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MAXIMUM ACCELERATION OF EARTHQUAKE MOTION AT ROCKY GROUND

by

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1. INTRODUCTION

For earthquake-resistant design of structures with their foundations on rocky ground such as dams, bridges, and nuclear power plants, and subsurface facilities such as underground pouwerhouses and tunnels constructed in rock, it is of funda-
powerhouses and tunnels constructed in rock, it is of founda-
at rocky ground. Also, the earthquake motion at rocky ground as input to the surface layer is of importance in analyzing and predicting the behaviors of ordinary ground during earthquake.

On the other hand, according to the results of earthquake damage investigations, it is known that the types and scales of damage to structures differ greatly according to rocky ground, diluvial ground, and alluvial ground, and it is clear that the earthquake motion of rocky ground is fundamental to a rational examination of earthquake resistances of structures. However, most seismometers are installed at alluvial ground, diluvial ground, and in buildings, and there are few cases in which they are installed on rocky ground with the purpose of earthquake observation.

Because of such a situation, the method of determining earthquake motion on the earthquake basement founded on dynamic characteristics of the surface-layer ground according to earthquake records taken at the ground surface has been adopted, but needless to say, the most desirable method is to directly examine the earthquake motion records of rocky ground.

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Having started from 1962, the authors are now carrying on earthquake motion observations of rocky ground at four locations, and the results of the observations have been successively published. With earthquakes of magnitude 7 class or greater, which have occurred in recent years, it has become possible to obtain earthquake records on or inside rocky ground according to installation of strong motion accelerometers at damsites.

The properties of distance attenuation of maximum acceleration of earthquake motion in rocky ground obtained in earthquake observations will be described here. In this connection, there is the method of considering the observation values in the same earthquake (hereafter called fixed earthquake observation) and the method of considering numerous earthquake observation values obtained at the same location (hereafter called fixed measuring point observation). Each has its features in connection with various factors such as region, earthquake mechanism, etc. Here, the records of earthquake observations carried out by the authors at two measuring points for many years will first be examined. Figure 1 shows the two measuring points introduced here and the locations of the earthquakes considered.

2. FIXED MEASURING POINT OBSERVATIONS

2.1 Earthquake Observations at Kinugawa Automatic Control Station

This observation point is located at a rocky area in the mountains of the Kanto Region approximately 150 km north of Tokyo. The geology at this site is green tuff of the Tertiary to Quaternary periods, and according to data from bore holes, the geology is as shown in Table 1. There are three layers of clayed green tuff 10 to 30 cm in thickness near the surface, while weathered green tuff may be seen at several places. It is known that the existence of these soft strata affects the properties of earthquake motion near the surface. According to the results of velocity logging, the propagation velocities of P waves are mostly in the range of about 3.5 to 3.9 km/sec, and when propagation velocity is estimated from earthquake waveforms at the surface layer portion, it will be 1.6 to 1.7 km for S waves.

Figure 2 shows the arrangement of the seismometers. Accelerometers No. 1 to No. 5 are installed in the vertical shaft leading to the underground power station with displacement meters also placed at the No. 1 and No. 5 locations. Measurements are horizontal, in the E-W direction. The accelerometers are moving-coil types of natural frequency of 3 Hz with overall characteristics that of magnification constant from 1 to 25 Hz.

In the present report, the records of the No. 4 and No. 5 accelerometers out of No. 1 to No. 5 will be focused on. The reason is that with these acceleration waveforms it is recog-

Table 2 Maximum Horizontal Accelerations of Earthquakes at Vertical Shaft of Kinugawa A.C.S.

No.	Date			Magnitude	Depth (Km)	Epicentral distance (Km)	Hypocentral distance (Km)	Acceleration (gal)	note
	Year	Month	Day						
3	1963	12	24	5.2	40	86		5.0	
4	1964	2	5	6.0	40	131		2.4	
6	1964	3	25	5.3	40	133		1.9	
7	1964	3	25	5.0	60	170	180	1.3	
22	1964	5	30	6.2	40	150		1.9	
25	1964	6	7	5.4	40	135		1.1	
26	1964	6	16	7.5	40	176		5.41	
38	1964	6	22	5.1	60	69	91	5.9	
44	1964	11	3	5.2	100	238	258	0.7	
48	1964	11	14	5.1	40	92	100	6.1	
49	1964	11	15	5.1	60	79	99	10.5	
57	1965	1	24	5.2	60	127	141	3.7	
58	1965	1	27	5.6	80	91	121	5.1	
65	1965	4	6	5.5	60	89	107	13.8	
67	1965	4	20	6.1	20	250		0.8	
73	1965	5	24	5.2	20	204		0.6	
74	1965	5	31	5.5	120	112	164	5.4	
79	1965	9	11	5.5	60	155	166	1.0	
84	1965	9	18	6.7	40	170		5.85	
87	1965	11	14	5.6	40	142		2.1	
93	1966	1	20	5.3	0	183		0.9	
94	1966	1	24	5.0	60	178	188	0.5	
96	1966	3	14	5.0	40	125		2.2	
97	1966	4	3	5.8	20	177		3.9	
100	1966	5	17	5.1	40	152		0.4	
111	1966	10	28	5.0	60	130	143	1.1	
115	1967	1	17	6.3	30	264		0.9	
123	1967	9	15	5.6	40	175		0.9	
124	1967	9	19	5.0	40	200		0.6	
125	1967	9	20	5.2	80	110	136	4.7	
127	1967	11	4	5.8	50	204	211	1.4	
129	1967	11	10	5.3	80	155	174	1.4	
131	1967	11	19	6.0	50	145	153	3.8	
135	1968	2	26	5.4	50	190	196	0.8	
138	1968	3	7	5.1	50	152	160	1.0	
143	1968	8	8	5.6	10	175		1.4	
146	1968	10	8	5.3	70	148	164	2.7	
150	1969	4	9	5.6	100	10	100	3.0	
152	1969	5	13	5.2	50	95	107	7.9	
155	1969	6	23	5.2	50	185	192	1.5	
156	1969	7	23	5.5	40	190		1.4	
157	1969	9	9	6.6	0	254		0.5	
159	1971	2	26	5.5	0	128		0.8	
160	1971	3	22	5.4	10	220		0.4	
161	1971	4	5	6.0	50	280	284	0.4	
164	1971	6	13	5.3	40	130	136	1.0	
167	1971	7	23	5.3	10	156		0.9	
168	1971	7	27	5.1	80	105	132	4.0	
172	1971	9	8	5.5	40	172		0.5	
174	1971	10	11	5.2	40	130		0.5	

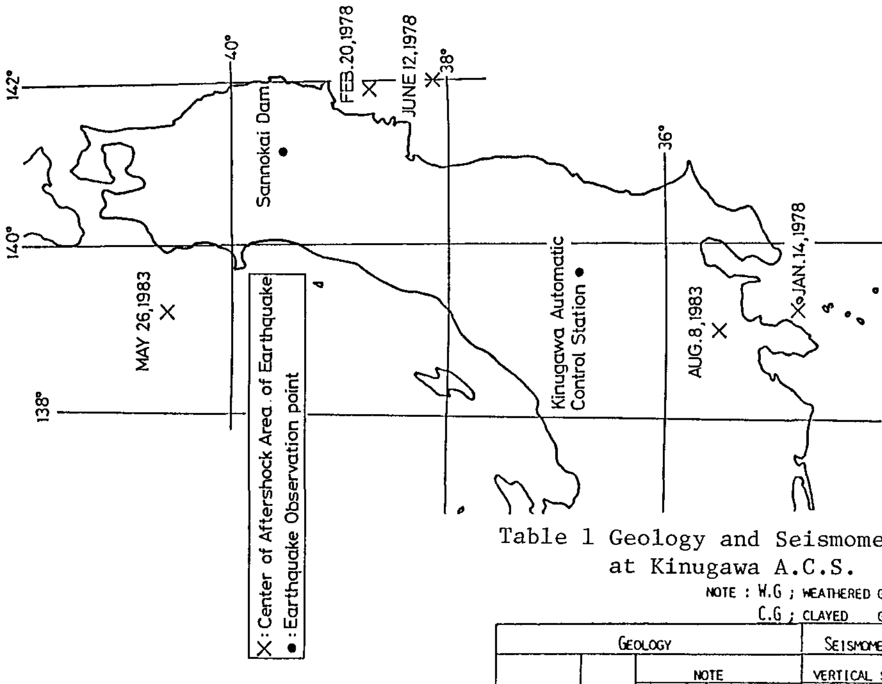
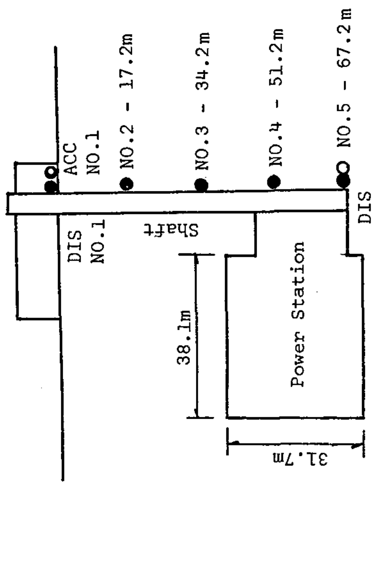


Fig. 1 Earthquake Observation Point and Center of Aftersback Area Concerned.



O Displacement Seismograph
● Acceleration Seismograph

Fig. 2 Locations of Seismometers at Kinugawa A.C.S.

Table 1 Geology and Seismometers at Kinugawa A.C.S.

NOTE : W.G ; WEATHERED GREEN TUFF
C.G ; CLAYED GREEN TUFF

GEOLOGY				SEISMOMETERS	
GEOLOGY	DEPTH (M)	NOTE DEPTH(M)	NOTE	VERTICAL SHAFT DEPTH(M)	VERTICAL SHAFT SIGN
ALLUVIAL DEPOSITE	0	0		0	ACC.NO.1 DIS.NO.1
COARSE GRAINED GREEN TUFF	7.9	10.90 11.05	W.G		
		11.40 11.60	W.G		
		15.70 16.0	C.G	17.2	ACC.NO.2
		22.15 22.60	W.G		
		36.0 36.2	C.G	34.2	ACC.NO.3
COARSE GRAINED G.T FINE GRAINED G.T SLATY TUFF	42.25	47.0 47.1	C.G	51.2	ACC.NO.4
COARSE GRAINED GREEN TUFF	57.50			67.2	ACC.NO.5 DIS.NO.2

(continued)

No.	Date			Magnitude	Depth (Km)	Epicentral distance (Km)	Hypocentral distance (Km)	Acceleration (gal)	note
	Year	Month	Day						
176	1972	1	4	5.0	40	130		1.0	
186	1972	11	6	5.1	40	85		3.8	
196	1973	5	5	5.3	50	160	168	1.2	
202	1973	6	20	5.0	60	90	108	8.1	
204	1973	7	20	5.9	40	130		2.8	
208	1973	8	24	5.0	110	35	115	3.3	
212	1973	9	30	5.9	50	157	165	2.3	
213	1973	10	1	5.8	60	168	178	1.0	
216	1973	12	22	5.0	70	185	198	0.6	
219	1974	3	3	6.1	60	175	185	2.4	
221	1974	4	4	5.2	90	140	166	0.9	
223	1974	5	5	5.5	40	215		0.8	
224	1974	5	9	6.9	10	260		2.6	
225	1974	7	8	6.3	40	142		5.9	
227	1974	8	4	5.8	50	93	106	29.1	
237	1975	1	21	5.9	30	252			
238	1975	2	8	5.4	60	120	134	3.6	
239	1975	3	11	5.1	130	35	135	7.5	
240	1975	3	30	5.4	70	84	109	7.8	
243	1975	4	12	5.0	50	86	99	6.7	
244	1975	4	18	5.0	50	79	93	9.0	
246	1975	5	4	6.0	30	220		0.6	
255	1975	8	15	5.5	50	130	139	1.0	
264	1976	2	25	5.0	90	130	158	1.6	
265	1976	2	29	5.0	50	117	127	5.9	
272	1976	6	16	5.5	20	160		1.7	
276	1976	10	6	5.9	70	155	170	6.6	
282	1976	12	29	5.8	130	52	140	1.8	
285	1977	4	19	5.1	60	92	110		
286	1977	6	8	5.8	70	253	263	0.5	
291	1978	1	14	7.0	0	230		1.3	
294	1978	2	20	6.7	50	310	314	2.1	
296	1978	3	20	5.5	60	83	102	41.2	
297	1978	4	7	6.1	30	250		1.1	
299	1978	6	12	7.4	40	250		6.5	

(Date; Japan Standard Time)

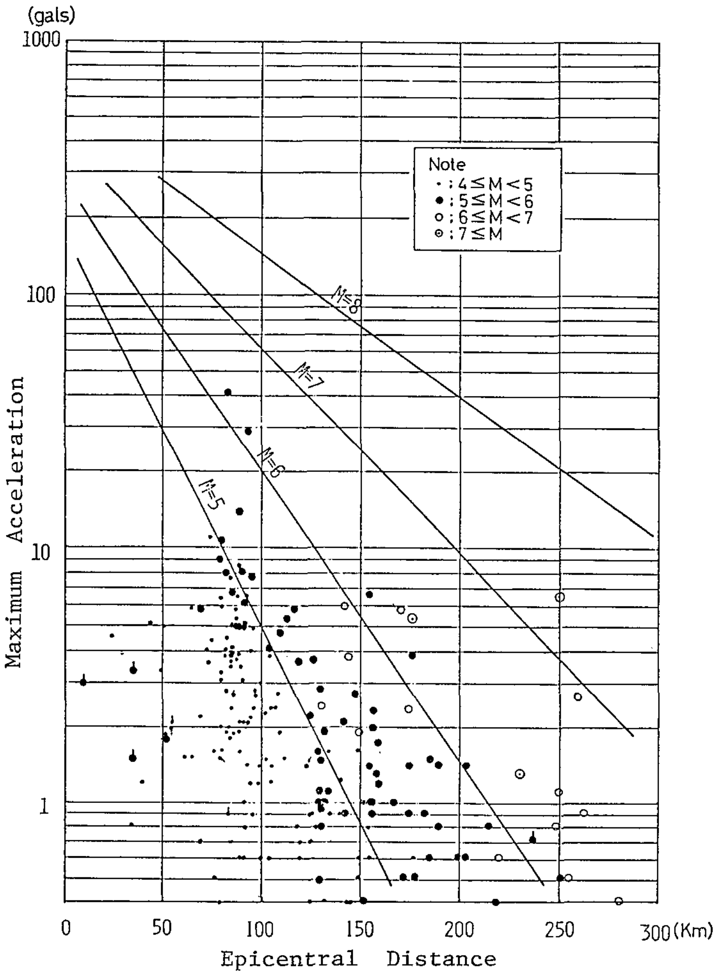


Fig. 3 Maximum Acceleration and Epicentral Distance at Kinugawa A.C.S.

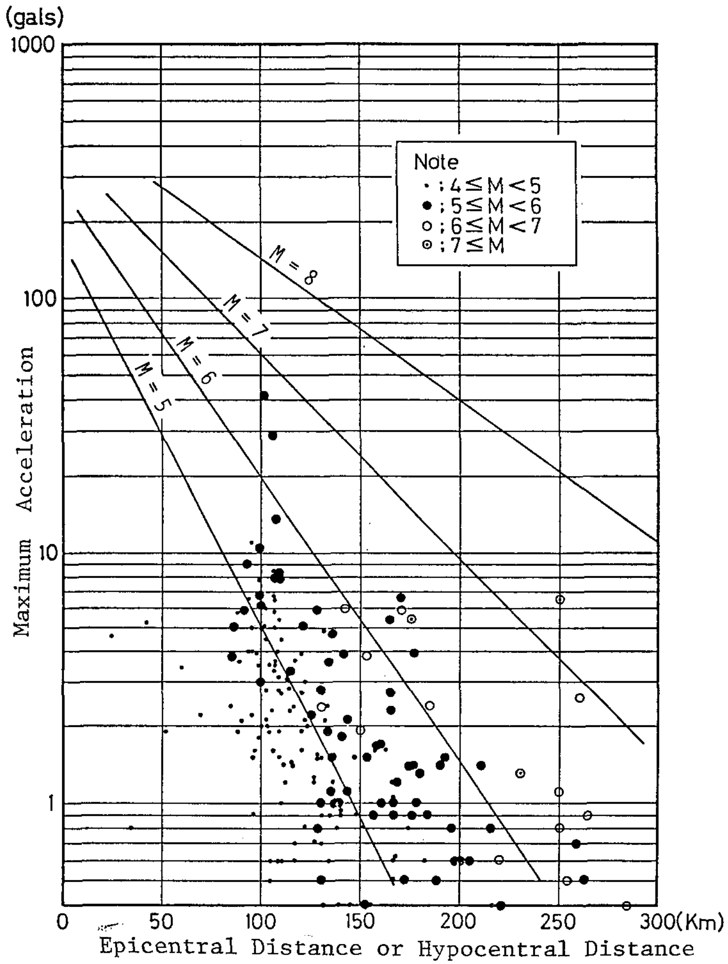


Fig. 4 Maximum Acceleration and Epicentral Distance or Hypocentral Distance if Depth over 40km, at Kinugawa A.C.S.

Table 3 Maximum Horizontal Accelerations of Earthquakes at Sannokai Dam

No.	Date Year	Month	Day	Magnitude	Depth (Km)	Epicentral distance (Km)	Hypocentral distance (Km)	Acceleration (gal)	note
12	1964	5	7	6.9	0	236		3.4	
18	1964	5	8	6.5	0	220		8.8	Niigata Earthq.
29	1964	6	16	7.5	40	204		55.0	
31	1964	7	12	6.0	0	194		5.9	
61	1966	11	19	5.1	40	183		0.7	
64	1967	1	17	6.3	30	173		22.1	
66	1967	1	24	5.7	50	225	230	4.5	
82	1968	2	26	5.4	50	225	230	0.9	1968Tokachi-oki Earthq.
85	1968	4	21	5.8	60	128	141	1.8	
89	1968	5	16	7.9	0	210		65.4	
90	1968	5	16	5.4	10	230		0.7	
91	1968	5	17	6.1	50	240	245	2.4	
92	1968	5	17	5.6	10	250		1.2	
93	1968	5	17	5.2	0	210		1.6	
97	1968	5	17	5.9	0	230		0.6	
98	1968	5	17	6.7	30	205		2.3	
103	1968	5	17	5.7	60	238	245	0.9	
104	1968	5	17	5.7	40	261		0.6	
105	1968	5	18	5.7	20	207		0.7	
106	1968	6	22	6.1	70	259	268	1.1	
108	1968	6	28	5.0	30	143		7.6	
111	1968	7	5	6.4	50	157	165	11.6	
112	1968	7	7	5.1	10	154		1.4	
114	1968	7	12	6.4	40	207		2.9	
115	1968	7	12	5.8	30	203		0.9	
118	1969	10	18	5.8	130	55	141	29.0	
119	1969	10	19	5.0	0	124		2.7	
124	1970	3	23	5.7	150	83	171	1.2	
127	1971	8	2	7.0	60	292	298	12.8	
128	1971	9	23	5.0	50	171	178	2.4	
129	1971	9	24	6.1	40	222		1.6	
135	1972	3	20	6.4	80	165	183	15.6	
138	1972	5	14	5.8	30	235		0.8	
139	1972	5	18	5.4	30	190		1.4	
142	1972	8	20	5.3	20	140		1.4	
144	1972	9	4	5.4	80	230	244	0.9	
146	1972	9	25	5.2	50	143	151	3.2	
147	1972	11	2	5.8	90	267	282	3.1	
149	1973	2	15	5.2	110	70	130	8.8	
152	1973	7	6	5.2	30	153		2.0	
154	1973	11	13	5.5	60	152	163	3.0	
155	1973	11	19	6.4	50	118	128	30.6	
156	1973	11	20	5.5	50	130	139	5.2	
158	1974	3	7	5.1	40	137		3.3	
161	1974	8	11	5.0	40	135		3.3	
162	1974	9	4	5.6	40	103		12.4	
165	1974	10	10	6.2	20	245		4.9	
171	1978	2	20	6.7	50	115	125	56.0	

(Date: Japan Standard Time)

nized that the effects of clay layers and weathered layers near the surface may be considered to be almost nil.

Table 2 lists earthquakes with epicentral distances not more than 300 km and maximum accelerations at No. 4 or No. 5 not less than 0.4 gal from among earthquakes of M = 5 and greater recorded during the 15-year period of December 1963 to June 1978. The particulars of the earthquakes are those enounced by the Japan Meteorological Agency. It must be noted, however, that not all earthquakes meeting the above-mentioned conditions have been included since there was trouble with the seismometers at times.

Figure 3 shows the relation between epicentral distance and maximum acceleration. It can be seen that there is a fairly distinct boundary between M = 5 and M = 6. The stemmed dots, large and small, in the figure are for focal depths of 100 km or more, and maximum accelerations in cases of deep hypocenters are fairly small compared with cases of shallow hypocenters. Therefore, in cases of focal depths exceeding 40 km, hypocentral distances were taken and similarly shown, and the result is Fig. 4. Compared with Fig. 3, a number of points which had had epicentral distances within 150 km have shifted to the right, and at the same time, points which had been to the left as exceptions shifted to the right, and it may be seen that grouping according to magnitude had become even better.

The straight lines in the figure, as described later, were obtained from an empirical formula for distance attenuation of maximum acceleration established by the authors.

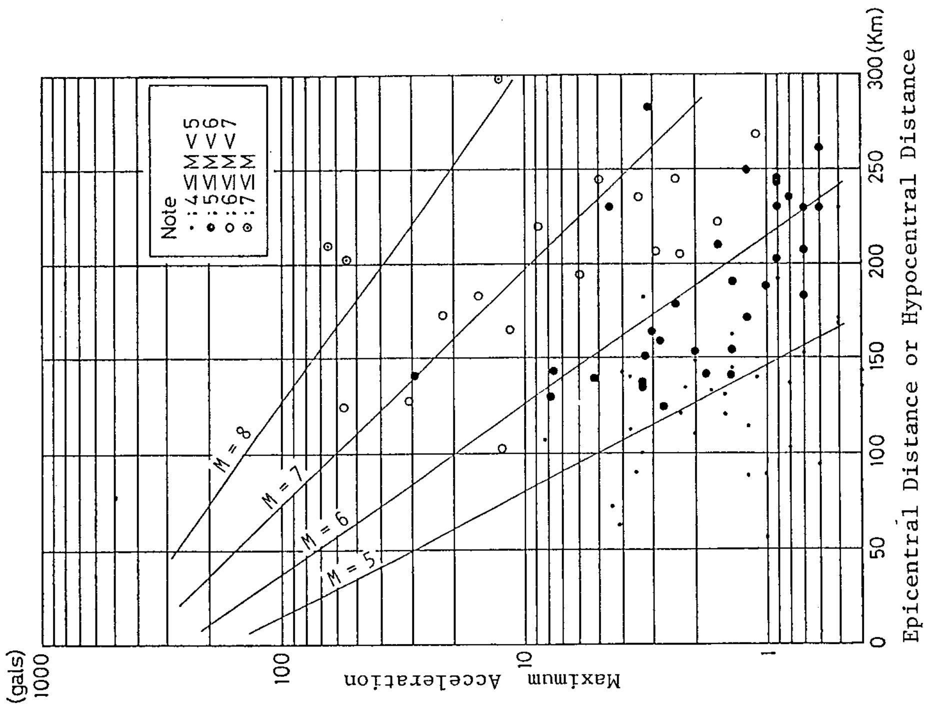


Fig. 5 Maximum Acceleration and Epicentral Distance or Hypocentral Distance if Depth over 40km, at Sannokai Dam

2.2 Earthquake Observations at Sannokai Dam

Earthquake observations have been going on since 1963 at Sannokai Dam (earth dam) of height of about 37 m located approximately 20 km south-southwest of the city of Morioka, Iwata Prefecture, in the Tohoku Region. This dam was constructed on lava and green tuff, and accelerometers for measuring earthquake motions on the basal rock are buried in the dam body at the rock-anchoring end of the dam at the left abutment. The types of the accelerometers are the same as at Kinugawa A.C.S, and the frequency characteristics are also practically the same. The directions of observations comprise two horizontal components and the vertical component. At Sannokai, in order to obtain correspondence with the case of Kinugawa A.C.S., the maximum value of the accelerations of the two horizontal components was selected and maximum acceleration and hypocentral distance were coordinated. The signs in Fig. 5 are the same as in Fig. 3. Hypocentral distances were adopted in cases of focal depths exceeding 40 km. The centers of the aftershock areas of the Niigata Earthquake of 1964 and the Tokachi-oki Earthquake of 1968 were taken to be 139°12'E, 38°25'N and 143°0'E, 24°45'N, respectively.

2.3 Empirical Formula for Distance Attenuation of Maximum Acceleration

The earthquakes observed at Kinugawa Control Station mainly had their epicenters in the Tohoku Region, the northern and eastern parts of the Kanto Region and the offshore areas to the east of the Kanto and Tohoku coasts, while at Sannokai Dam, earthquakes occurring in the Tohoku Region and its surrounding sea area were mainly reoorded so that there are parts in common for the two. On examination of Figs. 4 and 5, the boundaries between magnitudes 4 and 5, and 5 and 6 are fairly distinct for both, and it may be seen that they are approximately straight lines. With regard to the measurements at the latter being slightly higher, it may well be said that there were reasons of tectonics, but it is thought that maximum values out of measurements in two directions horizontally having been adopted, that measurements were at the ground surface, and that the conditions of seismometer installation were different had effects.

However, the distributions of the measurement values in Figs. 4 and 5 can be seen to indicate extremely good resemblances. Putting the two together taking into account the differences in the measurement values, it is thought possible for characters applicable to a wider range of magnitude to be discerned. Thereupon, based on these data, the empirical formula below, indicating the relation between epicentral distance or distance from the center of the aftershock area and maximum acceleration for rocky ground not affected much by the surface portion, was prepared with ranges not too far from epicenters as the objects.

$$\log_{10}\frac{\alpha}{1000} = \frac{\Delta+50}{100}\,(-4.93+0.89M-0.043M^2)$$

where, α: maximum acceleration (gal)
Δ: distance from center of aftershock area or epicentral distance (hypocentral distance when focal depth exceeds 40 km) (km)
M: magnitude (JMS)

This straight line is shown in Figs. 3 to 10 with magnitude as the parameter. Although it is necessary for further studies to be made regarding the vicinities of epicenters of large-scale earthquakes, considering the fact that the accuracy of magnitude estimates is normally said to be around ±0.3, it may be looked upon as expressing the distance attenuation of maximum acceleration with fairly good accuracy.

3. FIXED EARTHQUAKE OBSERVATIONS

3.1 Earthquake Occurring Offshore of Iwate Prefecture on February 20, 1978

An earthquake of M = 6.7 with its epicenter offshore of Ofunado City on the Pacific Ocean side of the northeastern part of Honshu occurred. The particulars of the earthquake are given below.

. Time of Occurrence	1337 hours (Japan time), February 20, 1978
. Location of Epicenter	142°12'E, 34°45'N
. Focal Depth	50 km
. Magnitude	6.7

At Ofunado City, at an epicentral distance of approximately 40 km in case of this earthquake, damage such as cracking in reinforced concrete buildings was produced. Figure 6 shows the relation between distance measured from the center of the aftershock area (estimated at 141°55'E, 38°45'N) and maximum acceleration, the figures accompanying the black dots indicating observation point numbers.

The numbers 19 and 20 indicate the values obtained at Kinugawa Control Station and Sannokai Dam, respectively. The numbers 2, 7, 8, and 12 are not at the Pacific Ocean side but the Sea of Japan side, and as can be seen in other cases, these appear to generally indicate relatively small values. In the case of this earthquake, the distance attenuation of maximum acceleration roughly follows the line of M = 7, and seen from the empirical formula, it can be said that the value of maximum acceleration is high compared with the magnitude of this earthquake.

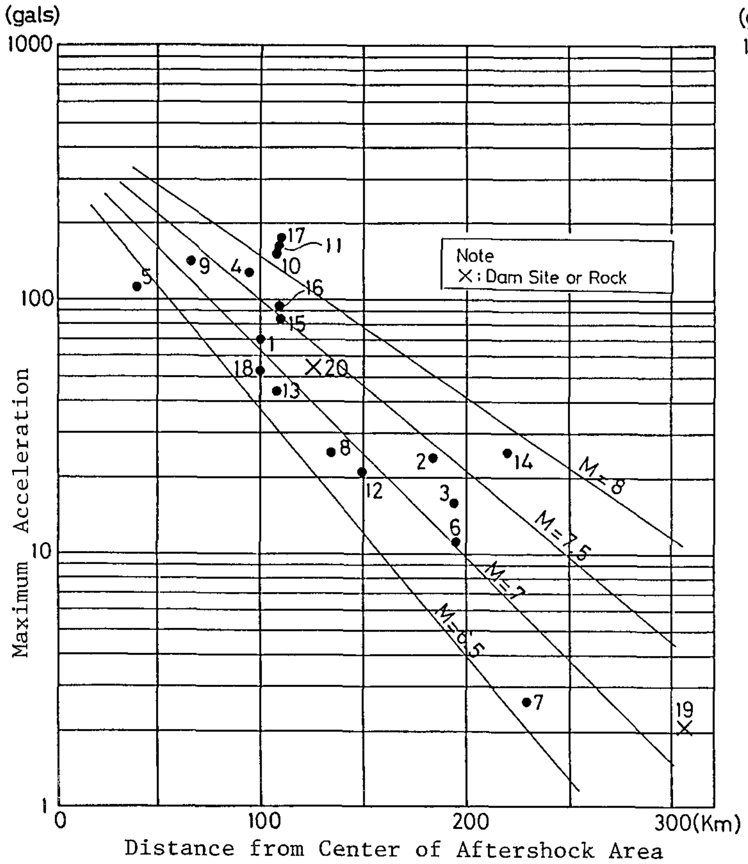


Fig. 6 Maximum Acceleration and Distance from Center of Aftershock Area of Earthquake, Feb. 20, 1978 (M=6.7)

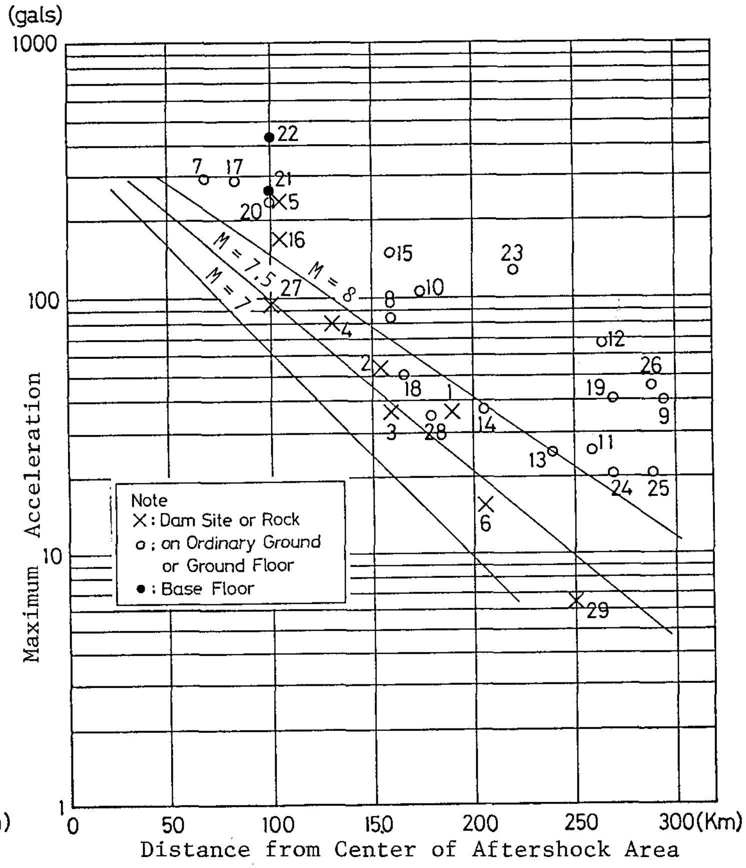


Fig. 7 Maximum Acceleration and Distance from Center of Aftershock Area of Miyagi-Ken Oki Earthquake, June 12, 1978 (M=7.5)

3.2 1978 Miyagi-ken-oki Earthquake

That on June 12, 1978, an earthquake of M = 7.4 occurred off the coast of Miyagi Prefecture in the northeastern part of Honshu and caused great damage is as previously reported. The particulars of the earthquake are as follows:

. Time of Occurrence	1714 hours (Japan time) June 12, 1978
. Location of Epicenter	142°10'E, 38°09'N
. Focal Depth	40 km
. Magnitude	7.4

There are many seismometers installed in this area, and it was possible to obtain records on rocky ground, on ground, and at basements of buildings. With the center of the aftershock area at 140°0'E, 38°10'N, the relation between the distance from this center and the maximum acceleration is as shown in Fig. 7. The points No. 1 to No. 5 are records obtained at the dam or damsite. The point No. 6 is on weathered rock barely on the Akita side of the border between Iwate and Akita Prefectures, while No. 7 is where there is rocky ground under an alluvial layer of thickness of 2 to 3 m. The points Nos. 11 to 19 were of locations in bays, with No. 11 and No. 14 not on the Pacific Ocean side but on the Sea of Japan side, while No. 16 is a record of a protruding part of bedrock. The record No. 20 is of a point on diluvial ground, while No. 27 is of a point in the urban part of Sendai City approximately 30 m underground, which can be considered to reach bedrock. The point No. 29 is at Kinugawa Control Station. As for No. 22, it is of the first basement of a building in urban Sendai, the waveform being fairly similar to that of No. 5, the features of the two being that the largest acceleration amplitude is extremely prominent compared with the second largest amplitude, with the second becoming only about 60% of the largest, the third largest and on down being successively smaller than the second. Regarding No. 5, the second largest amplitude is approximately 140 gal, and when this is adopted as the maximum value, the point of No. 5 will shift to a point close to No. 27.

Putting together the above, the maximum acceleration on the rocky ground was found to be located at the bottom area of the observation value group to rest approximately on the straight line obtained by the empirical formula.

3.3 1983 Nihon-kai Chubu Earthquake

On May 26, 1983, an earthquake of M = 7.7 occurred at the seabed offshore west of Akita and Aomori Prefectures in the northeastern part of Honshu, and damage was caused due to tsunami and liquefaction of ground. The particulars of the earthquake are as follows:

. Time of Occurrence — 1200 hours, May 26, 1983
. Location of Epicenter — 139°4'E, 40°21'N
. Focal Depth — 14 km
. Magnitude — 7.7

Since the epicenter was approximately 80 km from the coastline, it was possible to obtain records at a number of places more than 80 km in epicentral distance. Figure 8 shows maximum horizontal-direction accelerations with the center of the aftershock area at 40°37'N, 139°13'E, and the distances from this center. The points marked with x in the figure indicate records obtained at damsites, those with white dots records from on the ground, and those with black dots records from stories below the ground floor. The records other than from the damsites were maximum accelerations in the horizontal direction taken from data in PROMPT REPORT ON STRONG-MOTION ACCELEROGRAMS of the National Research Center for Disaster Prevention without regard to directions.

To note the records from damsites, Nos. 86, 87, 88, 89, 90, 91, and 75, were from concrete gravity dams, Nos. 86, 90, 91 and 75 being inside inspection galleries, and Nos. 87, 88, and 89 inside damsite administration offices. Concrete arch dams were Nos. 76 and 78, 79, with No. 76 recorded on rocky ground, and Nos. 78 and 79 at the same dam but on rocky ground and in the inspection gallery.

Rockfill dam records are Nos. 73, 93, 53, (81, 82), with No. 73 measured on bedrock, No. 93 inside an office, No. 53 in an inspection gallery, and Nos. 81 and 82 at the same dam, in a side adit and the inspection gallery, respectively. The record No. 92 is from observations at Sannokai Dam previously mentioned. The records of No. 75 and No. 53 show fairly low levels of acceleration, these measuring points being at locations closer to the Pacific Ocean side. Furthermore, although it will not be clear until further studies have been made, it is felt that the values at fill dams are somewhat on the higher side. The point No. 17 is on diluvial ground, while Nos. 27, 29, and 30, are on soft ground, and No. 39 on weathered bedrock. As for Nos. 1, 2, 17, 22, 27, and 31, they are values from ground in harbor areas.

According to the above, the maximum acceleration of the damsite is at the bottom area of the observation value group for a distribution in a relatively narrow range, and it may be seen that they are in the neighborhood of the line expressed by the empirical formula. It is thought that these facts indicate the characteristics of maximum acceleration in rocky ground.

3.4 1978 Izu-Oshima Kinkai Earthquake

This was an earthquake with its epicenter off the east coast of the middle part of Izu Peninsula at the southern tip of the Kanto Region of Honshu, with damage mostly from behaviors of ground such as collapses of slopes, etc. occurring. The particulars of this earthquake are as follows:

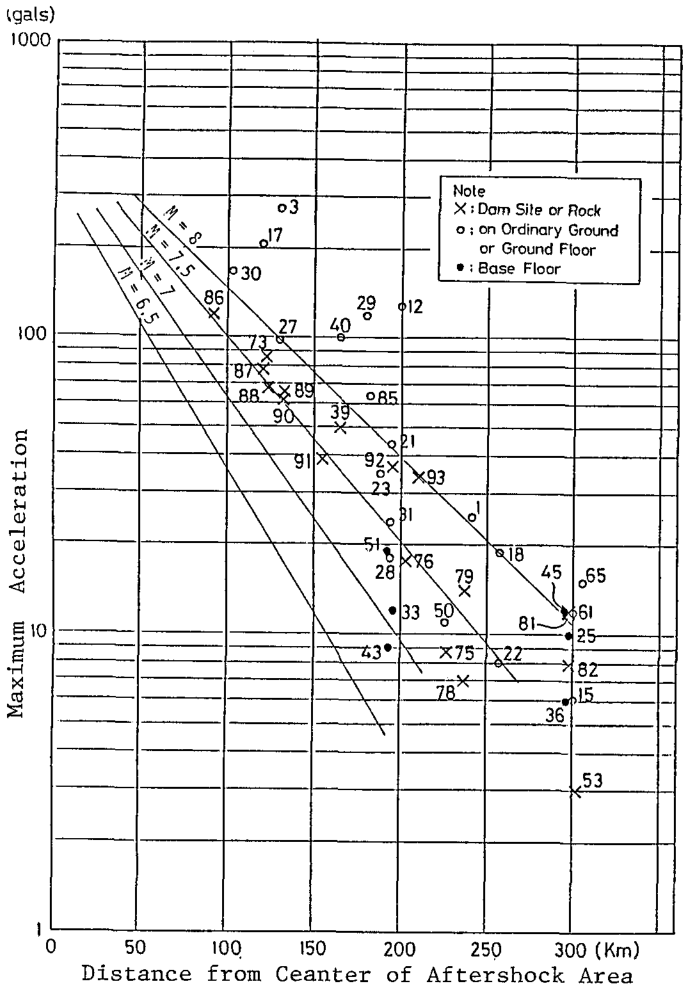


Fig. 8 Maximum Acceleration and Distance from Center of Aftershock Area of Nihon-kai Chubu Earthquake, May 26, 1983 (M=7.7)

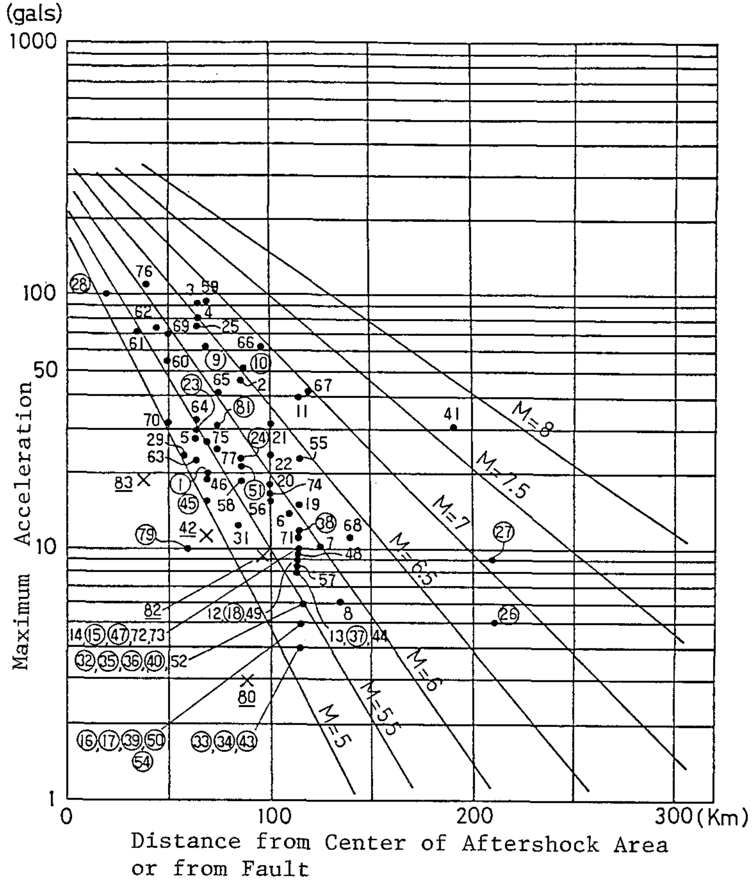


Fig. 9 Maximum Acceleration and Distance from Center of Aftershock Area or from Fault of Izu-Oshima Kinkai Earthquake, Jan. 14, 1978 (M=7.0)

. Time of Occurrence — 1324 hours, January 14, 1978
. Location of Epicenter — 139°14'E, 34°45'N
. Focal Depth — 3 km
. Magnitude — 7.0

A fault having a strike roughly west-northwest passing through the town of Inatori showed displacement to the right of 20 to 60 cm at the ground surface. Earthquake damage was localized in spite of the fact that the magnitude of the earthquake was 7.0, and this closely resembled the case of the Izuhanto-oki Earthquake (M = 6.9) which occurred approximately 25 km to the south in 1974.

Figure 9 shows maximum accelerations in the horizontal direction on ground or at basement floors of buildings read off mainly from data of the National Research Center for Disaster Prevention plotted with epicentral distance (in case of a site near a fault the distance from the fault) as the axis. Encircled numbers indicate observation values from basements of buildings.

Measurements obtained at rocky ground are extremely scarce. The record No. 83 was obtained inside an adit in rocky ground, the acceleration at the ground surface directly above having been approximately 70 gal. No. 1 was on ground consisting of an embankment of several meters on rocky ground which had then been thoroughly compacted, No. 42 was from inside an adit in rocky ground, No. 82 from on rocky ground at a damsite, and No. 80 from on rocky ground.

It can be seen in this figure that in the case of this earthquake also, the values obtained on rocky ground are distributed at the bottom area of the group of observation values.

As a whole, a relation between epicentral distance and maximum acceleration completely different from the cases of the earthquakes described in 3.1 through 3.3 is found, and it can be seen that distance attenuation is prominent, variation in maximum acceleration according to measuring point is large if epicentral distance is constant, and maximum acceleration at the basement floor of a building is small compared with the ground surface.

3.5 Kanagawa-Yamanashi Kenkyo Earthquake of August 8, 1983

This earthquake, occurring at the border between Kanagawa and Yamanashi Prefectures which corresponds to the southern part of the Kanto Region and the Tokai District at the same time resulted in little damage, but it is surmised from damage conditions and earthquake observations that tremors were strong in the vicinity of the epicenter. The particulars of this earthquake are the following;

. Time of Occurrence — 1248 hours, August 8, 1983
. Location of Epicenter — 135°01'E, 35°32'N
. Focal Depth — 20 km
. Magnitude — 6.0

Figure 10 consists of maximum accelerations in the horizontal direction on ground or at the basements of buildings selected mainly from data of the National Research Center for Disaster Prevention and shown with epicentral distance as the axis. Mark X's indicate values at the rock ground, white dots indicate on the ground and black dots measurements at basements of buildings and at points fairly deep under the ground surface. That the measurements are concentrated at around epicentral distance of 70 km is because of the many buildings in the central part of Tokyo where earthquake observations are being carried out.

Observation data obtained at rocky ground are extremely scarce for this earthquake also. The record No. 84 was obtained on rocky ground near a dam, while the encircled x at epicentral distance of 14 km and 93 gal was measured at a point approximately 40 m inside bedrock at the same damsite. No. 102 is a record obtained on rocky ground. As for Nos. 90 and 91, they were observed at the sites of rockfill and concrete gravity dams, respectively.

From this figure, simiarly to the case described in 3.4, it may be seen that the degree of attenuation according to epicentral distance is prominent, that compared with maximum acceleration values on ground, those at basements of buildings are low, and that maximum accelerations on ground are at the bottom area of the group of observation values.

4. CONCLUSION

The maximum accelerations in the horizontal direction only were focused on in this study with earthquake motions at rocky ground the objects of consideration, and the extents and attenuations according to distance were investigated based on the results of earthquake observations. As a consequence, the following may be said:

i) An empirical formula to show the relations of maximum acceleraton and magnitude according to the Richter scale and distance from the center of an aftershock area applicable to the Tohoku Region and the northern part of the Kanto Region of Honshu was obtained.

ii) Cases for which the empirical formula could not be applied were found for earthquakes in the southern part of the Kanto Region. Further studies are necessary in this regard.

These are considered to depend greatly on the region, earthquake mechanism, and scale of seismotectonic earthquake, and it is intended for this to be examined hereafter.

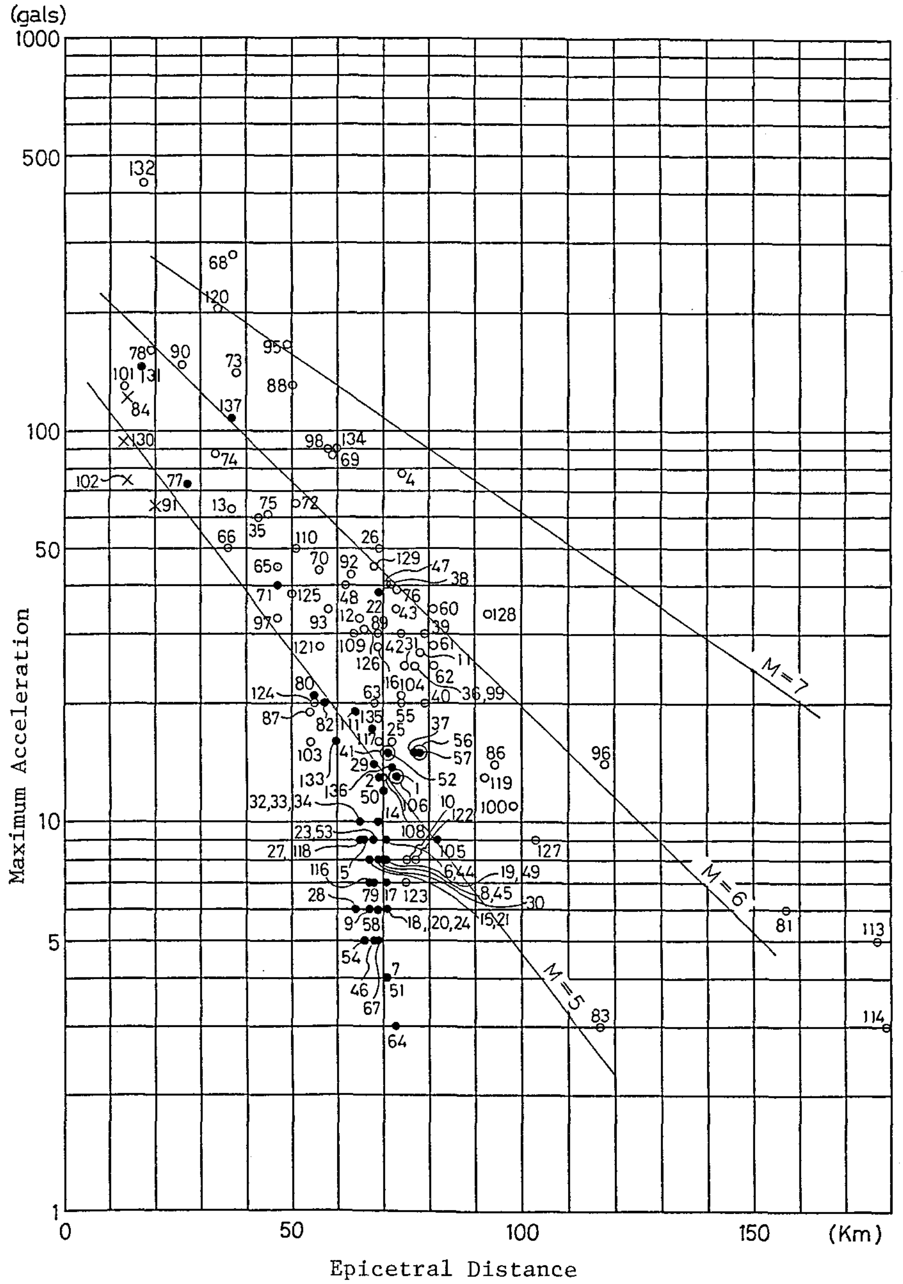


Fig. 10 Maximum Acceleration and Epicetral Distance of Kanagawa-Yamanashi Kenkyo Earthquake, Aug. 8, 1983 (M=6.0)

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