7. Damage to Buildings in Inundation Areas Induced by Tsunami

7.1 Introduction

The purpose of this investigation is to understand an overview of buildings damaged by tsunami, in order to obtain basic data and information required to evaluate mechanisms for causing damage to the buildings and to contribute to tsunami load and tsunami-resistant designs for buildings such as tsunami evacuation buildings. The investigation was conducted by collecting building damage cases caused by tsunami, classifying the damage patterns for different structural categories, and making a comparison between the calculated tsunami force acting on buildings and the strength of the buildings.

The tsunami damage survey team* organized in the Joint Survey Team consists of 27 members, for voluntary investigation. The team collected national and international standards and codes concerning tsunami evacuation buildings and tsunami loads and surveyed about 100 buildings and structures in three site investigations.

7.2 Classification and Discussion of Damage Patterns

7.2.1 Reinforced concrete buildings

1) Collapse of first floor

A case that column capitals and bases on the first floor in a building were subject to bending failure and subsequently to story collapse was seen in a 2-story building (Photo 7.2-1).

The building had column-to-beam frames. The first floor had relatively small number of walls, but many concrete block walls were placed on the second floor. The first and second floors of the building in Photo 7.2-1 were used as shop and dwelling, respectively. The relevant building was estimated to have structural characteristics of low strength and stiffness on the first floor. As an opening on the second floor was not large, it is assumed that the second floor suffered a large tsunami wave pressure and the shear force acting on the first floor exceeded the lateral load-bearing capacity, resulting in the collapse of the building. Story collapse of the first floor has not been observed in 3-story or higher buildings in the investigations. In 3-story buildings, in general, reinforced concrete walls are often used in the first floor. Therefore, the strength of the first floor of 3-story buildings is considered to have been larger than that of 2-story buildings.

Photo 7.2-1 Story collapse of a 2-story reinforced concreted building

2) Overturning

Overturning was observed in 4-story or lower buildings. In all overturned buildings, the maximum inundation depth exceeded their height. Overturning types include buildings that fell sidelong (Photo 7.2-2) and buildings that turned upside down. Most of the overturned buildings were of mat foundation. In some overturned buildings on pile foundation, piles were pulled out.

Photo 7.2-2 Overturning of a 3-story reinforced concrete building

Overturning cases were often seen in 4-story or lower buildings with relatively small size of openings. However, there were many cases that 4-story or lower buildings with large size of openings were not overturned. Consequently, the size of opening on an exterior wall is considered to have greatly affected overturning.

In some cases, there were tsunami traces at the heights of the upper end of openings on the top floor inside the buildings whose heights were exceeded by maximum inundation depths. It is considered that air has accumulated in the space between the ceiling and the upper end of openings. Overturning is considered to occur when an overturning moment by tsunami wave force exceeds an overturning strength by a dead load of a building (considering the effect of buoyancy as required). A building, in which the distance from the upper end of an opening on each floor to a ceiling is long, may be overturned even by a slight horizontal tsunami force when buoyancy significantly acts on the building.

3) Movement and washout

Most of the overturned buildings were moved from their original positions. It is estimated that large buoyancy acted on the buildings. Moved and overturned buildings left no dragged traces on the ground. One of the buildings moved over a concrete block fence that had about 2m height on an adjoining land without destroying the fence (Photo 7.2-3). The building seems to have floated up by buoyancy. Some of the 2-story apartment houses with the same shape that were overturned were washed away and missing. A buoyancy and large horizontal force seem to have acted on these buildings.

Photo 7.2-3 A 2-story reinforced concrete building that moved over the fence and overturned

4) Tilting by scouring

When tsunami acted on a building, a strong stream was generated around the corner of the building, resulting in many large holes on the ground that were bored by scouring. In one case, a building on mat foundation fell into a hole bored by scouring (Photo 7.2-4).

Photo 7.2-4 A 2-story reinforced concrete building that was tilted by scouring

5) Fracture of wall (fracture of opening)

When tsunami acts on openings in a building and openings of the opposite side of the building are smaller than the affected openings, a stream flowing from the affected openings concentrates on the opposite small openings. In one observed case related to this event, a stream generated by tsunami provided a large pressure to a reinforced concrete non-structural wall around small opposite openings. The pressure enlarged the concrete wall to the outside and fractured the wall reinforcement. A tsunami wave force that acts on a building will be reduced if the size of opening affected by the force becomes larger. The same trend is considered to apply to an outlet surface of the stream.

Cases that such wall reinforcement was fractured were often seen in wall members with single layer bar arrangement. In one damaged building (Photo 7.2-5), a 300 mm-thick shear wall with double layer bar arrangement and a support span of more than 10 m and without the second and third floor slabs was bent inside by tsunami wave pressure. However, a shear wall in an area (Photo 7.2-5 Back of the building, right-hand side), where there was a floor on the second story and a support span was not long in the same building, was not bent.

Photo 7.2-5 Out-of-plane fracture of reinforced concrete shear wall without floor

6) Debris impact

Debris impact was seen in most of the non-structural members such as window and ceiling materials. The number of cases of clear damage to skeletons was not large, but in one observed case, a multi-story wall in an apartment house was probably bored by debris impact (Photo 7.2-6).

Photo 7.2-6 Wall opening probably generated by debris impact

7.2.2 Steel buildings

1) Movement and washout by fracture of exposed column base

A typical case of building movement and washout was that a building moved and flew due to the fracture of anchor bolts and/or base plates at steel exposed column bases and the fracture of a weld between the column and the base plate (Photo 7.2-7). In most cases, foundation and some column bases were left in the site, but the upper structure of the building was moved beyond the site or missing.

Photo 7.2-7 Steel building overturned by fracture of column base anchor bolts

2) Movement and washout by fracture of capital connection

In damage cases relatively often seen that a capital connection on the first or second floor in a building was fractured, then the building was moved and washed away. When a column base has a large strength like concrete encases type or embedded type, this type of fracture is considered to occur. In one case (Photo 7.2-8), foundation in a building, and several columns on the first floor (or up to the second floor) were left on the site, and the columns fell in the same direction.

In most cases, welds between diaphragms with lower flanges and the first-floor columns were fractured and the sections of the columns were exposed. In one building, flanges of the second-floor H-shaped beams were torn. Based on the deformation states near the column bases, it is estimated that a tensile force acted on the first-floor columns, and then the first-floor capital connections were fractured after the first floor was greatly tilted to the same extent as the inclination of the remaining columns.

Photo 7.2-8 First-floor columns falling in the same direction

3) Overturning

One case that a whole building including foundation was overturned, was confirmed. Most of the AAC panels of claddings were left (Photo 7.2-9).

Photo 7.2-9 Overturning of a 3-story steel building

4) Collapse

Skeleton collapse including story collapse of the first floor was seen in a 2-story steel building (Photo 7.2-10). Partial collapse of a warehouse was also seen on the coast.

Photo 7.2-10 Story collapse of first floor in a 2-story steel building

5) Large residual deformation

Slight tilting was often observed with remaining their skeletons in steel buildings. In one case (Photo 7.2-11), a gabled roof frame building did not collapsed despite large residual deformation.

Photo 7.2-11 Tilted gabled roof frame

6) Full fracture and washout of cladding and internal finishing materials

Cladding materials such as AAC panel were almost fully fractured and washed away, and then a steel frame as a skeleton was remaining. This case was often observed (Photo 7.2-12). It is considered that an external force that acted on the skeleton became small due to early washout of the cladding materials. In the remaining building, slight tilting of the skeleton, member deformation on the face affected by tsunami, and members locally damaged possibly by debris impact, were observed.

Photo 7.2-12 A remaining 3-story steel building

In another damage case, openings on the face affected by tsunami and on its opposite face, or transverse faces were severely damaged and fractured possibly due to stream runoff.

7.3 Database for Investigated Buildings

Outer dimensions of about 100 buildings and dimensions of their skeletons were measured in the site investigation. Maximum inundation depths were measured from tsunami traces on surveyed buildings and surrounding buildings. These measurement results were integrated into a database for investigated buildings. Building name, address, building use, construction year, designation as tsunami evacuation building, structure category, number of stories, outer dimension, distance from seacoast (river), GPS position, altitude, surrounding circumstances, damage situations, etc., were recorded in the database. In addition, photos of investigated buildings that were taken from four directions as possible were attached to the database. Based on the database, the joint survey team estimated strengths of the buildings and tsunami loads on them, and is evaluating whether the estimated values are consistent with the damage situations.

7.4 Damage to Wood Buildings

7.4.1 Objectives of damage survey

Many of wood buildings built in the Pacific coast of Tohoku region were washed away by the tsunami caused by the 2011 Tohoku Earthquake. However, there were not few wood houses that remained in tsunami affected areas. The field surveys were conducted to grasp the outline of the damage to the wood buildings due to tsunami and the characteristics or conditions of the building washed away and remained.

7.4.2 Outline of survey

The field surveys were carried out both in plain area and slope land. The surveyed area and survey schedule were shown in Fig. 7.4-1 and Table 7.4-1, respectively. However, in the surveyed city and town, we didn't survey all the area of the city and town exhaustively, and surveyed only a part of the inundated area selectively. Therefore, what are mentioned in the followings are the knowledge which was provided in the surveyed area at the surveyed time.

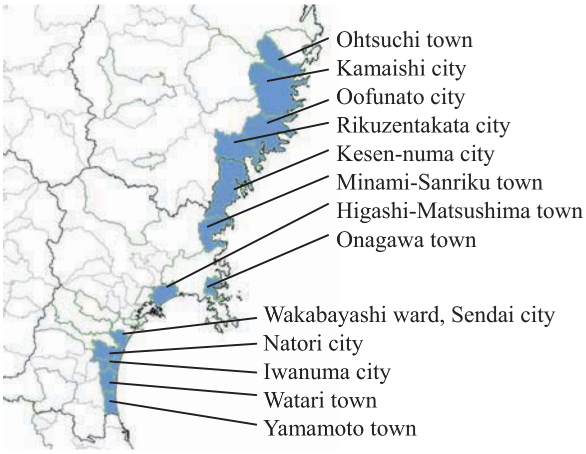

Fig. 7.4-1. Locations of surveyed area

Table 7.4-1. Survey schedule

Category	Surveyed cities and towns	Date of survey
Plain area	Wakabayashi ward in Sendai city, Natori city, Iwanuma city, Watari town, and Ymamoto town in Miyagi prefecture	April 6-8, 2011.
Slope land	Ohtsuchi town, Kamaishi city, Oofunato city, and Rikuzen-takata city in Iwate pref., Kesen-numa city, Minami-Sanriku town, Onagawa town, Higashi-Matsushima town in Miyagi pref.	May 25-27, 2011.

7.4.3 Damage in Plain Area

There were few things to block tsunami in plain area, a lot of wood buildings suffered crushing damage due to tsunami caused by the 2011 off the Pacific coast Thohoku Earthquake. The water depth in the surveyed area estimated by the water trace on the building wall was shown Table 7.4-2.

(1) Damage to wood houses

In the area with over 5 m water depth, most of the wood houses in the inundated area were washed away by the tsunami. How the houses were washed away; as for the case which the whole house including foundations was washed away (Photo 7.4-1), the case which only foundations were left (Photo 7.4-2), the case which sills and foundations were left (Photo 7.4-3), the case which sills, foundations and floor boards were left (Photo 7.4-4), and so on, were observed. There were several cases that the hold down fastener was failed, as shown in Photo 7.4-5. The foundations or wall of bath room made by concrete block often remained, as shown in Photo 7.4-2.

(2) Wood buildings remained in Arahama and Arahama-shin, Wakabayashi ward, Sendai city

Most of wood houses near the shore were washed away. However, not all the houses were washed away. For example, many houses which were located far from the shore remained, as shown in Photo 7.4-6. The houses in the downstream of RC building remained, as shown in Photo 7.4-7.

A line of wood houses remained were confirmed in Arahama-shin, Wakabayashi ward, Sendai city, as shown in Photo 7.4-8. The front survived house of the line was non-wooden. The water depth in this area was estimated at the level about 4-5 m. On the other hand, some wood houses which didn’t have survived buildings in the direction where the tsunami came remained, but suffered heavy damage, as shown in Photo 7.4-9. Several such houses were confirmed in each surveyed area, and they were built by the construction methods with many metal fasteners.

Table 7.4-2. Estimated water depth

Surveyed area	Estimated water depth (m)
Arahama, Wakabayashi ward, Sendai city	6-8
Arahama-shin, Wakabayashi ward, Sendai city	5-6
Yuriage, Natori	5-6
North of Arahama port, Watari town	6
West of Arahama port, Watari town	4

Photo.7.4-1. Foundations washed away.

Photo.7.4-2. Only foundation remained.

Photo.7.4-3. Foundation and sills remsined.

Photo.7.4-4. Sills, foundation and floor boards remained.

Photo.7.4-5. Failed hold down fastener.

Photo.7.4-6. Many wood houses remained.

Photo.7.4-7. Wood house remained in the downstream of RC building in Arahama, Wakabayashi ward, Sendai city.

Photo 7.4-8. A line of wood houses remained
in Arahama-shin, Wakabayashi ward, Sendai city.

Photo 7.4-9. Remained house which didn't have survived buildings
in the direction where the tsunami came in Arahama-shin, Wakabayashi ward, Sendai city.

(3) Remained wood buildings in Yuriage, Natori city

Wood buildings also suffered crushing damage due to tsunami, as shown in Fig. 7.4-2. The parts of buildings remained, for example foundation, sill, and so on, were as same as mentioned in (1). Figures in rectangles in Fig. 7.4-2 show the locations of buildings mentioned in the followings. The wood house (Photo 7.4-10:$\boxed{1}$) united with the foundation and carried away. In the original position of it, steel tube piles remained as shown in Photo 7.4-11($\boxed{2}$). Because a temple building (Photo 7.4-12:$\boxed{3}$) and a steel-frame house ($\boxed{4}$) were damaged heavily and remained, tsunami wave force was reduced to some extent, and the neighboring wood house with store avoided being carried away, as shown in Photo 7.4-13 ($\boxed{5}$). It might be possible for the survived low-rise building to make wave force reduce.

In the south east of Hiroura bridge ($\boxed{6}$), there was protect forest (Photo 7.4-14:$\boxed{7}$) of the pine trees with about 20 cm diameter at breast-height. The water depth was estimated to be about 5-6 m by the flotsam attaching to trees. A part of this protect forest fell down completely, in the downstream of this, the wood house (Photo 7.4-15:$\boxed{8}$) was washed away. On the other hand, in the downstream of survived protect forest, wood houses were selectively carried away and an example of the remained house was shown in Photo 7.4.16 ($\boxed{9}$). It seems to be generally thought that protect forest reduces wave force. However, because it cannot be thought that the strength of trees falling down continually was quite different by their location, it would be natural to think that the wave force or the speed of the tsunami were different by factors such as the depth of water or the submarine topography in this case. There was a house (Photo 7.4-17:10) remained in the area where there was no building and no protect forest existed in the direction of the wave. In addition, the relatively new Japanese conventional post and beam wood house (Photo 7.4-18 :11) and light frame construction house (Photo 7.4-19 :12) were confirmed at the location where there were no survived buildings in the direction of waves. Besides, in the downstream of the former, another Japanese conventional post and beam wood house (13) remained in. The water depth was estimated to be about 3.5 m in these locations.

In the downstream of large RC building, houses with low structural specification (Photo 7.4-20 :14) also remained, as shown in Photo 7.4-20. On the other hand, in the location where was the downstream of the relatively large factory building (Photo 7.4-21 :15), the wood house (16) with relatively better structural specifications avoided being carried away, selectively.

Photo 7.4-10. Wood house (1) that was carried away with the base in Yuriage, Natori city.

Photo 7.4-11. Steel tube pile left at the the original position (2) of house in photo 7.4-10.

Photo 7.4-12. Heavily damaged temple (3) building in Yuriage, Natori city.

Photo 7.4-13. Wood house with store (5) remained in the downstream of the survived buildings in Yuriage.

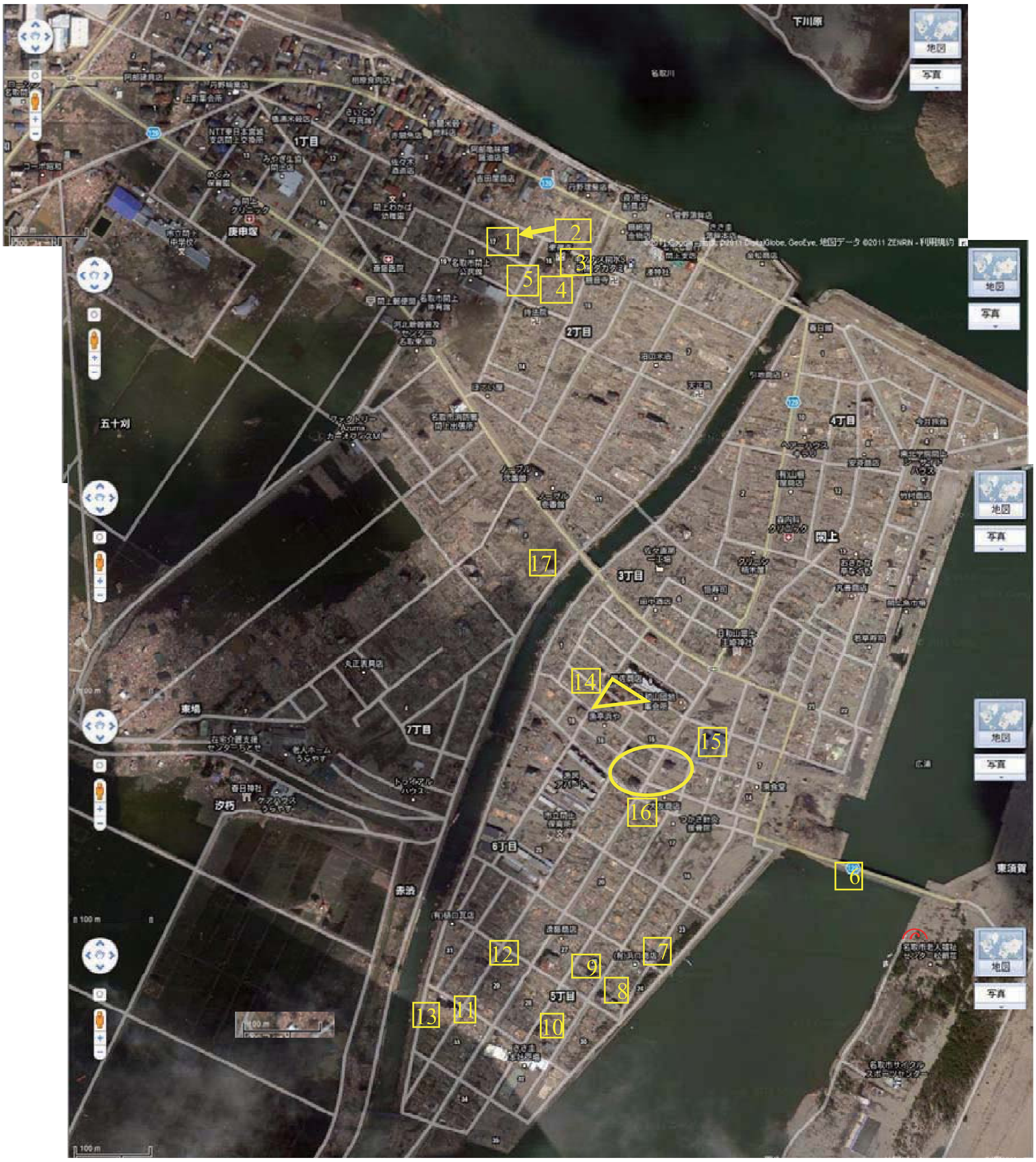

Fig. 7.4-2. Aerial photograph and the location related to surveyed buildings in Yuriage, Natori city.

Photo 7.4-14. Protect forest ($\boxed{7}$) in Yuriage, Natori city.

Photo 7.4-15. Fallen Protect forest and wood house ($\boxed{8}$) washed away in Yuriage, Natori city.

Photo 7.4-16. Protect forest and wood house ($\boxed{9}$) remained in Yuriage.

Photo 7.4-17. Wood house ($\boxed{10}$) remained without the effect of protect forest.

Photo 7.4-18. Japanese conventional post and beam wood house ($\boxed{11}$) remained alone.

Photo 7.4-19. Light frame construction wood house ($\boxed{12}$) remained alone

Photo 7.4-20. Group of wood houses ($\boxed{14}$) which were not washed away in the downstream of a RC apartment house in Yuriage

Factory building

Photo 7.4-21. Wood houses ($\boxed{15}$) which were not washed away selectively in the downstream of a factory building.

(4) Remained wood buildings in Arahama, Watari town

Arahama district in Watari town is surrounded with sea shore and faces the Pacific Ocean in the east, and there is a port in the south side, as shown in Fig. 7.4-3. In the area between Pacific Ocean and Arahama port, most of wood houses were washed away. In the north area of the Arahama port, the water depth was estimated about 6 m. Many of wood houses were washed away. On the other hand, in the west area of the Arahama port, the water depth was estimated about 4 m. Many of wood houses remained. Remained parts, for example foundation, sill, and so on, were as mentioned in (1).

In the area between Pacific Ocean and Arahama port, remained wood buildings were Glulam frame structure (Photo 7.4-22) and a mixed structure (Photo 7.4-23) which has 1st story of RC structure and wooden 2nd story. In other cases, the part of the L-shaped wood house (Photo 7.4-24) whose part with short horizontal length in the direction of wave pressure was washed away, and another part with long horizontal length remained. It was confirmed that metal fasteners were used in the column end joints, and considered that the structural performance of this house was better.

In the north area of the Arahama port, a 3-story wood house (Photo 7.4-25) remained. The reason might be that the lateral strength of 1st story in 3-story building was larger than that in 2-story building.

In the west area of the Arahama port, it was confirmed that the wood house (Photo 7.4-26) was crashed by two ships but remained. The reason was that the wave pressure was low and the structural performance of the house was high because the house was relatively new.

Fig. 7.4-3. Aerial photograph and the water depth estimated in Arahama, Watari town.

Photo 7.4-22. Glulam frame structure remained in Arahama, Watari town.

Photo 7.4-23. Mixed structure which has 1st story of RC structure and wooden 2nd story.

Photo 7.4-24. L-shaped wood house whose part was washed away in the east of Arahama port.

Photo 7.4-25. 3-story wood house remained in the north of Arahama port.

Photo 7.4-26. Wood house remained in spite of ships' crashing in the west of Arahama port.

7.4.4 Damage in Slope Land

The damage in Akasaki-cho, Oofunato city was reported as an example of the tsunami damage in several surveyed slope lands. Akasaki-cho is located in the east of Oofunato bay, and is a gradual slope land. Fig. 7.4-4 shows the aerial photograph and the locations related to surveyed buildings. Similar to plain areas, many of wood houses were washed away by tsunami here in Oofunato. According to the resident of a house (Photo 7.4-27:$\boxed{1}$) located just near the shore, the height of the tsunami reached to the top of 2nd story, and the house went under the water completely. The house was damaged in a part, however it remained. The neighbouring work shed ($\boxed{2}$) whose sill came off from floor concrete moved. On the other hand, a 2-story wood house (Photo 7.4-28:$\boxed{3}$) opposite to the house ($\boxed{1}$) across the street along the sea suffered almost no damage. Two houses next to the house ($\boxed{1}$) and shed ($\boxed{2}$) remained. There is a hill in the back of them (in the north side), and there is a possibility that the hill affected the strength of the wave force caused by the tsunami. A Japanese traditional post and beam frame house (Photo 7.4-29:$\boxed{5}$) built on the street along the sea remained under the water depth of about 5-6 m, in spite of partial failure of walls. Close to this house, a wood house (Photo 7.4-30:$\boxed{6}$) remained under about 6 m water depth in spite of partial failure in the roof system. It was considered that this failure caused by the floating materials. There was a house ($\boxed{7}$) remained in the next, but a house which was guessed to have many hold down fasteners ($\boxed{8}$) was washed away. The house with hold down fastener may not remain by severe tsunami.

At the location where we went up the slope land from these houses, a light steel-frame house ($\boxed{9}$) remained in under the about 5 m water depth. In the next of this house, the 1-story old wood house (Photo 7.4-31:$\boxed{10}$) whose structural specification was not so good, but the anchor bolts were installed remained. In addition, a warehouse with mud walls (Photo 7.4-32:$\boxed{11}$) was remained and an old wood house without anchors (Photo 7.4-33:$\boxed{12}$) turned and moved horizontally. Because the wood house under about 5 m water depth were almost washed away in plain areas, it might be possible for the slope land to make lateral force caused by tsunami a little smaller.

Fig. 7.4-4. Aerial photograph and the locations related to surveyed buildings in Akasaki-cho, Oofunato city.

Photo 7.4-27. Wood house ($\boxed{1}$) remained under the water depth of over 7 m in Akasaki-cho, Oofunato city.

Photo 7.4-28. Wood house ($\boxed{3}$) without damage under the water depth of over 7 m in Akasaki-cho, Oofunato city.

Photo 7.4-29. Japanese traditional wood house ($\boxed{5}$) which was not carried away under about 5 m water depth in Akasaki-cho, Oofunato city.

Photo 7.4-30. Wood house ($\boxed{6}$) which was not carried away in spite of damage on 1st floor roof system in Akasaki-cho, Oofunato city.

Photo 7.4-31. Survived house ($\boxed{9}$) which seemed to have comparatively slight structural specifications in Akasaki-cho, Oofunato city.

Photo 7.4-32. Survived soil warehouse ($\boxed{10}$) which seemed to have comparatively slight structural specifications in Akasaki-cho, Oofunato city.

Photo 7.4-33. Survived old house (12) which rotated and moved horizontally in Akasaki-cho, Oofunato city.

7.4.5 Survey summaries

Results of surveys are summarized as follows;

1) Not all of the low-rise wood houses were washed away by the tsunami.
2) In the downstream of survived buildings more than a middle-rise or higher buildings, many wood houses remained regardless of structural specifications.
3) In the downstream of survived low-rise buildings, or at the location far from survived middle-rise buildings, only the wood houses with excellent structural specification remained.
4) In the location where there were almost no survived buildings in the direction of tsunami, there were some cases that a wood house remained alone. In that case, there were many examples that some columns or walls were carried away in the direction where tsunami came.
5) Having metal fastener or not in the column end joints such as the hold down fastener didn't decide whether the house was carried away or remain in.
6) It was possible for the slope land to make lateral force caused by tsunami a little smaller than in plain areas.

7.5 Conclusion

This paper classified the damage patterns for different structural categories and briefly discussed the factors that had caused various types of damage. Based on the results of the relevant investigation, the survey team is now conducting an additional site investigation as required and collecting design documents for damaged buildings, while further evaluating the effects of building openings and buoyancy and proceeding with the elucidation of mechanisms for causing damage and the identification of tsunami loads on buildings.

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8. Damage of Buildings, etc. due to Fire

8.1 Objective of Survey

Large number of fires occurred in wide area due to the earthquake and tsunami brought severe damage to buildings. The entire image of the fires is analyzed in this chapter. Investigation has been conducted in order to grasp the circumstances of the fire spreading and fire stopping in large city fires and the damage of building fires.

8.1.1 Number of Fire Occurrence

In this earthquake disaster, enormous tsunami damage occurred, but large number of fires were also identified in the areas damaged by tsunami. This is a major feature of fire damage in this earthquake disaster.

The total 345 fires including non-building fires reported (as of April 20, 2011) by Fire and Disaster Management Agency (FDMA) of Ministry of Internal Affairs and Communications (MIC)[8.1-1]. Table 8.1-1 shows the number of fires in each prefecture. In Miyagi, more than half of the total number of fires was occurred. These 345 fires include not only fires occurred in the mainshock at 14:46 on March 11, but also ones in aftershocks.

Table 8.1-1 Number of Fires by prefectures

Prefecture	Number of Fires
Aomori	5
Iwate	26
Miyagi	194
Akita	1
Fukushima	11
Ibaraki	37
Gunma	2
Saitama	13
Chiba	14
Tokyo	35
Kanagawa	6
Shizuoka	1
Total	345

(FDMA, as of April 20)

8.1.2 Seismic Intensity and Fire Occurrence

In Japan, the relation between fire break-out ratio and seismic intensity has been often discussed in order to identify the feature of earthquake fire[8.1-2].

The relation between seismic intensity and fire break-out ratio in this earthquake is shown in Fig. 8.1-1 and Table 8.1-2. The numbers of fires in some municipalities without seismic intensity data are omitted.

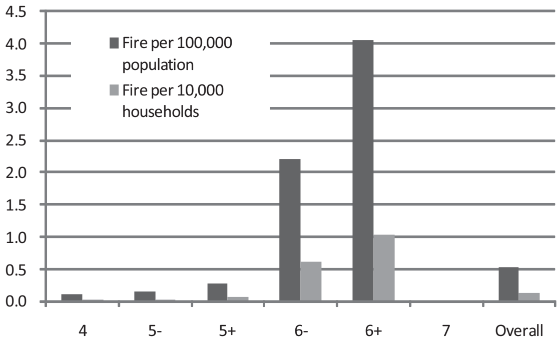


Fig. 8.1-1 Relation between fire break-out ratio and seismic intensity

Table 8.1-2 Seismic intensity, number of fire and fire break-out ratio

Seismic intensity	Population	Number of households	Number of fire	Fire per 100,000 population	Fire per 10,000 households
4	11,156,088	4,225,871	12	0.108	0.028
5−	19,042,953	8,292,245	31	0.163	0.037
5+	20,092,544	8,381,820	56	0.279	0.067
6−	4,254,959	1,543,580	94	2.209	0.609
6+	3,115,586	1,213,129	126	4.044	1.039
7	74,938	23,441	0	0.000	0.000
Overall	59,928,945	24,482,678	320	0.534	0.131

And the distribution of seismic intensity, number of fires and municipalities damaged by tsunami are geographically shown in Fig. 8.1-2.

Total data of the maximum seismic intensity by municipalities is based on the reports on seismic intensity released on May 30 and April 25, 2011 by the Japan Metrological Agency (JMA) of MLIT.

For this totaling, the municipalities in the prefectures which seismic intensity were 5 lower (5-) or more are included and the municipalities where seismic intensity has not been obtained or not yet been investigated are excluded from this totaling.

In only one area where seismic intensity 7 was observed, however, no fire was reported. The tendency that the higher the seismic intensity, the higher the fire break-out ratio, is observed in the municipalities where seismic intensity 6 lower (6-) or less was recorded.

In the cases of the 1995 Hyogo-ken Nambu (Kobe) earthquake and the 2004 Niigata-ken Chuetsu earthquake, in which seismic intensity 7 were recorded, fire ratio per 10,000

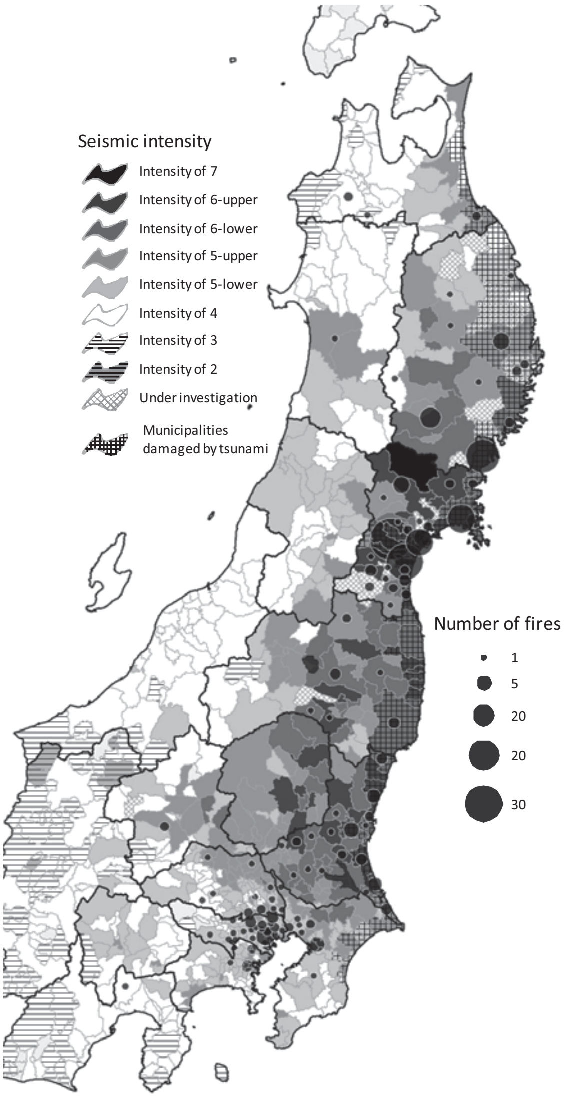


Fig. 8.1-2 Distribution of seismic intensity, number of fires and municipalities damaged by tsunami

households was 2~6 cases, but as for the 2011 Tohoku earthquake, the fire break-out ratio has become lower than the ratio for the 1995 Hyogo-ken Nambu earthquake.

However, in the areas of seismic intensity 6 upper (6+) in 2004 Chuetsu Earthquake, the ratio was around 0.7. Therefore, fire break-out ratio of 1.0 in the area of seismic intensity 6 upper of this earthquake is regarded as the same or a little higher value. The principal reason why the ratio of this earthquake is the same or a little higher, may be due to that many fires broke out in the damaged area by tsunami.

8.2 Damage by Fire due to Tsunami

There should be a distinction between fire occurred in areas damaged by tsunami (hereinafter referred to “tsunami fire”) and fire occurred in other areas (hereinafter referred to “earthquake fire”), however at present, detailed information about the fire scene are not provided. Therefore, this report do not distinguish tsunami fire from earthquake fire out of the 345 fires.

Table 8.2-1 Number and break-out ratio of tsunami fire

Seismic intensity	Population	Number of households	Area of tsunami invasion [km^2]	Number of fire	Number of fire per 1km2 area of tsunami invasion	Fire per 100,000 population	Fire per 10,000 households
4	86,147	32,875	14	0	0.000	0.000	0.000
5−	207,519	73,107	16.5	3	0.182	1.446	0.410
5+	680,002	252,323	44.5	13	0.292	1.912	0.515
6−	1,492,701	557,650	280.5	68	0.242	4.556	1.219
6+	1,580,722	660,780	179	108	0.603	6.832	1.634
Not available	122,413	45,838	27	21	0.778	17.155	4.581
Total	4,169,504	1,622,573	561.5	213	0.379	5.109	1.313

Therefore, it is assumed the fires reported in the municipalities damaged by tsunami as tsunami fires and the fires reported in other municipalities as earthquake fires. The features of each fire on fire occurrence circumstance will be reported. Table 8.2-1 illustrates the list of number and break-out ratio of tsunami fire. The data has been acquired by totaling of the number of fire occurrence by the municipality areas of tsunami invasion.

It would be said that the features of tsunami fire which was reported in damaged area by tsunami, the area of fire spread extended to wider area where the

Photo 8.2-1 Tsunami fire at an elementary school (Ishinomaki city, Miyagi prefecture)

debris of buildings etc and automobiles which drifted and crashed would become cause of fire and fire spreading route.

Ishinomaki, one of the coastal cities of Miyagi prefecture, had huge damage due to tsunami and also had large fire that spread widely. As for the investigation soon after the earthquake disaster, the joint survey team could not find any information about the initiation of the fire; however, the team identified the range of fire spread.

Photo 8.2-1 shows a fire scene of an elementary school building located at about 1 km from the coast. Almost all of the 3-story school building had been burnt by the flame flared up from cars, combustible debris and oil and so forth that drifted and accumulated by tsunami in the schoolyard in front of the building.

Building at a port was one of the most damaged buildings by tsunami with not only tidal wave but also debris, cars and ships and so forth drifted by tsunami (Photo 8.2-2 and 8.2-3). Several hundred automobiles which have been parked in a parking zone, being drifted to a port warehouse by the tsunami, caused fire at the place where it accumulated.

The cause of the fire is unclear, but it is assumed that the car collided severely each other, the gasoline tank of the cars were damaged, and sparked by malfunction of the electrical system by the seawater. There was no spread of fire in the interior of the building, only the external wall has been damaged by fire.

Photo 8.2-4 shows the fire at a coastal village after several hours of tsunami invasion. The fire continued for

Photo 8.2-2 Tsunami fire at a port warehouse (Sendai city, Miyagi prefecture)

Photo 8.2-3 Vehicle fire due to tsunami at a parking lot (Iwanuma city, Miyagi prefecture)

Photo 8.2-4 Fire at a site of 8 buildings due to tsunami (Noda-village, Iwate prefecture), Courtesy of Noda-village

over 12 hours. Firefighters could not access to the site because the road had been destroyed by the tsunami.

8.3 Damage by Fire due to Earthquake Motion

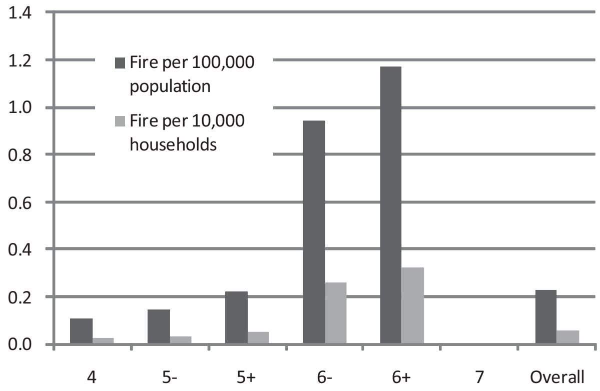


Fig. 8.3-1 Relation between break-out ratio of fire due to earthquake motion and seismic intensity

Concerning the fires reported in the municipalities which did not have the damage of tsunami, the feature of fire occurrence circumstance as an earthquake fire is shown below.

Major cause of the fire was heat sources contacting surrounding combustibles with the earthquake motion and electric fires at the recovery of power supply from power failure and misuse of the candle which was used for the light in the midst of blackout nights which were also seen as the past cases.

Table 8.3-1 Number and break-out ratio of fire due to earthquake motion

Seismic intensity	Population	Number of households	Number of fire	Fire per 100,000 population	Fire per 10,000 households
4	11,069,941	4,192,996	12	0.108	0.029
5−	18,835,434	8,219,138	28	0.149	0.034
5+	19,412,542	8,129,497	43	0.222	0.053
6−	2,762,258	985,930	26	0.941	0.264
6+	1,534,864	552,349	18	1.173	0.326
7	74,938	23,441	0	0.000	0.000
Overall	55,881,854	22,905,943	128	0.229	0.056

The relation between seismic intensity and break-out ratio of fire due to earthquake motion is shown in Fig. 8.3-1 and Table 8.3-1. Mass media have reported intensively fire due to tsunami, but many fire cases due to earthquake motion were also identified by this data. Some building fires were presented in the following.

Photo 8.3-1 shows a house fire scene of one victim in an inland rural

Photo 8.3-1 Fire scene of a house (Oushu city, Iwate prefecture)

district. The fire broke out not soon after the mainshock but at 10 pm of the same day. The cause of the fire has not been identified clearly, but, it is thought to be by the spark or hot exhaust gas leaked from the gap of smoke duct of a boiler for heating and bathing, due to earthquake motions.

Photo 8.3-2 shows a factory building fire in which half of the building burned. The cause of the fire is assumed to be ignition by falling of fluorescent light on the ceiling to the floor where the thinner spilled due to earthquake motions by the mainshock.

Photo 8.3-3 shows another house fire case in which two wooden houses were completely burnt out and three houses were partly burnt. The cause of fire is assumed to be misuse of candlelight for lighting in the midst of power failure on the night of the next day of the mainshock.

For a condominium fire, one case has been investigated: the fire broke out when electricity supply has been recovered at the night of the next day of the mainshock. The fire broke out on the 7th floor of a 17-story medium scale condominium. The residents of the room of fire origin were absent at the time, but some neighbors were aware of the fire and informed the fire station. Because of early suppression by firefighters, there was no spread of fire to the upper floor and the next rooms (Photo 8.3-4).

Photo 8.3-2 Fire scene at a factory building (Oushu city, Iwate prefecture)

Photo 8.3-3 Fire scene at a house (Oushu city, Iwate prefecture)

Photo 8.3-4 Fire scene at a condominium (Sendai city, Miyagi prefecture)

References

8.1-1) FDMA, MIC: http://www.fdma.go.jp/bn/higaihou/pdf/jishin/109.pdf (in Japanese, accessed September 1, 2011)

8.1-2) Editorial Committee for the Report on the Hanshin-Awaji Earthquake Disaster: Report on the Hanshin-Awaji Earthquake Disaster, Building Series Volume 6, Fire Damage and Civil Activities, Damage to Information Systems, AIJ, ISBN: 4-8189-2006-1, pp.51, October, 1998 (in Japanese)

9. Response of Seismically Isolated Buildings

9.1 Outline of Surveyed Buildings

Miyagi prefecture and nearby areas have experienced disastrous earthquakes frequently, thus there are many seismically isolated buildings (hereinafter referred to as SI buildings) constructed in those areas. The Joint Survey Team was dispatched on 1st and 2nd June, 2011 to observe performance of SI buildings during the earthquake and asked persons in charge of the buildings about the damage. In total, 16 SI buildings in Miyagi prefecture and one SI building in Yamagata prefecture were surveyed. Table 9.1-1 shows the list of SI buildings surveyed.

Table 9.1-1 List of SI buildings surveyed on 1st and 2nd June, 2011

	Usage	Year of Construction	Super-Structure		Isolation Device*2	Existence of Record		JMA Seismic Intensity at the nearest observatory
			Type*1	# of Floors		Displacement (scratch)	Acceleration	
A	Office	2009*3	SRC	9	HRB	○	○	6 lower
B	Warehouse	1996	S	1	HRB	○		6 lower
C	Condominium	2007	RC	14	NRB, LD, USD			6 lower
D	Condominium	2011	RC	12	LRB, USD			6 lower
E	Condominium	2009	RC	15	LRB, ESB	○		6 lower
F	Condominium	2009	RC	10	HRB, ESB			6 lower
G	Hospital	2001	RC	6	LRB, ESB			6 lower
H	Office	1999	RC	18	NRB, ESB	○	○	6 lower
I	Hotel	1998	RC	12	NRB, LD, LSD			6 upper
J	Fire station	2006	S	3	LRB, SB, OD			6 upper
K	Hospital	2002	RC	5	LRB, NRB, OD			6 upper
L	Fire station	2008	RC	3	LRB, ESB, USD	○		6 lower to 6 upper
M	Hospital	2006	S	6	NRB, NRB+USD, USD, ESB	○		5 upper
N	Fire station	2007	RC	3	NRB, ESB, OD	○		5 upper to 6 lower
O	Hospital	2003	RC	4	NRB, LRB, ESB, LSD			6 lower
P	Hospital	2000	RC	10	NRB, LD, LSD		○	4
Q	Hospital	2002	SRC	4	LRB, SB, OD	○		5 upper

*1 SRC: Steel Reinforced Concrete, RC: Reinforced Concrete, S: Steel

*2 NRB: Natural Rubber Bearing, LRB: Lead Rubber Bearing, HRB: High-damping Rubber Bearing, ESB: Elastic Sliding Bearing, SB: Sliding Bearing, LD: Lead Damper, USD: U-Shaped Steel Damper, LSD: Loop-Shaped Steel Damper, OD: Oil Damper (Hereinafter referred to as above abbreviations)

*3 Newly constructed in 1982 and retrofitted by seismic isolation in 2009.

9.2 Behavior of Seismically Isolated Buildings

In this section, 5 SI buildings (A, B, C, L and M in Table 9.1-1) are picked up to describe typical damages and situations under the 2011 Tohoku earthquake (mainly at mainshock).

9.2.1 SI building (A)

(1) Building information

The SI building (A) is a steel reinforced concrete office building with 9-story super-structure and 2-story basement, located in Miyagino ward in Sendai city (Photo 9.2-1). The building was retrofitted by using base isolation technique putting isolation devices on the top of columns in B1F. The floor plan has the 26.4 m × 54 m rectangular shape and 44 HRBs are installed.

(a) Overview of the building (b) Sign board to warn about seismic gap

Photo 9.2-1 SI building (A) – SRC office building –

(2) Building performance during the earthquake

Observation results are summarized as follows:

a) According to the person in charge of the building, no furniture was turned over and no structural damage was observed.
b) However, some damage was observed at the cover-panels of fire protection and the expansion joints near the boundary between isolated and non-isolated floors (Photo 9.2-2). It seems that parts of expansion joints were not well operated due to the large displacement of SI floor during the earthquake.
c) The ground surrounding the building partially subsided around 10 cm.

(a) Damage to the panel (b) Damage to the expansion joint

Photo 9.2-2 Damage near the boundary between isolated and non-isolated floors

(3) Earthquake motion records

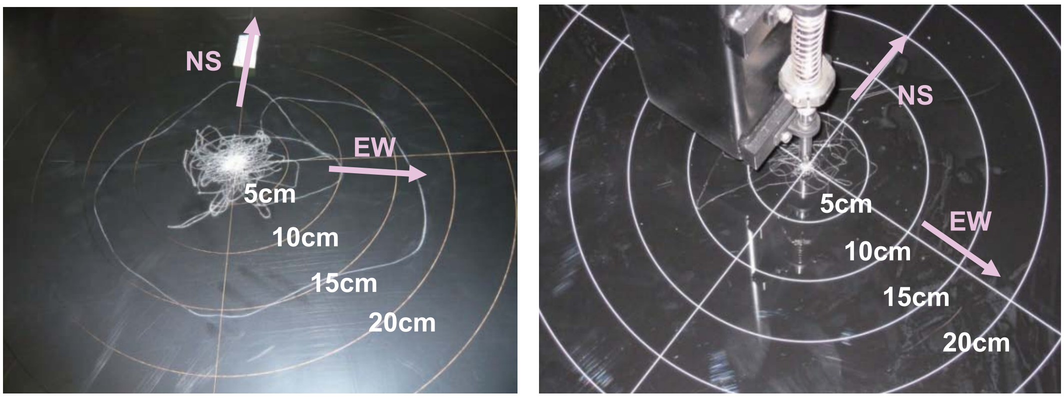
Accelerometers were installed in this building at B2F, 1F and 9F (top floor). A scratch board was also installed in B1F to record the displacement of isolation interface. Furthermore, there is an accelerometer installed by JMA in the basement of an adjacent building. The maximum acceleration values of these accelerometers at the mainshock are listed in Table 9.2-1.

Table 9.2-1 Maximum acceleration values

Location	Direction		
	NS [gal]	EW [gal]	Vertical Z [gal]
Basement of adjacent building	409.9	317.9	251.4
B2F (below SI)	289.0	250.8	234.9
1F (above SI)	120.5	143.7	373.7
9F	141.7	169.9	523.9

From the trace on the scratch board installed on the SI floor (Photo 9.2-3), the maximum displacement was estimated as around 18 cm at the mainshock on 11 March, 2011 and around 10 cm at an aftershock on 7 April, 2011 (Photo 9.2-4).

Photo 9.2-3 Scratch board installed on the SI floor



(a) Trace at the mainshock on 11 Mar. (b) Trace at an aftershock on 7 Apr.

Photo 9.2-4 Trace of displacement of SI floor during earthquake

9.2.2 SI building (B)

(1) Building information

The SI building (B) is a one-story steel warehouse constructed in 1996, located in Miyagino ward in Sendai city (Photo 9.2-5). The building height is 30 m. There are 20 HRBs with diameter 850 mm and 4 HRBs with diameter 800 mm arranged in the basement with 51.6 m × 31.7 m rectangular shape.

Photo 9.2-5 SI building (B) – Steel warehouse -

(2) Building performance during the earthquake

Since the building is located near the Sendai-Shiogama bay, tsunami reached the building and the SI floor was submerged under water. The building also suffered the damage to outer walls by the collision of floating debris (Photo 9.2-6). Observation results are summarized as follows:

a) According to the person in charge of the building, other warehouses nearby had trouble of cargo-shift or collapse of stuff by the earthquake. On the contrary, this SI warehouse had no such trouble at all. Since this warehouse is a freezer, tsunami water entered in the freezer space was frozen. It took 16 days to remove the water from the SI floor.
b) Tsunami height was estimated around 4.0 m from the trace of water on the wall (Photo 9.2-7) and damage situation of surrounding buildings (Photo 9.2-8). There was no information about the direction and impact force of tsunami.
c) The ground was excavated in northeast corner of the building around 1.0 m depth, probably because of the water flow from the building at the moment of tsunami (Photo 9.2-9).
d) From visual inspection, there was no harmful scratch or inflation of the rubber of HRB, however, severe rust was observed at the steel plates and bolts (Photo 9.2-10).

Photo 9.2-6 Damage due to debris

Photo 9.2-7 Trace of tsunami water

Photo 9.2-8 Tsunami damage to surrounding buildings

Photo 9.2-9 Excavation of ground

Photo 9.2-10 Rust of High-damping rubber bearing

(3) Earthquake motion records

From the trace on the scratch board in the SI floor, the maximum displacement was estimated as around 21 cm at the mainshock (Photo 9.2-11).

Photo 9.2-11 Trace of displacement of the SI floor on the scratch board

9.2.3 SI building (C)

(1) Building information

The SI building (C) is a 14-story reinforced concrete building used for condominium, located in Miyagino ward in Sendai city (Photo 9.2-12). The building has U-shaped plan and corners of the building are separated by expansion joints. There are 24 NRBs, 8 LDs and 13 USDs installed in the SI floor.

(a) Overview of the building (b) Sign board to warn about seismic gap

Photo 9.2-12 SI building (C) – RC condominium building –

(2) Building performance during the earthquake

Observation results are summarized as follows:

a) According to the person in charge of the building, no furniture was turned over and no structural damage was observed inside of rooms. However, the damage to the expansion joint was observed.

b) Drop of the ceramic tiles on outer wall (Photo 9.2-13) and shear crack on the wall in the first floor parking space (Photo 9.2-14) were observed. The subsidence of ground around 10 cm was observed around the building.

c) No damage was found to RBs by visual inspection (Photo 9.2-15), however, paint of USDs was peeled off (Photo 9.2-16) and many cracks were found on LDs (Photo 9.2-17).

Photo 9.2-13 Drop of ceramic tiles

Photo 9.2-14 Shear crack on the wall

Photo 9.2-15 Natural rubber bearing

Photo 9.2-16 U-shaped steel damper

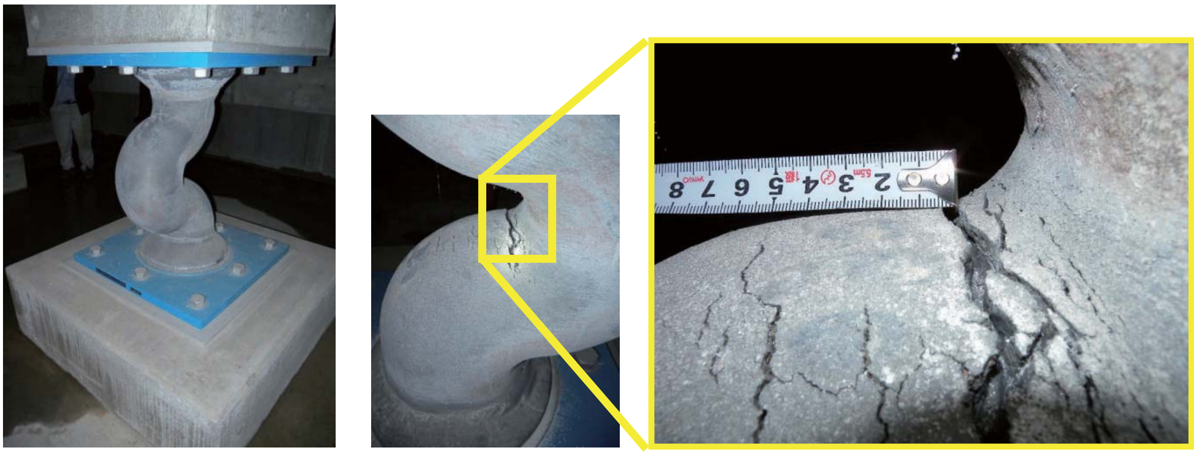


Photo 9.2-17 Lead damper and cracks on the surface

9.2.4 SI building (L)

(1) Building information

The SI building (L) is a 3-story reinforced concrete building used for fire station, located in Tome city (Photo 9.2-18). The following SI devices are installed in the basement with L-shaped plan; 61 m in the east-west direction and 58 m in the north-south direction:

- 34 LRBs (6 with diameter 650 mm and 28 with diameter 700 mm)
- 11 ESBs (6 with diameter 500 mm and 5 with diameter 600 mm)
- 8 USDs

(a) Overview of the building (b) Sign board to warn about seismic gap

Photo 9.2-18 SI building (L) – RC fire station building –

(2) Building performance during the earthquake

Observation results are summarized as follows:

a) According to the person in charge of the building, no furniture was turned over and no structural damage was observed.

b) Because of the movement of the SI floor during the earthquake, the bolts of steel dampers became loose and the paint on the dampers was peeled off widely. Furthermore, a large amount of residual deformation of steel was remained (Photo 9.2-19).

(3) Earthquake motion records

According to the scratch board in the SI floor, the maximum displacement was estimated as around 40 cm northward (Photo 9.2-20). The displacement was also confirmed from the trace of scratch found at the expansion joint outside of the building.

(a) Peeling off of paint (2) Deformation of steel

Photo 9.2-19 Deformation of U-shaped steel damper

(a) Around 40 cm northward (b) Around 15 cm eastward and 22 cm westward

Photo 9.2-20 Trace of displacement of the SI floor on the scratch board

9.2.5 SI building (M)

(1) Building information

The SI building (M) is a 6-story steel building with one story basement used for hospital, located in Ishinomaki city (Photo 9.2-21). Lower part of the building up to second story has the 100 m × 100 m square plan and higher part has 100 m × 25 m plan. The following SI devices are installed in the basement:

- 6 NRBs with diameter 1000 mm
- 16 NRBs with diameter 1000 mm with USD
- 74 ESBs (30 with 400 mm diameter, 25 with 600 mm diameter, 11 with 800 mm diameter and 8 with 900 mm diameter)

(2) Building performance during the earthquake

Observation results are summarized as follows:

a) According to the person in charge of the building, up-down shaking happened together with horizontal shaking during the earthquake. On the 6th floor, contents inside of the rooms such as refrigerators and shelves were moved or turned over, and the fire protection steel door moved to open and hit against the ceiling by vertical shaking causing the damage to the lamp covers. Above the 4th floor, PC monitors were turned over.

b) In the penthouse, anti-vibration rubber of a power generator was moved and the bottom part of a water tank was broken.

c) Because of the movement of the SI floor during the earthquake, the bolts of the steel dampers became loose and the paint on the dampers was peeled off (Photo 9.2-22).

d) The ground around the building subsided around 20 cm.

(a) Overview of the building (b) Sign board to warn about seismic gap

Photo 9.2-21 SI building (M) – Steel hospital building –

(3) Earthquake motion records

From the trace on the scratch board in the SI floor, the maximum displacement was estimated as around 25 cm westward (Photo 9.2-23). The displacement was also confirmed from the trace of displacement of the ESB (Photo 9.2-24).

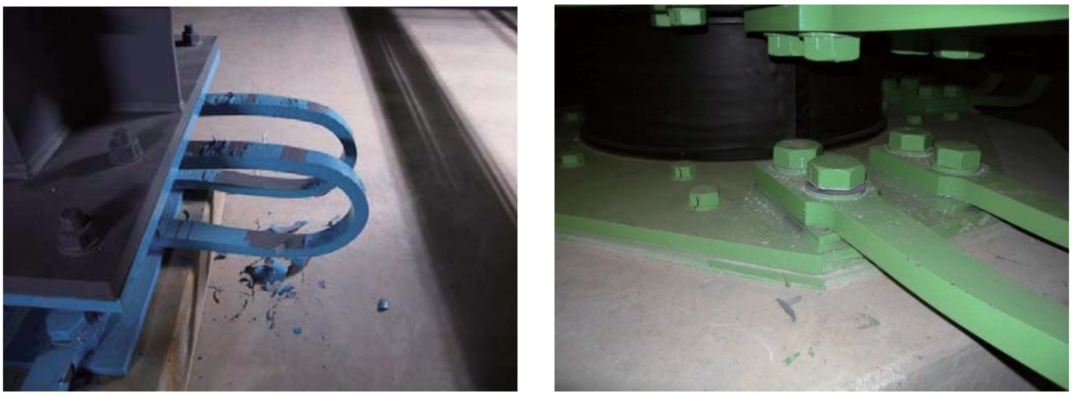


Photo 9.2-22 Peeling off of paint and loose of the bolts of U-shaped steel dampers

Photo 9.2-23 Trace of displacement of the SI floor on the scratch board

Photo 9.2-24 Trace of displacement of elastic sliding bearing

9.3 Results of Survey

Investigation results of 16 SI buildings in Miyagi prefecture and one SI building in Yamagata prefecture are summarized as follows:

a) Super-structures of the SI buildings suffered almost no damage even under strong shaking with JMA intensity 6 upper. It verifies the performance of the SI buildings.

b) There are 8 buildings with scratch boards to measure displacement of the SI floor.

In most cases, the maximum displacement has been estimated as around 20 cm. There was one case with the maximum displacement estimated over 40 cm.

c) In some buildings, damage was observed at the expansion joints. It seems that parts of expansion joints were not well operated due to the large displacement of the SI floor during the earthquake.

d) Subsidence of ground around the building was observed in some buildings.

e) Many cracks were found in lead dampers. A number of cracks might be increased by aftershocks.

f) Peeling off of paint was observed widely for U-shaped steel dampers. In some cases, residual deformation of steel remained.

10. Concluding Remarks

Although more than five months have passed after the earthquake occurred, approximately 90,000 evacuees still live in difficulties and whole damage of the disaster cannot be captured. These facts make us realize that the disaster was unprecedented huge one. It was also the first experience for us that the investigation areas needed to be limited considering the influence of the accident in the Fukushima-dai-ichi nuclear power plant and that we had to be concerned with the safety of staff members against frequent aftershocks including large ones.

This report summarized the survey results described in our quick report already published in Japanese with some additional survey results on the seismically isolated buildings. The outline of each chapter is as follows;

The first chapter forms “Introduction” to briefly figure how NILIM and BRI cooperated to prepare the system (The Joint Survey Team on building damage) in order to respond to the support requests of affected areas and how the team conducted various surveys and researches after occurrence of the earthquake.

The second chapter titled "Outline of Research and Field Survey" describes the outline of the researches and field surveys and the names of the staff members who were in charge of the works.

The third chapter titled as “Overview of Damage” reviews outline of the 2011 Tohoku earthquake, applied situation of enforcement of the laws related to disaster management, data on human and physical damage and situation of provision of temporary houses etc. mainly based on the officially announced data as of April 20 when this report was summarized (if new data becomes available, this report uses updated data indicating new date).

The fourth chapter, “Outline of Earthquake and Tsunami”, provides research results on earthquake source, models of tsunami source and maximum height of tsunami and so on.

The fifth chapter describes “Earthquake Motion Observation and Results” that includes characteristics of earthquake records from BRI strong motion observation network etc. It is noteworthy that the data of above-mentioned BRI earthquake data was referred globally as the first seismic data of the earthquake, since the data network system of the National Research Institute for Earth Science and Disaster Prevention (NIED) that was usually one of the first data resource from earthquake did not work well because damage to network facilities had occurred immediately after the earthquake.

The sixth chapter titled “Damage to Buildings by Earthquake Motions” summarizes the policy of the investigation and the results of damage surveys on wood, steel frame, and reinforced concrete structures, residential land, foundation and non-structural elements. The results are summarized as follows.

1) Wood houses: The damage of upper structure was observed in several areas however the damage to wood houses seemed not so heavy as an impression in Kurihara city where seismic intensity 7 was recorded. Many damage of structure were observed due to deformation of developed residential land in Sendai city, Miyagi prefecture and Yaita city, Tochigi prefecture. The damage to roof tiles could be more observed in both Fukushima and Ibaraki prefectures than in Miyagi prefecture where major earthquakes frequently occurred since the 1978 Miyagi-ken-oki Earthquake. The damage types are similar to those of the past earthquakes.

2) Steel frame structures: There was almost no damage to main steel structure members such as columns and beams. Damage of vertical braces’ rupture etc. was observed in the school gymnasium that was constructed in the years of old seismic code (before 1981) however the damage ratio was smaller than the case of the 2004 Niigata-ken Chuetsu Earthquake. On the other hand, damage to non-structural elements including falling of ceilings was observed comparatively more than the past cases.

3) Reinforced concrete structures: Most of structural damage to reinforced concrete structure was observed in the buildings designed with the previous seismic code. The number of damaged reinforced concrete buildings was not so large as considered with the seismic intensity observed nearby. The damage types were mostly similar to the past seismic damages that included severe damage such as loss of axial force bearing capacity due to shear failure of columns.

4) Residential land, Foundation: Liquefaction occurred in so wide areas that could not be seen during the past earthquakes in Japan. Research on the mechanism and considerations of counter-measures will be necessary not only for individual buildings but also for infrastructure like roadway structures, water supply and sewage systems. In some residential lands, heavy damage such as ground failure was observed similar to the damaging earthquakes in the past.

5) Damage to non-structural elements of buildings of comparatively old construction types was confirmed in many cases. In addition, break and falling of non-structural elements at rather higher parts were also confirmed.

The seventh chapter describes “Damage to Buildings in Inundation Areas Induced by Tsunami” that includes research on the existing guidelines regarding the building design methodologies against tsunami. This chapter introduces conducted surveys on remaining, collapsed or washed away buildings in the major tsunami affected areas from the north in Yamada town, Iwate prefecture to the south in Yamamoto town, Miyagi prefecture. The surveys included measuring damage of buildings, depth of tsunami and structural element data for calculating horizontal load bearing capacity and other values. After verification of existing guidelines, a proposal was prepared in order to make the guidelines more rationalized ones.

The eighth chapter on “Damage of Buildings, etc. due to Fire” summarizes results of field surveys on fires in tsunami affected areas and shake-induced fires in other areas and clarifies the features of damage. The result shows that many usual type of fires due to earthquake happened even though fires in tsunami affected areas were noticed and reported more.

The ninth chapter summarizes “Response of Seismically Isolated Building” including outline of surveyed buildings and the behavior of seismically isolated buildings.

The damage surveys in this report were conducted as carefully as possible, using around 200 person-days (130 persons). However, whole damage of the earthquake may not be covered, considering the damage of wide areas. Further surveys will be continuously carried out.

Recovery and rehabilitation of the affected areas have advanced slowly but steadily, while the introduction (Section 1) of this report says that whole damage cannot be grasped yet. The government set up the Reconstruction Design Council on April 11, which submitted its report of recommendation in June, 2011. The MLIT also established various working committees. In the field of buildings, the Building Structural Code Committee (chaired by Prof. Tetsuo Kubo, the University of Tokyo) that aims to review draft structural code of buildings in the NILIM, is analyzing the damages and promote related technical reviews and so on in cooperation with BRI in order to secure the safety of buildings based on damages caused by the 2011 Tohoku earthquake.

NILIM and BRI would like to contribute to the society through this report and the advanced technical knowledge. It will be very much appreciated if related organizations and individuals will cooperate with us continuously in the future.

Lastly, NILIM and BRI would express deepest condolence to the victims of the tsunami and earthquake and their family members as well as sufferers affected from the disaster. In addition, we would like to express our heartfelt appreciation to people from around the world for their warm support and cordial friendship.

Note 1: A comment via e-mail sent from U.S.A. dated on March 17,
“I learned that the NIED servers were out, so the shaking must have been pretty bad. I was able to see the BRI ground motions and some reports on buildings. Very good and quick work”

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