BULLETIN OF EARTHQUAKE RESISTANT STRUCTURE RESEARCH CENTER

NO. 32

MARCH 1999

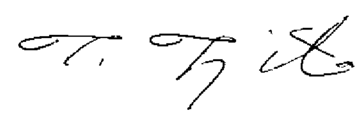
Contents

INSTITUTE OF INDUSTRIAL SCIENCE
UNIVERSITY OF TOKYO

FOREWARD

Japan is the country where seismic isolation is most widely used for civil engineering structures in the world. Particularly, after the Hanshin-Awaji Earthquake of 17 January, 1995 in which effectiveness of the seismic isolation was demonstrated, base-isolated buildings and bridges became more popular. I feel proud that I could contribute to this progress of the seismic isolation as one of the pioneers in research and development of seismic isolation rubber bearings in Japan.

After the earthquake, the seismic isolation has begun to be applied to tall buildings of about 100 m heights, and the rubber bearings have begun to be installed in not only the bases of the buildings but also the intermediate stories of them Furthermore, non-rubber type seismic isolation systems using mechanical bearings such as ball bearings, roller bearings and sliding bearings have begun to be used for wooden houses. Thus the seismic isolation technology is being diversified in applications and devices used.



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Report of the Damage caused by the Mid-North Iwate Earthquake of September 3, 1998

by

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1. INTRODUCTION

An intense earthquake shook northwestern area of Iwate prefecture at 16:58, September 3, 1998, injuring 10 people. An intensity 6-weak on the Japan-Meteorological Agency (JMA) scale of 7 was registered in Shizukuishi (**Fig. 1**), the one of two biggest shakes exceeding 6 we have had in Japan since the latest revision of the JMA scale in 1996. The hypocenter of the earthquake (39.8N, 140.9E, focal depth = 10 km, origin time 16:58, JMA) was located about 20 km north-west of Morioka city. The magnitude of the main shock was 6.1 on JMA scale.

The focal depth of this earthquake was quite shallow enough for one of the activated faults to appear across a paddy field, the fact is quite unusual for earthquakes of this magnitude. Aqueducts, drains and a tunnel crossing this fault reaching the ground surface were thus inevitably dislocated and crumbled.

The authors investigated the damaged area (Sept. 5-7 and Sept. 9-11) in Shizukuishi (**Fig. 2**). Within the limited time, they made every effort to find the damages caused by largely deformed soils. Their findings are hereby discussed being based on the observed records.

2. STRONG GROUND MOTION

Shizukuishi is located in the middle of the Shizukuishi Basin surrounded by peaks of northern Oou mountains and Mt. Iwate, mostly volcanoes rising to elevations of more than 1,000 meters. The volcanoes were quite active during the Quaternary Period, and this area has been covered deep with their products. Rivers from these mountains have carried over centuries volcanic ashes and other suspended matters in their waters, and have formed the basin[1].

The area was on strict guard against a possible eruption of Mt. Iwate, because frequent volcanism-related tremors had been observed for a month. Though this symptom did not lead to any actual eruption after all, JMA had taken a quick action of spreading a dense observation network over the area. The earthquake that followed this symptom was, thus, eventually recorded by these seismometers. After this earthquake, it was first suspected that the earthquake might have some link with the volcanic activity. But it was evidenced later by an actual fault, which appeared on the ground surface, that the earthquake was caused by the dip-slip movement of this fault

Figs 3(a)-(c) and **Figs. 3(d)-(f)** show the recorded strong ground motions at Amihari spa and the municipal office of Shizukuishi town, respectively. Peak acceleration of 714 cm/s^2 was reached at Amihari spa about 3 km north-east of the epicenter, whereas the peak acceleration reached at Segata in Shizukuishi town, 10-15 km south of the epicenter, was 68 cm/s^2. This remarkable attenuation is seemingly consistent with the fact that no serious damage was reportedly found in downtown Shizukuishi.

3. DAMAGE TO GRAVES

Even though the seismometers densely arranged around Mt. Iwate allowed the intense ground motions to be recorded, much more information would be necessary for discussing the damage within a small limited zone caused by this shallow earthquake. Damage to graves was thus investigated at three graveyards at Ueno, Nishine and Nagayama in Shizukuishi.

These graveyards are all situated on the basin, about 7-10 km south of the epicenter. Slight damage to graves was found in this investigation; some minor toppling of gravestones and lantern and/or rotation of pedestal stone assemblages. From aspect ratios of the toppled or rocked gravestones, the possible maximum acceleration does not seem to have reached 400 cm/s^2 in these graveyards Scratches left on pedestal stones also provide useful pieces of information. Assuming that the frictional coefficient between gravestones is 0.5, the peak velocity in Nishine graveyard might have exceeded 280 cm/s.

(1) *Ueno graveyard*

This graveyard is located 10 km south-east of the epicenter, a small grassy hill surrounded by paddy fields. Total 104 graves covering up the hill face south. Among them, one masonry lantern was toppled, and scratches on five pedestal stone assemblages evidenced the rotating rocking and/or sliding movements of pillar stones supported by them (**Table 1**).

(2) *Nishine graveyard*

Nishine graveyard, about 7 km away from the epicenter, spreads over a wet soil deposit with a small swamp on its south. Among 255 graves facing south, 10 gravestones were found dislocated on their pedestals (**Table 2**).

(3) *Nagayama graveyard*

This graveyard, about 8 km south of the epicenter, is situated on a terraced hillside. Among 207 graves facing south or west, 11 gravestones were found rotated or slipped on their pedestals

(Table 3).

4. DAMAGE CAUSED BY THE FAULT

The activated fault planes were found roughly lined up at random intervals near a scarp formed along the Kakkonda glen. One of the faults which appeared in a paddy field was a straight raised mark extending a couple of hundred meters' distance, clearly showing a compressional dip-slip movement of this fault (**Photo 1**) The averaged upward movement of the soil caused by the reverse faulting reached or exceeded ten centimeters in this paddy field. This movement of the fault caused concrete walls covering up a drain to be cracked and dislocated (**Photo 2**). A fault plane branching off the lined major fault planes crossed the Kakkonda river and buckled the pavement of the prefectural route 100 (**Photo 3**).

These faults observed on the ground surface form a part of Shizukuishi-Seien fault belt whose presence has been suggested by many geologists[1] Continual movement of this fault belt has formed the scarp along the Kakkonda river, and by virtue of this configuration, some hydroelectric power stations were constructed along the Kakkonda river. A concrete outlet tunnel of the second Kakkonda hydroelectric power station runs across one of the fault planes that appeared as the straight rising mark in the paddy field mentioned already. It was, thus, inevitable that the circular tunnel wall was cracked up into several large pieces and smaller fragments (**Photo 4**). Some pieces of the cracked wall were pushed in the tunnel reducing the tunnel's cross-section[2]. One cracked piece of about 2 m high and 2 m wide completely fell down onto the invert allowing the soil with big boulders (30 ~ 50 cm) to be squeezed into the tunnel. An open aqueduct leading to this hydroelectric power station was also damaged (**Photo 5**). Diagonal cracks found on its concrete walls are suggestive that the aqueduct might have experienced compressional force in its axial direction No clear evidence of the motions of the surrounding soil was found there. It is, however, quite probable that there were some fault planes that reached the ground surface causing this damage, and yet could not be clearly seen.

5. EARTHQUAKE-INDUCED LANDSLIDES

Traffic on the prefectural route 100, called Nishiyama-Obonai Line, was suspended by a number of earthquake-induced landslides along the Kakkonda glen, causing about 100 people at Takinoue Spa to be held up for a night. Total 55 landslides took place between Takinoue and Genbu spas. Locations of major landslides are shown in **Fig. 4** along with a pair of photographs of a typical slide (**Photo 6**). When the photographs are viewed side by side through a stereoscope, they are perceived as a single image in three-dimensional space. When used to focusing both eyes on these photographs, these separate perceptions of the two eyes can be combined and interpreted in terms of depth even without a stereoscope. On the visualized 3D failure surface, one would see the mass of tightly-joined basalt rocks half embedded in surface soil. **Photo 7**, showing a basalt rock layer sandwiched in between loamy soils, suggests that molten rock forced its way into the soft volcanic soil deposit. The soft soils might have been responsible for amplifying the seismic motion to such extent that the soils with basalt rocks were shaken off the slopes.

Needless to say, slope failures and precipitation closely correlate to each other. **Fig. 5** shows the precipitation record at Kakkonda meteorological observatory, which is very close to the dislocated fault planes. It is clear from this figure that a spell of 6 days rain was followed by the earthquake of Sept. 3. **Fig. 6** shows the number of tremors observed at the Mt. Iwate observation station of JMA. A great number of volcanism-related tremors preceded the earthquake of Sept. 3, and thus might have been another cause of making the loamy soils loose

6. SUMMARY

The shallow focal depth of this earthquake seems to have featured the damage to slopes and embedded structures The activated fault planes were found roughly lined up at random intervals on the ground surface near a scarp formed along the Kakkonda glen; the fact is quite unusual for earthquakes of this magnitude of 6.1. Since the fault planes reached the ground surface, aqueducts, drains and a tunnel crossing this fault were inevitably damaged The authors investigated the damaged area (Sept. 5-7 and Sept. 9-11) in Shizukuishi. They made every effort to find the damages mostly caused by largely deformed soils. The report is just a collection of the findings obtained through the investigation, to be sure, but the authors sincerely wish that the report will serve as a subject for further discussions.

ACKNOWLEDGMENT

The authors wish to express their sincere thanks and appreciation to Mr. Masamitsu AONUMA, Division of Public Works, Tohoku Electric Power Company and Mr. Yoshio MIBUTA, Division of Public Works, Ryowa Kensetsu Co., Ltd., who have kindly provided the important pieces of information about the damage to the outlet tunnel of the second Kakkonda hydroelectric power station. The authors also would like to thank Mr. Koichi ODAJIMA, Division of Public Works, Iwate Prefecture, for providing us with some significant information about the locations of landslides. Thanks are due to the Japan Meteorological Agency for providing us with the precipitation record at the Kakkonda meteorological observatory and the tremor data at the Mt. Iwate observation station.

REFERENCES

1) Oide, K., Nakagawa, H and Kanisawa, S.: Regional Geology of Japan, Part 2 TOHOKU, Kyoritsu Shuppan, 1989.

2) Tohoku Electric Power Company: Report of the Damage to the Facilities of the Second Kakkonda Hydroelectric Power Station due to the Mt. Iwate south-west earthquake of Sept.3, 1998.

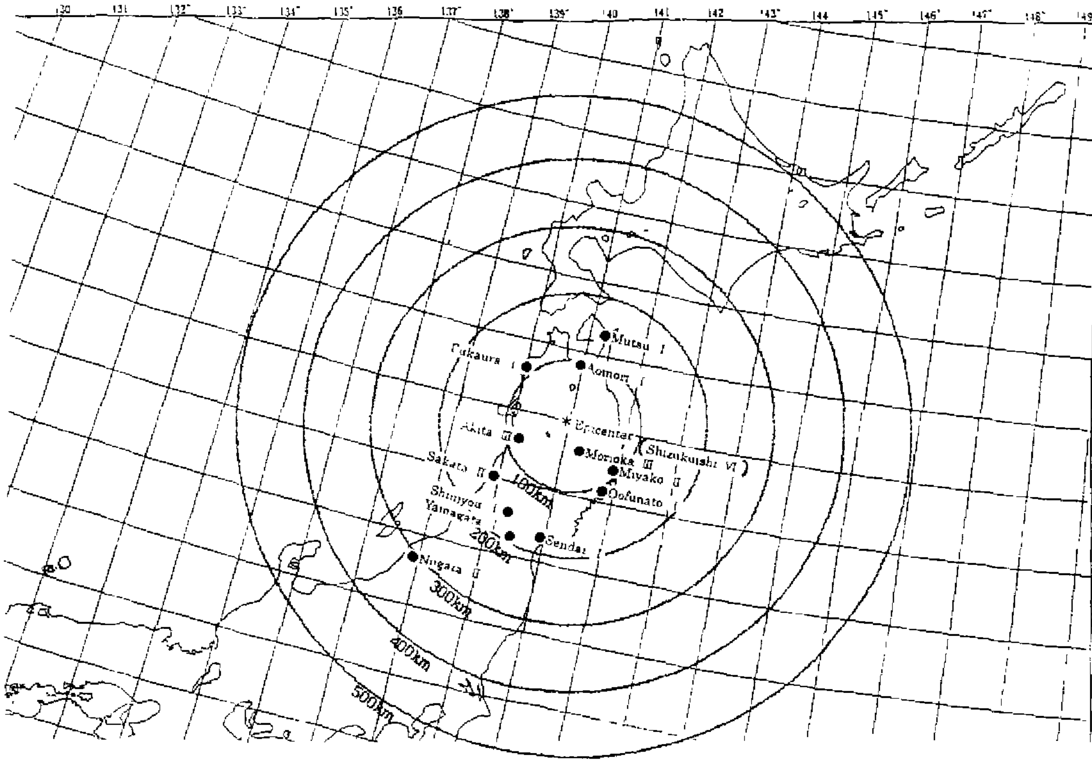


Fig 1 Epicenter and JMA intensity distribution

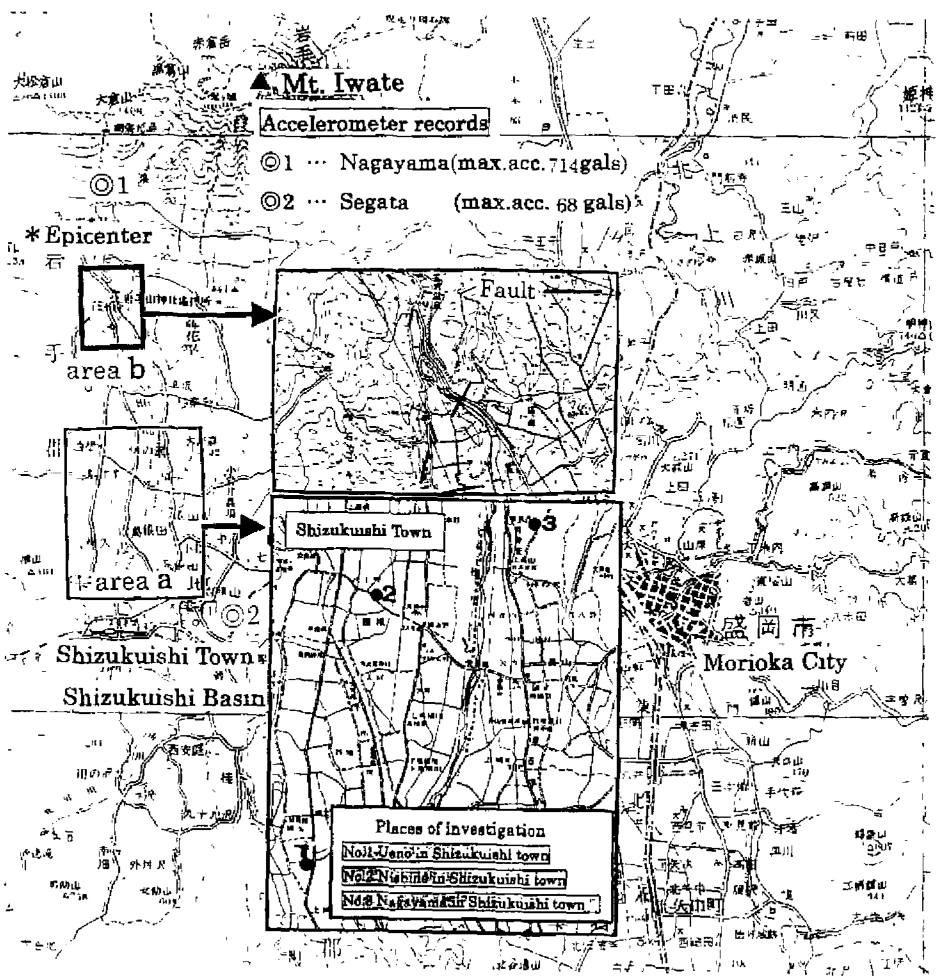
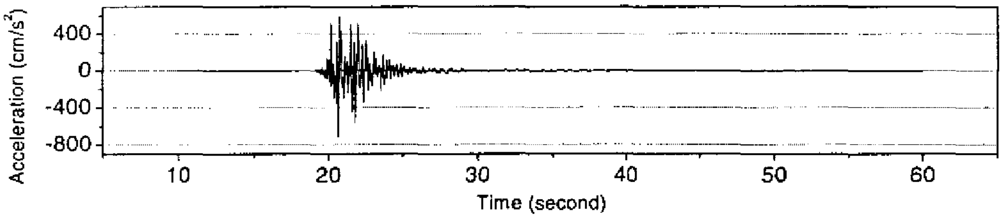
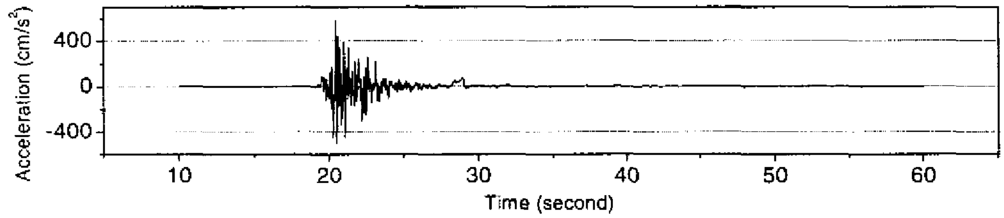


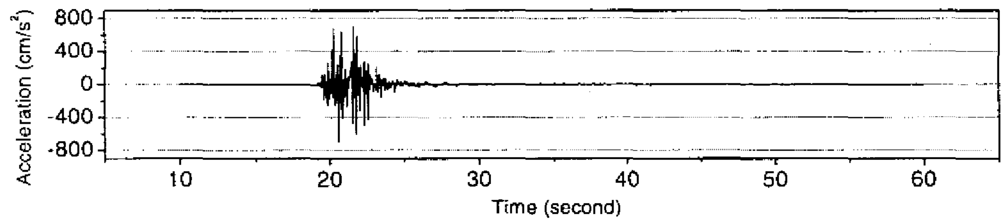
Fig 2 Investigated area



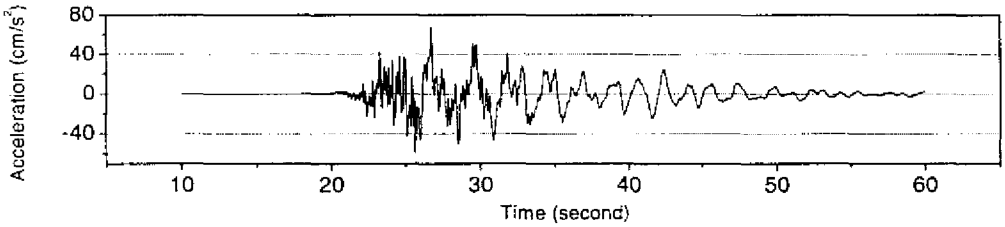
(a) N-S component (Nagayama)



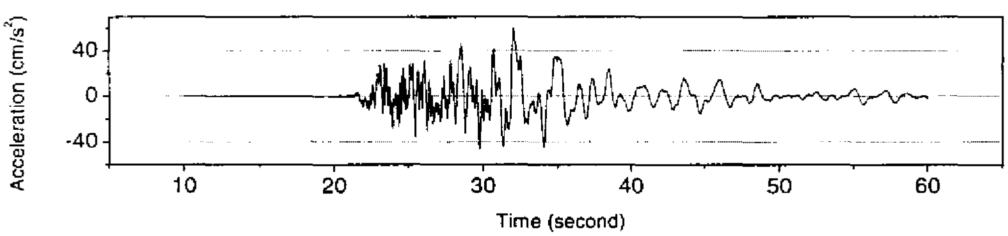
(b) E-W component (Nagayama)



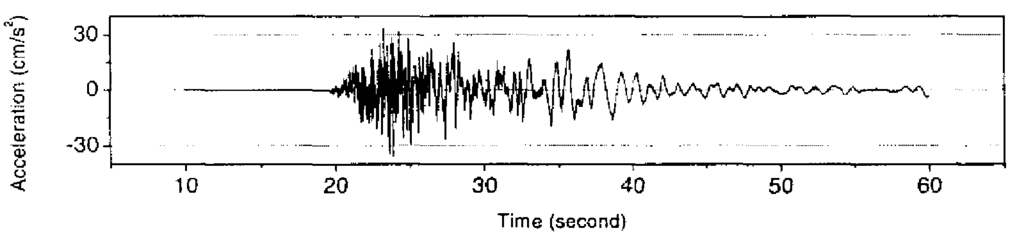
(c) Vertical component (Nagayama)



(d) N-S component (Segata)



(e) E-W component (Segata)



(f) Vertical component (Segata)

Fig.3 Acceleration-time histories in Shizukuishi (16:58, Sept. 3, 1998)

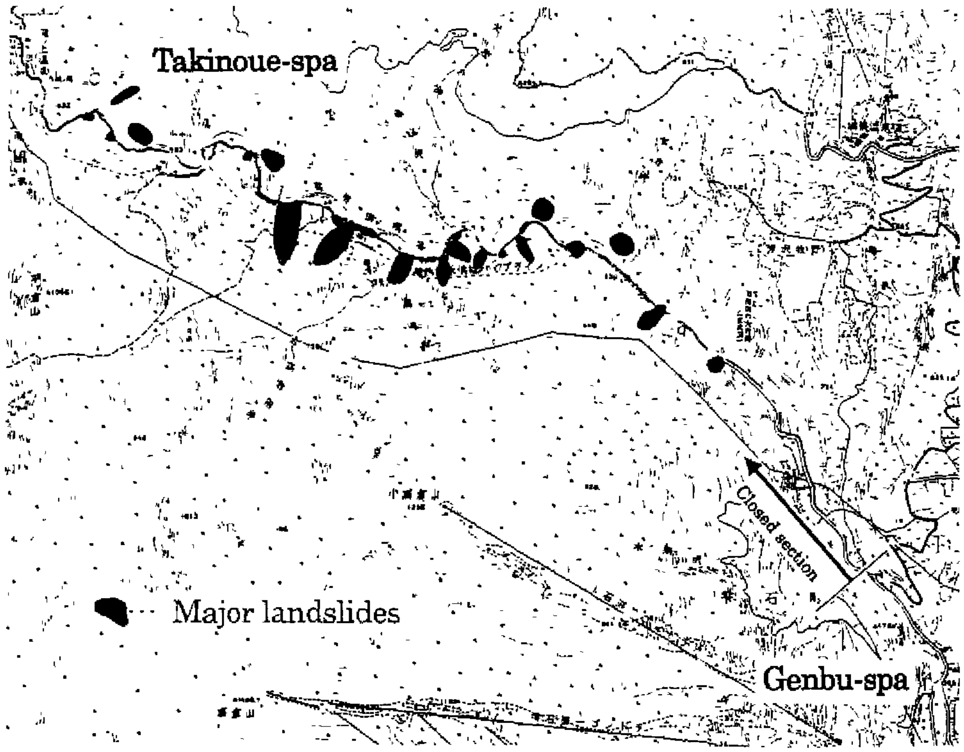


Fig.4 Location of major landslides

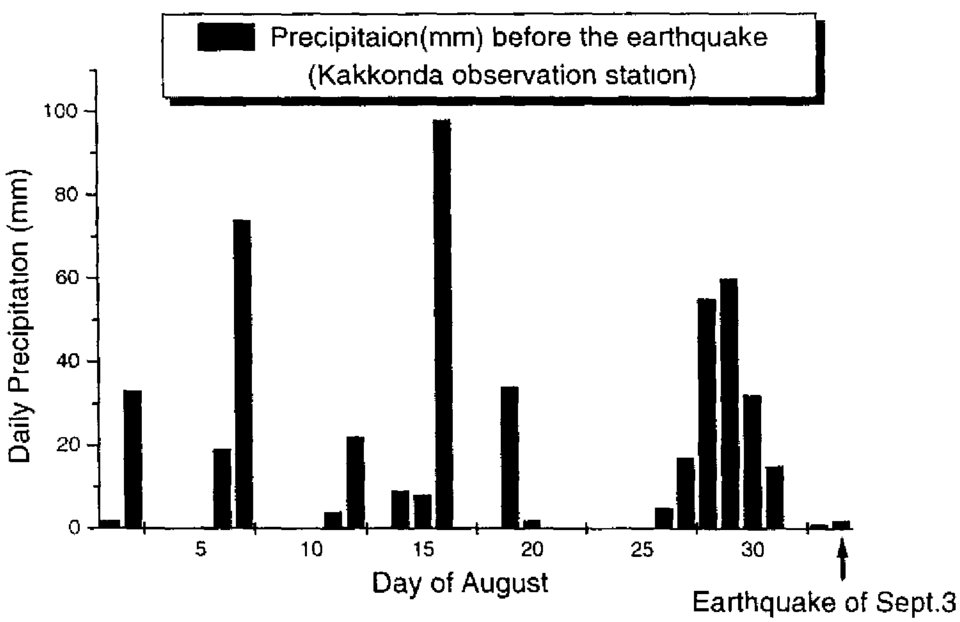


Fig.5 Precipitation record (Kakkonda meteorological observatory)

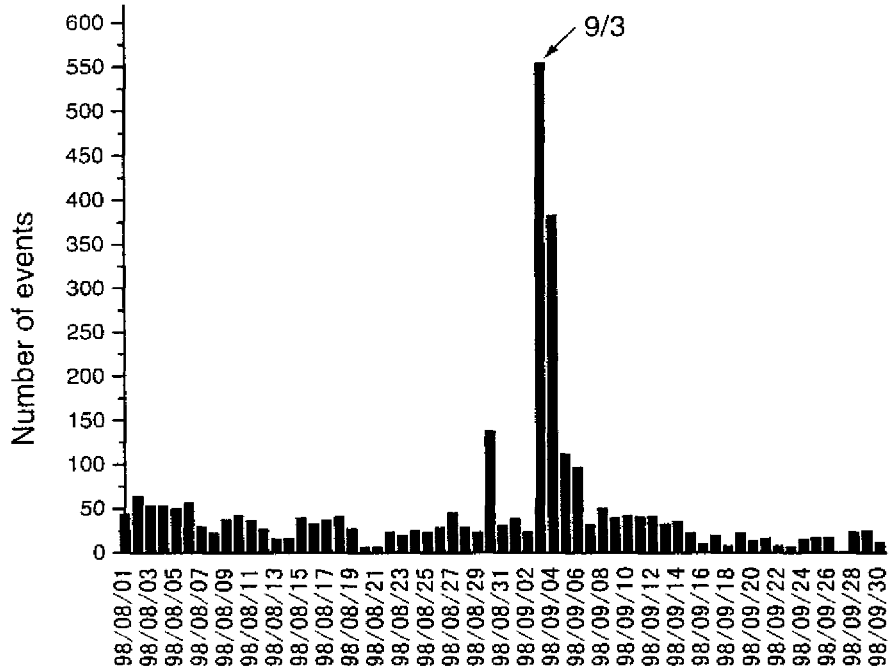


Fig.6 Number of tremors observed (Matsukawa observation station, Tohoku University) (provided by Japan Meteorological Agency)

Table1 Damage to the gravestones (Ueno graveyard)

Grave-stone No.	Toppled/ Not toppled	Sliding distance(mm)	Direction of rotation Anti-Clockwise /Clockwise	Angle of rotation (degree)	Aspect ratio (Width /Height)
1	T	0	0	0	0.26
2	N	0	A	0.17	0.42
3	N	35(south)	A	8.73	0 41
4	N	45(north)	0	0	0.37
5	N	0	A	3.06	0.41

Table2 Damage to the gravestones (Nishine graveyard)

Grave-stone No.	Toppled / Not toppled	Sliding distance(mm)	Direction of rotation Anti-Clockwise /Clockwise	Angle of rotation (degree)	Aspect ratio (Width / Height)
1	N	0	C	3.94	0.33
2	N	0	C	1.02	0.33
3	N	5(north)	A	2.86	0.41
4	N	60(south)	C	14.93	0.40
5	N	80(south)	C	6.98	0.38
6	N	5(north)	C	0.92	0.40
7	N	0	C	4.84	0.39
8	N	0	C	3.94	0.41
9	N	0	C	3.63	0.41
10	N	10(north)	A	1.84	0.38

Table3 Damage to the gravestones (Nagayama graveyard)

Grave-stone No	Toppled / Not toppled	Sliding distance(mm)	Direction of rotation Anti-Clockwise / Clockwise	Angle of rotation (degree)	Aspect ratio (Width / Height)
1	N	2(south)	A	0.38	0.41
2	N	0	A	11.30	0.40
3	N	50(east)	0	0.92	0.40
4	N	0	A	8.09	0.40
5	N	60(east)	A	12.99	0.40
6	N	5(west)	C	2.96	0.41
7	N	0	A	3.63	0.41
8	N	0	A	4.86	0.39
9	N	0	C	3.52	0.41
10	N	0	A	7.43	0.39
11	N	30(north)	C	5.35	0.44

Photo 1 Fault that appeared in paddy field

Photo 2 Damaged concrete wall of drain