Building Damage in May 26, 2003 Miyagi-Offshore Earthquake

by

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ABSTRACT

This paper reports the damage survey on building structures at the Miyagi-Offshore Earthquake occurred on May 26, 2003. The maximum ground acceleration recorded at the K-net strong motion observation stations was large and its response spectrum in the shorter period exceeds the requirement of the Seismic Building Standard, but the structural damage to buildings was observed not so severe. The reason of the phenomena was discussed.

KEYWORDS: Miyagi-Offshore Earthquake, damage survey to buildings, strong motion records, response

1. INTRODUCTION

At 6:24 p.m. on May 26, 2003, an earthquake occurred off the coast of Miyagi Prefecture in Japan. The earthquake intensity registered as a low Level 6 (Table 1) on the Japan Meteorological Agency Seismic Intensity Scale in the southern coastal regions and southern inland regions of Iwate Prefecture, and a high Level 5 in surrounding regions. Local government agencies and relevant organizations issued reports on earthquake damage; the scale of the damage was smaller than the level that would normally be expected from an earthquake with an intensity of low level 6. For this reason, although the primary objective of this survey was to assess damage to structures, another objective was to survey the damage at locations where data on earthquake motion was obtained, in order to determine the relationship between earthquake motion and damage to structures.

The survey of damage to structures was conducted jointly by the National Institute for Land and Infrastructure Management (NILIM) and the Building Research Institute on May 29 and 30, 2003. The locations surveyed were Kitakami City, Tono City, Kamaishi City, Ofunato City, Ichinoseki City, Sumita-cho, Daito-cho and Sanriku-cho in Iwate Prefecture and Kesennuma City in Miyagi Prefecture. Figure 1 shows the surveyed locations together with the epicenter of the earthquake and the earthquake motion accelerations recorded at the K-NET observation sites.

At all of the communities with the exception of Sumita-cho and Daito-cho, interviews were conducted at the city office or the like to determine the structures to be surveyed, and the damage to structures near the K-NET observation sites of the National Research Institute for Earth Science and Disaster Prevention (NIED) (an independent administrative agency) was surveyed. In Sumita-cho and Daito-cho, the survey focused primarily on damage to wooden homes.

2. EARTHQUAKE MOTIONS AND THEIR PROPERTIES

2.1. Characteristics of Observational Records at K-NET Observation Sites

The study of earthquake motion properties will focus primarily on the observational records at K-NET observation sites where the structural damage surveys were conducted. Data relating to K-NET observational records is cited from the K-NET web site 1).

Table 2 shows the maximum values for acceleration recorded at the K-NET observation sites and the maximum values for the velocity waveforms derived through integration of these records. The table includes values for Ishidoriya

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-cho and Oshika-cho, which were not included in the current survey. The maximum values for acceleration records at some of the observation sites exceeded the gravitational acceleration (9.8 m/sec^2). The maximum value for calculated velocity waveform for Oshika-cho exceeded 0.5 m/sec, and the value for Kitakami City exceeded 0.3 m/sec. The other values were approximately 0.2 m/sec or less.

Figure 2 shows the acceleration response spectrum (damping ratio 5%) for the recorded acceleration at K-NET observation sites. All of the acceleration response spectrums for the horizontal components consisted of short-period earthquake motion, with a large response for 0.1 - 0.2 second. For the up -down acceleration response spectrum, the short-period component of 0.04 - 0.1 second was dominant. The horizontal components in the acceleration response spectrum for Kesennuma and Tono contained many components of approximately 0.3 and 0.4 second, respectively.

2.2. Damage near K-NET Observation Sites

2.2.1 K-NET observation site at Kitakami City（NS 5.05m/sec^2, EW 4.32m/sec^2）

The address was 214-1 Torikui, Futago-cho, Kitakami City, Iwate Prefecture. The K-NET observation site was in the middle of a rural landscape with houses and rice paddies. At the nearby Futago Community Center (steel frame construction, built in 1985), gaps had developed between the ceiling and walls. At the adjoining gymnasium, gaps had developed between the steel frame girders of the roof and the wall exterior. Some items appear to have fallen off shelves at the time of the earthquake.

2.2.2 K-NET observation site at Tono City(NS 3.91m/sec^2, EW 3.58m/sec^2)

The address was 16-31-2 Shiraiwa, Matsuzaki-cho, Tono City, Iwate Prefecture. The K-NET observation site was right next to the fire brigade headquarters in an urban area. At the Tono Fire Brigade Headquarters (a two-story reinforced concrete building), fine cracks had developed in the non-structural wall at the entrance and the columns next to the entrance. In addition, there was some glass breakage, but there was no toppling of furniture, etc.

2.2.3 K-NET observation site at Kamaishi City(NS 5.94m/sec^2, EW 10.39m/sec^2)

The address was 11-1 Nakatsuma-cho 3-chome, Kamaishi City, Iwate Prefecture. The K-NET observation site was located in an area with residences and a park. There was an apartment building (three-story reinforced concrete wall structure) right nearby, but no damage was discovered on either the superstructure or near the foundation.

2.2.4 K-NET observation site at Ofunato City (NS 2.73m/sec^2, EW 3.67m/sec^2)

The address was 15 Aza-Utsunosawa, Morimachi, Ofunato City, Iwate Prefecture. The K-NET observation site was on a small hill beside the Ofunato City Hall. At the Ofunato City Hall (a reinforced concrete building), there was almost no structural damage, but there was breakage of glass and damage to the water pipes for the water receiving tank on the building.

2.2.5 K-NET observation site at Kesennuma City(NS3.91m/sec^2, EW 3.58m/sec^2)

The address was 3-1 Sasagajin, Kesennuma City, Miyagi Prefecture. At the nearby Kesennuma Elementary School, the damage was limited to cracked glass, and there was almost no structural damage.

2.2.6 K-NET observation site at Ichinoseki City(NS 3.21m/sec^2, EW 1.72m/sec^2)

The address was 140-3 Aza-Nakano, Yamame, Ichinoseki City, Miyagi Prefecture. The K-NET observation site was next to the Ryoban District Fire Co-operative. There was no damage to the Ryoban District Fire Co-operative building.

2.3. Comparison with Earthquake Motions established in Building Standard Law

With the revision of the Building Standard Law in 1998, methods that included the time history response method and the critical load-carrying capacity calculation method were specified for the verification of building earthquake safety. These earthquake motions, used for verification purposes, were established based on an outcropped engineering bedrock (a layer of considerable thickness with shear wave velocity of approximately 400 m/sec or greater). The observed earthquake motions are compared with the earthquake motions in the outcropped engineering bedrock. The ground conditions at the K-NET locations in Iwate and Miyagi Prefectures have an extremely thin sedimentary layer near the surface, but in most cases they can be thought of as being located on ground that is about the same as the outcropped engineering bedrock, and can be considered as located on ground that corresponds to the outcropped engineering bedrock specified in the Building Standard Law.

Figure 3 shows the acceleration response spectrum for recorded acceleration observed at Ofunato and Ichinoseki (damping ratio 5%), and the acceleration response spectrum at the outcropped engineering bedrock as specified in the Building Standard Law (damping ratio 5%). At Ofunato, the value exceeded the acceleration response spectrum (during a major earthquake) in the Building Standard Law within the period range of 0.4 second or less. However, above the period of 0.4 second, the value is below the Building Standard law value and decreases as the period becomes longer. In Ichinoseki, the value was about the same as the acceleration response spectrum for a major earthquake specified in the Building Standard Law within the period range of 0.1 second or less, but the value was less than this Building Standard Law value within the period range of more than 0.5 second and was about the same as the acceleration response spectrum for a moderate earthquake) specified in the Building Standard Law.

3. RESULTS OF DAMAGE SURVEY OF STRUCTURES

3.1. Damage Status in Iwate and Miyagi Prefectures and Nature of Damage

Table 3 shows the degree of injury and number of casualties and the degree of damage to residences and the number of residences damaged in Iwate and Miyagi Prefectures. There were comparatively few injuries in the two prefectures: 20 major injuries and 135 minor injuries. In terms of residential damage, although two residences in Ofunato City were designated as having suffered "total collapse," there were comparatively few "partial collapse" residences (21 in all). Table 4 sums up the status of damage and the number of residences in the category of "partial damage" in the Tono Regional Development Bureau area. There were a great many incidents of fallen roof tiles, and many instances of toppled walls and wall cracking as well.

3.2. Results of Individual Damage Surveys

3.2.1 Kitakami City

1) Kitakami City Hall

The Kitakami City Hall was built in December 1972. It is a reinforced concrete structure with two stories in the low-rise section and six stories in the high-rise section (Photo 1). No particular structural damage was observed. Diagonal cracking was observed in the glass facing the entrance in the low-rise section (Photo 2).

3.2.2 Tono City

1) Tono Kaze-no-Oka ("Michi no Eki" roadside rest station)

On the grounds of the Tono Kaze-no-Oka "Michi no Eki" (roadside rest station) located on National Route 283 is a structure that uses large size timber members. The structure uses a large section size member truss configuration with a three dimensional truss without vertical members (Photo 3). There was some structural damage, but the building manager reported that the earthquake caused an extremely large number of roof tiles to move. At the time the survey was conducted, repair of the roof tiles had already begun (Photo 4). The structure is located at the foot of a cliff, and there was a gap of around 5 cm between the ground and the building. In addition, near the cliff, there was cracking in the surface of the ground parallel to the ridgeline of the cliff. The reason for the damage to the roof tiles was thought to be that the axial force of the large section member of the truss configuration acted on the roof, causing the roof surface to experience short period vibrations.

2) Tono City Office

In the main building (3-story reinforced concrete building built in 1964) of the Tono City Office, shear failure was observed in two short columns (moderate damage to one column and minor damage to the other - see Photo 5) and damage to one column with a concrete rock pocket. (Photo 6), as well as cracking in the earthquake-resisting walls and beams inside. In the Tono City Office annex (two-story reinforced concrete building built in 1957 as well, cracking was observed on the walls inside, but the damage was light compared to that in the main building.

3.2.3 Kamaishi City

1) Osano Elementary School

At the older Osano Municipal Elementary School building (three-story reinforced concrete building, constructed in 1973) in Kamaishi City, shear failure over a wide area was observed on the north side outer walls and walls between openings in the ridge direction (Photo 7). Almost no damage was discovered on the columns and the shear walls in the span direction. In addition, there were fallen ceiling panels at the entrance (Photo 8) and the ceiling panels in the hall of the new building (built in 1987) were damaged. No damage to the structural frames of the new building was observed.

3.2.4 Ofunato City

1) Ofunato High School

At the building of the Ofunato High School (three-story reinforced concrete building constructed in 1963 - Photo 9), the exterior column on the north side of the second floor had sustained shear failure (Photo 10), and shear cracking was also observed on the ғ exterior column on the north side of the third floor. Damage was also noted in the expansion joints. On the first floor, there are other small rooms in addition to the classrooms, and there are more walls on this floor than on the second and third floors, and for this reason the damage is thought to have occurred on the second floor and above.

2) Residences

Residences in Ofunato City were reported to have sustained the most damage in this earthquake. According to a survey by Ofunato City, two residences suffered “severe damage” and six suffered “partial collapse.” The two severely damaged residences were on land developed for housing lots located on a hill with a good view facing Ofunato Harbor (Photo 11). As far as could be determined, residences in the surrounding area suffered fallen roof tiles, blocks in block fences toppled and cracking of the retaining walls.

The severe-damage structures were a traditional one-story wood frame residence and a two-story lightweight steel frame prefabricated residence built 12 years ago. The one-story wooden residence had some residual story drift, but the mud-plastered wall had toppled, exposing the bamboo lath (Photo 12 / Photo 13). In addition, the toppling of the mud-plastered wall made it possible to confirm that steel reinforcing braces were used in places. Some damage was sustained to the sash due to the fallen roof tiles and the tilting of the building. The concrete was broken in places on the north side of the retaining wall.

The lightweight steel frame prefabricated residence located beside the wooden residence likewise had some residual story drift and, although it appeared to have not suffered major damage, it had suffered severe interior damage. Externally, there were cracks in the ground near the foundation facing the retaining wall and the concrete of the foundation was broken near anchor bolts (Photo 14). In addition, the exterior siding had come loose and the sash was damaged. Inside the structure, the built-in storage facilities in the kitchen and the entrance had toppled or fallen (Photo 15). Joint-failures were observed on almost all of the interior walls, and some of the gypsum boards on the interior had fallen, indicating the severe shaking of the structure. It is difficult to believe that an earthquake with a measured intensity of approximately 0.3 - 0.4 m/sec could have caused this level of damage to a prefabricated house that should have had comparatively high quality maintenance in design and construction. Although it is not clear whether the fact that the vibration of the structure was amplified due to the local geographical features (on a slope), or whether damage to the retaining wall caused the vibrations of the structure to be amplified, it is thought that earthquake motion at this location was different from that on level ground This topic should be pursued in a follow-up study.

In other locations, wooden residences sustained fallen roof tiles, distortion of sash frames due to tilting, cracked and fallen mortar on the exterior walls, and foundation cracking. A concrete-block-masonry residence in Akazaki-cho, built 33 years ago, was judged as having suffered partial-collapse because of breakage of the blocks and their joints (Photo 16).

3.2.5 Kesennuma City

1) Hashigami Elementary School

At the Hashigami Elementary School (three-story steel reinforced concrete building constructed in 1985), the foundation anchor bolts had been ruptured or pulled out (Photo 18) at the steel frame tower on the roof (two-story - Photo 17). There was also minor cracking on the walls and columns inside the school building, and broken window glass and deflection of braces were observed at the steel frame gymnasium.

4. RELATION BETWEEN EARTHQUAKE MOTION AND DAMAGE TO STRUCTURE

4.1. Earthquake records investigated

The earthquake records investigated were those measured at six K-NET sites (Kamaishi (IWT007), Ofunato (IWT008), Kitakami (IWT012) and Kesennuma (MYG001)), for which damage surveys were conducted near the observation sites, as well as Oshika (MYG011), where a comparatively large record of 10 m/sec^2 was recorded, and Ishidoriya-cho (IWT014), near the place where damage to a JR railway bridge was observed. At Kamaishi and Oshika, acceleration in the east - west direction was predominant, and extremely strong acceleration in the up - down direction was recorded as well. In 4.2 and 4.3, to eliminate the needle position misalignment of the acceleration records, the mean value for total time was subtracted from the recorded acceleration data released on K-NET.

4.2. Discussion on acceleration response spectrum

Figure 4 shows the acceleration response spectrum for the east - west and north - south components for the six waves. The Rt curve (a value calculated from the natural period of the structure and the ground classification) for Class 2 ground is also shown in the figure. The Rt curve indicates the design base shear (Co = 1.0) of the structure required under the Building Standard Law, which corresponds to the elastic response for the structure. In practical design, the Rt value is reduced by the structural properties factor (Ds) considering the energy absorption due to the plasticization of the structure.

Figure 5 shows the comparatively large acceleration response spectrums for Kamaishi EW, Oshika NS, Ishidoriya NS and Kitakami NS, as well as that for the seismic waves (NS component) recorded at the Great Hanshin-Awaji Earthquake (January 1995) at the Kobe Marine Observatory and Kobe Port Island. The Rt curves for Class 1 through 3 ground are also shown in the figure. In the records for Kamaishi, Oshika and Kitakami, it can be seen that the response spectrum widely exceeds the Rt curve in the natural period of up to around 0.5 second. However, in the Kamaishi record, when the natural period of the structure exceeds 0.5 second, the response acceleration drops dramatically. In contrast, in the Oshika and Kitakami records, the response is comparatively great up to around 0.75 second. If the structural properties factor (Ds) is around 0.5, the natural period of the structure will be elongated by the damage it sustains, and a slightly damaged structure will suffer more damage because the response spectrum for the Oshika NS component has a relatively large value between 0.5 and 0.75 second. The response analysis results show that a structure with a natural period of up to around 0.5 second and a Ds value of 0.5 would sustain severe damage and its plasticity response would be around 3.5.

This might be explained by factors that include the following:
(1) Due to the interaction between the ground and the structure, the actual elastic natural period of many structures was about 0.5 second or greater.
(2) The earthquake motion observed at the surface of the ground was different from the actual input motion to the structure at the base.
(3) The structure was not subjected to the major earthquake motion due to the local distortion of the ground and the like.
(4) The response of the actual structure was less than the response of the analytical model under fixed foundation conditions due to the effect of radiation damping from the structure to the ground.

In the future, as earthquake motions recorded in the free field are inadequate in order to investigate these causes, a strong-motion observation network for measuring the behavior of structures themselves is needed.

4.3. Study using demand spectra

A study of the relationship between earthquake motion and damage is conducted using the demand spectra prescribed in the critical load-carrying capacity calculation in the Building Standard Law. Figure 6 shows the response curves for recorded seismic waves in each direction at 5% damping. The demand spectra for Class 2 ground is also shown in the figure. Whereas the bottom horizontal axis indicates the lateral displacement response, the top horizontal axis shows the lateral drift angle at half of the total height of the structure with a floor height of three meters. The actual story drift angle is the value of the horizontal axis divided by 100N (N: number of floors in structure). As is evident from the figure, in each case, when the observed wave is compared to the demand spectra prescribed by the critical load-carrying capacity, the value for Sa (vertical axis) is extremely high, but the value for Sd (horizontal axis) is extremely small. Accordingly, compared to cases in which the demand spectra prescribed in critical load-carrying capacity calculations is used, the response of the structure is expected to be limited to extremely small deformation.

Figures 7 and 8 show the demand spectra for Kamaishi EW, Oshika NS, Ishidoriya NS and Kitakami NS waves with damping ratios of 5% and 10%, respectively. The restoration force curves for an elastic period of 0.3 second and Ds = 0.5 are also shown in the figures. Moreover, considering the decrease in initial stiffness due to hairline cracks and so on, the curve with a stiffness reduction factor of 0.5 is shown.

Even if the effect of hysteresis damping is discounted (5% damping), with the exception of the Oshika NS component and the Kitakami NS component, the plasticity ratio is 2 or less, and it is difficult to imagine that the structure would be very greatly affected. However, for the Oshika NS and Kitakami NS components, a plasticity ratio of about 4 is expected, even discounting the effect of hysteresis damping (10% damping). In such cases, the story drift angle of the structure is 4 / (100N), N being the number of floors - about 1/100 for a four-story building. As stated in 10.4.2, in order to investigate the reason that there was little actual damage observed for Oshika and Kitakami, a strong-motion measurement network for observing the behavior of structures is needed.
Figure 9 shows a comparison with the Kobe Marine Observatory NS wave recorded at the time of the Great Hanshin-Awaji Earthquake (January 1995) with a damping ratio of 10%. As the figure shows, the value for Sd (horizontal axis) for the recent earthquake is small compared to that recorded by the Kobe Marine Observatory, and this matches the level of damage.

5. CONCLUSION

Firstly, the following conclusions can be reached with regard to earthquake motions.
(1) The acceleration response spectrum (damping ratio 5%) for the recorded acceleration in Ofunato exceeded the acceleration response spectrum for outcropped engineering bedrock for a major earthquake in the Building Standard Law for the period range of 0.4 second or less. However, for the period range exceeding 0.4 second, the Ofunato spectrum was below the

Building Standard Law spectrum, and the component decreased as the period became longer. In Ichinoseki records, the acceleration response spectrum for a period range of 0.1 second or less was about the same as the acceleration response spectrum in the Building Standard Law (for a major earthquake), and at a period range of more than 0.5 second, it was almost the same as the acceleration response spectrum for a moderate earthquake in the Building Standard Law.

(2) The acceleration response spectrums show that, compared to the Rt curve in the Building Standard Law, in general a great response was produced for structures at a period of 0.5 second or less, but the input decreased dramatically when the period for the structure exceeded 0.5 second.

(3) The demand spectra shows that, for structures with a period of around 0.3 second in which the response was relatively dominant, damage with a plasticity rate of around 4 is predicted to occur in response to the Oshika NS wave and the Kitakami NS wave. However, for the other waveforms, not much damage is predicted to occur. In addition, a comparison with the records of the Great Hanshin-Awaji Earthquake (January 1995) reveals that the Sd (horizontal axis) for the record of the recent earthquake is extremely small compared to that of the Great Hanshin-Awaji Earthquake.

Next, the conclusions relating to the damage to structures are as follows.
(1) In general, there was some damage to structures.

(2) Only two private residences in Ofunato City, Iwate Prefecture were classified as having suffered “severe damage” and it is thought that amplification of the earthquake motion due to the effect of the topography (meaning the location at the edge of a hill) led to the total collapse.

(3) As regards reinforced concrete structures, structural damage was observed at the Tono City Hall, the Osano Elementary School in Kamaishi City and a high school in Ofunato City, but no major damage was noted at any other structures.

(4) As regards steel frame structures, damage to exterior walls and glass was discovered at some structures, but there was some structural damage. However, at the steel frame gymnasium at the Hashigami Elementary School in Kasennuma City, residual deflection of the vertical braces and the horizontal roof braces was observed, and rupture and pulling out of the foundation anchor bolts had occurred on the steel frame tower (2-story) on the top story of the three-story reinforced concrete school building.

(5) Toppling of exterior walls and damage to roof tiles was observed at some residences, but in general the damage is thought to have been slight.

(6) There was almost no structural damage to structures near the locations where strong earthquake intensities were recorded (K-NET observation sites).

As noted above, little major damage to structures was observed in this survey. Nevertheless, at the briefing [2] held at the Tohoku Branch of the Architectural Institute of Japan, which cooperated in the conducting of this survey, conspicuous structural damage in the form of rupture and buckling of the brace members at the gymnasium and so on, buckling of truss members, and damage to the anchor sections of roof trusses were reported. Furthermore, fallen exterior and interior materials and roof materials, damaged and fallen smokeproof glass fallen air conditioner ducts, books falling off shelves and the like were also reported, and therefore damage that had the potential for loss of function of buildings or injury occurred.

Finally, even though considerable damage would be anticipated from the records of observed earth movements, in actuality almost no major damage was observed. In order to investigate this phenomenon, in addition to earthquake motions observed in the free field, a strong-motion measurement network for structures themselves is needed.

In addition, with regard to the damage to non-structural members that might lead to loss of function of buildings or personal injury even if there is no structural damage to the building, it is thought that a study of methods for the installation of such members that takes into consideration the building earthquake response (response acceleration and response deformation) is needed.

6. ACKNOWLEDGEMENT

The authors would like to express their appreciation for the assistance provided by the Tohoku Regional Development Bureau of the Ministry of Land, Infrastructure and Transport and the Regional Development Bureau of the Iwate Prefecture in the preparation of this survey, as well as the administrative agencies and government disaster-related agencies in the areas in which the survey was conducted, which provided valuable information and the like at a time when they were surely very busy trying to cope in the immediate aftermath of the earthquake. The survey has also been conducted thanks to the exchange of information and other cooperation from the Liaison Council for the Disaster Survey of the Tohoku Branch of the Architectural Institute of Japan.

7. REFERENCES

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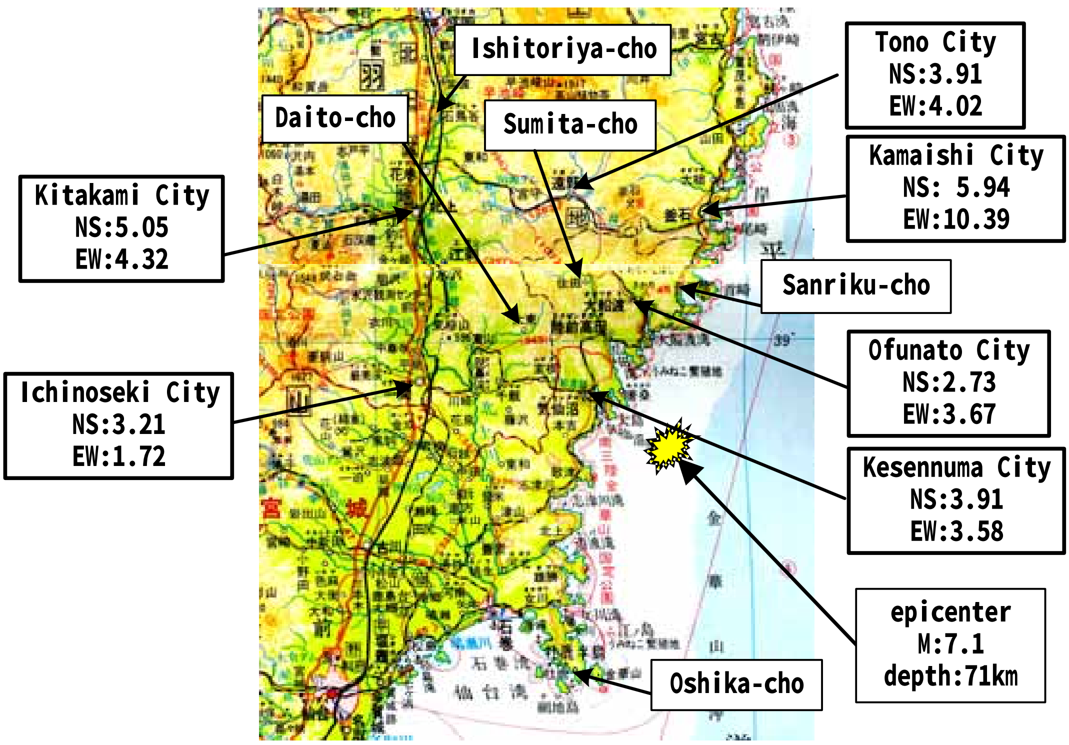


Figure 1 Surveyed communities, earthquake epicenter and earthquake motion acceleration (unit: m/sec^2) at K-NET measurement sites

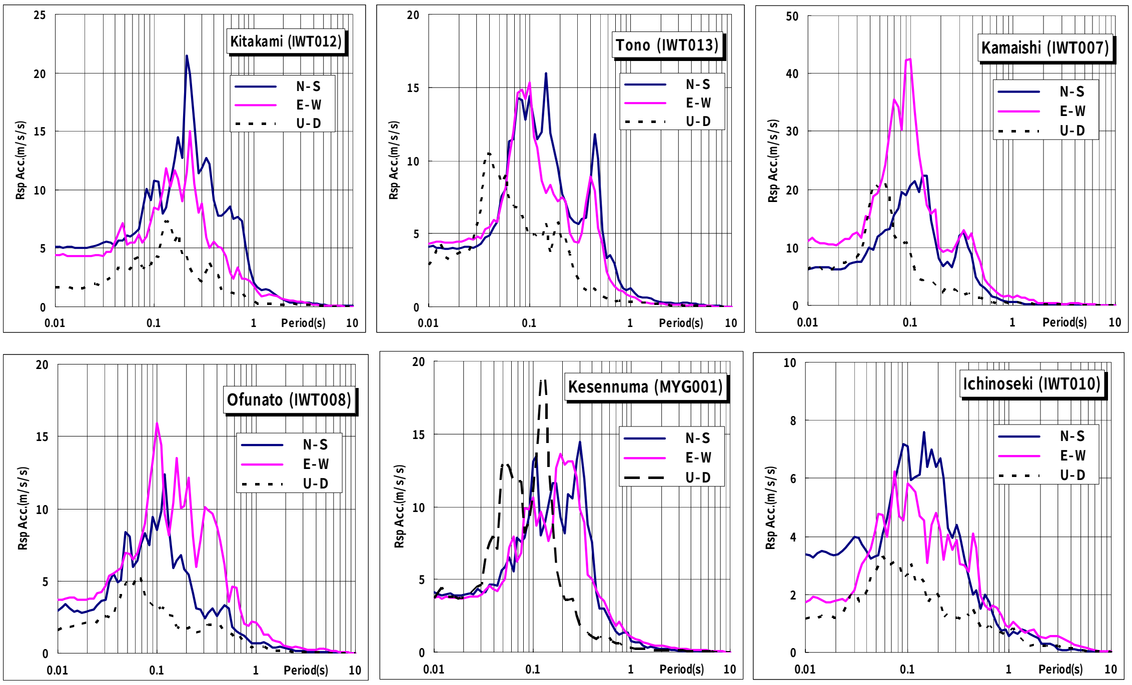
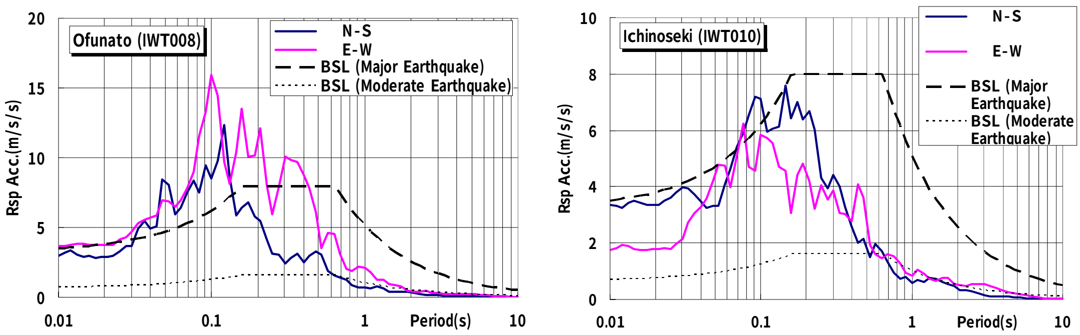


Figure 2 Acceleration response spectrum (damping ratio 5%) for recorded acceleration at K-NET observation sites



a) Ofunato (IWT008) b) Ichinoseki (IWT010)

Figure 3 Comparison of the acceleration response spectra (damping ratio 5%) for K-NET observation records at Ofunato and Ichinoseki and for the outcropped engineering bedrock in the Building Standard Law

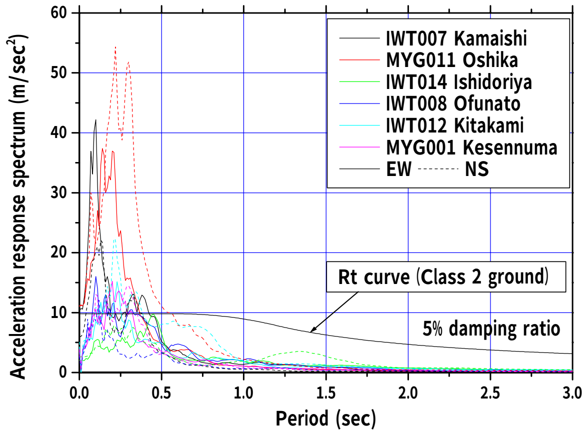


Figure 4 Acceleration response spectrum for horizontal records

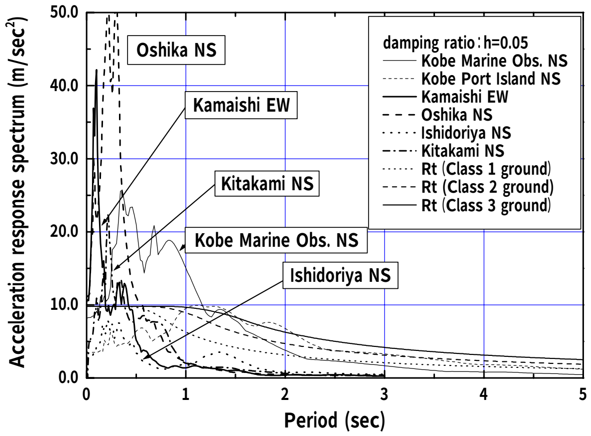


Figure 5 Acceleration response spectrum for major records and Great Hanshin-Awaji Earthquake (January 1995)

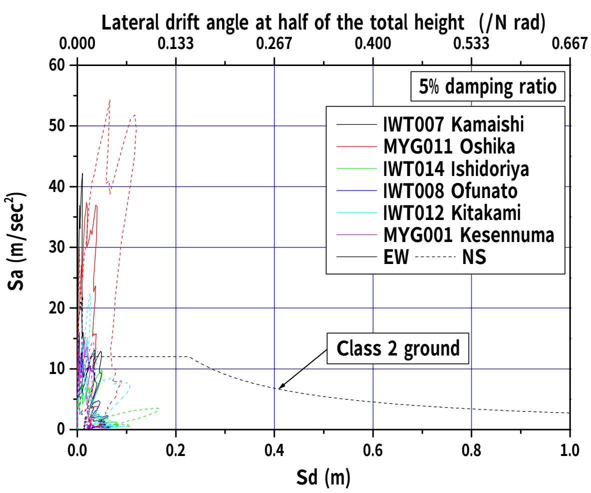


Figure 6 Requirement curves for observed waves (5% damping)

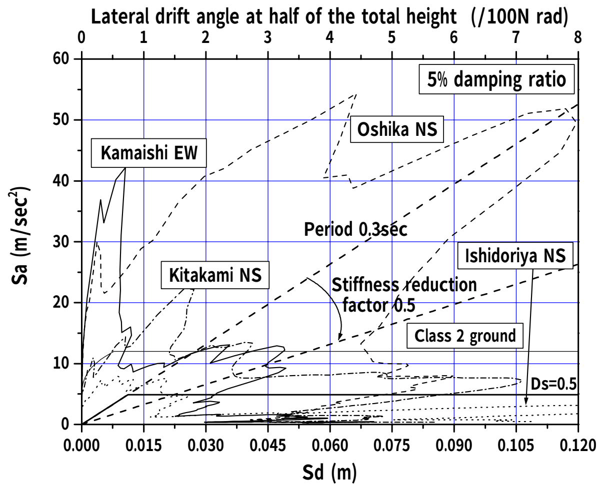


Figure 7 Requirement curves for observed waves (5% damping / 4 major waves)

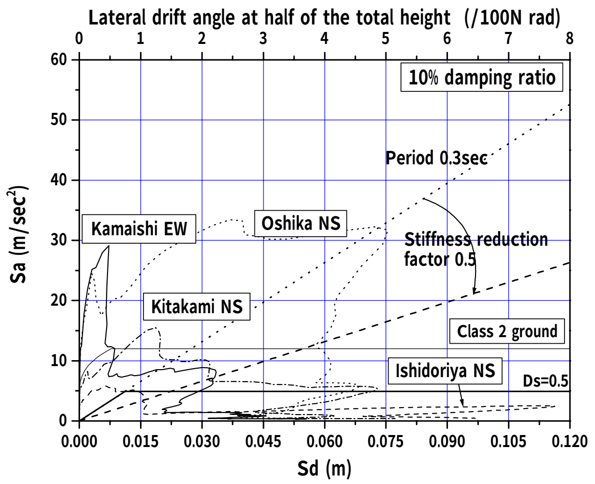


Figure 8 Requirement curves for observed waves (10% damping / 4 major waves)

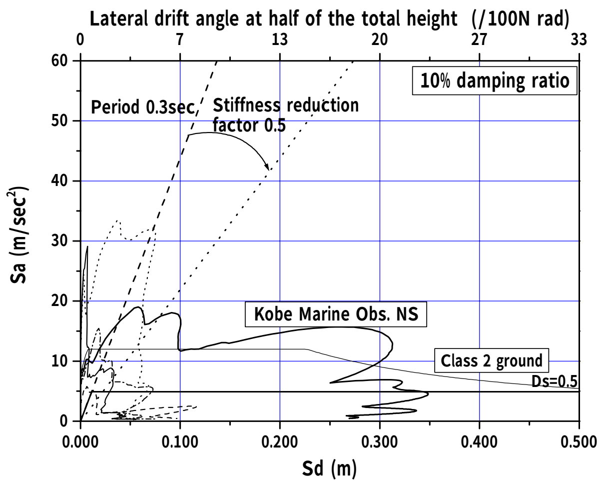


Figure 9 Requirement curves for observed waves (10% damping / 4 major waves and Kobe Marine Observatory NS wave)

Table 1 A Part of JMA Seismic Intensity Scale List
(http://www.kishou.go.jp/know/shindo/shindokai.html)

scale	contents
Low level 5	People : Most people try to escape from a danger. Some people find it difficult to move. Indoor : Hanging objects swing violently. Most Unstable ornaments fall. Occasionally, dishes in a cupboard and books on a bookshelf fall and furniture moves. Outdoor : People notice electric-light poles swing. occasionally, windowpanes are broken and fall, unreinforced concrete-block walls collapse, and roads suffer damage. Wooden houses : Occasionally, less earthquake-resistant houses suffer damage to walls and pillars. RC building : Occasionally, cracks are formed in walls of less earthquake-resistant buildings. Life lines : A Safety device cuts off the gas service at some houses. On rare occasions water pipes are damaged and water service is interrupted. (Electrical service is interrupted at some houses) Ground & slope : Occasionally, cracks appear in soft ground. and rock falls and small slope failures take place in mountainous districts.
High level 5	People : Many people are considerably frightened and find it difficult to move. Indoor : Most dishes in a cupboard and most books on a bookshelf fall. Occasionally, a TV set on a rack falls, heavy furniture such as a chest of drawers falls, sliding doors slip out of their groove and the deformation of a door frame makes it impossible to open the door. Outdoor : In many cases, unreinforced concrete-block walls collapse and tombstones overturn. Many automobiles stop because it becomes difficult to drive. Occasionally, poorly-installed vending machines fall. Wooden houses : Occasionally, less earthquake-resistant houses suffer heavy damage to walls and pillars and lean. RC building : Occasionally, large cracks are formed in walls, crossbeams and pillars of less earthquake-resistant buildings and even highly earthquake-resistant buildings have cracks in walls. Life lines : Occasionally, gas pipes and / or water mains are damaged. (Occasionally, gas service and / or water service are interrupted in some regions) Ground & slope : same as noted at Low level 5.
Low level 6	People : Difficult to keep standing. Indoor : A lot of heavy and unfixed furniture moves and falls. It is impossible to open the door in many cases. Outdoor : In some buildings, wall tiles and windowpanes are damaged and fall. Wooden houses : Occasionally, less earthquake-resistant houses collapse and even walls and pillars of highly earthquake-resistant houses are damaged. RC building : Occasionally, walls and pillars of less earthquake-resistant buildings are destroyed and even highly earthquake-resistant buildings have large cracks in walls, crossbeams and pillars. Life lines : Gas pipes and / or water mains are damaged.(In some regions, gas service and water service are interrupted and electrical service is interrupted occasionally.) Ground & slope : Occasionally, cracks appear in the ground, and landslides take place.

High level 6	People : Impossible to keep standing and to move without crawling. Indoor : Most heavy and unfixed furniture moves and falls. Occasionally, sliding doors are thrown from their groove. Outdoor : In many buildings, wall tiles and windowpanes are damaged and fall. Most unreinforced concrete-block walls collapse. Wooden houses : Many, less earthquake-resistant houses collapse. In some cases, even walls and pillars of highly earthquake-resistant houses are heavy damaged. RC building : Occasionally, less earthquake-resistant buildings collapse. In some cases, even highly earthquake-resistant buildings suffer damage to walls and pillars. Life lines : Occasionally, gas mains and / or water mains are damaged.(Electrical service is interrupted in some regions. Occasionally, gas service and / or water service are interrupted over a large area.) Ground & slope : same as noted at Low level 6.

Table 2 Maximum values for acceleration at K-NET observation sites and calculated velocity

K-NET site (site code)	Calculated seismic Intensity	Recorded acceleration (m/s^2)			Calculated velocity (m/s)		
		NS	EW	UD	NS	EW	UD
Kitakami City(IWT012)	5.4	5.05	4.32	1.57	0.326	0.171	0.062
Tono City (IWT013)	5.2	3.91	4.02	2.66	0.168	0.120	0.057
Kamaishi City(IWT007)	5.4	5.94	10.39	5.92	0.164	0.246	0.065
Ofunato City (IWT008)	5.1	2.73	3.67	1.55	0.087	0.215	0.041
Kesennuma City(MYG001)	5.3	3.91	3.58	3.44	0.168	0.150	0.095
Ichinoseki City(IWT010)	4.6	3.21	1.72	1.13	0.110	0.155	0.060
Ishitoriya-cho (IWT014)	5.0	2.60	1.97	1.30	0.222	0.156	0.083
Oshika-cho (MYG011)	6.1	11.01	11.14	8.25	0.518	0.361	0.209

Table 3 Number of casualties and damaged residences in Iwate and Miyagi Prefectures

Location	No. of Casualties		No. of Damaged Residences			
	Severe injured	Light injured	Major	Moderate	Partial	Flooded up to floors
Iwate Prefecture						
Morioka Region	1	5	0	0	40	0
Hanamaki Region	1	6	0	0	0	0
Kitakami Region	4	12	0	0	3	0
Mizuosawa Region	1	17	0	0	131	0
Ichinoseki Region	0	1	0	0	14	0
Senmaya Region	2	5	0	0	65	0
Ofunato Region	1	23	2	9	492	1
Tono Region	0	1	0	0	232	0
Kamaishi Region	0	2	0	1	145	0
Miyako Region	0	8	0	0	59	0
Kuji Region	0	1	0	0	2	0
Ninohe Region	0	0	0	0	0	0
Total of Iwate Pref.	10	81	2	10	1,183	1
Miyagi Prefecture						
Ogawara Region	0	1	0	0	0	0
Sendai Region	1	11	0	0	45	0
Furukawa Region	2	16	0	0	30	0
Tsukidate Region	1	7	0	1	94	0
Hasama Region	3	1	0	0	202	0
Ishinomaki Region	2	8	0	0	150	0
Kesennuma Region	1	10	0	10	512	0
Total of Miyagi Pref.	10	54	0	11	1,033	0

(Source: Iwate Prefectural Development Department, Buildings & Residences Section and Miyagi Prefecture Civil Engineering Department, Buildings & Residences Section)

Table 4 Status of Damage to Partially Damaged Buildings at Tono Regional Development Bureau and Number of Buildings Affected

Status of Damage	No. of Buildings
Fallen roof tiles	119
Toppled walls	40
Wall cracks	26
Structure leaning	1
Gas leak	1
Window glass broken	13
Fallen ceiling, etc.	3
Stairway cracking	2
Other	27
Total	232

(Source: Buildings & Residences Section, Land Development Department, Iwate Pref.)

Photo 1Kitakami City Hall

Photo 2 Glass cracking

Photo 3 Truss construction using large section members

Photo 4 Repair work for roof tiles

Photo 5 Shear cracking on the columns beside the entrance

Photo 6 Damage to the columns at the rear of the main building

Photo 7 Damage to the wall between openings
in the first floor corridor of the old building

Photo 8 Fallen ceiling panels
at front entrance

Photo 9 Ofunato High School

Photo 10 Shear cracking to the
Second floor columns of the old building

Photo 11 Two "severe-damage" residences

Photo 12 Damage to outer wall of
one-story wooden residence

Photo 13 Damage to inner wall of one-story wooden residence

Photo 14 Damage to lightweight steel frame prefabricated residence

Photo 15 Fallen storage facilities in kitchen

Photo 16 Damage to concrete- block -masonry structure

Photo 17 Damage to steel frame tower on roof

Photo 18 Rupture of foundation anchors on tower