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FORMATION PROCESS OF AKITA URBAN AREA AND REPEATED EARTHQUAKE DAMAGE AFTER 1896

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ABSTRACT: The 1983 Nihonkai-Chubu Earthquake (M7.7) marked its 40th anniversary in 2023. In Akita City, this earthquake caused three fatalities and damage to residential buildings, including 35 completely destroyed houses and 235 partially damaged houses. Akita City has also experienced earthquake damage from several past events, including the 1896 Rikuu Earthquake, the 1914 Akita Senboku Earthquake, and the 1964 Niigata Earthquake. This study focuses on the damage in Akita City caused by these four earthquakes. The characteristics and spatial distribution of the damage are compiled and examined, and the damage distribution is compared with historical topographic maps from the corresponding periods. Through this analysis, the historical record of earthquake damage in Akita City is outlined. Records of past earthquake damage and their spatial distribution constitute essential baseline data for urban disaster mitigation planning. Based on these results, the relationship between the historical earthquake damage record and the process of urban development in Akita City is discussed.

Keywords: *Akita city, Earthquake damage history, Urban formation, Rikuu Earthquake of 1896, Akita Senboku Earthquake of 1914, Niigata Earthquake of 1964, Nihonkai-Chubu Earthquake of 1983*

1. INTRODUCTION

Akita City has repeatedly sustained damage from earthquakes occurring both along the Sea of Japan coast and in inland areas around the Yokote Basin. Notable damaging events include the 1964 Niigata Earthquake and the 1983 Nihonkai-Chubu (Japan Sea) Earthquake, as well as inland earthquakes such as the 1896 Rikuu Earthquake and the 1914 Akita Senboku Earthquake. In addition, in the case of great earthquakes of approximately M8 occurring along the Pacific coast of the Tohoku region, the affected area extends not only along the Pacific side but also to the Sea of Japan side. For example, the 1968 Tokachi-Oki Earthquake caused direct damage in Akita City, including subsidence of quay walls at Akita Port[1)]. The author has been conducting historical investigations of damage-causing earthquakes that have affected Akita Prefecture since the Meiji era, based on contemporary survey reports, administrative records, and local newspaper articles. Previous studies have clarified the damage and its spatial distribution associated with past earthquakes that affected Akita City, such as the 1896 Rikuu, 1914 Akita Senboku, and 1964 Niigata earthquakes[2)–4)]. In this study, the damage caused by the 1983

Nihonkai-Chubu Earthquake, which marked its 40th anniversary in 2023, is reexamined, and its characteristics are investigated in detail together with the damage history of earlier events. The process of urban development is traced using historical topographic maps published by the Geospatial Information Authority of Japan. Examining the history of earthquake damage from the perspective of urban development is considered important for future urban disaster mitigation.

2. OVERVIEW OF EARTHQUAKES THAT CAUSED DAMAGE IN AKITA CITY

Earthquakes that have caused damage in Akita City since the Meiji period were selected from the Comprehensive Catalog of Damaging Earthquakes in Japan (Usami et al.[5]) and are listed in Table 1. The numbering follows the sequential earthquake identification numbers assigned in the catalog. Figure 1 shows the spatial distribution of epicenters of earthquakes that have affected Akita City. Among these events, this study focuses on four earthquakes: the 1983 Nihonkai-Chubu Earthquake, as well as the 1896 Rikuu, 1914 Akita Senboku, and 1964 Niigata earthquakes, all of which caused relatively significant damage in Akita City, including the complete collapse of residential buildings.

According to the Comprehensive Catalog of Damaging Earthquakes in Japan, the damage in Akita City caused by the 1983 Nihonkai-Chubu Earthquake included three fatalities, 35 completely destroyed houses, and 235 partially damaged houses[5]. The 1896 Rikuu Earthquake caused damage to residential buildings, with three completely destroyed and 12 partially damaged houses; for individual structures, damage such as wall cracking and chimney collapse was reported in schools and the prefectural office[2]. The 1914 Akita Senboku Earthquake resulted in three completely destroyed and four partially damaged houses in Akita City. In addition, severe damage and collapse were observed in townhouses and public buildings. The characteristics of damage were diverse, reflecting urban conditions, including fires caused by ruptured chemicals and damage to water supply pipelines and oil transmission pipes[3]. The 1964 Niigata Earthquake caused one fatality in Akita City, with one completely destroyed and 12 partially damaged houses[4].

Table 1 Major earthquakes causing damage in Akita City (1894–1983)

No.	Day/Mo/Yr	M	Earthquake Name	Major damage in Akita City
311	22/10/1894	7.0	Shonai Earthquake	Minor wall damage (merchant houses)
317*	31/08/1896	7.2	Rikuu Earthquake	Injured 1, Houses completely destroyed 3, Partially damaged 12, Damaged 77
398*	15/03/1914	7.1	Akita Senboku Earthquake	Injured 3, Houses completely destroyed 3, Partially damaged 3, Damaged 93
494	01/05/1939	6.8	Oga Earthquake	Wall cracks at Akita Prefectural Government Office
561	07/05/1964	6.9	Off Oga peninsular Earthquake	Wall cracks at Akita Prefectural Government Office
562*	16/06/1964	7.5	Niigata Earthquake	Dead 1, Injured 3, Houses completely destroyed 1, Partially damaged 3, Damaged 1100
580	16/05/1968	7.9	Tokachi-Oki Earthquake	Wall cracks (riot police barracks, employment office), Quay wall subsidence (Akita Port)
645*	26/05/1983	7.7	Nihonkai-Chubu Earthquake	Dead 3, Injured 7, Houses completely destroyed 35, Partially damaged 235

* Indicates earthquakes analyzed in this study

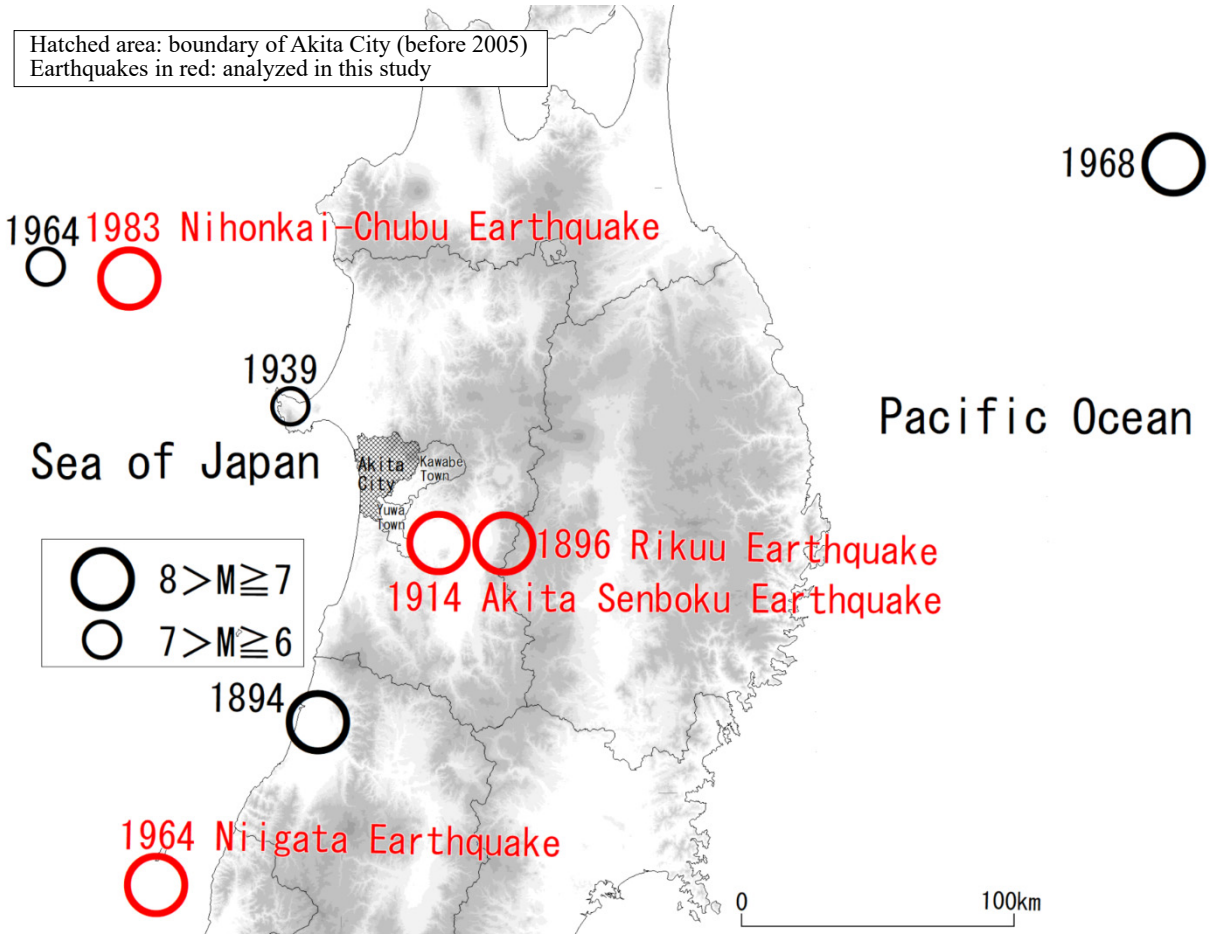


Fig. 1 Epicentral distribution of earthquakes causing damage to Akita City (1894–1983)

3. URBAN DEVELOPMENT OF AKITA CITY AND THE HISTORY OF STRONG-MOTION OBSERVATIONS

3.1 Historical Background and Urban Development of Akita City

In this study, the spatial extent of Akita City is defined as the municipal boundary at the time of the 1983 Nihonkai-Chubu Earthquake, i.e., prior to the municipal mergers of the Heisei era in 2005. Figure 2 illustrates the temporal changes in the urban area of Akita City between 1912 and 1981, before the occurrence of the 1983 Nihonkai-Chubu Earthquake. The base maps are 1:50,000-scale topographic maps published in 1912 and 1981. The 1912 map represents the earliest topographic map covering the study area. The municipal boundaries and town and village names at the time of the enforcement of the municipal system in 1889 are shown in Fig. 2(a). In addition, the locations of major rivers—the Omono River, the Asahi River, and the Taihei River—are indicated. Figure 2(b) also shows the location of the strong-motion observation station operating in 1981 (marked with a star), together with explanatory annotations. Akita City is located near the central part of Akita Prefecture along the coast of the Sea of Japan. The Sea of Japan lies to the west, while the Taihei mountain range extends to the east. The Omono River flows through the southern part of the city. The Asahi River runs through the central urban area, where it joins the Taihei River, and both rivers discharge into Akita Port.

Following the Meiji Restoration, Kubota Town was reorganized as Akita Town, and with the enforcement of the municipal system in 1889 it became the only city in Akita Prefecture. At that time,

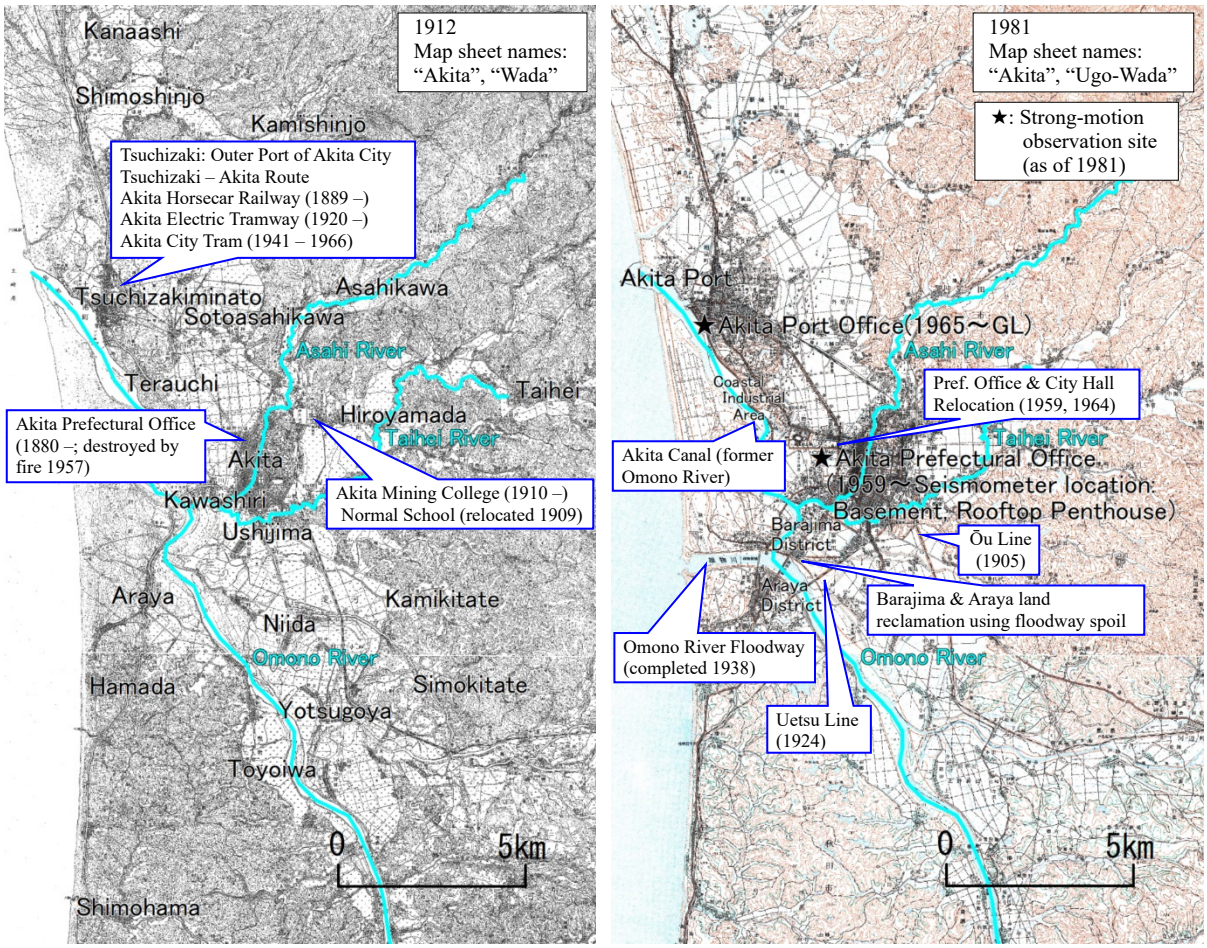
the city covered an area of 6.87 km² and had 6,598 households with a population of approximately 29,000. The population increased rapidly after the relocation of the 17th Infantry Regiment from Sendai in 1898, and particularly after the opening of the Ou Main Line railway in 1905. Akita City originally developed as an inland town, with Tsuchizaki serving as its outer port. Prior to the opening of the Ou Main Line, the Akita Horsecar Railway, which connected Akita and Tsuchizaki, began operation in 1889. This line later evolved into the Akita Electric Railway and subsequently the Akita City Tram, which continued to link the two areas until its abolition in 1966. The Akita Prefectural Government Office, which was established in 1872, was relocated several times, including temporary use of the main keep of Kubota Castle. In 1880 a new government building was completed at the present-day Nakadori district. After the second prefectural government building was destroyed by fire in 1957, a new building was constructed in 1959 in the present Sanno district of Akita City, which at that time was largely composed of paddy fields. This relocation marked the beginning of the development of the Sanno area as the administrative center of the city. In 1910, the Akita Mining College was established as the first higher education institution in Akita Prefecture. In 1909, the Akita Prefectural Normal School was relocated to the adjacent site, and the two institutions formed an integrated educational district. This area corresponds to the present-day Tegata campus of Akita University, located in Tegata Gakuenmachi. Meanwhile, the Omono River, which flows through the southern part of Akita City, repeatedly caused inundation damage to residential areas during periods of heavy rainfall, hindering regional development. Use the above-mentioned rules for indentation. Following severe flood damage in 1917, construction of the Omono River Floodway was initiated as a flood control measure to protect the region. The project involved excavating a channel through a hill in the Araya district to divert the river directly into the Sea of Japan. After 21 years of construction, the floodway was completed in 1938. This large-scale river improvement project enabled land development in the surrounding low-lying wetlands, particularly in the Barajima and Araya districts. The former river channel was subsequently developed into the Akita Canal, and a coastal industrial zone emerged in the area. These developments formed the foundation for the expansion of Akita Port and the subsequent economic growth of Akita City.

Changes in the administrative boundary of Akita City occurred through a series of municipal mergers and incorporations. Ushijima Town (Kawabe District) was incorporated in 1924, followed by Kawajiri Village (Minami-Akita District) in 1926. In 1933, Asahikawa Village (Minami-Akita District) was incorporated. In 1941, three towns and one village—Tsuchizaki-Minato Town, Terauchi Town, Araya Town, and Hiroyamada Village—were merged into Akita City. U In 1954, a large-scale municipal consolidation incorporated several surrounding rural municipalities, including Taihei Village, Soto-Asahikawa Village, Iijima Village, Shimo-Shinjo Village, Kami-Shinjo Village, Hamada Village, Toyoiwa Village, Niida Village, Yotsugoya Village, Kamikitade Village, Shimokitade Village, and Shimohama Village. In the following year (1955), Kanazashi Village was also incorporated. Through these mergers, the present municipal area of Akita City, covering approximately 458.9 km², was established. Subsequently, during the Heisei-era municipal consolidation in 2005, the neighboring towns of Kawabe and Yuwa, located to the east of Akita City, were incorporated, expanding the total municipal area to 906.1 km². The population of Akita City increased steadily throughout the twentieth century, from approximately 36,000 in 1920 to 217,000 in 1965, 296,000 in 1985, and 317,000 in 2000. Following the merger with Kawabe and Yuwa in 2005, the population reached approximately 333,000. However, after peaking in 2005, the population began to decline, decreasing to about 308,000 by 2020.

3.2 History of Strong-Motion Observations in Akita City

Strong-Motion observation began in the United States following a lecture by Kyoji Suehiro, which motivated the development of the first strong-motion accelerograph in 1932. In the following year, instrumental records were obtained during the 1933 Long Beach Earthquake, marking the beginning of modern strong-motion observation. In Japan, the SMAC-type accelerograph was developed after the 1948 Fukui Earthquake, and systematic strong-motion observations began in 1953[6]. At the time of the 1983 Nihonkai-Chubu Earthquake, two strong-motion observation sites were operating in Akita City: the Akita Prefectural Government Office (installed in both the basement and the rooftop tower) and the Akita Port Offices[7]. During the 1964 Niigata Earthquake, the strong-motion records obtained in Niigata

and Akita constituted the first full-scale instrumental records in Japan to capture a damaging earthquake. In Akita City, such a record was obtained at the Akita Prefectural Government Office, located approximately 135 km from the epicenter. The recorded peak accelerations were approximately 100 Gal in the basement and about 300 Gal (Gal = cm/s^2) were at the rooftop level. At that time, these values were among the largest strong-motion records obtained in buildings and attracted considerable attention. During the 1983 Nihonkai-Chubu Earthquake, numerous strong-motion records were obtained throughout Hokkaido and the Tohoku region. In Akita City, the strong-motion record obtained on the ground surface at the Akita Port Office showed a peak ground acceleration (PGA) of 205 Gal[8].



(a) 1:50,000 topographic map surveyed in 1912 (b) 1:50,000 topographic map surveyed in 1981

Fig. 2 Urban development of Akita City (place names, annotations, and rivers [light blue] added)

4. DAMAGE CAUSED BY THE 1983 NIHONKAI-CHUBU EARTHQUAKE IN AKITA CITY

Figure 3 shows the spatial distribution of damage in Akita City caused by the 1983 Nihonkai-Chubu Earthquake, including residential building damage, damage to individual structures, and areas where soil liquefaction occurred. The base map used in the figure is a 1:50,000-scale topographic map published in 1981. In the figure, damage to individual buildings is indicated by blue circles, other types of damage by blue squares, and human casualties by blue triangles. Areas where liquefaction occurred are shown by red hatching. The distribution of damage to residential buildings was compiled based on the damage distribution map presented in the survey report of the Japan Society of Civil Engineers9), while damage to individual buildings was derived from the survey report of the Architectural Institute of Japan[10]. In addition, the locations and extents of liquefaction were identified with reference to the

liquefaction history map of Japan compiled by Wakamatsu[11]. Most of the damage in Akita City was attributed to soil liquefaction, with damage concentrated in the Araya and Barajima districts, as well as in Akita Port and the coastal industrial zone. These areas also experienced small-scale liquefaction during the 1964 Niigata Earthquake. The most severe damage was observed in the Motomachi and Matsumimachi areas of Araya, where residential buildings experienced tilting, utility poles subsided, and concrete block walls collapsed. In addition, underground lifeline facilities sustained significant damage. The area around Araya-Motomachi had been developed through land reclamation using sediments excavated during the construction of the Omono River floodway in the early Shōwa period. The Araya district along the southern bank of the Omono River has long been known as an area with a thriving brewing industry, supported by abundant groundwater in the coastal dune deposits. At Akita Port, widespread soil liquefaction occurred, causing damage to port facilities and related structures. In addition, many other areas suffered localized damage due to soil liquefaction; in the Narayama and Kami-Iijima districts, severe damage including the total collapse of houses was observed. The heavily damaged areas in the Narayama district were located on reclaimed former channels of the Taihei River, while the Shimo-Iijima district lies along the boundary between coastal dunes and alluvial lowlands, where damage was observed particularly in filled paddy fields. The coastal industrial zone on the right bank of the former Omono River channel also consists of reclaimed river channels and floodplains. Regarding human casualties, one fatality occurred when an advertising tower on a department store in Omachi collapsed and fell onto the roof of the building. In addition, a fishing boat at the mouth of the Omono River capsized due to a tsunami, resulting in the deaths of two people.

5. HISTORICAL EARTHQUAKE DAMAGE IN AKITA CITY

The damages and their spatial distributions within Akita City associated with the 1896 Rikuu Earthquake, the 1914 Akita Senboku Earthquake, and the 1964 Niigata Earthquake—all of which occurred prior to the 1983 Nihonkai-Chubu Earthquake —as clarified in our previous studies[2)–4)], are presented here.

5.1 The 1896 Rikuu Earthquake

Figure 4 shows the spatial distribution of damage within the present-day area of Akita City during the 1896 Rikuu Earthquake. Locations where complete collapse of dwelling houses occurred are indicated by solid circle as ●, those where houses were severely damaged with wall failures are indicated by open circle as ○, those with other minor damage are indicated by diamond as ◇, and sites of liquefaction are indicated by red inverted triangle as ▽. Figure 5 shows the distribution of damage in the urban area of Akita City, plotted on a contemporary map based on the identified locations of individual buildings. The base map used is a 1:50,000-scale topographic map published in 1912. Although this is the earliest available map of the area at this scale, it was produced 16 years after the Rikuu Earthquake; therefore, it includes features such as railway extensions and newly established facilities that did not exist at the time of the earthquake. To distinguish these later developments, their opening years are indicated with pink annotations. For individual buildings, damage such as wall failures and the collapse of chimneys was reported for several facilities, including schools and the prefectural government office. Regarding the damage in Akita City, Sone reported in the Report of the Earthquake Investigation Committee[12] that “earthquake damage was particularly severe in Nakayachimachi in the central part of the city,” and that “the entire city is underlain by soft ground with no shallow hard stratum, with Nakayachimachi representing the most typical example.”

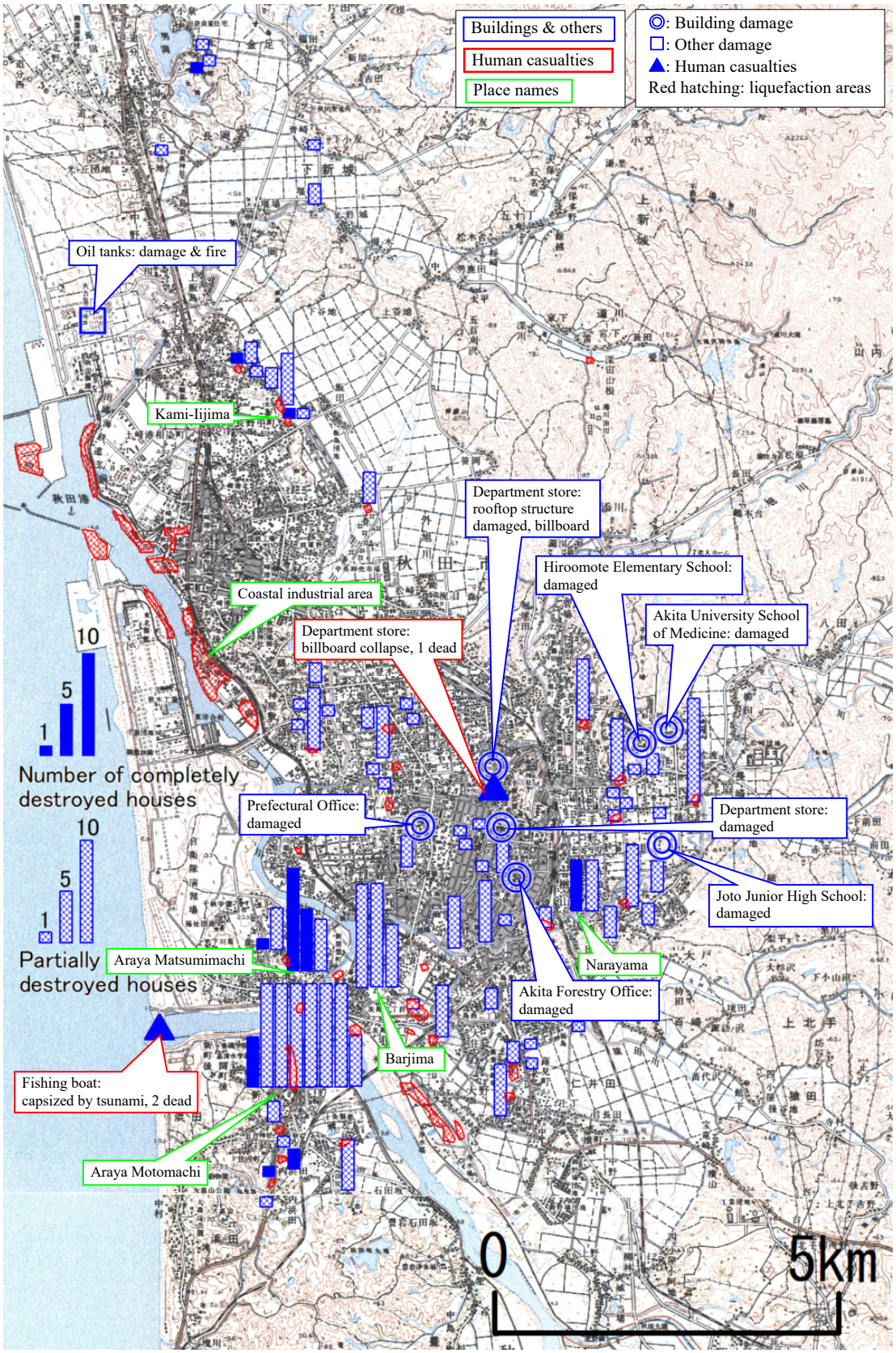


Fig. 3 Distribution of damage from the 1983 Nihonkai-Chubu Earthquake
(Base map: 1:50,000 topographic map surveyed in 1981; annotations added)

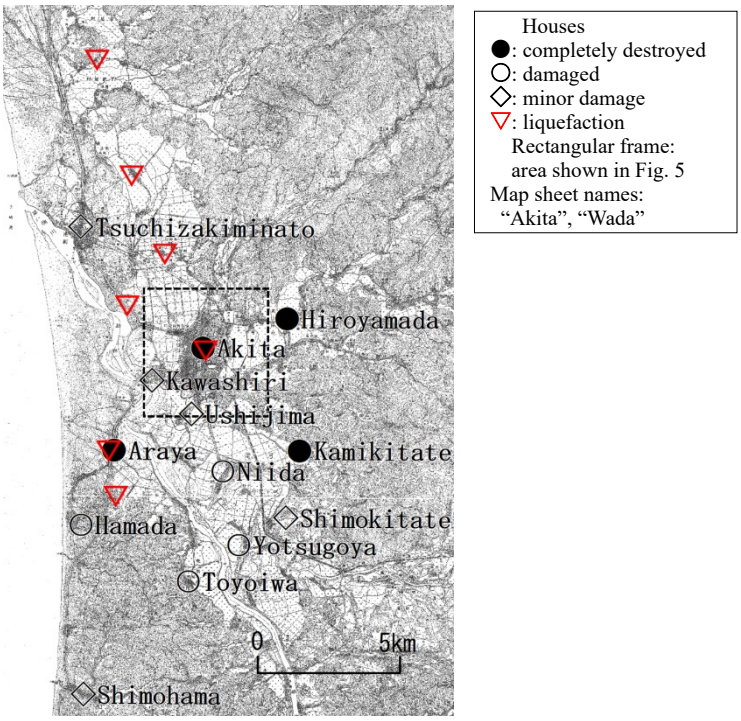


Fig. 4 Distribution of damage from the 1896 Rikuu Earthquake
(Base map: 1:50,000 topographic map surveyed in 1912; annotations added)

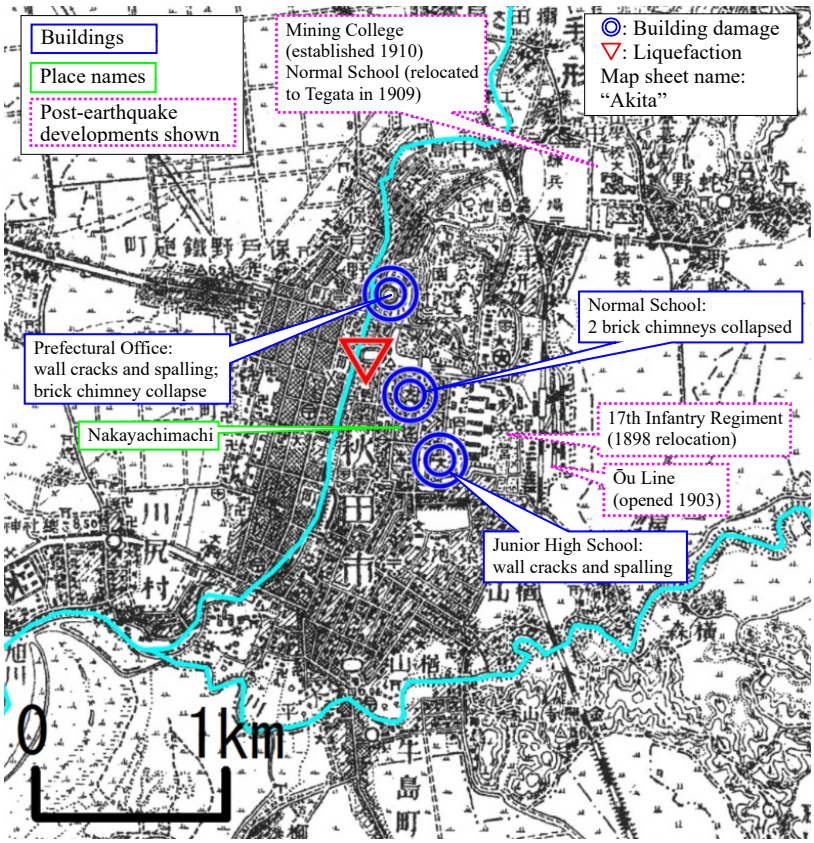


Fig. 5 Detailed damage distribution in the urban area of Akita at the time of the earthquake
(Base map: 1:50,000 topographic map surveyed in 1912; annotations and rivers [light blue] added)

5.2 The 1914 Akita Senboku Earthquake

Figure 6 shows the spatial distribution of damage within the present-day area of Akita City during the 1914 Akita Senboku Earthquake. Locations where complete collapse of residential houses occurred are indicated by solid circles, sites where houses suffered significant damage such as wall failures are shown by open circles, and locations with minor damage are indicated by diamonds. No cases of soil liquefaction were reported within the Akita City area during this earthquake. Although Akita City is located more than 30 km from the epicenter, the earthquake caused the complete collapse of several houses and damage to public buildings. The most severely affected area was Niida Village along the Omono River, where three houses completely collapsed and eleven were partially damaged. The next most heavily affected area was Hiroyamada Village, located along the Taihei River, where one house completely collapsed and another was partially damaged. Figure 7 shows the detailed damage in the urban area of Akita City on a contemporary map. The locations of individual buildings, ground damage, and other damage were identified and plotted. The figure also shows the zones of "most severe intensity" (solid red line) and "severe intensity" (dashed red line) based on the report by Imamura[13] in the Report of the Earthquake Investigation Committee. Areas with completely collapsed houses fall within the zone of "most severe intensity," and many of the towns where half-collapse of houses occurred are also concentrated within this zone. Although damage is widely distributed across the urban area of Akita City, damage of half-collapse or greater is concentrated in the western districts along the Asahi River, such as Kawabata and Ōmachi. These areas are all low-lying plains, suggesting a relationship with local ground conditions. In addition, damage was concentrated in the Tegata district, located east of Senshu Park and near Akita Station. These areas were formerly marshlands: the area near Akita Station was historically known as Naganuma, while the Tegata district was called Tegata Lagoon. Damage to individual buildings was particularly concentrated along the present-day Nakadori area south of Senshu Park. Ground damage included cracks in the road in front of Akita Station and subsidence and cracking of the road in front of the Red Cross Hospital.

5.3 The 1964 Niigata Earthquake

Figure 8 shows the spatial distribution of damage within the Akita City area during the 1964 Niigata Earthquake. Damage to residential houses is indicated by blue open circles, damage to individual buildings by blue double circles, ground damage by blue triangles, and human casualties by blue solid triangles. Locations where soil liquefaction was observed are indicated by red inverted triangles. The base map used is a 1:50,000 topographic map published in 1963. The distribution of damage to residential houses and individual buildings was compiled based on previous studies[4] derived from damage investigation reports on the Niigata Earthquake and contemporaneous local newspaper accounts. Residential building damage was reported in the districts of Barajima, Araya, Hodono, Narayama, and Teramachi. Except for Teramachi, many houses in these areas tilted due to ground cracking and ground subsidence, indicating that most of the residential damage was associated with ground deformation. In Barajima, ground cracking and subsidence occurred at more than ten locations, and lifeline facilities were also damaged. In Teramachi, cracks in the walls of residential houses were reported. As noted earlier, Barajima, Araya, and Narayama also experienced damage during the 1983 Nihonkai-Chubu Earthquake. Damage to individual buildings included settlement and tilting due to ground subsidence, as well as structural damage such as wall cracking and spalling, broken lightning rods, and shattered window glass at schools and other public buildings. One fatality resulted from being trapped beneath a collapsed concrete block wall.

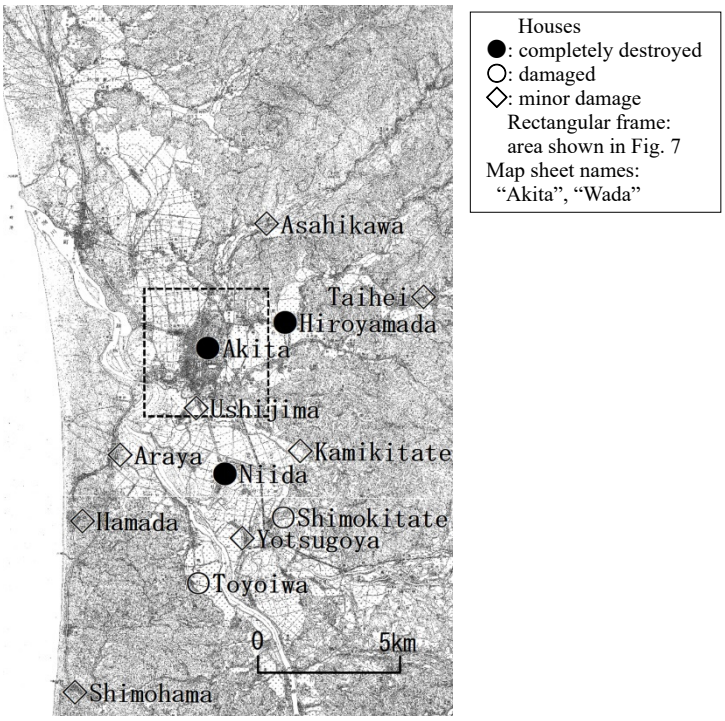


Fig. 6 Distribution of damage caused by the 1914 Akita Senboku Earthquake
(Base map: 1:50,000 topographic map surveyed in 1912)

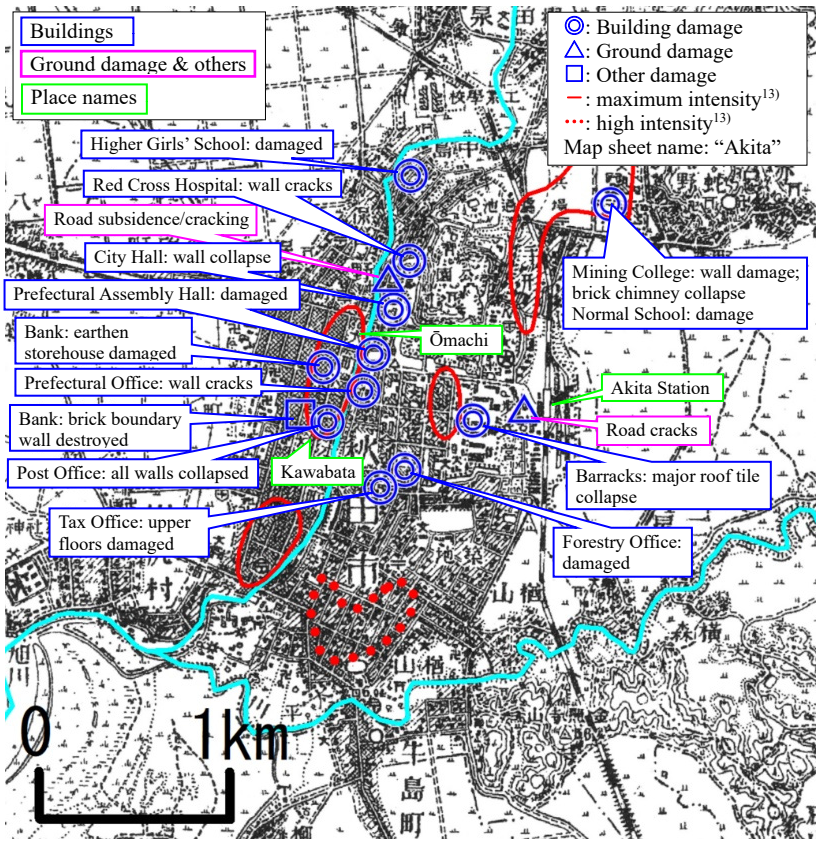


Fig. 7 Detailed damage distribution in the Akita urban area at the time of the earthquake
(Base map: 1:50,000 topographic map surveyed in 1912, with annotations and rivers added)

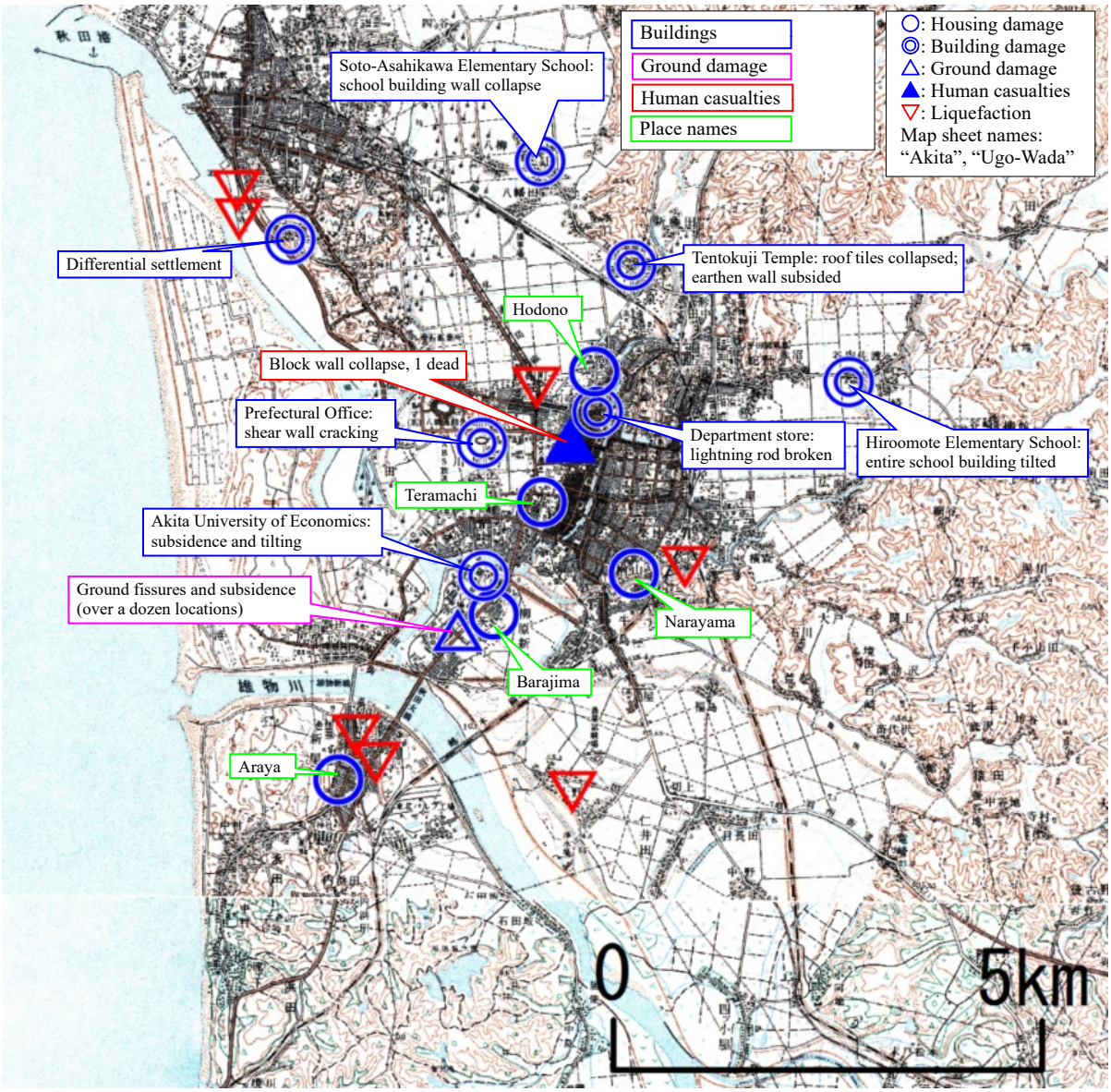
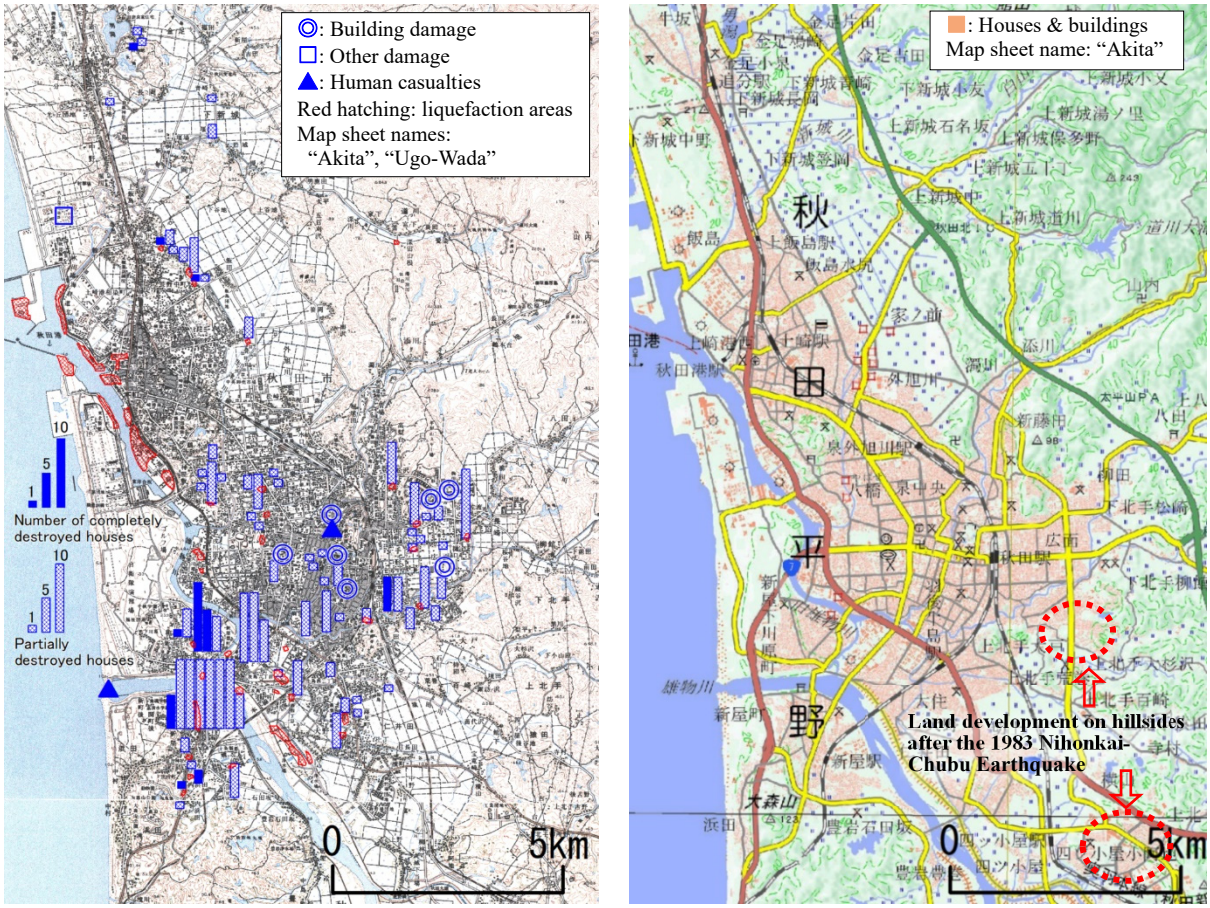


Fig. 8 Distribution of damage caused by the 1964 Niigata Earthquake
(Base map: 1:50,000 topographic map surveyed in 1963, with annotations added)

6. URBAN DEVELOPMENT OF AKITA CITY AND EARTHQUAKE DAMAGE

As of 2024, 41 years have passed since the occurrence of the 1983 Nihonkai-Chubu Earthquake, and the urban area of Akita City has further expanded. Figure 9 shows topographic maps of Akita City at the time of the earthquake and at present. Figure 9(a) also reproduces the distribution of damage to houses and buildings caused by the earthquake is also reproduced. In Fig. 9(b), areas of land development that have been created since the 1983 Nihonkai-Chubu Earthquake are outlined with red dashed lines. For the present topographic map, as the 1:50,000 series has not been updated in Akita since 2007, the Digital Map 200,000 (updated in 2021) is used in Fig. 9(b). Damage in Akita City during the 1983 Nihonkai-Chubu Earthquake was characterized by prominent ground liquefaction. The damage distribution was spatially concentrated, with most of the affected areas consisting of newly developed residential districts, and the impacts extended to lifeline infrastructure. Although ground liquefaction also occurred during the 1896 Rikuu Earthquake, it was not the primary cause of damage, being limited mainly to liquefaction

in paddy fields. Following subsequent urban expansion, the 1964 Niigata Earthquake caused damage primarily due to liquefaction and ground deformation of reclaimed land, affecting residential houses and other structures. The lowlands of the Akita Plain contain numerous place names incorporating terms such as “yachi” (marsh) and “numa” (swamp), indicating that extensive areas have developed into low-lying, water-saturated terrain. These wetlands were traditionally utilized as paddy fields; however, since the 1950s, rapid residential development through land reclamation and embankment filling has taken place. In addition, numerous former river channels can be observed along the Omono River, Asahi River, and Taihei River. Some of these have been reclaimed and are now used as industrial sites or residential land. The coastal industrial zone on the right bank of the former Omono River is also situated on reclaimed river channels and floodplains. Among the reclaimed lands on low-lying wetlands and former river channels, the areas of Barajima, Ushijima, and Araya, as well as the reclaimed land on the right bank of the former Omono River, were primarily developed using sandy materials derived from coastal dune deposits excavated during the construction of the Omono River diversion channel. Even after the 1983 Nihonkai-Chubu Earthquake, new developments on reclaimed land have continued, suggesting that areas with high disaster risk have been expanding year by year.



(a) 1:50,000 topographic map surveyed in 1981 (b) 1:200,000 topographic map updated in 2021

Fig. 9 Damage from the 1983 Nihonkai-Chubu (Japan Sea) Earthquake and the present-day topography of Akita City

7. CONCLUSIONS

Revisiting the damage caused by the 1983 Nihonkai-Chubu Earthquake, which marked its 40th anniversary in 2023, this study constructs a detailed damage distribution map for Akita City based on

contemporaneous damage reports. In addition, damage associated with earlier earthquakes—the 1896 Rikuu Earthquake, the 1914 Akita-Semboku Earthquake, and the 1964 Niigata Earthquake—is systematically compiled, and their spatial distributions are overlaid on historical topographic maps corresponding to each period. Comparative analysis of these four events demonstrates that the historic urban districts of Akita City have repeatedly experienced earthquake damage since the Meiji era. Notably, during the 1964 Niigata Earthquake and the 1983 Nihonkai-Chubu Earthquake, damage attributable to liquefaction and ground deformation of reclaimed land was particularly pronounced. The spatial distribution of damage is highly clustered, with the most severely affected areas corresponding to land reclaimed using sediments excavated during the construction of the Omono River diversion channel in the early Showa period. Furthermore, the majority of heavily damaged areas are located in newly developed residential zones situated on reclaimed former paddy fields, abandoned river channels, and floodplains that were originally low-lying wetlands. These results highlight the strong linkage between urban formation processes and earthquake damage patterns, emphasizing the necessity of incorporating landform evolution and urbanization history into seismic risk assessments. Such insights are critical for understanding earthquake risk in Akita City. Moreover, as of 2024, more than four decades after the 1983 event, urbanization has continued through the infilling of former paddy fields and residential development on hilly terrain, indicating that areas exposed to elevated disaster risk have been progressively expanding.

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