A QUICK REPORT

ON

MIE-KEN KAMEYAMA EARTHQUAKE ON APRIL 15, 2007

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1 INTRODUCTION

The Kameyama earthquake earthquake occurred at 12:19 on JST on April 15, 2007 and it had a magnitude (Mj) of 5.3 on the magnitude scale of Japan Meteorological Agency. The earthquake injured 12 people and caused some structural damage.

The strong ground motions were quite high in the epicentral area with high frequency components although its moment magnitude was only 5.0. The earthquake fault was associated with Mukumoto sub-segment of the northern segment of Nunobiki-sanchi-toen fault zone. This fault dips beneath Suzuka Mountain range. Since the earthquake was small and hypocenter was 16km deep, no surface ruptures were observed in Geino town, which is the closest settlement to the earthquake epicenter.

The earthquake caused some damage to some old wooden houses with heavy roofs. The ceiling panels of a drive-inn building were fallen and injured the customers. The northern masonry wall of Kameyama Castle, built in 1590, collapsed. The embankments of rivers and some bridges of roadways were damaged. The earthquake induced some small scale slope failures in the vicinity of the mountainous terrain.

The region also has some abandoned lignite mines and underground quarries for abrasion sand (migaki suna), which were exploited using room and pillar mining method.

The authors investigated the earthquake-affected area for one day and covered many parts of the area of concern (Figure 1.1). This report covers both scientific and engineering aspects of the earthquake. Some emphases were given to the investigation results of the Kameyama Castle wall collapse and to the stability of abandoned room and pillar mines in Tsu City. A cave-in above an abandoned underground quarry for abrasion sand occurred in the Handa district of Tsu City in August 2006 and it was one of the major items of this investigation.

The material presented in this report is the interpretation and compilation of the available materials and information released by mass media, various earthquake-related institutes in Japan and other countries as well as the own observations of the authors and their measurements and computations.

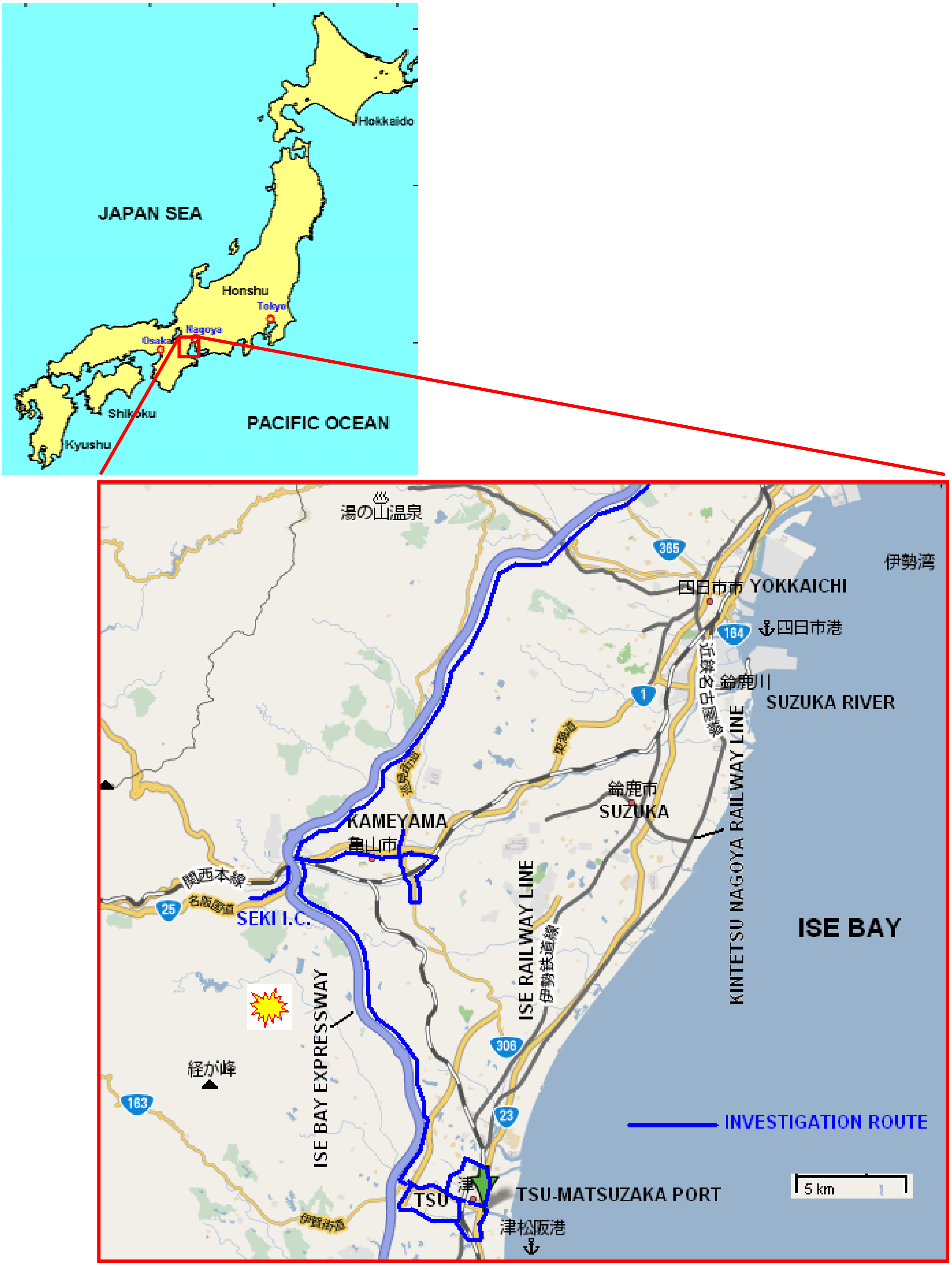


Figure 1.1: Routes followed during the investigation (original map from Google)

2 GEOGRAPHY

The earthquake was located in Mie Prefecture at the eastern part of the Kii Peninsula of Honshu Island of Japan as shown in Figure 2.1. Mie prefecture (Mie-ken) is a part of the Kinki region on Honshu Island. The capital is the city of Tsu. Aichi, Gifu, Shiga, Kyoto, Nara, and Wakayama prefectures border Mie prefecture. As of 2000, Mie prefecture's 5,776.44 km^2 land is divided into 64.8% forest, 11.5% agriculture, 6% residential area, 3.8% roads, and 3.6% rivers. The population is about 1,860,000 and the main cities are Tsu, Ise, Suzuka, Yokkaichi, Toba and Kameyama. (Figure 2.1). The other larger towns affected by the earthquake are Geino, Nabari and Hakusan. The most heavily shaked places were Geino town and Kameyama City.

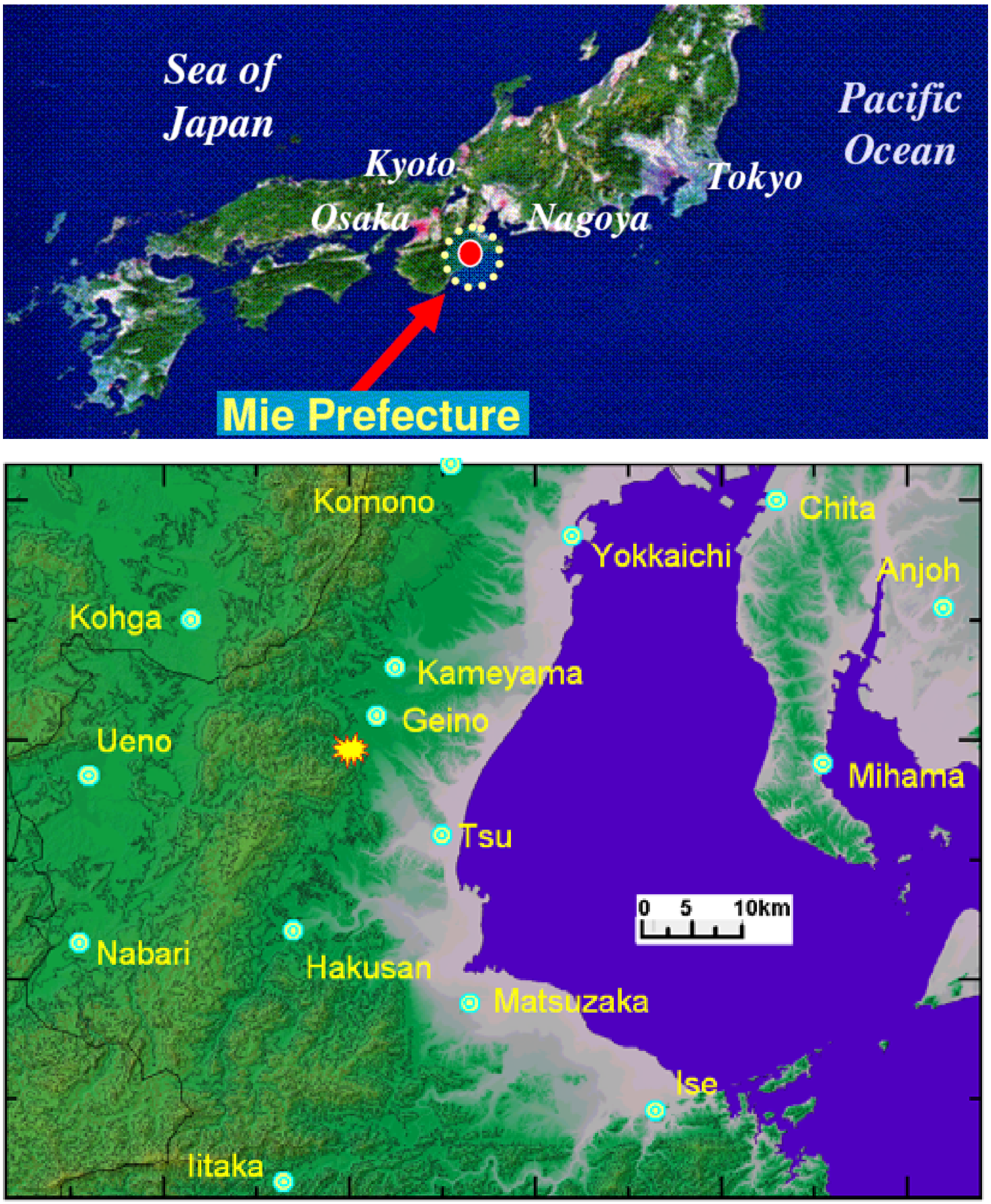


Figure 2.1 Location of cities and towns in the epicentral area

3 GEOLOGY AND TECTONICS

The geology of the earthquake epicenter area is shown in Figure 3.1. The geology broadly consists of Pre-Miocene formations, Miocene formations, Pliocene Tokai Group, terrace deposits and alluvium (i.e. Yoshikawa and Yoshida, 1989). Pre-Miocene formations constitute the basement rock of the region and they are either metamorphic rocks and dioritic granite or granite. Miocene rocks are soft sedimentary rocks of mudstone, sandstone, siltstone and conglomerate and it also contains lignite seams. Tokai group generally consists lacustrine and fluvial deposits composed of gravel, sand and mud with volcanic ash layers and it includes turbiditic lignite seams. The group is about 1200m thick and it is divided into the Saigyodani, Kusuhara, Kameyama and Sakuramura Formations in ascending order. Tokai Group is widely distributed in the Kameyama area.

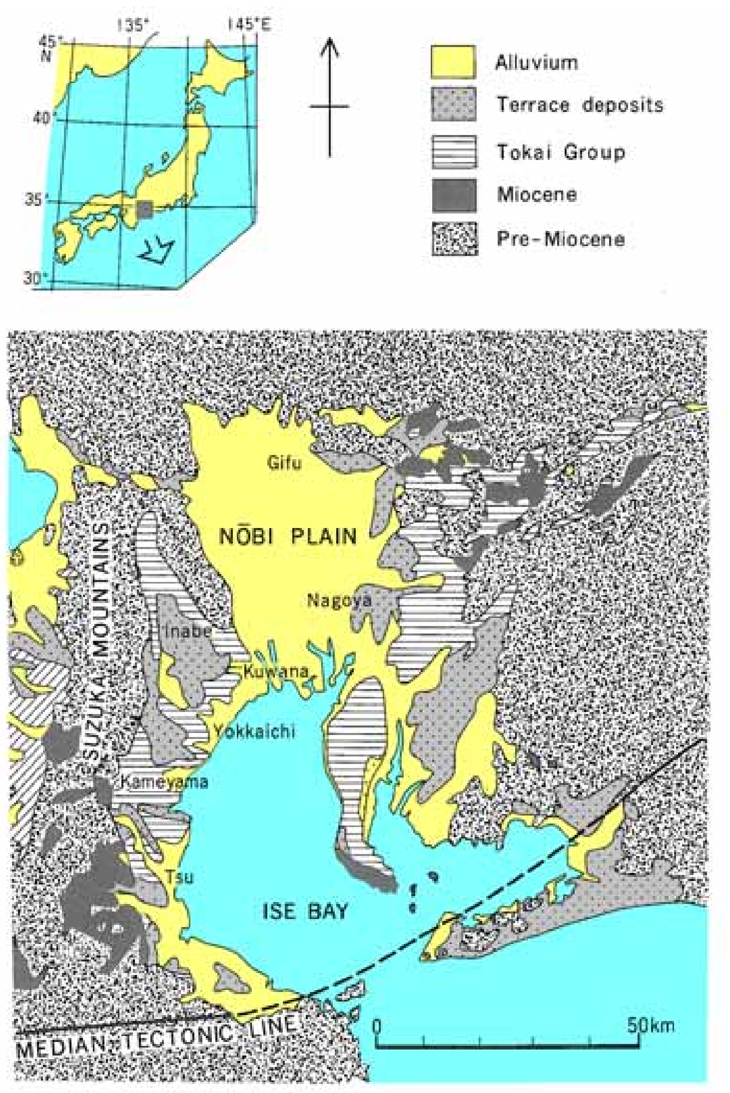


Figure 3.1: Geology of the earthquake epicenter area (from Yoshikawa and Yoshida, 1989)

The tectonics of the region is well studied and many active faults are identified through paleo-seismological trenches (Mie Prefecture, 2007). The active faults are named as Yoro fault, Kuwana fault, Yokkaichi fault, Suzuka-toen fault, Nunobiki-sanchi-toen fault, Ise Bay faults (Figure 3.2). Median Tectonic Line (MTL), which is a dextral thrust tectonic structure, runs almost in E-W direction in the south of the epicentral area. The fault activated during the earthquake is associated with Nunobiki-sanchi-toen fault (Mie Active Fault Studies Committee, 1999). This fault is divided into northern segment (L=27km) and southern segment (19km). The northern segment is also divided into three sub-segments. The epicentral estimations and post-seismicity implies that the Mukumoto sub-segment is activated during this earthquake (Figure 3.3). Although the seismic reflection studies imply that the fault dips to the west with an inclination ranging between 45-50^{o}, some of trenches yielded also east-dipping ruptures. These structures are probably due to the decolment of the fault front near ground surface.

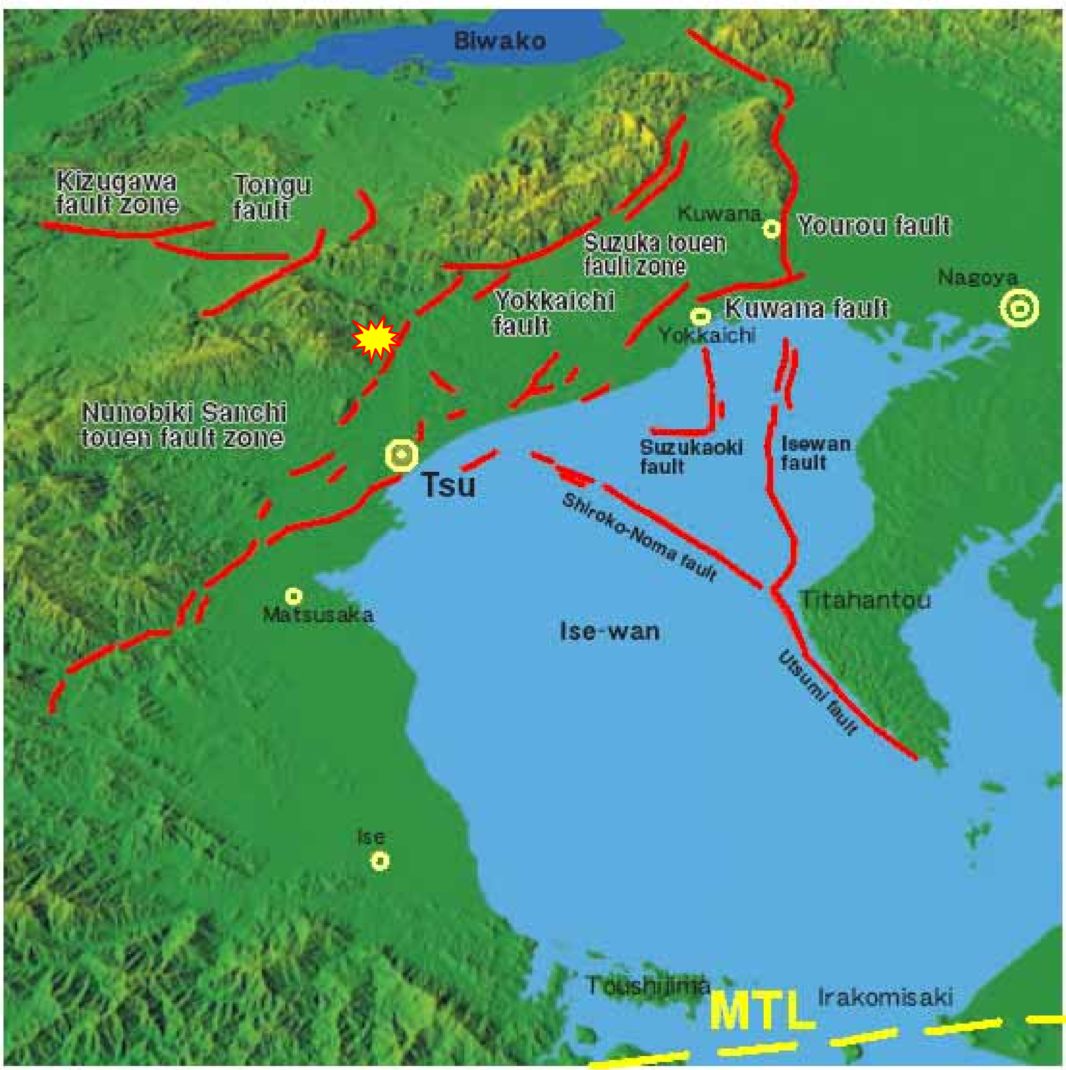


Figure 3.2 Faults of Mie prefecture and its close vicinity (modified from Mie Prefecture)

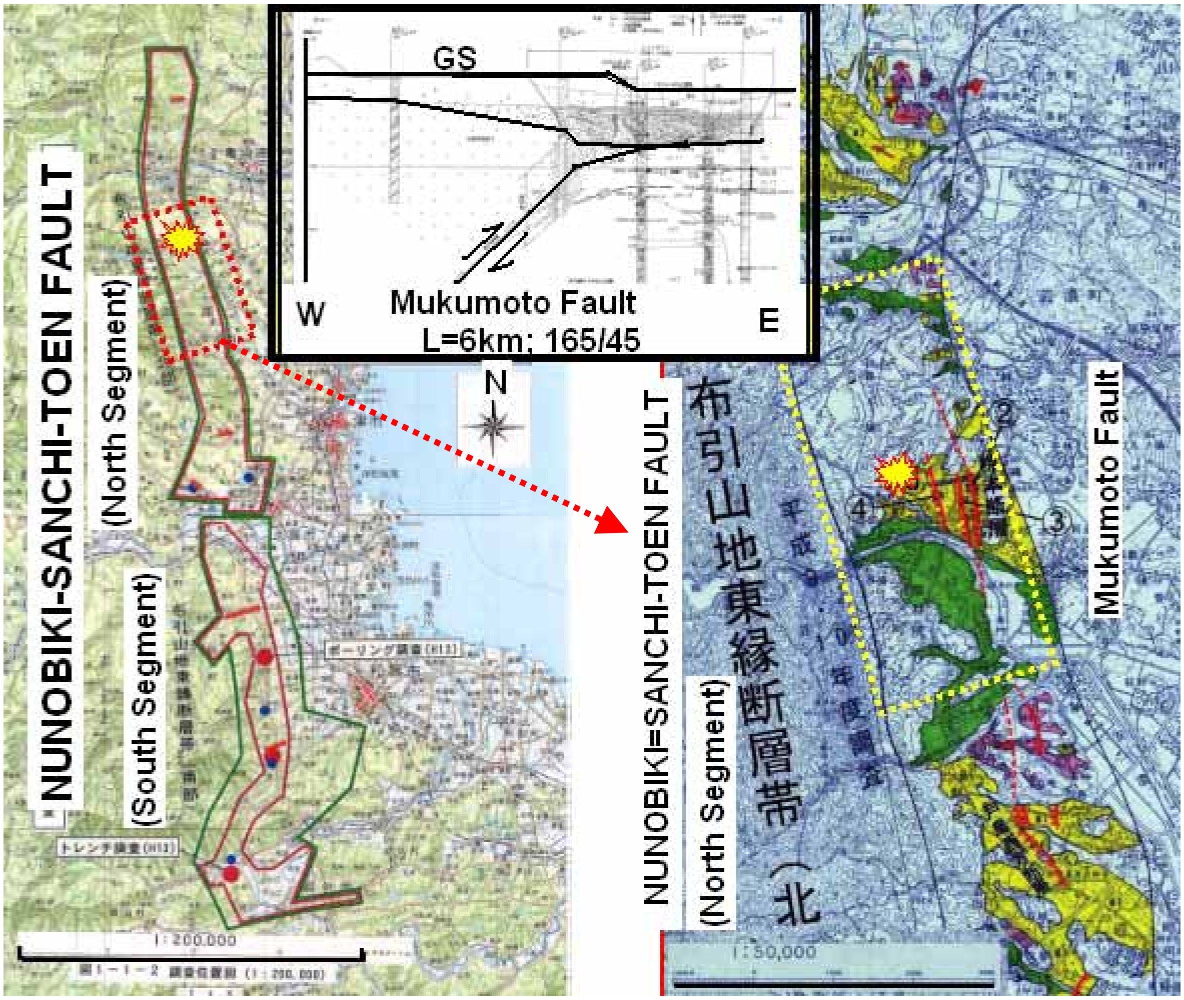


Figure 3.3: Segmentation of Nunobiki-sanchi-toen fault and the location of Mukumoto fault (re-arranged from Mie Active Fault Studies Committee Report , 1999)

4 SEISMICITY AND CHARACTERISTICS OF THE EARTHQUAKE

4.1 Past Seismicity

The past seismological records indicate that the region experiences some large events from time to time. Most of the events are either inter-plate or intra-plate type. Figure 4.1 shows epicenters of seismic events (M>3) for last 30 years while Figure 4.2 shows the same dat together with damaging earthquakes (M>6) in the last 150 years. The seismicity shown in Figures 4.1 and 4.2 is aligned in certain directions, which generally correspond to known tectonic structures. The bottom part of Figure 4.1 shows projections of the hypocenter of earthquakes on an E-W cross-section. It is seems that the subducting Pacific plate may extend beneath Ise Bay and the subduction front of the Pacific plate may be inferred from Figures 4.1 and 4.2. Another important feature is that the hypocenters at the western side of Kii Peninsula are aligned along a plane dipping eastward. No large seismic activity in the region is noted in the last 30 years.

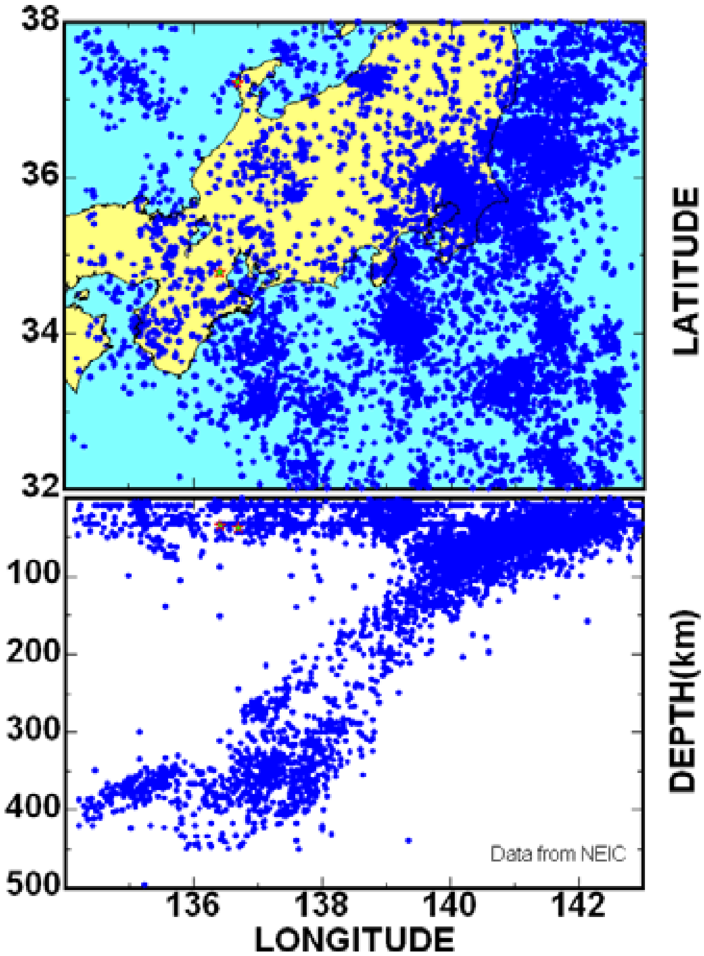


Figure 4.1: Seismicity of the region between 1973-2007 bounded by latitudes N34-38 and longitudes E134-143 (data from USGS-NEIC)

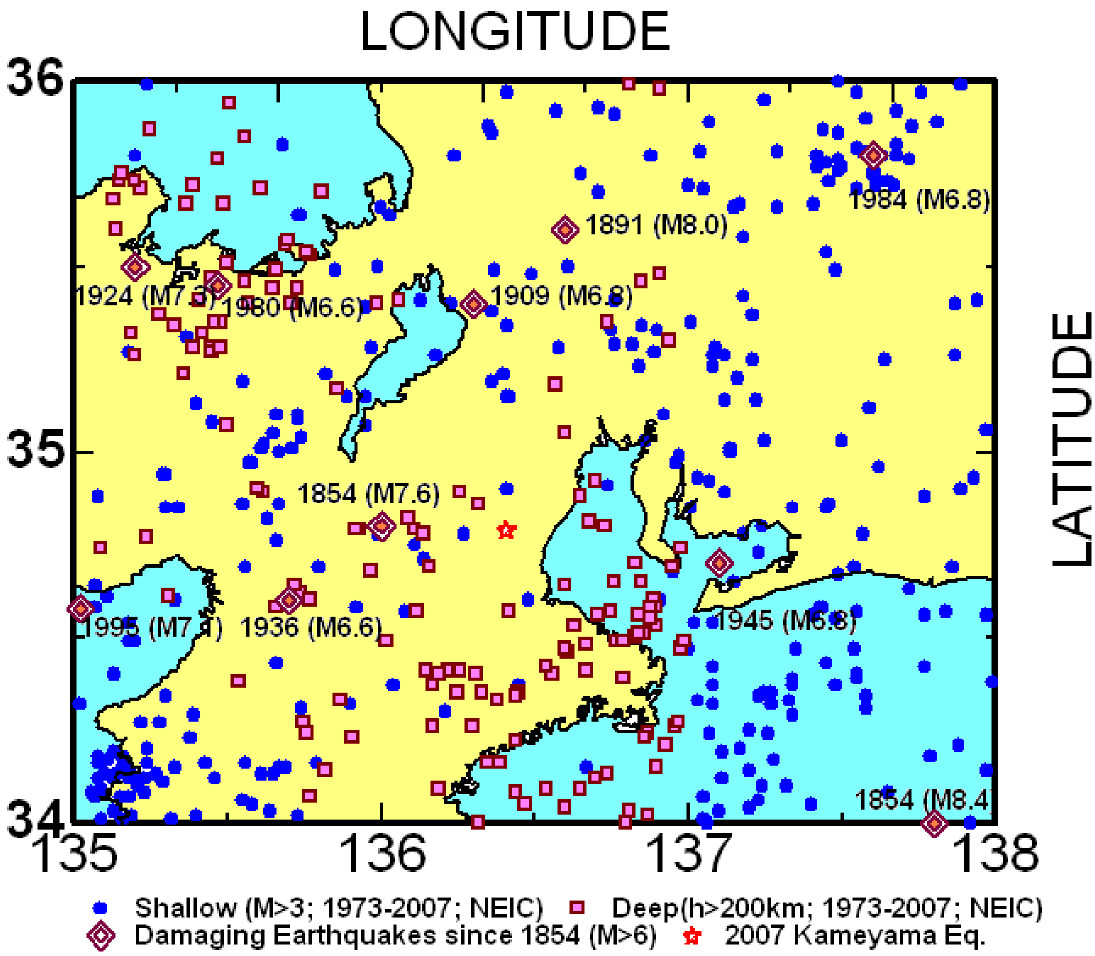


Figure 4.2: Past seismicity together with locations damaging earthquakes (M>6) in the last 150 years.

4.2 Characteristics of the Earthquake

The seismic parameters of the earthquake and its focal plane solutions estimated by different seismological institutes in Japan and worldwide are listed in Table 4.1 and illustrated in Figure 4.3. If the west dipping fault is chosen as the causative fault, the fundamental mode of faulting was thrust-type with a slight sinistral or dextral component depending upon the institute. The focal plane solutions were provided by JMA and Hi-Net and F-Net systems of NIED. These institutes estimated that the fault dipping SW would be the causative fault from the computed mechanisms and the dip of the causative fault should be ranging between 42-45^{o}.

Table 4.1: Parameters of the earthquake estimated by different institutes

Institute	Latitude	Longitude	Depth (km)	Magnitude	Strike	Dip	Rake Angle
JMA	37.79	136.407	16	Mj=5.3	NP1 145° NP2 325	43° 47°	90° 90°
USGS	37.537	136.438	16	Mw=5.0	NP1 NP2		
Hi-NET (NIED)				Mw=5.0	NP1 152 ° NP2 326 °	42 ° 49 °	95 ° 86 °
F-NET (NIED)			11	Mw=5.0	NP1 148° NP2 347°	45° 46°	77° 103°

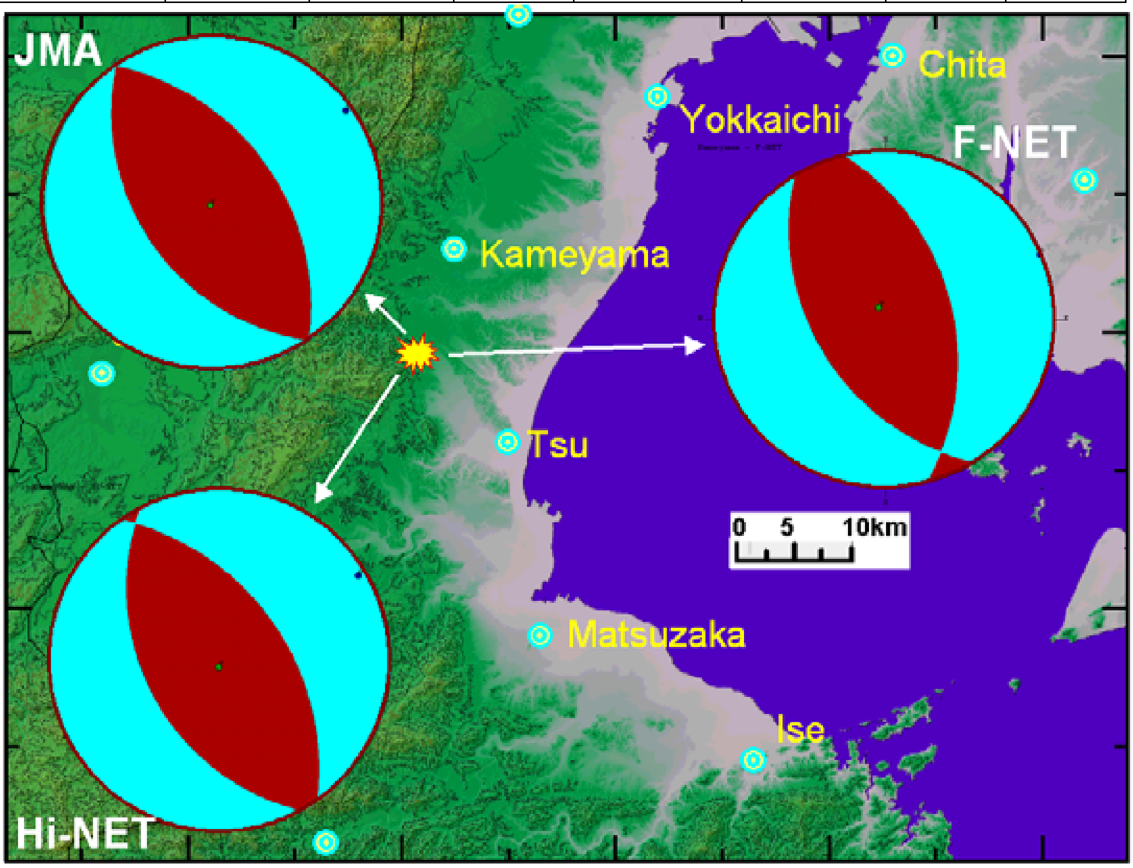


Figure 4.3: Focal plane solutions by different seismological institutes

4.3 Fore-Post Seismicity and Shock Distributions

Following the earlier reports of the main shock, it was found that there was a foreshock with a magnitude of 3.2 about 2 minutes before the main shock. The mechanisms of this foreshock obtained by JMA and Hi-NET were almost the same as those for the main-shock.

Since the epicenter data of aftershocks determined by Japan Meteorological Agency (JMA) are only available on INTERNET, the data released by the JMA is used to infer the possible dimensions of the activated fault plane. Figure 4.4 shows the epicenter distributions together with cross-sectional and longitudinal distributions of aftershocks in selected directions. The distribution of aftershocks on April 15 indicates that the main fault should be about 4-5km long and 5-6km wide as seen in Figure 4.4. In addition, it is expected that it would not cause any surface rupture as the rupture area is relatively deep. Furthermore, the after-shock activity implies that the inclination of the fault would be quite similar to that estimated from focal plane solutions (Figure 4.4). Nevertheless, the same aftershock activity implies the earthquake also activated a conjugate fault zone to the main fault.

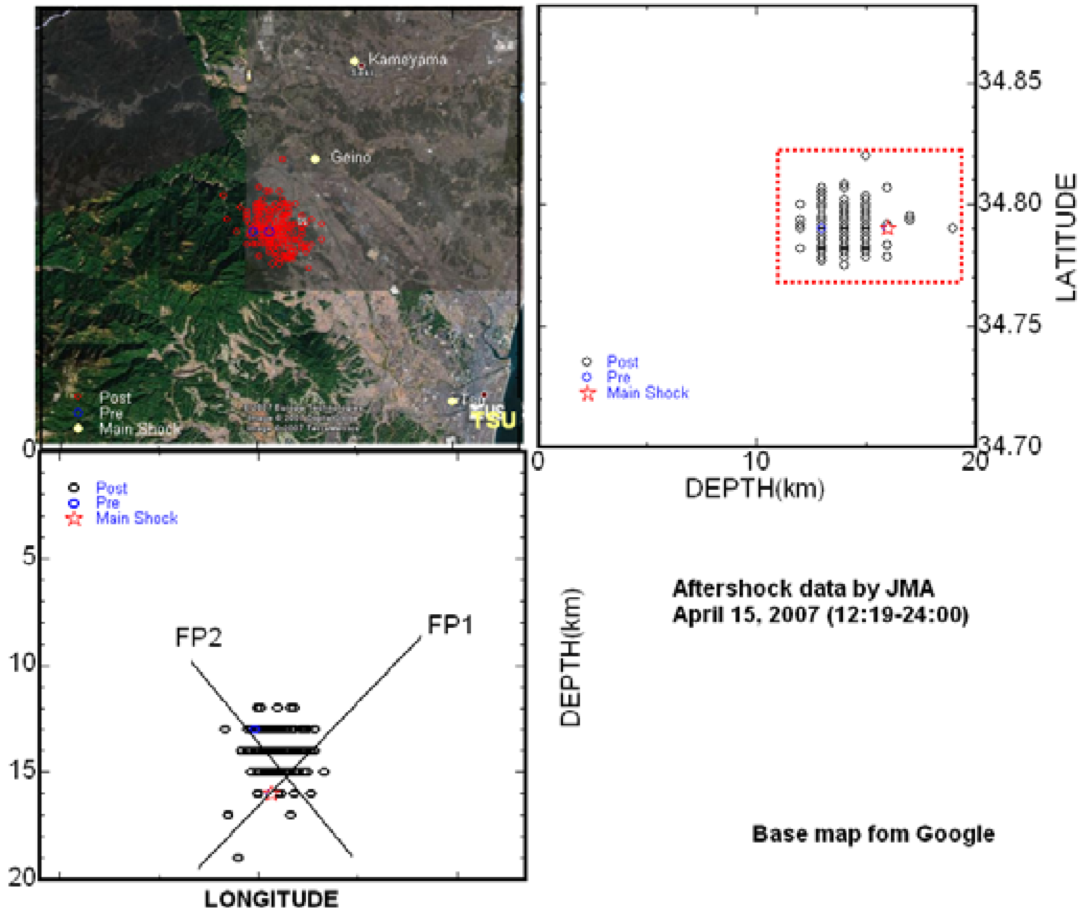


Figure 4.4: Aftershock activity and inferred size of the earthquake fault

5 STRONG GROUND MOTIONS

The strong motion networks of Japan Meteorological Agency and K-Net and Kik-Net of NIED recorded very high ground accelerations in the epicentral area although the moment magnitude (Mw) of this earthquake was only 5.0. The maximum ground acceleration was observed at Geino strong ground motion station of KIK-NET, which was 3km away from epicenter, and it was about 850 gal at ground surface while the maximum acceleration was 338 gal at base (rock), implying an amplification factor of 2.3-2.5. Figure 5.1 shows the acceleration records at several locations around the epicenter. As noted from the acceleration records, they are strikingly different from each other. These records clearly indicate that there is a strong directivity effect associated with rupturing process as noted from Figure 5.1. The contours of maximum ground acceleration are plotted in Figure 5.2. The observed results indicate that the amplification of accelerations on soft ground may be several times that on the hard ground. The damage observed in the epicentral area clearly confirm this conclusion. Figures 5.3 and 5.4 are comparisons of attenuation of maximum ground acceleration and velocity with empirical relations. In-spite of the small magnitude of this earthquake, the maximum ground acceleration and velocity exceed those estimated from empirical equations. This topic probably deserves further studies.

Figure 5.5 shows the ground response spectra for Kameyama station of K-NET. The response spectra implies that the ground above the basement rock has a natural period of 0.122 seconds. The Figures 5.6 to 5.8 show acceleration response spectra for Geino strong motion station (base and ground surface), Kameyama and Tsu records with a damping ratio of 5%. Basicaly the response spectra of all stations are similar while their absolute values are different. The peak acceleration spectra values imply that the structures having small natural periods might be affected by this earthquake. Nevertheless, the acceleration response spectra exceeds the design levels even though the earthquake has a small magnitude.

Figure 5.9 shows the normalized response spectra for the base and surface records of Geino station for EW component. Although the acceleration response of the ground surface is affected by the existing of soft layers above the basement rock, its effect is not so pronounced for this earthquake.

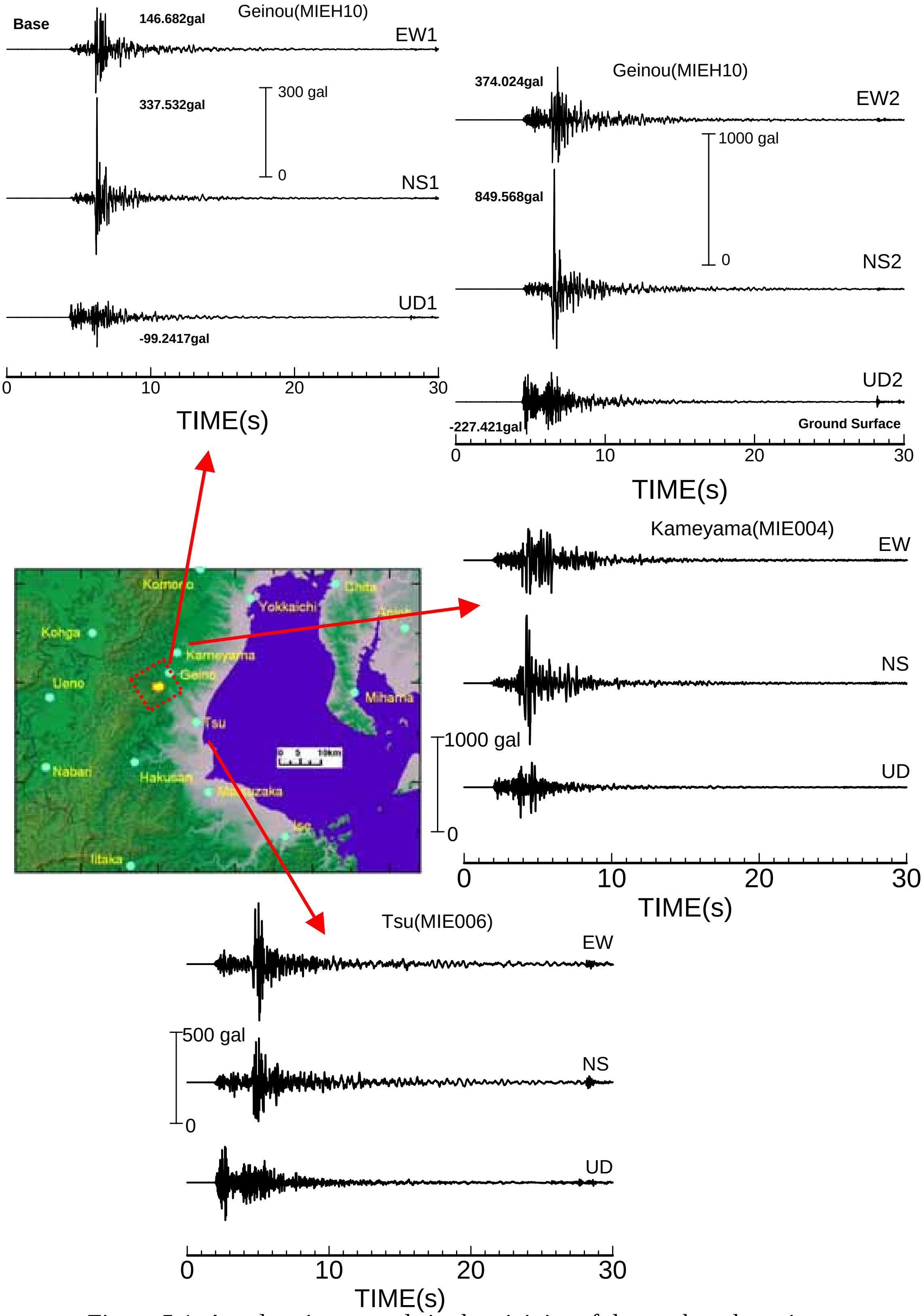


Figure 5.1: Acceleration records in the vicinity of the earthquake epicenter

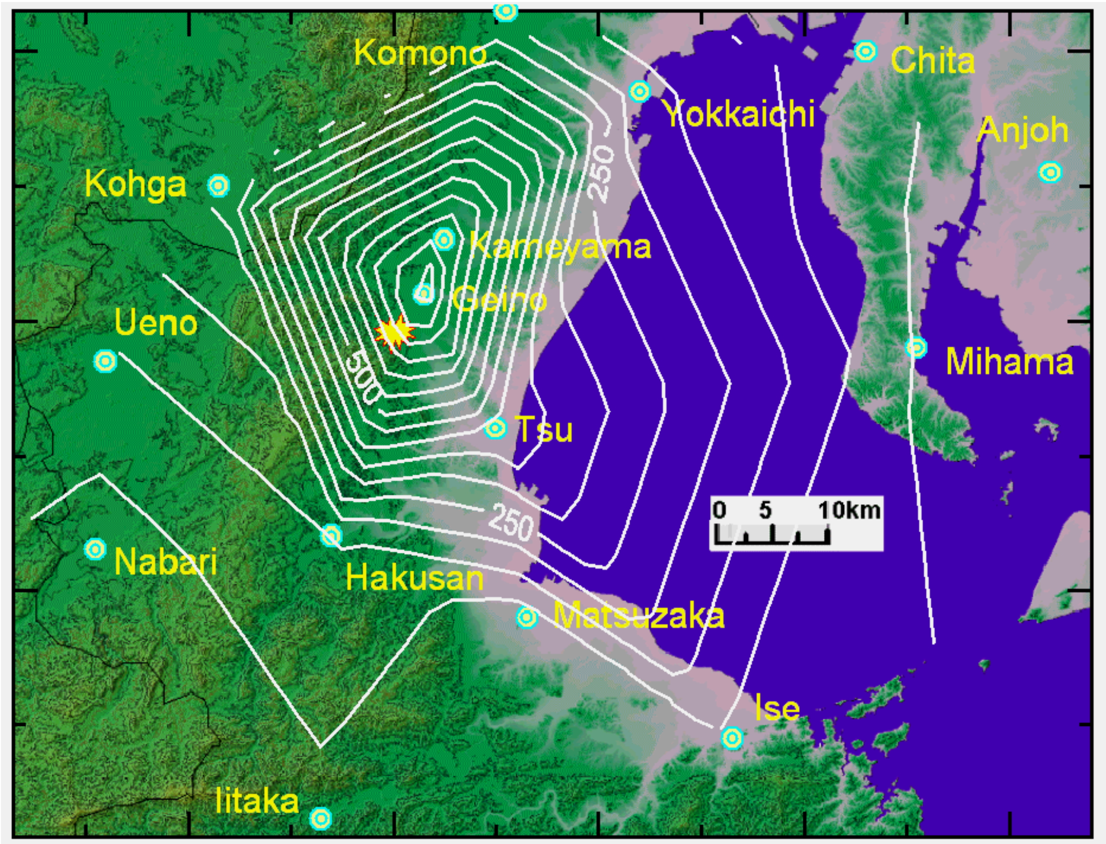


Figure 5.2: Contours of maximum ground acceleration (Amax)

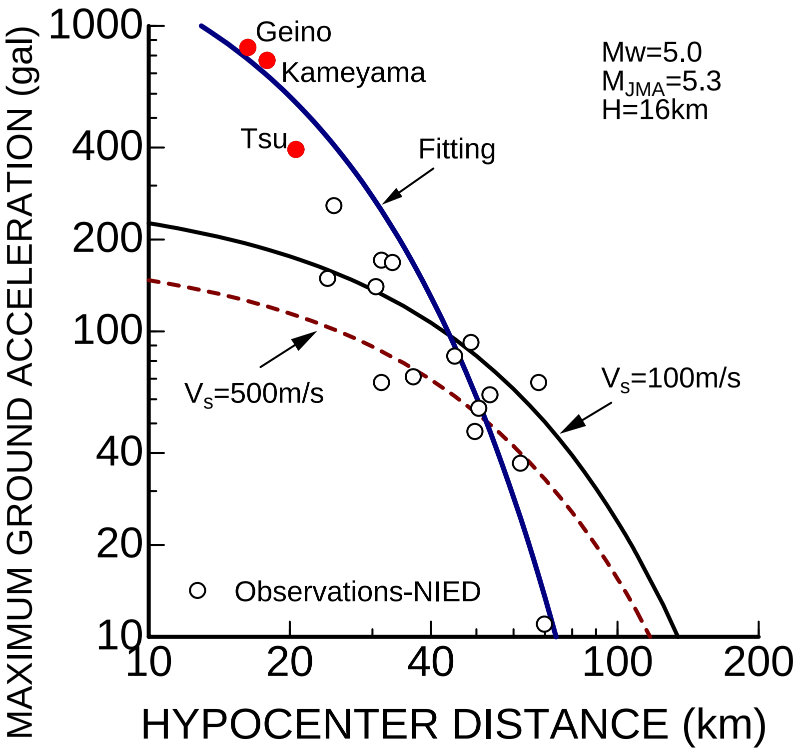


Figure 5.3: Attenuation of maximum ground acceleration (Amax)

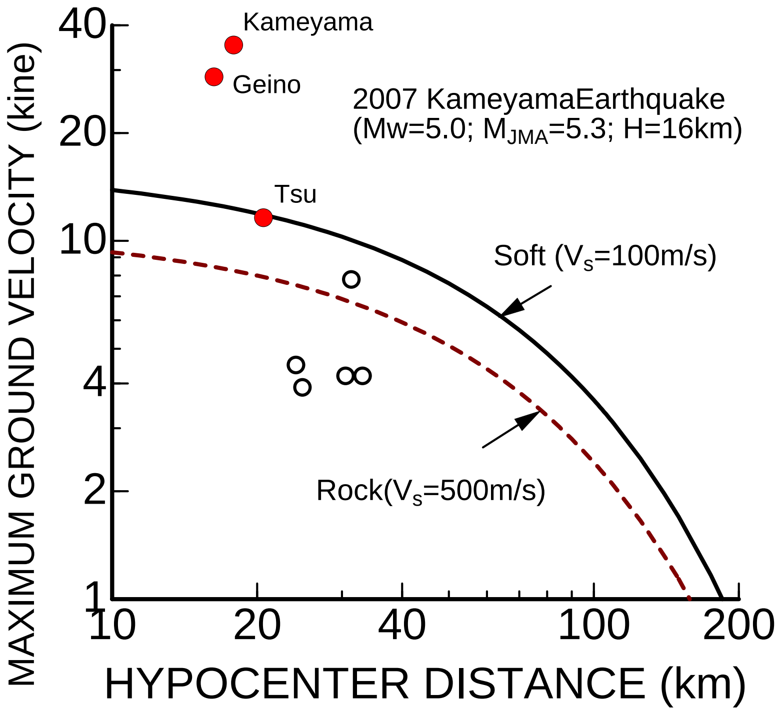


Figure 5.4: Attenuation of maximum ground velocity (Vmax)

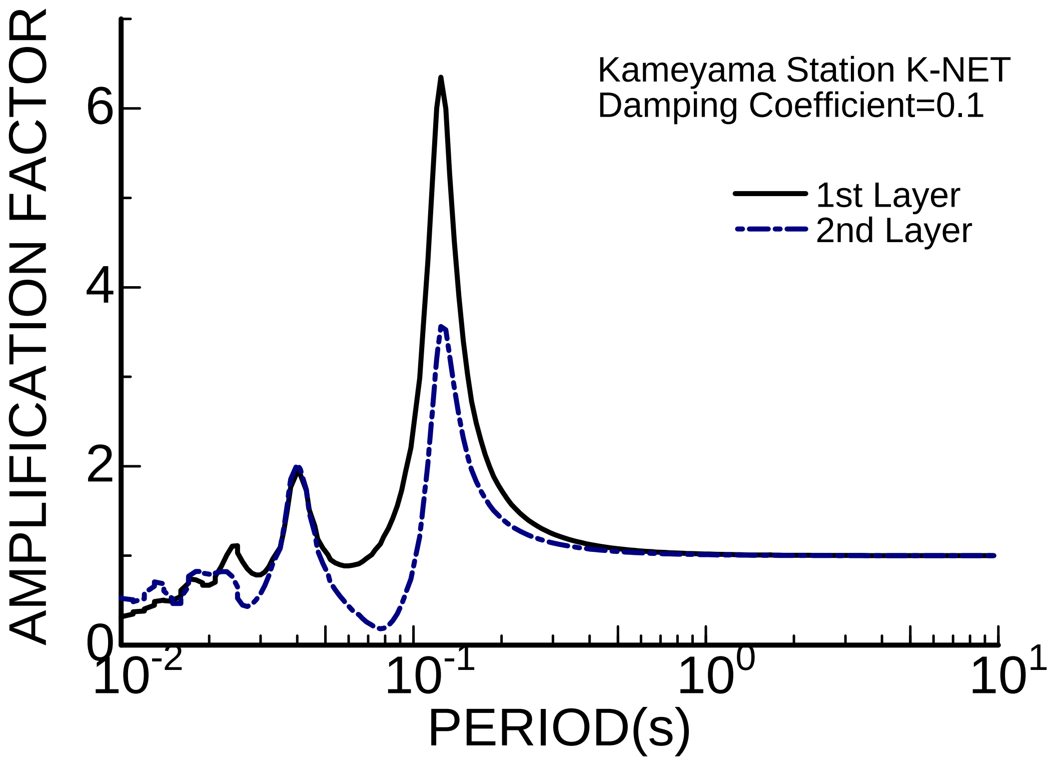


Figure 5.5: Ground response spectra for Kameyama Station of K-NET

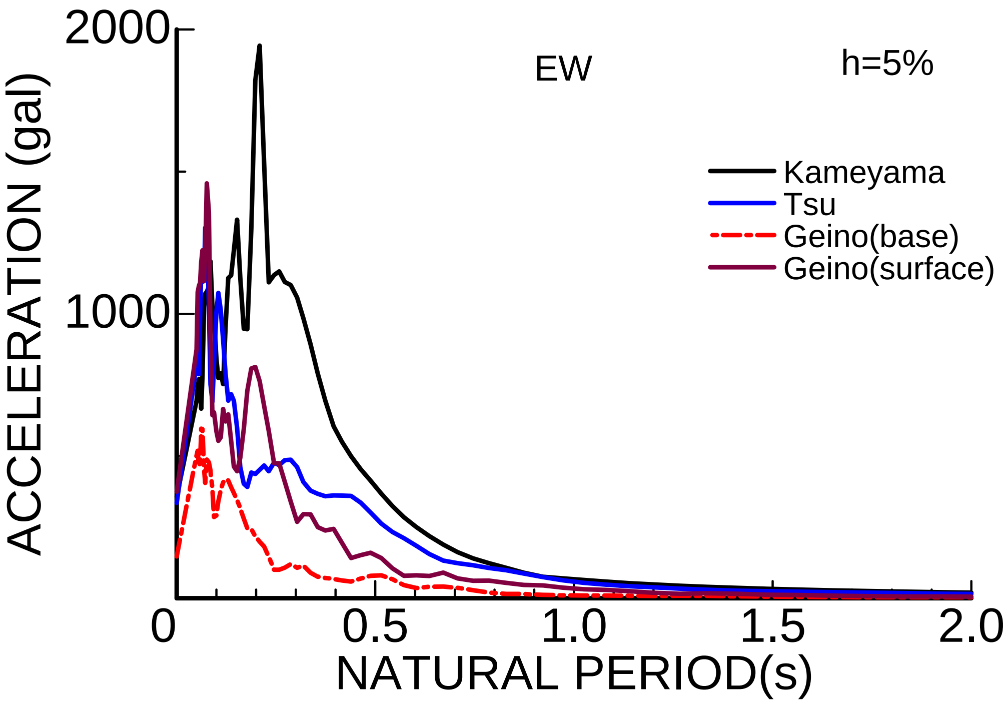


Figure 5.6: Acceleration response spectra for EW component

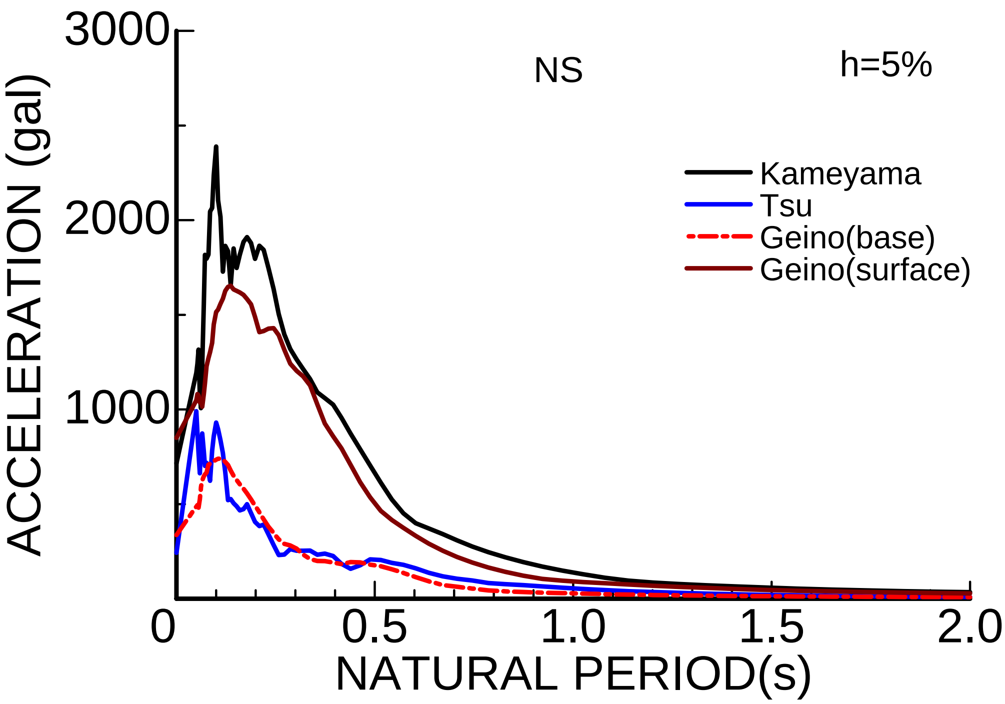


Figure 5.7: Acceleration response spectra for NS component

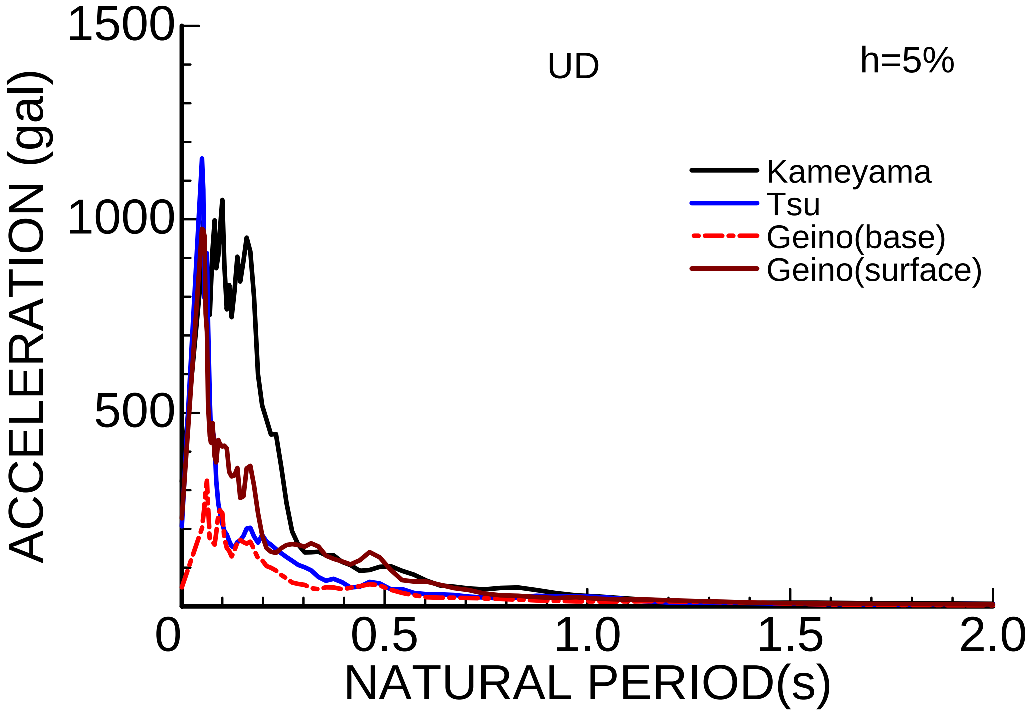


Figure 5.8: Acceleration response spectra for UD component

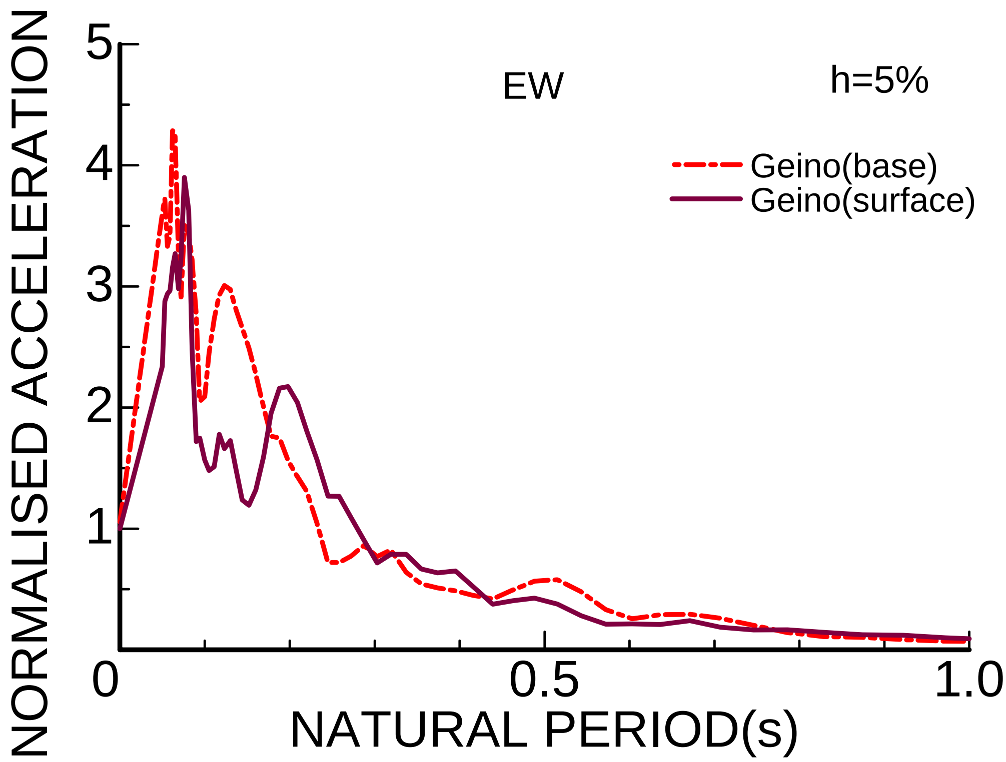


Figure 5.9: Normalized acceleration response spectra for EW component of Geino

6 STRUCTURAL AND GEOTECHNICAL DAMAGE

6.1 Building Damage

6.1.1 Wooden houses

Mainly old wooden houses were damaged. The mode of damage was quite similar to those observed in previous earthquakes.. The damage mechanism fundamentally involved hinging of wooden columns at the base and also at the connections between 1st floor and 2nd floor as a result of large horizontal earthquake forces (Figure 6.1). Many wooden houses suffered from cracking in the walls. The number of damages was highest in Kameyama city (109 households) while it was only 1 household in Geino town, which is the nearest settlement to the epicenter. 7 households were suffered some damage in Suzuka City, which is situated over relatively soft ground.

Figure 6.1: An example of heavily damaged wooden houses (from Kyodo News/AP)

6.1.2 Reinforced Concrete (RC) Buildings

RC buildings in the epicentral region are few and they are used as schools, public offices and a few as residential buildings. The number of stories is mostly 3 to 5. Furthermore, the infill walls of the RC buildings are reinforced concrete shear-walls. Some of public reinforced buildings were retrofitted with steel frame bracing. Almost all RC buildings performed well during the earthquake. However, Mie prefecture reported some light damage in the form of cracking in walls or floors. While there were 5 incidents of light damage to Public RC buildings Kameyama City, it was 7 incidents in the case of public RC buildings in Suzuka City. This may be due to poor ground conditions.

6.1.3 Ceiling Panel Collapses

Large halls for various social events at hotels, conference centers, indoor sport centers and restaurants generally have suspended ceiling panels. The fall of ceiling panels injured two people at the second floor of a drive-in restaurant nearby Seki I.C (Figure 6.2). The similar incidents also occurred in indoor sports halls and swimming pools in Suzuka City. Since the earthquake occurred on Sunday and the schools were closed, there was luckily no incident resulting in injury.

Figure 6.2: Views of collapsed ceiling panels (some pictures from various newspapers)

6.1.4 Temples

There was no damage to temples and their fort-gates (torii) made of granitic columns and beams in this earthquake. However, the masonry lantern monuments were dilapidated at their base or dislocated (Figure 6.3). The height of these lanterns was 210cm with a square base with a side length of 85cm. For example, the main compound of Kameyama Temple was intact although slight traces of dislocations were observed. The temple is about 18 km away from the hypocenter.

Figure 6.3: Dilapidated or dislocated masonry lantern at Kameyama Temple

6.2 Toppling or Dislocation of Cemetery Stones

Cemetery stones with good geometric shapes are commonly used in Japan. These well-shaped stones used to infer the ground motions caused by the earthquakes in the past and they are still utilized to infer the ground motions where strong motion instrumentation is scarce or non-existent. Figure 6.4 shows some pictures of cemetery stone dislocated and rotated in Kameyama City. The distance from the hypocenter to this cemetery was about 19 km. The dimensions of the stones are given in Table 6.1. All stones were rotated in a clock-wise sense. The rotation angle ranges between 20 and 25^{o}. Most of stones were made of diorite or granite and a few of them was made of tuff. Furthermore, their base is saw-cut without any polishing.

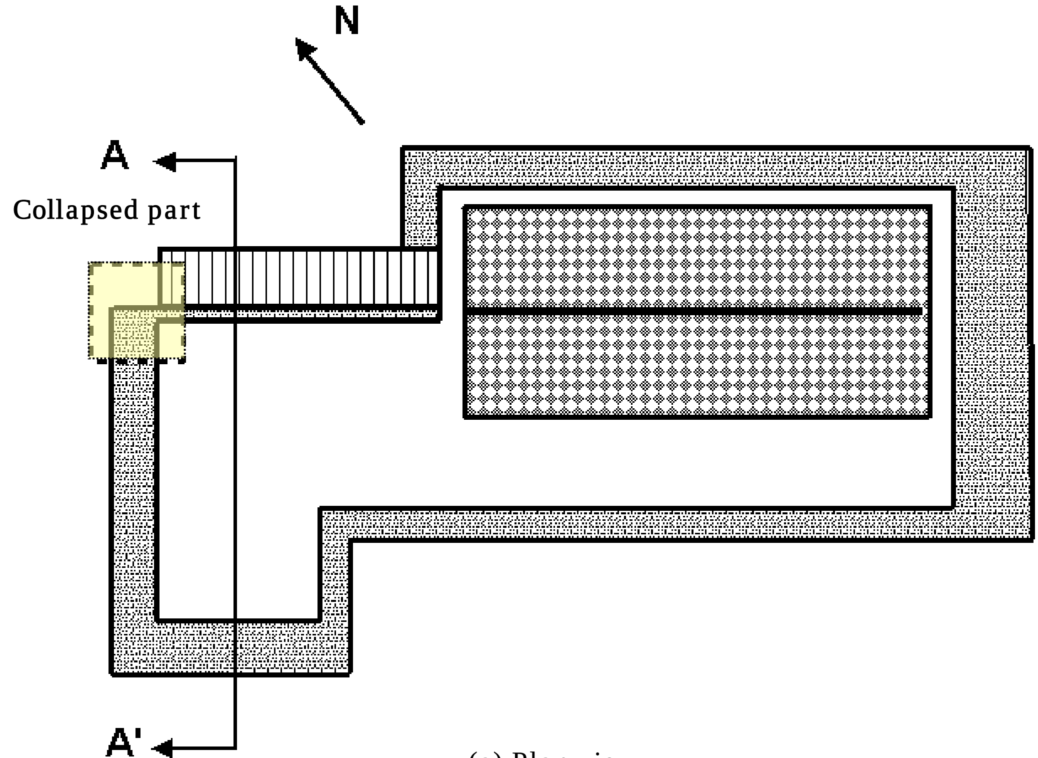
Figure 6.4: Dislocated and rotated cemetery stones

Table 6.1: Dimensions and rotation angle of cemetery stones

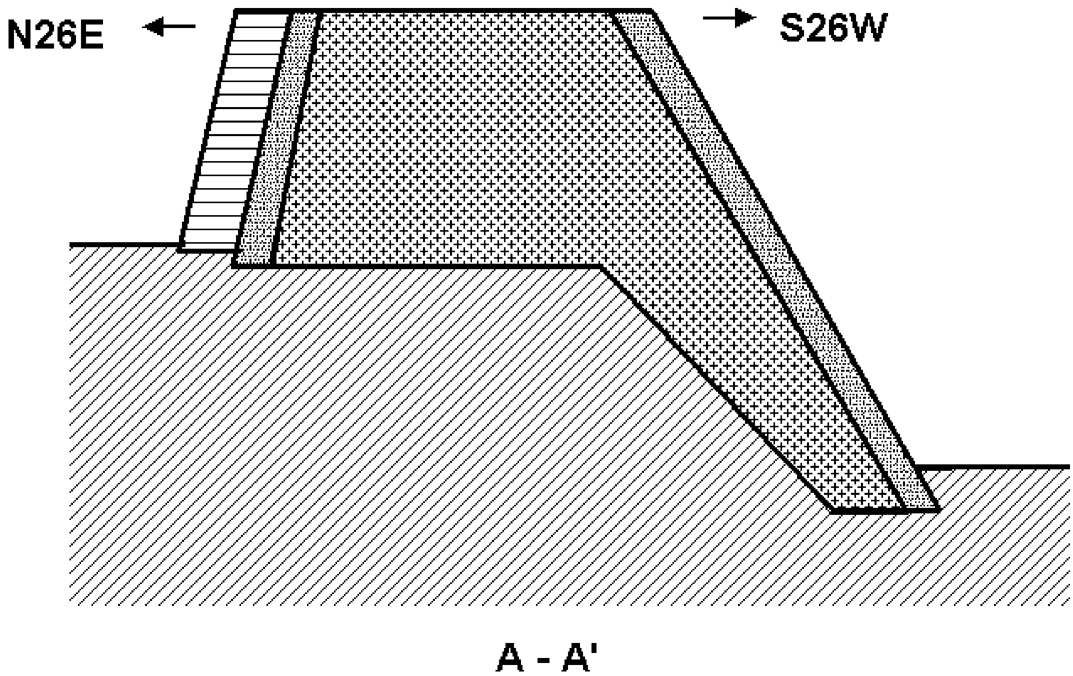
Stone Number	Height (mm)	Width (mm)	Breadth (mm)	Rotation Angle (^{o})
1	400	200	130	20
2	1600	340	340	25
3	640	200	200	

6.3 Kameyama Castle Wall Collapse

Kameyama castle was built in 1590 on a 10m high hill. The inclination of south, east and west walls is about 50^{o} while the inclination of north wall is much steeper and it is about 70-75^{o}. The earthquake caused the collapse of NW corner of the 5m high northern wall, where a masonry stone stair is located. The collapsed section was 2m wide and this section was actually damaged by a typhoon in 1972 and it was repaired. The stone used at corners was 30 cm wide, 30cm high and 55cm long and rock itself is either andesite or diorite. Figure 6.5 shows plan and cross-section illustrations of the castle while Figure 6.6 shows some views of the intact and collapsed sections of the castle.



(a) Plan view



(b) Cross-Section

Figure 6.5: Plan and cross sectional view of Kameyama Castle (not to scale)

(a) View of Castle from south

(b) SW corner

(c) Collapsed NE Corner

(d) Eastward view of NE corner

(e) Southward view of NE corner

Figure 6.6 Views of intact and collapsed section of Kameyama Castle

6.4 Transportation Facilities and Bridges

Land transportation in Mie Prefecture is done through state and prefectural roadways, Meihan National Highway and Ise-wan Expressway (Figure 1.1). Meihan National Highway and Ise-wan Expressway run next to the epicenter area. The visual inspection of the expressway and viaducts indicated there was no damage to the expressway and viaducts (Figure 6.7).

Figure 6.7: Non-damaged Ise-wan Expressway and overpasses

The authors also inspected the both state and prefectural roadways. The visual inspection indicated that there was no damage to roadways and viaducts. However, the ground was slightly settled nearby the foundations of the viaducts of an overpass on Route 3006 in Kameyama city over a railway line (Figure 6.8).

Bridges spanning over Suzuka River in Kameyama City are also inspected. Kashima Bridge is a relatively old cast-in place bridge without any retrofitting did not exhibit any damage (Figure 6.9). However, the southern approach embankment was damaged by the settlement and cracking. The inspection of Kameyama Bridge yielded that there was no damage.

There are three railway lines operated by Japan railways (JR), Kinki Nagoya Railways (Osaka-Nagoya railway line) and Meitetsu Railways in the region. There was no damage to railways caused by the earthquake except the fall of some roof tiles of Seki station. Train service on JR lines and private lines were either suspended until the safety checks done and/or run at slower speeds. 18 minutes delay occurred in Sanyo Shinkansen due to electricity blackout.

Figure 6.8: Overpass on Route 3006 spanning over a railway line in Kameyama City

Figure 6.9: Views of Kashima bridge and its damaged southern approach embankment over Suzuka River in Kameyama City

The large ports in the epicentral area are Tsu, Suzuka and Yokkaichi. The earthquake didi not induced any damage in these ports in-spite of high ground accelerations in Tsu and Suzuka Cities.

6.5 Damage to Kameyama Flood Control Gate

There was a flood control gate along Suzuka River in Kameyama City. The stucture is a top-heavy structure. The close inspection indicated that the embankment next the gate was settled more than 50mm. Furthermore, a concrete panel wall attached to the gate structure was slightly displaced and relative joint opening did occurred (Figure 6.10). Except these slight damages, the flood control gate was structurally intact.

Figure 6.10: Views of slightly damaged flood control gate

6.6 Geotechnical Damage

The earthquake induced some geotechnical damage such as embankment failures and surficial slope failures. The embankment damage was observed along Suzuka River at 10 locations. The damaged embankments were generally more than 4m. The embankment inclination is generally 45^{o}. When one side of the embankment is non-stepped while the other side is stepped, the cracking and settlement occurred on the non-stepped side (Figures 6.11 and 6.12). There was also some cracking of pavement on embankments with a relatively small height due to full saturation conditions next to rice paddies. No liquefaction incident induced by this earthquake was observed or reported.

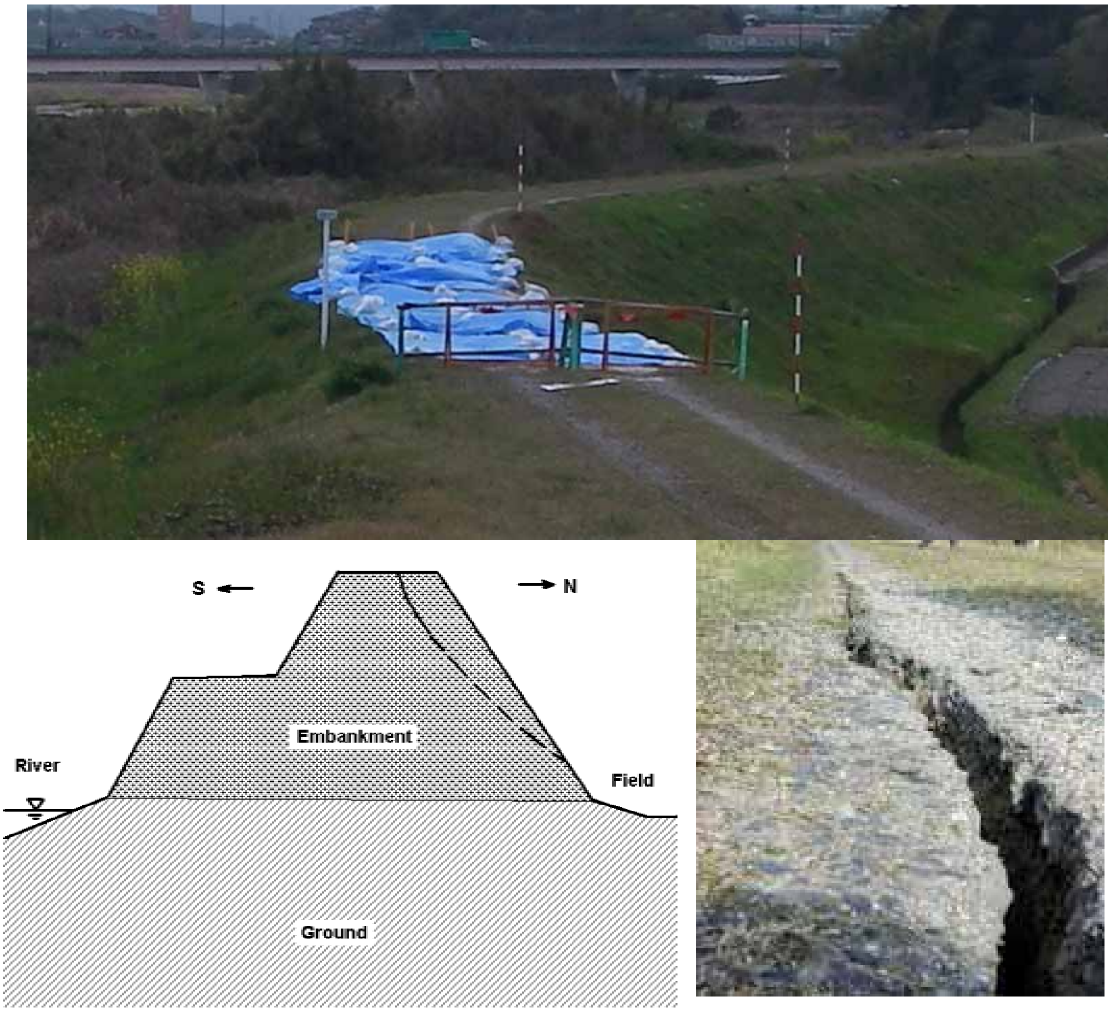


Figure 6.11: Damaged embankment along Suzuka River in Kameyama City

Figure 6.12: Damaged embankment along Suzuka River and rice paddies

6.7 Industrial Facilities

Sharp Company has a large plant in Kameyama City. The distance of the plant to the hypocenter is about 17km. Although the authors did not inspect this plant, the official report from Sharp Company stated that there was no damage in the factory since it was equipped with passive control damping systems. The factory was in full operation after 40 minutes following the safety check.

Figure 6.13: A view of the Kameyama Plant of Sharp Company

6.8 Effect of The Earthquake on Abandoned Lignite Mines and Underground Quarries

The 2003 Miyagi-Hokubu earthquake caused collapse or subsidence of ground above abandoned lignite mines (Aydan and Kawamoto, 2004). It is known that lignite was exploited in Mie prefecture Furthermore, abrasion sand (migaki suna) was quarried from open pits and underground quarries in the Handa district of Tsu City. Since ground motions were quite high both in Kameyama and Tsu Cities and Geino town, it is expected that the earthquake may have some effects on the abandoned underground mines and quarries in view of past experiences (Aydan et al. 2006). A large scale cave-in occurred in Handa district of Tsu City in August 2006 due to the exploitation of abrasion sand from underground quarries after heavy rains (Figure 6.14). The authors first inspected this cave-in site. The visual inspection of the site did not showed any further damage in this site. The ground settlement is monitored by Tsu city civil engineering section and their measurements did not show any effect of the earthquake at this locality.

The authors visited an abandoned underground quarry for abrasion sand in the same district. Adits are generally 250cm wide and 220cm high. The visual inspection of the accessible adits did not displayed any effect of the earthquake on the underground quarries. One reason may be the difference of ground conditions at such localities. Although the authors did not have any chance to visit abandoned lignite mines, there is so far no report of cave-in or subsidence of ground in Tsu City or other cities and towns in the epicentral area.

(a) Cave-in in August 2006

(b) After restoration before earthquake

(c) View of the restored site after the earthquake

Figure 6.14: Views of cave-in site before and after the earthquake

Figure 6.15: Non-damaged adits of an abandoned underground quarry in Tsu City

7 DAMAGE TO LIFELINES

7.1 Electricity

The electric supply to the earthquake stricken area was automatically shutdown following the earthquake. the electricity was restored at 14:00 (1 hour 20 minutes) on the same day following the earthquake. Chubu Electric Power Company provides the electricity supply of the area. Chubu Electric Power Company reported that there was no damage to thermal and hydraulic power plants and dams (Personal Communication).

The electricity distribution system in the region is done through poles and high-voltage transmission lines. None of transmission towers or electricity poles were damaged or toppled during this earthquake (Figure 7.1). Although the poles having transformers mounted particularly suffer more during the earthquakes, none of such poles were not damaged in-spite of high ground motions recorded in this earthquake. The main transmission lines are elevated and supported through 40-50m high steel pylons. Since power plants and the electricity distribution system were intact, the recovery of electricity was quite rapid.

Figure 7.1: Non-damaged pylons near Seki I.C. and non-damaged poles in Kameyama City

7.2 Water Network

The water network was damaged at three locations in Suzuka City. A water pipe was also ruptured in Tsu City. The water distribution systems in both cities were fully restored on the same day.

7.3 Sewage System

The sewage systems in the epicentral area were not damaged according to official reports (Mie Prefecture, 2007)

7.4 Telecommunications

Telecommunication system suffered the same problem due to heavy telecommunication traffic as observed in other earthquakes. However there was no incidence of damage or toppling of relaying towers. Besides the conventional telephone system, the mobile telephone systems of Docomo, Softbank and AU are used widespread. All mobile systems suffered from heavy telecommunication traffic following the earthquake. However, the systems become normal at 14:20 (2 hours) on the same day.

8 CONCLUSIONS

2007 Mie-ken Kameyama earthquake caused limited damage in the epicentral area in-spite of high ground motions induced by this relatively small magnitude earthquake. The main characteristics of this earthquake can be summarized as follows:

1) The faulting was of thrust type and it was an intra-plate earthquake. The earthquake was associated with Mukumoto sub-segment of Nunobiki-sanchi-toen fault zone. Since the hypocenter depth was 16 km and the size of rupture area was small, no surface ground ruptures were observed. Since un-ruptured parts still remain, it has a high potential for future earthquakes in this region.
2) High ground accelerations with pronounced directivity effects did occur although the magnitude of earthquake was relatively small. Due to close proximity of the epicenter, the shaking effects become more pronounced. Available attenuation relations could not estimate the attenuation of ground motions such as maximum ground acceleration and maximum ground velocity.
3) Ground liquefaction was not observed in the epicentral region.
4) Some embankment failures took place along Suzuka River and its branches.
5) Building damage was generally limited to roof tile files and some cracking in the walls and floors. The fall of suspended roof ceiling panels in large halls indicated the potential danger to the safety of occupants, which may be a great problem in future large earthquakes.
6) High ground shaking induced by this earthquake did not cause any structural damage to RC buildings, bridges, roads, highways, railways and expressways.
7) A part of dry masonry walls of Kameyama Castle collapsed. This collapsed castle wall deserves further studies in relation to clarify the causes of the collapse of masonry castle walls in Japan.
8) High ground motions did not have any distinguishable effect on abandoned lignite mines and underground quarries for abrasion sands.

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