human impact and damage to the buildings caused by the Noto Peninsula earthquake

(a) Human impact

Dead	Injured	Missing
401 (174*)	1,336	2

* Disaster-related disease

(b) Damage to residential buildings

Extensively damaged	Moderately damaged	Partially damaged	Total
6,421	22,823	103,768	133,037

(c) Damage to non-residential buildings

Public	Others	Total
131	35,654	133,037

Figure 4: Collapse of traditional wooden houses in the epicentral area (Waima City)

(a) Before Earthquake

(b) After Earthquake

Figure 5: Kamitokikuni Family House

Table 3: Number of damage to designated cultural properties by Noto Peninsula earthquake (Damage information from the Ministry of Education, Culture, Sports, Science and Technology)

National Treasures (Structures)		2
Important Cultural Property	Structures	56
	Fine Arts	6
Registered Tangible Cultural Properties (Structures)		184
Historic Sites		22
Special Places of Scenic Beauty		1
Places of Scenic Beauty		9
Natural Monuments		4
Registered Monuments		1
Cultural Landscapes		2
Groups of Traditional Buildings (Preservation District)		13
Important Tangible Folk Cultural Properties		4
Important Intangible Folk Cultural Properties		1
Others		121
Total		**426**

(a) Before Earthquake

(b) After Earthquake

Figure 6: Former Kadomi family house

Figure 7: Damaged registered tangible cultural properties along ”Ippon Sugi” Street

4.2. Groups of Traditional Buildings

The Noto Peninsula is a rural area where many historic townscapes and landscapes exist, where many tourists visit. The most severe damage was caused by the earthquake in the preservation district of groups of traditional buildings in Kuroshima-Wajima in the coast area. In this traditional district, the former Kadomi family house's complex constructed in 1871 was severe damaged, shown in Figure 6. The damaged architectural heritage that composed of 5 buildings were designated as the national important cultural property. After the Noto Peninsula Earthquake of 2007 caused damage to those heritage structures, they were

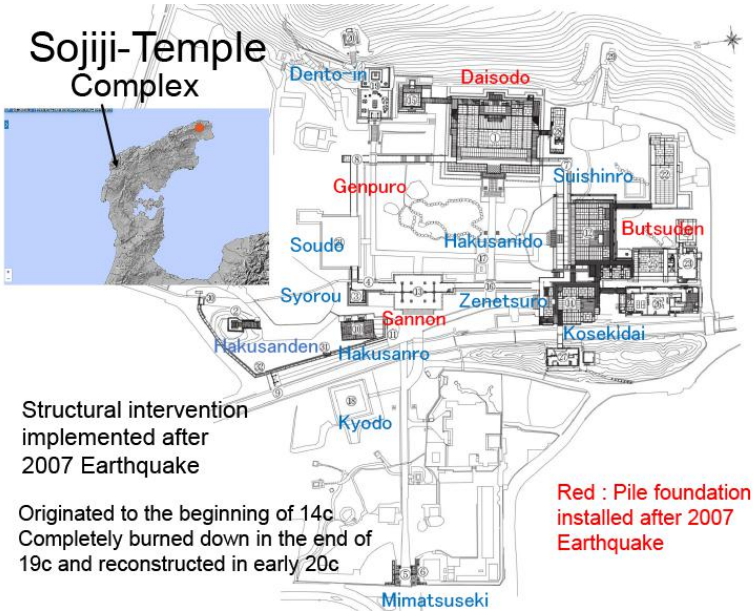


Figure 8: Building layout and earthquake-resistant measures implemented after 2007 Earthquake

(a) Daisodo Hall

(b) Butsuden Hall

Figure 9: Damage to halls in Soujiji Soin Temple

restored with seismic reinforcement, however, the main building collapsed during the Earthquake of 2024. In order to review the effectiveness of the seismic reinforcement performed after Earthquake of 2007, discission was made by the expert team from earthquake engineering point of view. The outcomes obtained from the discussion at national level was published by Agency for Cultural Affairs.

In Nanao City located 40km from the epicentre, the registered tangible cultural properties were damaged in the historic street called “Ippon Sugi”, shown in Figure 7. The recorded PGA was 0.46G at K-NET in Nanao City.

4.3. Damage to Historical Wooden Temples

The Sojiji Soin Temple belonging the Soto Zen sect was founded about seven hundred years ago. Most of the traditional wooden buildings that can be seen today in the temple site were reconstructed after the major fire at the end of the 19th century. (The main temple was relocated to Yokohama after the fire disaster.) The restoration work of the traditional wooden buildings had been performed with seismic reinforcement after the Earthquake of 2007 caused damage to those buildings. After those heritage structures were affected by the Noto Peninsula Earthquake of 2024, 16 architectural heritages were designated as important

Figure 10: Fire disastrous area of traditional morning market of Wajima

Figure 11: Disaster of residential area hit by tsunami along the coast of Suzu city

Figure 12: Rokko Cape Light house and its damage of equipment

Figure 13: Five-storied Stone Pagoda in Myosenji Temple

cultural properties by the national government. Figure 8 describes the complex of Sojiji Soin Temple, showing

Figure 14: Collapse of stone retaining wall in Kanazawa Castle

Figure 15: Damage to Shiroyone Denmai-da rice terraces

the location of the heritage structures and of the buildings that were retrofitted by employing pile foundations after the Earthquake of 2007. Although the heritage structures were affected by the Earthquake of 2024, it was found that many of the architectural heritages that had been reinforced to withstand earthquakes did not suffer serious damage, indicating the effectiveness of the seismic reinforcement after the Earthquake of 2007. However, the damage was concentrated at or nearby the connection between the wooden structures with different dynamic characteristics, shown in Figure 9. This indicates that, even if each building is earthquake-resistant and safe, connecting buildings with different dynamic behaviors would yield excessive loads at or nearby the joints and would cause damage, which might be a further subject.

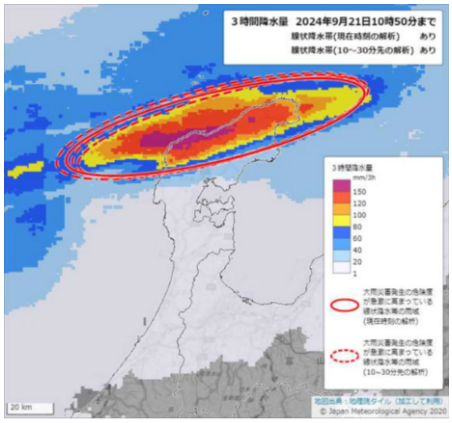
4.4. Fire Disaster in historic Area

The famous morning market and its surrounding area with traditional townscape in the city centre of Wajima was burned down, shown in Figure 10. In this disastrous area, about 300 buildings (48,000m2) was lost by the fire caused by the Earthquake of 2024. The fire hazard of density built-up area of wooden houses was recognized again.

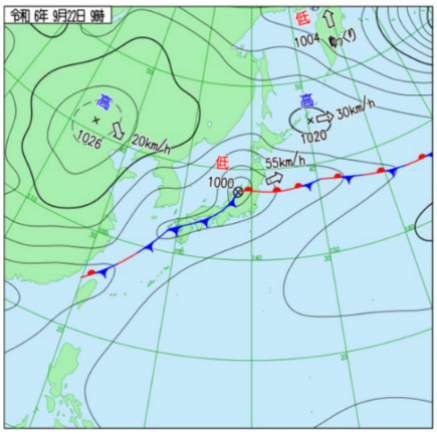
(a) Survey of damage

(b) Temporary reinforcement

Figure 16: Emergency response work at Wajima Kuroshima Preservation District of Groups of Traditional Buildings



(a) Rainfall map



(b) Atmospheric pressure map

Figure 17: Weather map when rainfall disaster that seriously affected Noto Peninsula (Japan Meteorological Agency)

4.5. Damage Caused by Tsunami

The coastal areas of Suzu City suffered extensive damage the tsunami of which hight was recorded to be as high as 4.3m. In this disastrous area, a number of traditional wooden houses were severely damaged or lost. Photo 11 shows the disastrous area hit by the tsunami.

4.6. Masonry Heritage Structures

There are a few heritage structures of masonry in the Noto Peninsula. In the present paper, two heritage structures of masonry in the earthquake-affected area are described.

One is the light house at Rokko Cape of stone masonry, which locates in the vicinity of the epicentre. This heritage structure was designed by a French engineer and constructed in 1883 by utilizing the andesite stones with the reinforced concrete slabs. It had been working for navigation of ships for more than 100 years. In its history, as the seismic diagnosis resulted in the lack of seismic safety, structural intervention utilizing epoxy resin replacement method were performed in 1997. The stone structure was slightly damaged with non-significant cracks at the joints, however, the glass lens in the lamp room was fallen or broken, shown in Photo 12. It was considered that the dynamic soil-structure interaction phenomenon might reduce the structural response and the heritage structure was not severely damaged, though the equipment was seriously damaged. After the damaged equipment was repaired, it started again shining light as a lighthouse.

Another historical masonry structure to be introduced is the five-storied stone pagoda in Myosenji Temple in Anamizu Town, where the extremely strong ground motions were recorded. This stone pagoda, constructed in 14th century, was designated as a national important cultural property. It was of interest that slight rotational displacement was caused by the Earthquake of 2024, but it survived against the earthquake, shown in Figure 13.

(a) Kamitokikuni family house

(b) Shimotokikuni family house

Figure 18: Disastrous situation of damaged cultural properties after extreme rainfall

Figure 19: Compound damage to Iwakura-ji temple

4.7. Historic Sites

Historic retaining stone walls in the Kanazawa Castle partially collapsed, shown in Photo 14. It was reported PGA in Kanazawa City at the epicentral distance of 100km was 0.22G. Following the experience of the Kumamoto Earthquake of 2016, when the stone retaining walls of Kumamoto Castle were severely damaged, the seismic resistance of castles' stone walls has attracted attention, and both research and countermeasures have been carried out in Japan.

4.8. Historic Site and Place of Scenic Beauty

Several historic sites and places of scenic beauty were damaged. Photo 15 shows the cracks of the ground caused in Shiroyone Senmai-da rice terraces, the national place of scenic beauty in Wajima. The more than 1,000 rice terraces are made in the beginning of 17th century on the slope facing the Sea of Japan. Shown in this photo, the surface soils moved and a number of cracks appeared. At the same time, the water supply route was cut off. This site is located on a landslide terrain and has a gentle slope.

5. Recovery from Earthquake Damage to Cultural Heritages

Emergency response to rescue the damaged cultural heritages was started after the devastating earthquake. At national level, "Cultural property doctor dispatch program" and "Cultural heritage rescue program" were conducted to rescue heritage structures and movable cultural properties, respectively by the Cultural Heritage Prevention Centre. Furthermore, the restoration program utilizing the prefectural funds were prepared for recover them. Also, crowd funding to support public-private joint project was provided. After the experience of Kobe Earthquake of 1995 that caused serious damage to numerous cultural heritages, social interest has grown in the seismic safety of the cultural heritages in Japan. Since then, earthquake-resistance measures for cultural properties have

been implemented in various phases in both political and technical measures. Following the experiences of the Great East Japan Earthquake in 2011 and the Kumamoto Earthquake of 2016, those measures have been further improved. Photo 16 examples the emergency response work to rescue the wooden heritage structure damaged by the Noto Peninsula Earthquake of 2024.

6. Compound Disaster Induced by Heavy Rainfall during Recovery Phase

6.1. Outlines of Weather Condition

During the recovery phase, in September 2024, there occurred so-called "linear precipitation band" which originated from the typhoon and caused the extremely heavy rainfall in Noto Peninsula where cultural heritages were damaged by the Earthquake of 2024. Figures 13(a) and (b) describe the rainfall and the atmospheric pressure map when the serious rainfall disaster was caused, respectively. The linear precipitation band was formed by active frontal activity. Table 4 shows the precipitation (Total and 1-hour, 3-hours) recorded in the earthquake-affected area of Wajima and Suzu. This extreme rainfall caused the floods of the rivers, the landslides and the debris flow at many places in the Noto Peninsula.

Table 4: Recorded rainfall characteristics at Wajima and Suzu

Rainfall Parameter	Wajima	Suzu
Total rainfall over 3 days (mm)	501	394
1-hour rainfall peak (mm)	121	85
3-hour rainfall peak (mm)	412	230

6.2. Compound Disaster of Cultural Heritages

A number of heritage structures and historic sites, although most of them had not been recovered and restored, suffered the disaster caused by the extremely rainfall. For the case of Kamitokikuni family house that collapsed by the Earthquake (See Chapter 4), the destructed building and the surrounding historic site were buried by the debris flow, shown in Photo 18. There had been historical documents in this important heritage structure, however, those were buried under the mud debris. Afterward, the historical documents designated by the prefecture were rescued, however, an estimated 20,000 documents that have yet to be investigated remain buried.

The adjacent Shimotokikuni family house, also designated as the national important cultural property, did not collapse but was severely damaged. This architectural heritage was also buried by the mudslide during the extremely rainfall in September, shown in Photo 18. Although consideration had been given to restoring those heritage structures damaged by the Earthquake of 1st Day of 2024, no measures had been taken to protect them from such meteorological disasters.

As climate change has become an international issue, compound damage to cultural heritages caused by earthquakes and extreme climate phenomena such as heavy rainfall would become a future issue for conservation of cultural heritages in seismic countries.

The traditional wooden structures of Iwakura-ji Temple located in the mid-slope of the mountain near Kamitokikuni family house were severely damaged by the Earthquake. The main hall of this temple was reconstructed in 1507 after the major fire. However, the extreme rainfall in September caused further damage to traditional buildings including the main hall, and some of the earthquake-damaged buildings were swept away by the terrible mudslides (See Photo19).

Note that the present disaster is not the first time that such a compound disaster has occurred in Japan; we have already experienced it in the past. The affected areas of the Fukui Earthquake of June 28, 1948 suffered greater damage by the river flooding caused by heavy rainfalls one month later.

7. Concluding Remarks

It should be expected to verify the systems (guidelines, rescue activities, recovery fund et al.) and the technologies that have been developed in Japan for disaster prevention of cultural heritages since the Kobe Earthquake of 1995.

A number of traditional wooden buildings suffered serious damage. Issues include the impact of the peninsula's mountainous topography and soil conditions on damage and restoration. Heritage structures damaged by the 2007 earthquake and reinforced are also being reviewed.

It is now in the recovery phase. The earthquake disaster occurred in a depopulated area where many historical and cultural heritages exist, therefore, economic problems have become apparent in the recovery process. Further public economic support would be needed for restoration of the damaged cultural heritages.

Heritage structures damaged by the Earthquake of 2024 suffered further damage due to the extreme rainfall disaster, having risen a new issue to protect them in seismic areas affected by climate change that may cause extremely heavy rainfall.

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