

THE WESTERN NAGANO PREFECTURE EARTHQUAKE, 1984 AND DAMS

May, 1985

Fill Type Dam Division
Dam Department
Public Works Research Institute
Ministry of Construction

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THE WESTERN NAGANO PREFECTURE EARTHQUAKE, 1984 AND DAMS

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Synopsis:

"The Western Nagano Prefecture Earthquake, 1984" occurred near Ohtaki village, Nagano Prefecture at 8:48 a.m. September 14, 1984. Makio Dam was located about 5 km from the epicenter. In addition to Makio Dam, there were several high dams within the epicentral distance of 100 km and the earthquake motions were recorded at some of them.

In Makio Dam, a few cracks were found at crest, but the dam body suffered no major casualties. Satisfactory behaviours of dams during the earthquake indicate that the dams can withstand near-field earthquakes very well.

Key Words : Earthquake, Aftershock, Rockfill Dam, Concrete Dam, Seismograph

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1. Introduction

"The Western Nagano Prefecture Earthquake, 1984" occurred near Ohtaki village, Nagano Prefecture at 8:48 a.m. September 14, 1984. Makio Dam was located near the epicenter (about 5 km from) and there were also several high dams within the epicentral distance of 100 km. Earthquake motions were recorded at some of their dam sites. A few cracks were found at the crest of Makio Dam, but the dam body suffered no major damages. Satisfactory behaviours of the dams during the earthquake indicate that the dams can withstand near-field earthquakes very well.

Figures of acceleration time history for Makio Dam, Nagawado Dam and Takane Dam in this report are by the courtesy of the following organizations, respectively.

- Water Resources Development Corporation
- Tokyo Electric Power Company
- Chubu Electric Power Company

2. General Description of the Earthquake

The earthquake of the magnitude of 6.8 on the Richter scale occurred in the Western Nagano Prefecture at 8:48 a.m. on September 14, 1984. The location of the epicenter of the earthquake was lat. $35^{\circ}49'N$. and long. $137^{\circ}33'E$., and the depth was 2 km. It was named "The Western Nagano Prefecture Earthquake, 1984" by the Japan Meteorological Agency. In this earthquake, there were 28 persons killed or missing, 8 injured, 51 houses completely destroyed, 363 houses partially destroyed, 190 destroyed locations in roads, one bridge made unusable and 51 landslides.

Many aftershocks occurred after the main earthquake. Strong motions due to these shocks were recorded at several dams.

Table 2.1 gives a general description of the main earthquake and aftershocks.

Figure 2.1 illustrates the distributions of epicenters of the main earthquake and aftershocks, while Figure

**Table 2.1 Description of main-shock and after-shocks
(after Meteorological Agency)**

Date	Location		Depth (km)	Magnitude
	N	E		
8:48 a.m. Sep. 14, 1984	$35^{\circ}49'$	$137^{\circ}33'$	2	6.8
12:49 p.m. Sep. 14, 1984	$35^{\circ}48'$	$137^{\circ}29'$	8	5.0
7:14 a.m. Sep. 15, 1984	$35^{\circ}47'$	$137^{\circ}28'$	6	6.2
9:12 a.m. Oct. 3, 1984	$35^{\circ}49'$	$137^{\circ}37'$	5	5.3
9:18 a.m. Oct. 9, 1984	$35^{\circ}51'$	$137^{\circ}37'$	8	4.2

2.1(a) shows the main shock and major aftershocks which were observed by Meteorological Agency, and Figure 2.1(b) shows the locations of aftershocks including micro-earthquakes observed by the Science Faculty of Nagoya University using micro-seismographs.

3. Observed Earthquake Motions

The characteristics of the earthquake motions recorded at the dams are described in this chapter.

Figure 3.1 shows the location of dams where the earthquake motions of the main shock were recorded, the monitored maximum acceleration and the epicentral distance from the dams. The location of dams where the motions of aftershocks were recorded are shown in Figure 3.2. From Figure 3.1, the peak horizontal acceleration at rock foundations ranges from 11 to 72 gal within the epicentral distance of 50 km.

Figure 3.3 shows the relationship between the maximum acceleration at rock foundations and the epicentral distance for the Western Nagano Earthquake (The Western Nagano Prefecture Earthquake, 1984). In this figure, the plotted empirical formulae by Okamoto and Kanai giving the peak acceleration from epicentral distance are also shown for reference, while the monitored motions are generally smaller than the values given by Okamoto and Kanai.

Figure 3.4 shows the relationship between the magnitude and the duration of the motion. The duration T is defined as the term (in second) between the first time that 20 % of the maximum acceleration appears, and the last time it appears. The duration of the Western Nagano Earthquake was thus 5~10 seconds according to this definition.

The estimated curve in Figure 3.4 was drawn based on the formula obtained by the Fill Type Dam Division by collecting and arranging the observed earthquake motions of the dam foundations.

3.1 The Observed Earthquake Motions at Makio Dam

The general description of Makio Dam is given in Table 4.1, and Figure 4.3 shows the maximum cross section of the dam.

Seismographs of Makio Dam ceased to function probably due to the power failure after they had monitored the high frequency motions for 1 second from the beginning of the main motion. Fortunately, the aftershock motions were recorded. The installed positions of accelerometers and displacement transducers are shown in Figure 3.5. Figures 3.6 to 3.13 are the accelerograms of aftershocks except that Figure 3.9 is the recorded velocity.

The Fill Type Dam Division installed the strong-motion seismographs at the left abutment and the crest of Makio Dam (on October 8: after the date of main shock) by these strong motion seismographs. Figures 3.12 to 3.13 are the earthquake motions recorded on October 11 to 21, 1984. The recorded accelerations were digitized for every 0.01 seconds. Figure 3.12 shows the accelerograms at the left abutment. The recorded maximum accelerations are 57 gal in the up/downstream direction, 84 gal in the dam axis direction and 27 gal in the vertical direction. Figures 3.14 to 3.15 are the power spectral of the accelerations in Figures 3.12 to 3.13.

3.2 Earthquake motions observed at other dams

Earthquake motions were recorded at several dams other than Makio Dam. The following three records have been digitized up to now.

(1) Iwaya Dam

Iwaya Dam is a rockfill dam with a central impervious clay core. The general description is shown in Table 3.1. The seismograph installation is shown in Figure 3.16. Figure 3.17 shows the accelerations of the main earthquake and Figure 3.18 shows those of the aftershocks for September 15, 1984.

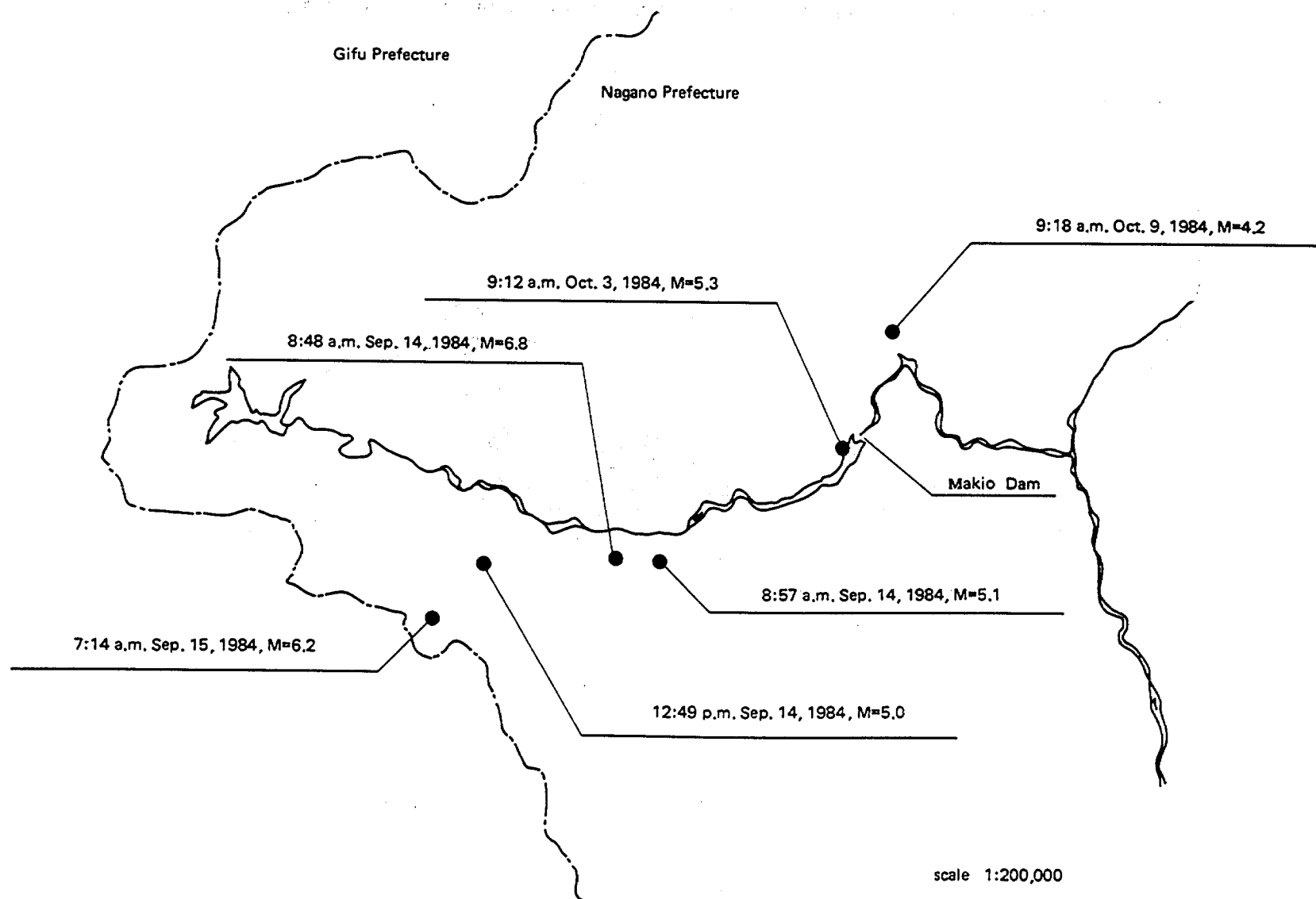


Fig. 2.1(a) Locations of epicenters (Courtesy of Meteorological Agency)

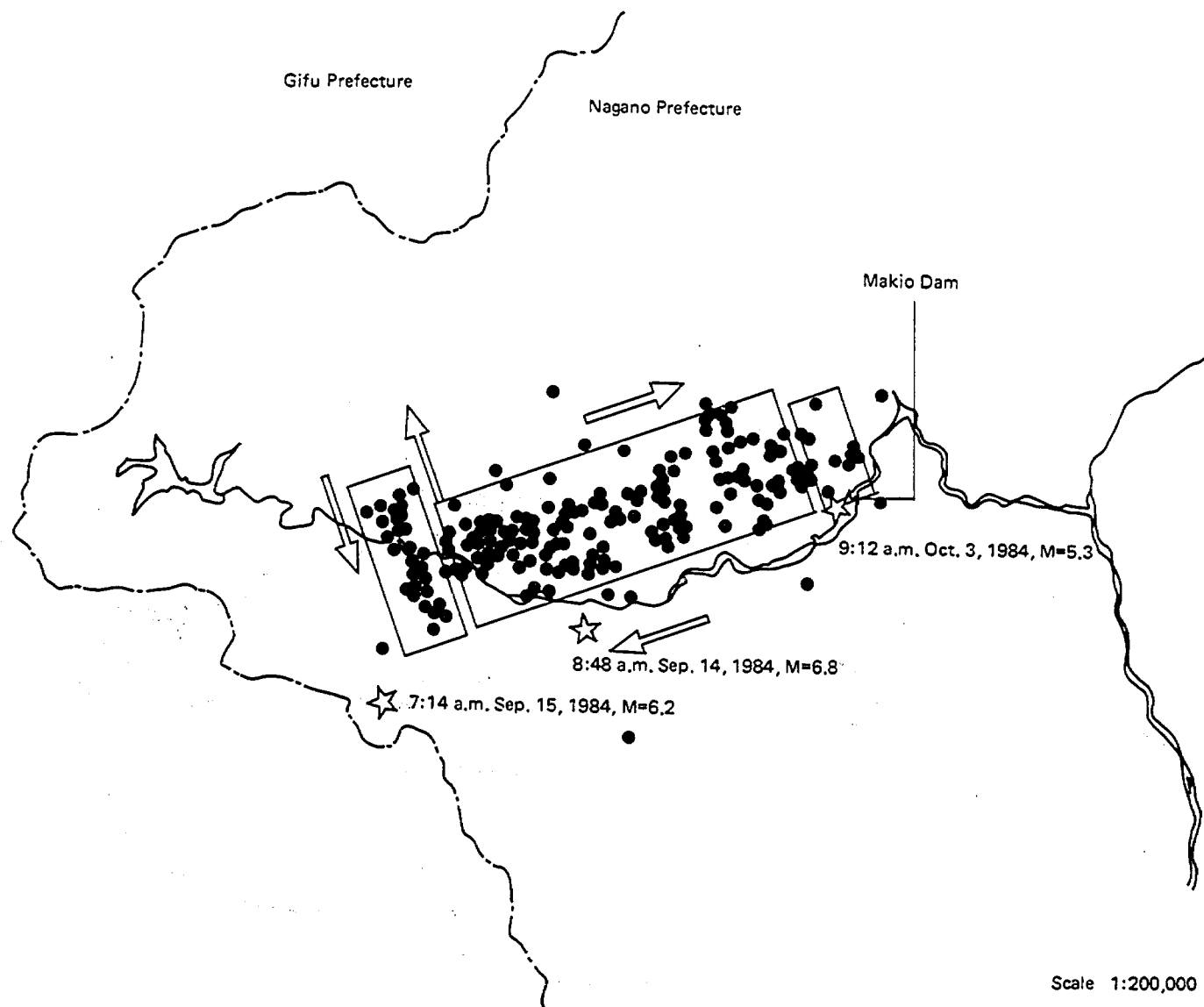
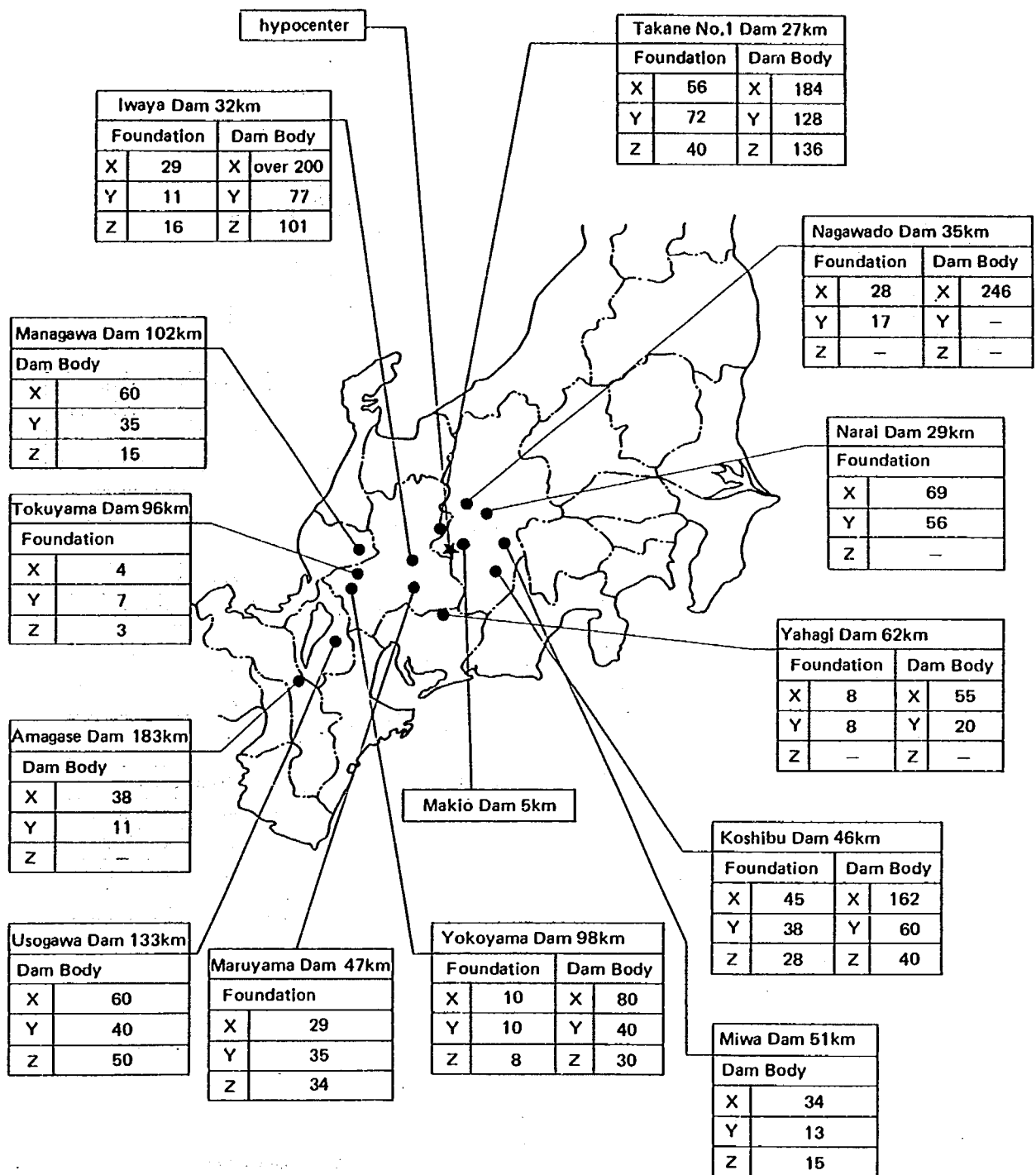
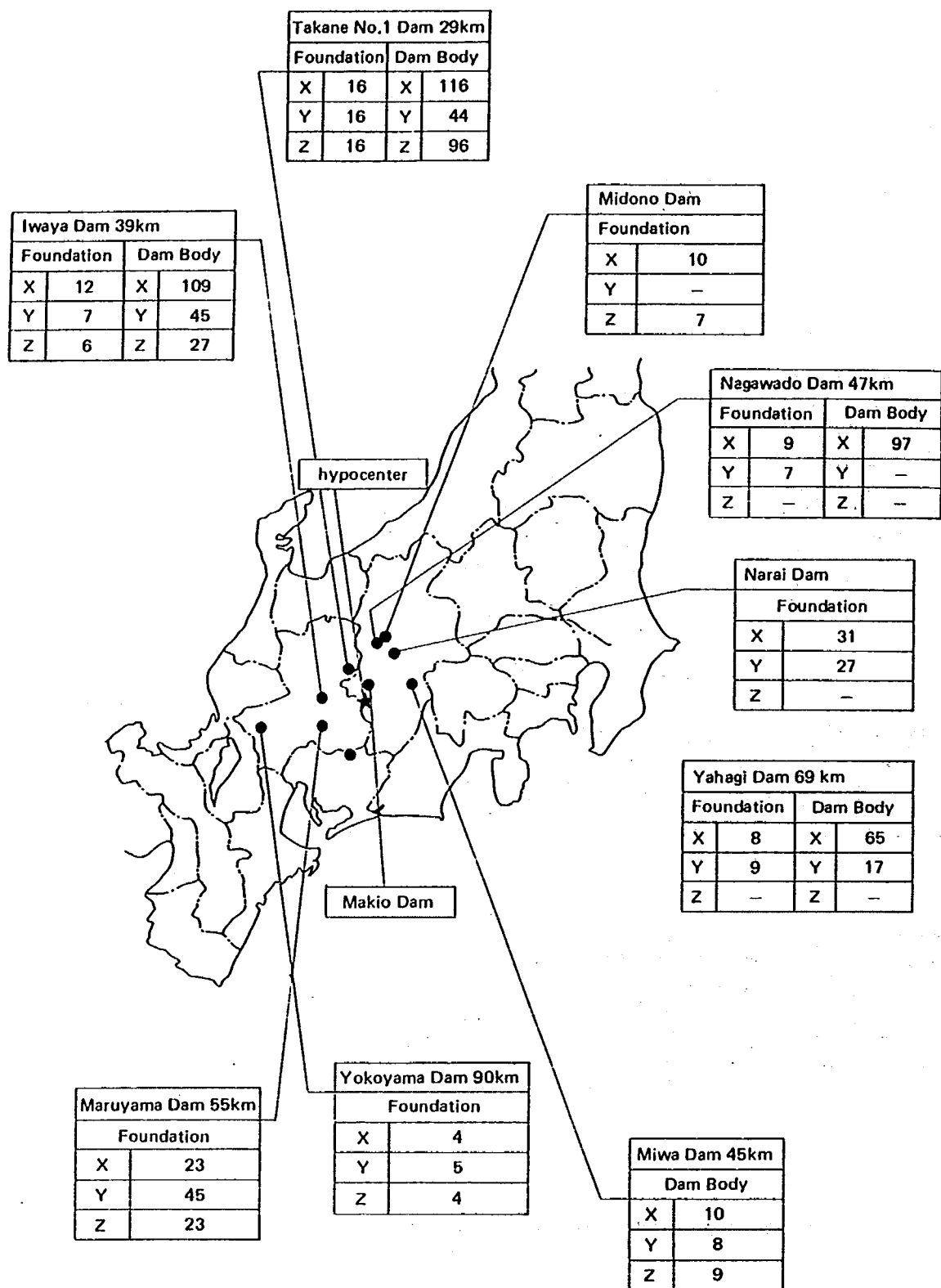


Fig. 2.1(b) Locations of epicenters (Courtesy of Science Faculty, Nagoya Univ.)



X : Up/Downstream direction Y : Dam axis direction Z : Vertical direction

Fig. 3.1 Maximum accelerations monitored at dams



X : Up/Downstream direction Y : Dam axis direction Z : Vertical direction

Fig. 3.2 Maximum accelerations at dams during the aftershock of September 15, 1984

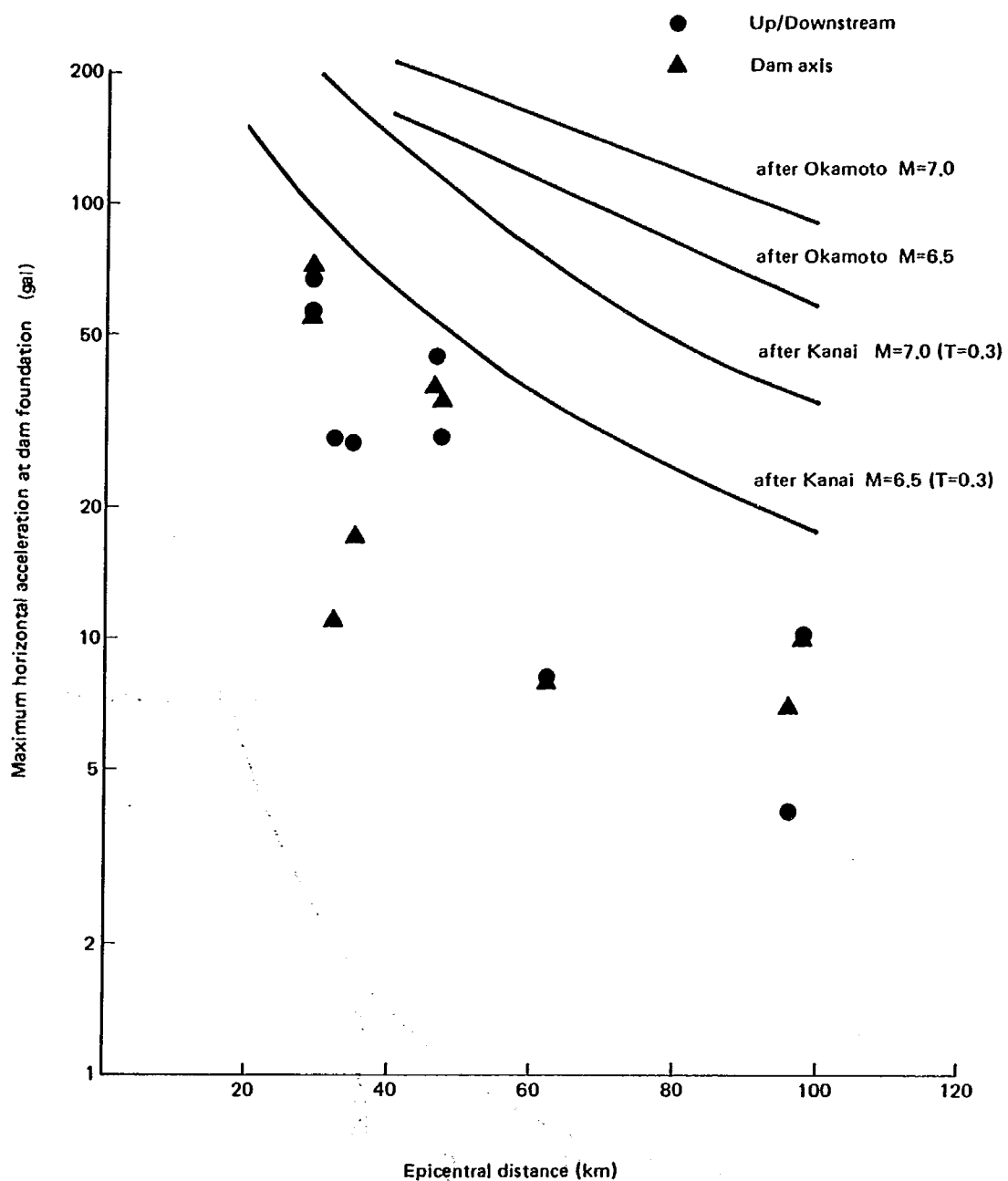


Fig. 3.3 Relationship between the maximum horizontal acceleration at dam foundation and the epicentral distance

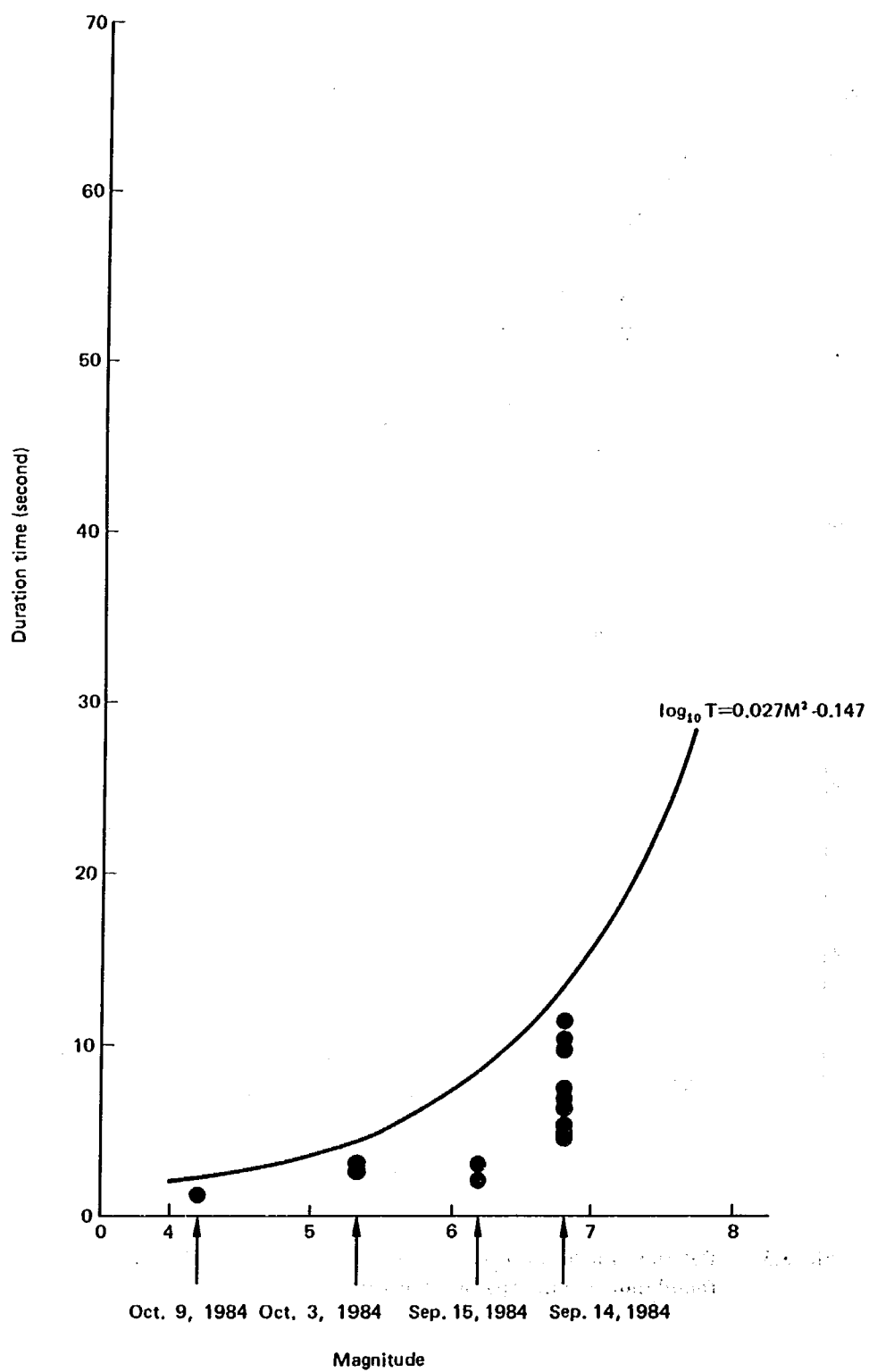


Fig. 3.4 Relationship between duration time and magnitude

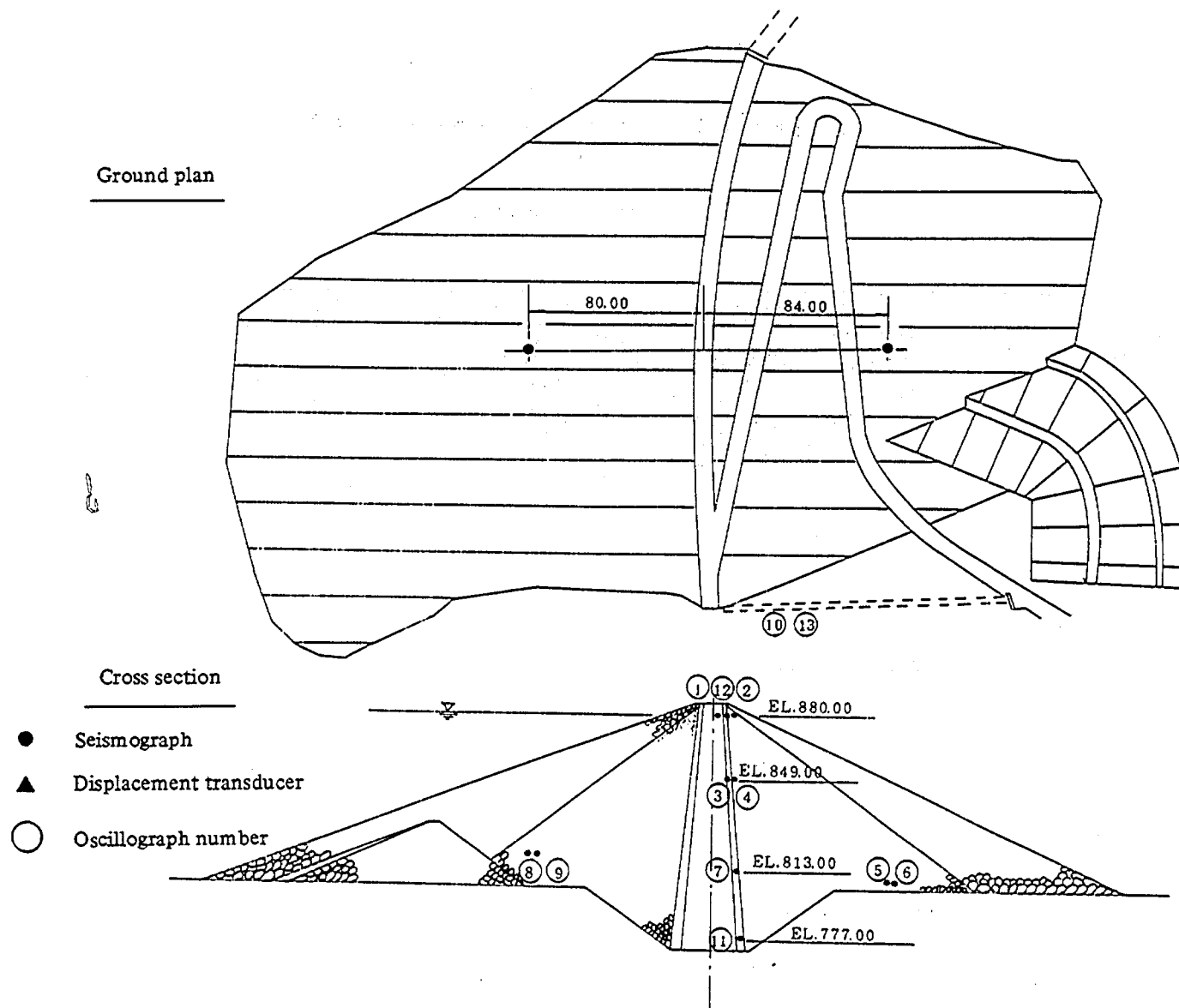


Fig. 3.5 Arrangement of instruments

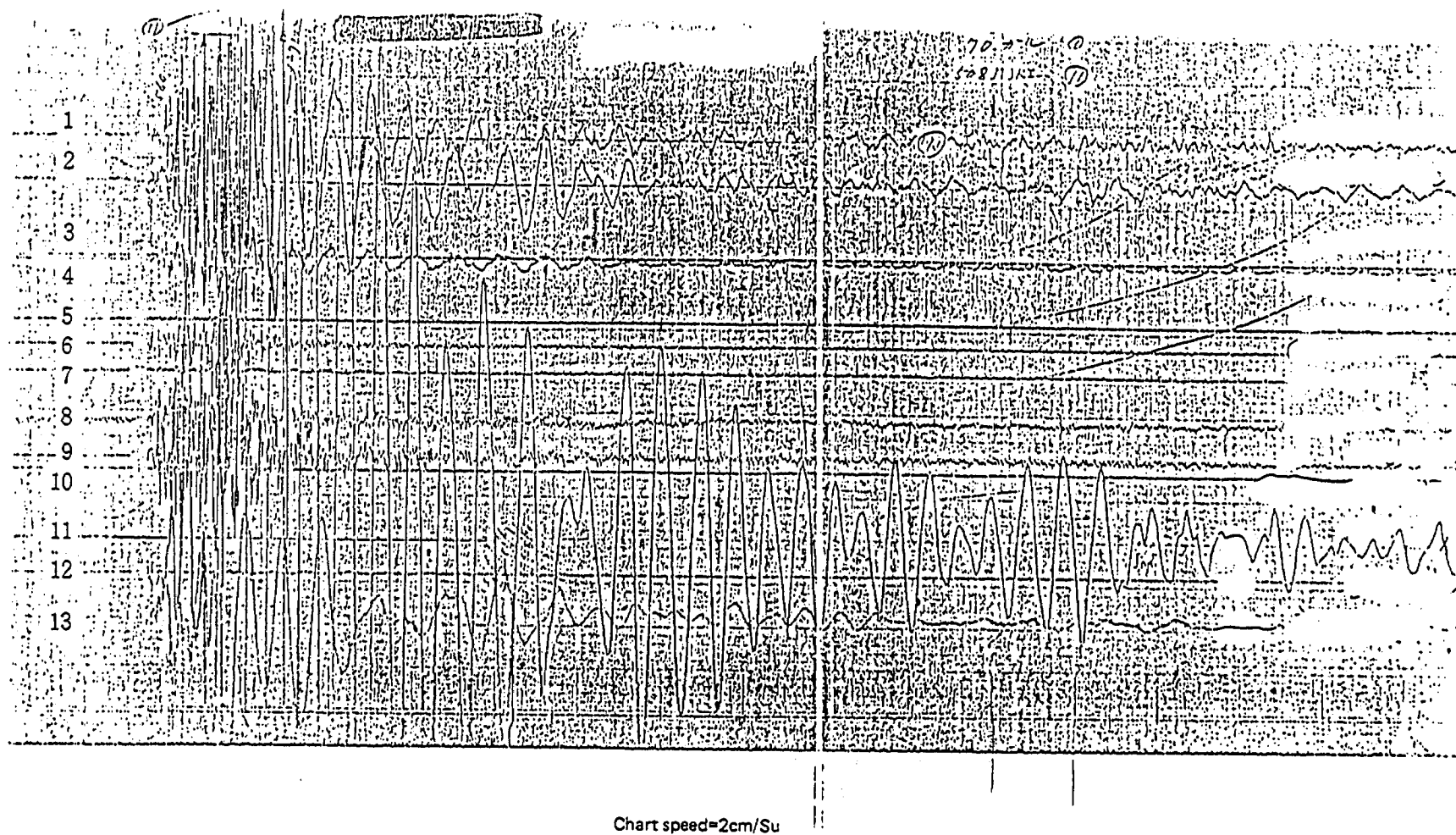
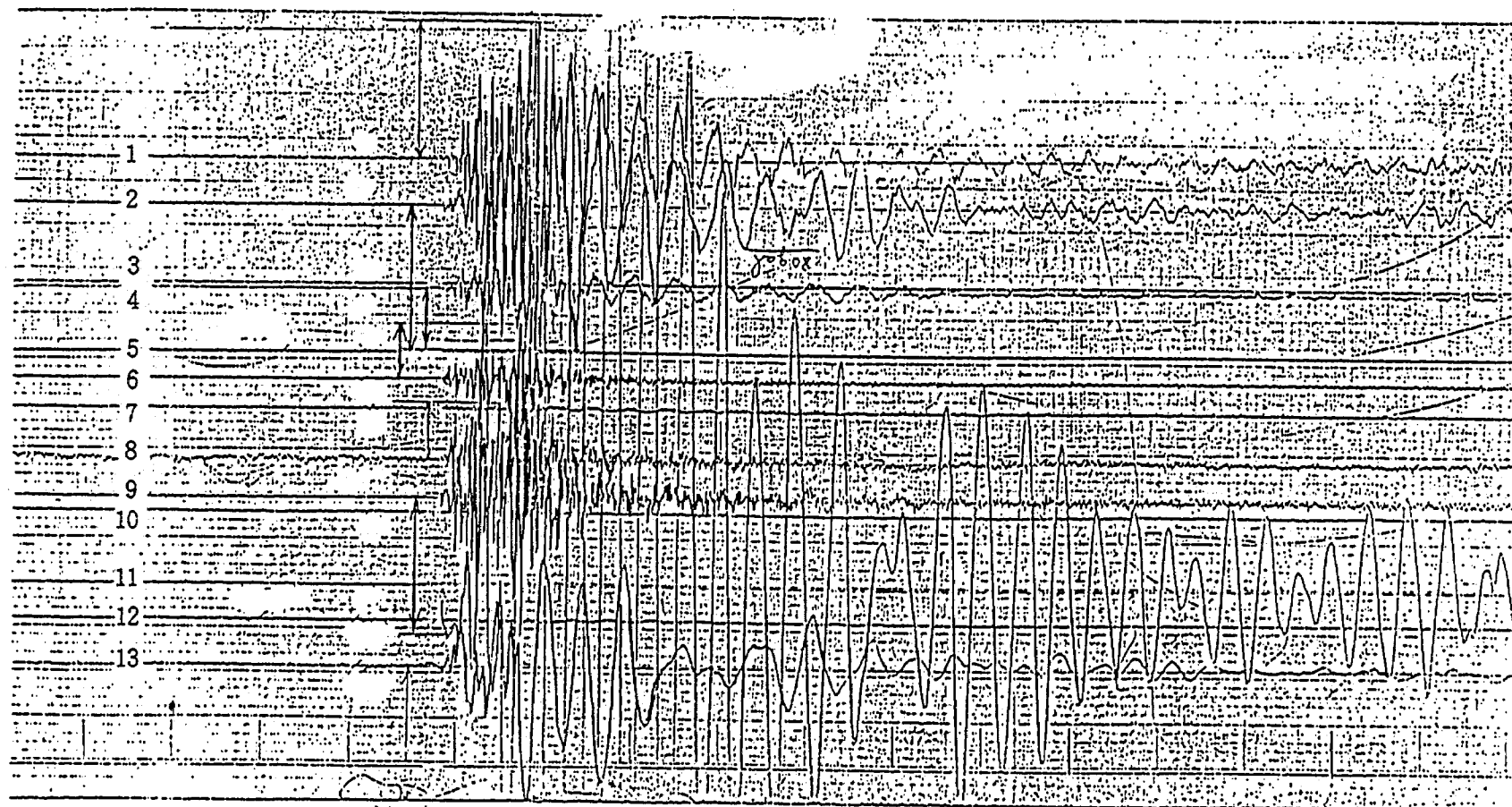


Fig. 3.6 Aftershock of September 14, 1984 at Makio Dam



Acceleration	(1) 77 gal	(6) 31 gal	Displacement	(11) 1.250 μ
	(2) 83 gal	(7) -		(12) -
	(3) -	(8) 33 gal		(13) 0.300 μ
	(4) 35 gal	(9) 77 gal		
	(5) -	(10) -		

Fig. 3.7 Aftershock of 7:14 a.m. September 15, 1984 at Makio Dam

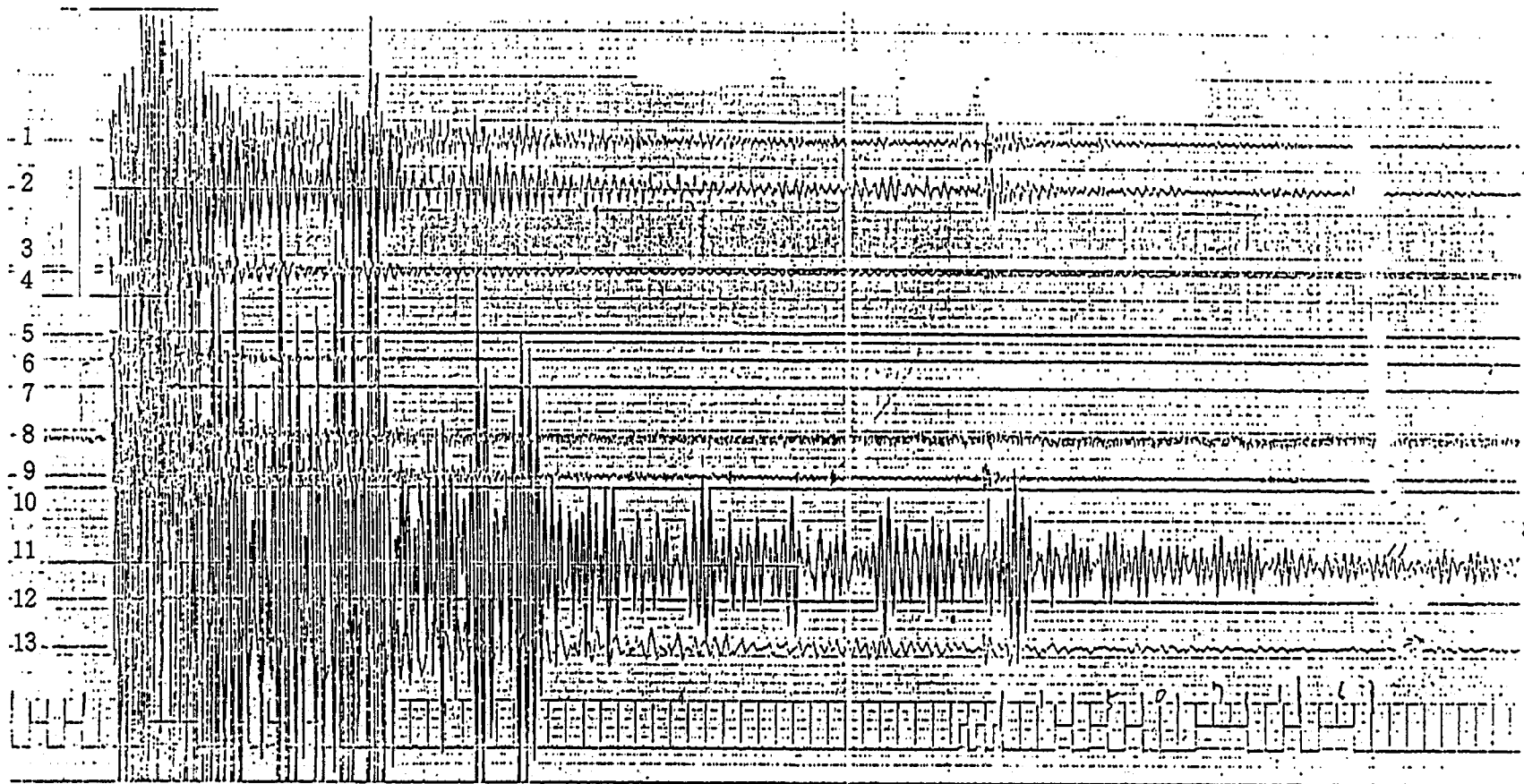


Fig. 3.8 Aftershock of 7:16 a.m. September 15, 1984 at Makio Dam

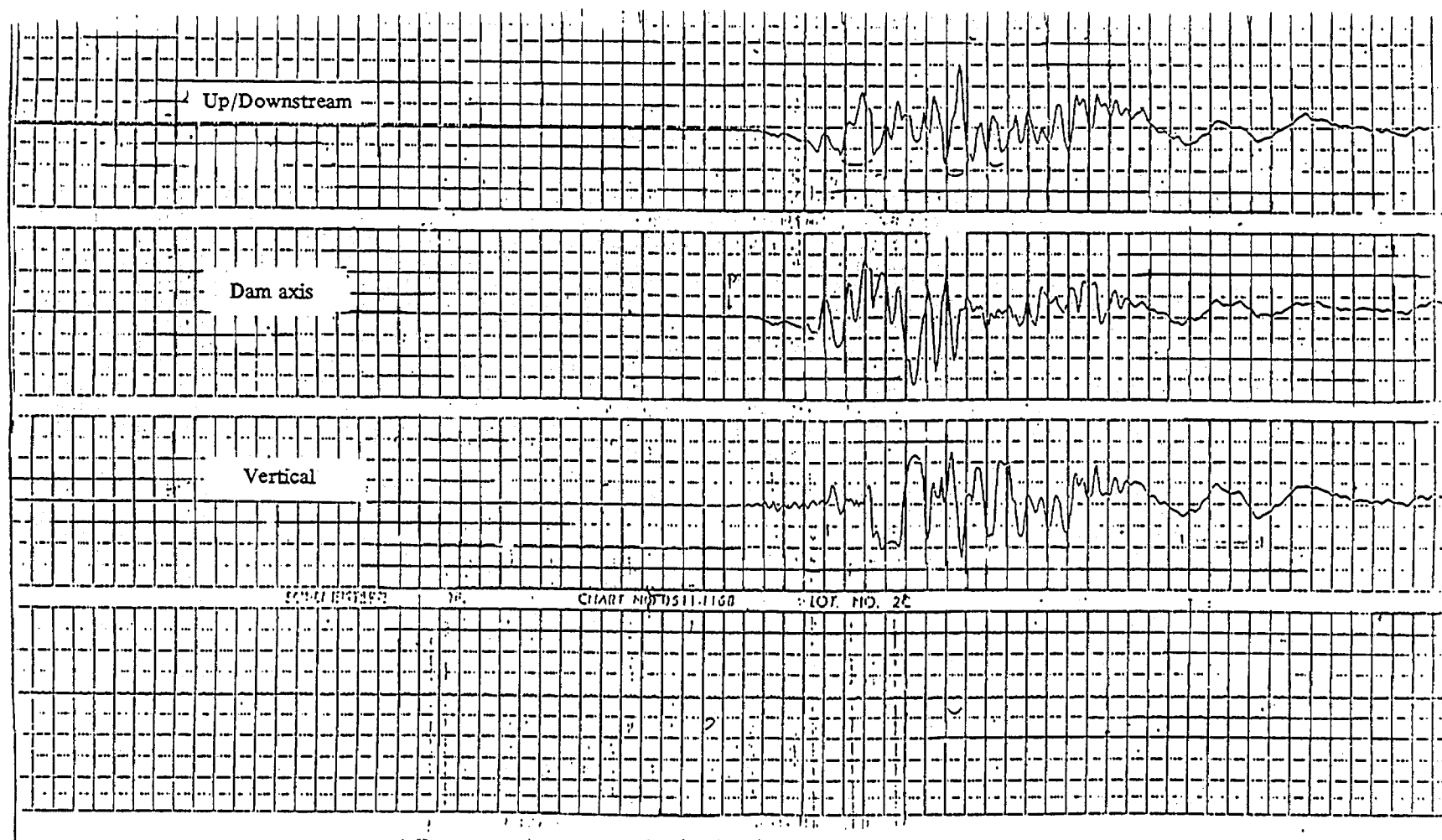


Fig. 3.9 Velocity of aftershock of 9:12 a.m. October 3, 1984 at Makio Dam
(Courtesy of Gifu University)

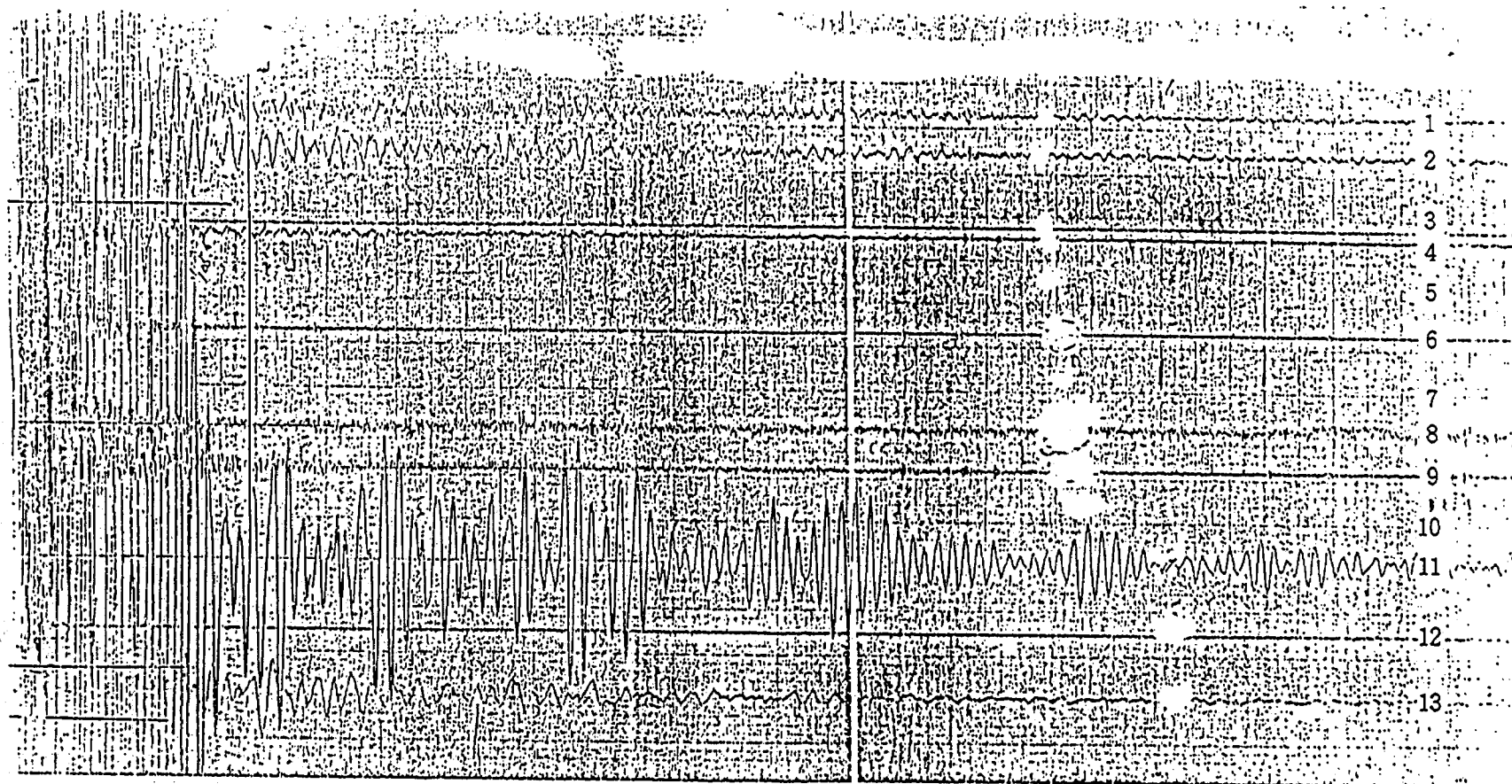
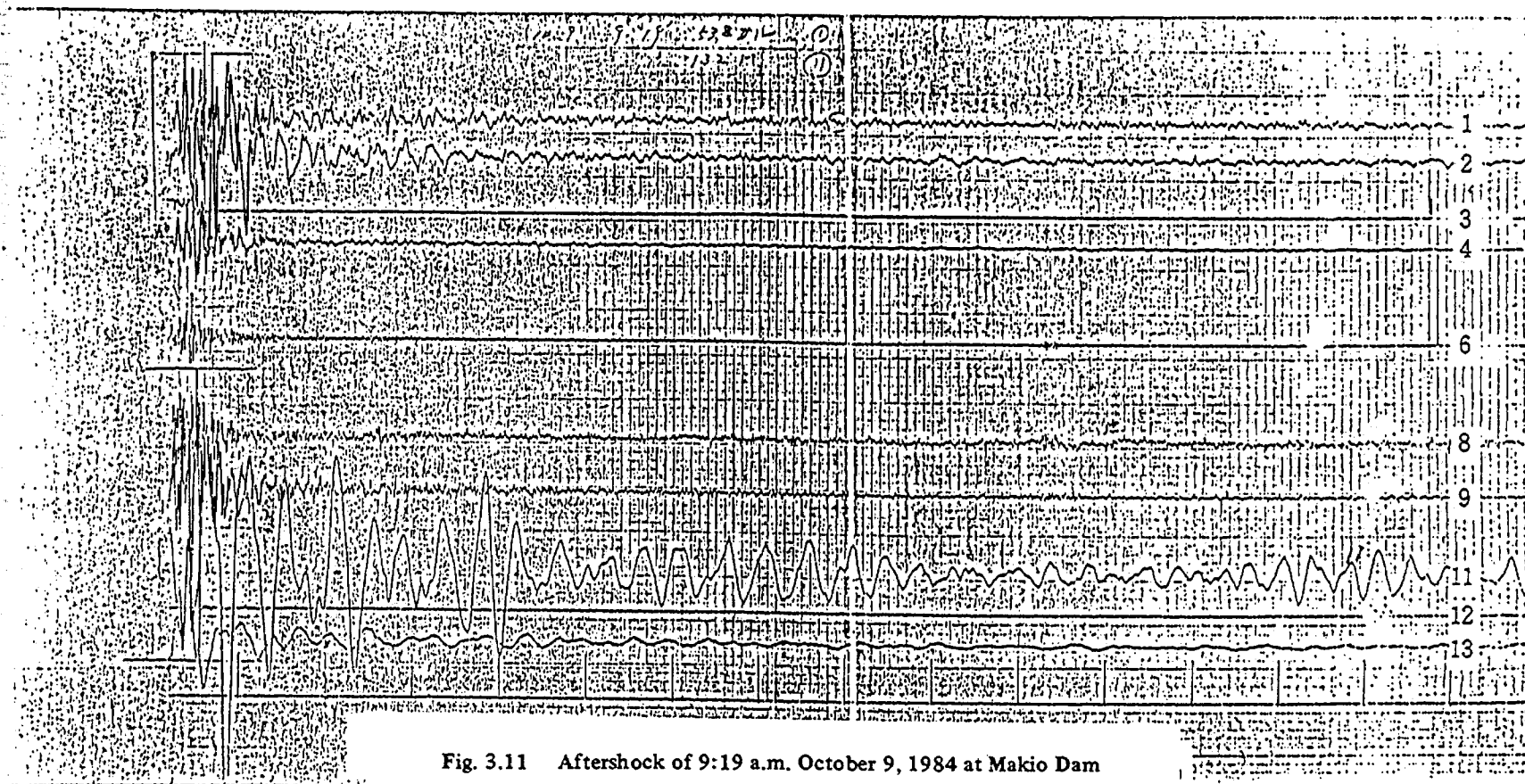
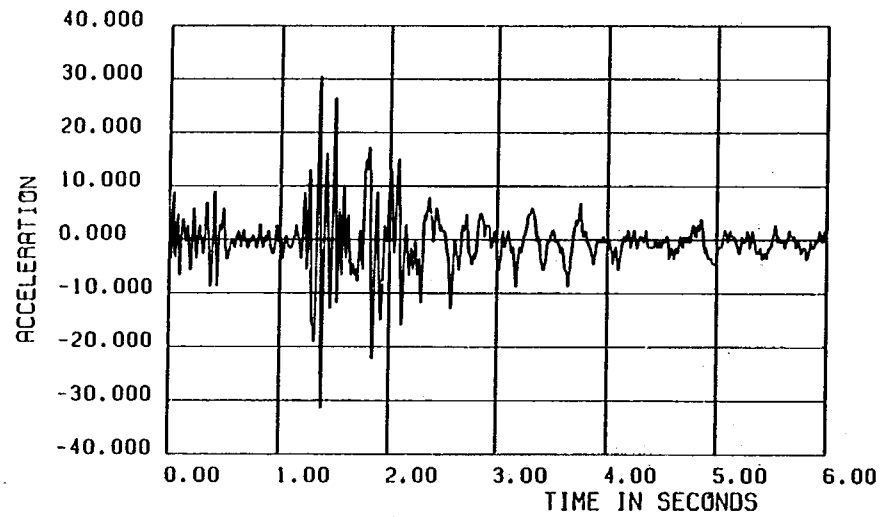


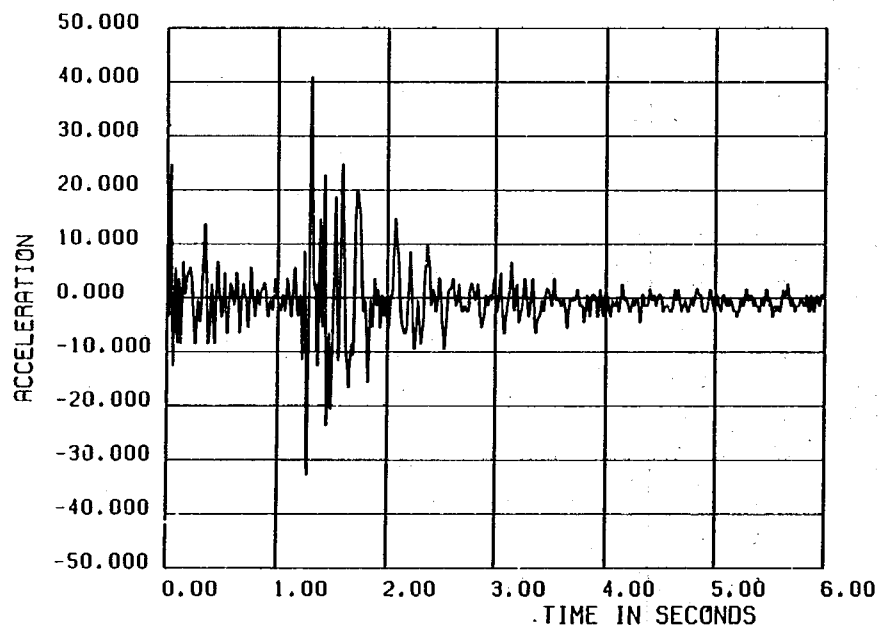
Chart speed = 0.8cm/sec

Fig. 3.10 Aftershock of 9:12 a.m. October 3, 1984 at Makio Dam

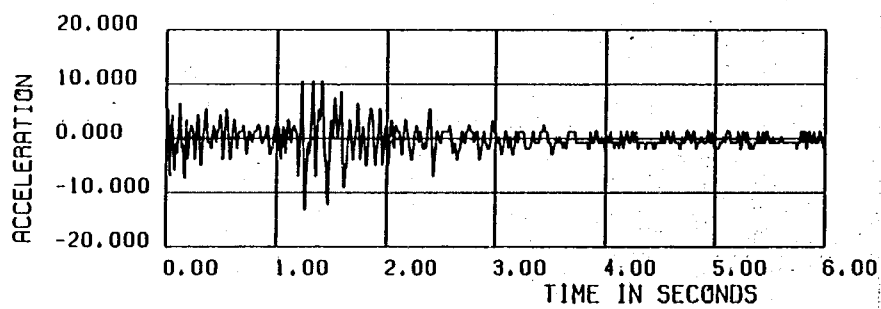




Up/Downstream

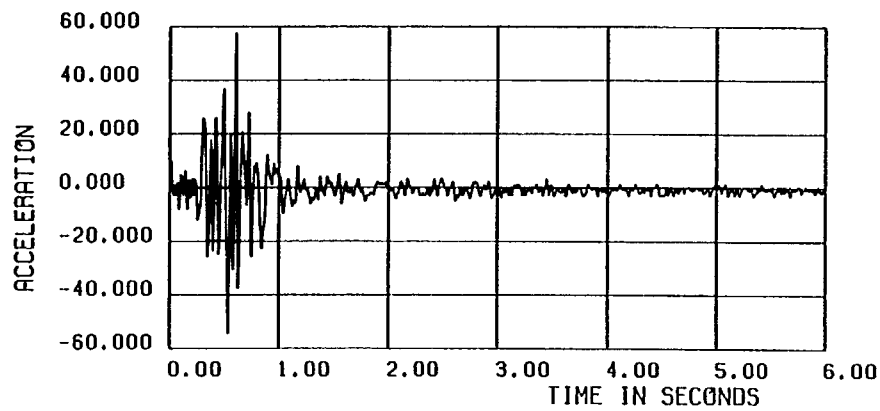


Dam axis

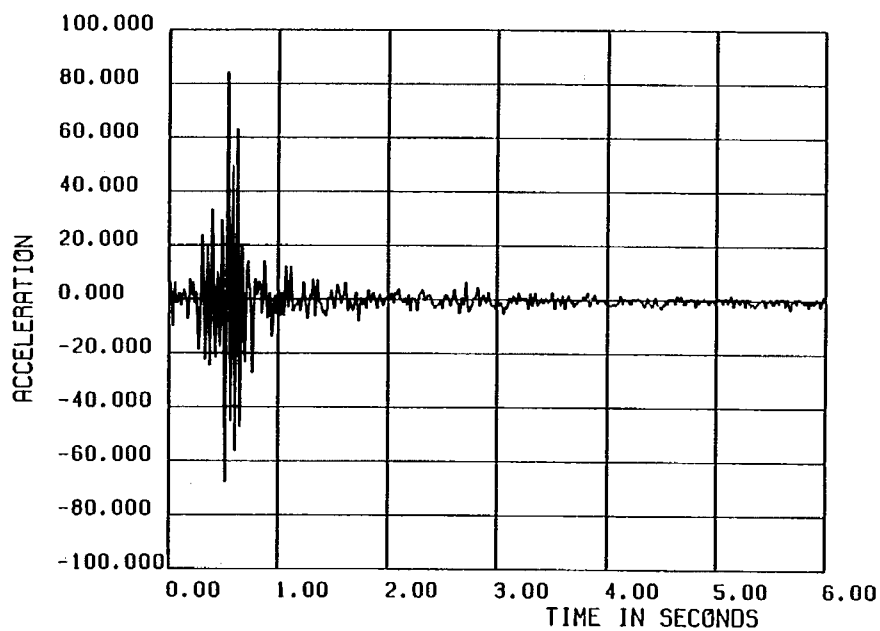


Vertical

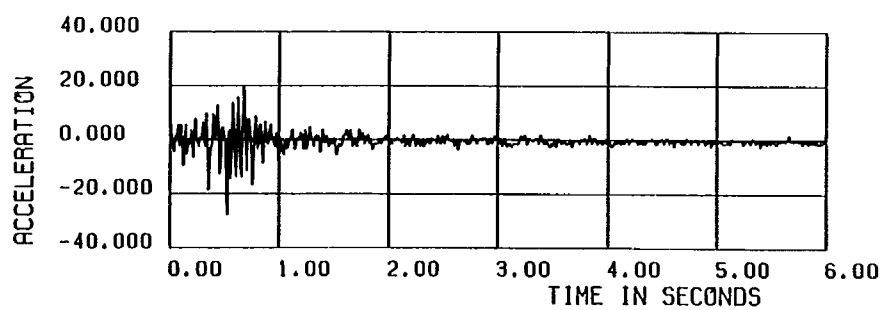
Fig. 3.13 Aftershock of October 11~21, 1984 at the crest of Makio Dam
(by P. W. R. I.)



Up/Downstream



Dam axis



Vertical

Fig. 3.12 Aftershock of October 9, 1984 at the foundation of Makio Dam
(by P. W. R. I.)

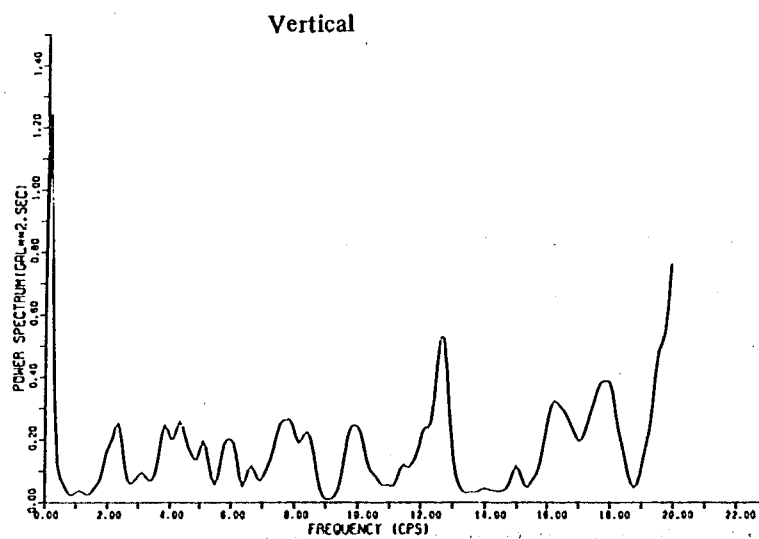
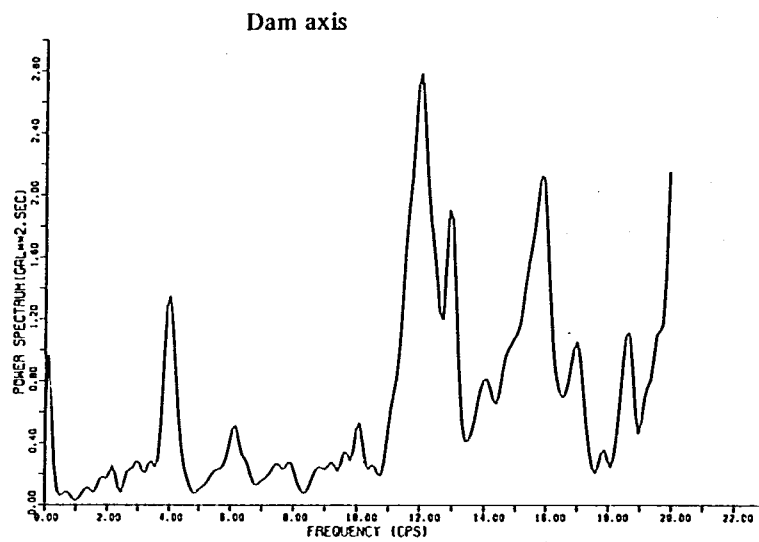
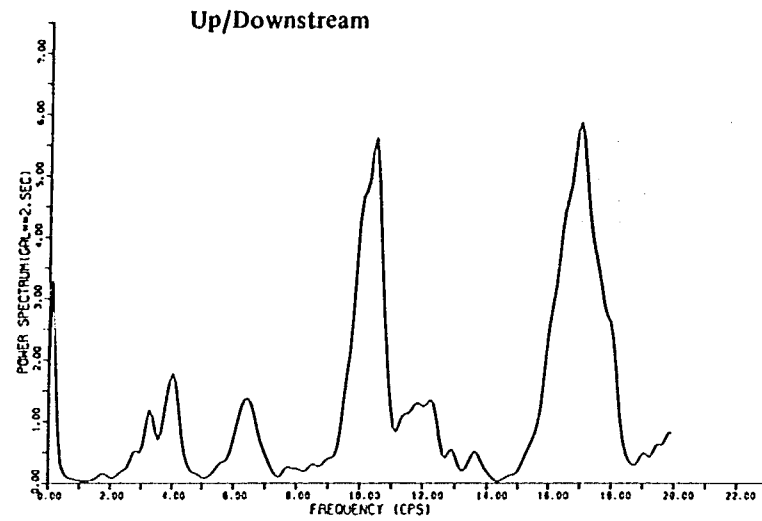


Fig. 3.14 Power spectrum of aftershock of October 9, 1984 at Makio Dam

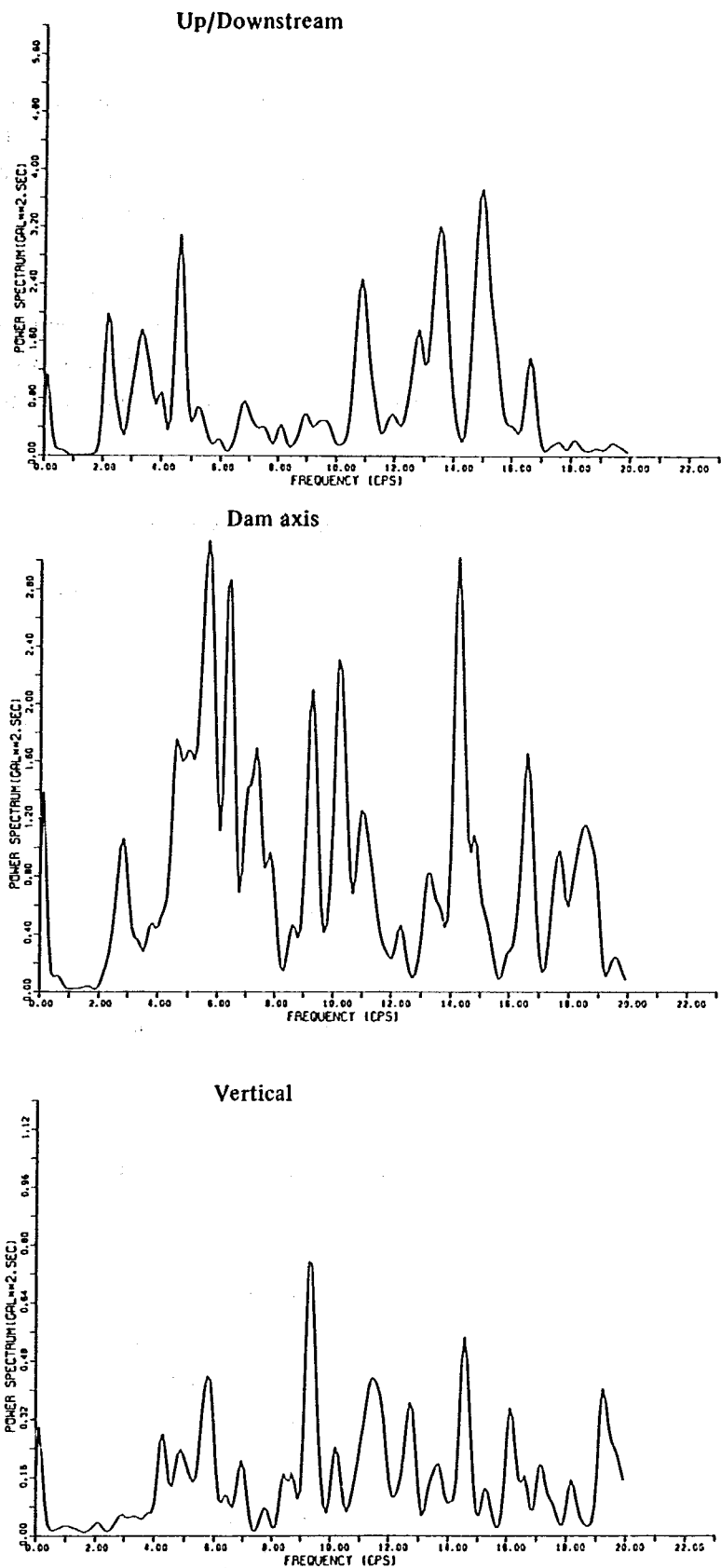


Fig. 3.15 Power spectrum of aftershock of October 11~21, 1984 at Makio

(2) Takane No.1 Dam

This is a 133 m high concrete arch dam. The general description and the installation positions of the seismographs are shown in Table 3.2 and Figure 3.19 respectively. The epicentral distance from Takane No.1 Dam is 27 km and the water level during the earthquake was at an elevation of 1,057.21 m. The seismographs were placed at the dam crest and the right abutment, and the maximum accelerations are 184 gal (up/downstream direction) and 72 gal (cross canyon direction), respectively (see Figures 3.20~3.22).

(3) Nagawado Dam

This is a 155 m high concrete arch dam. The general description is shown in Table 3.3. The arrangement of seismographs is shown in Figure 3.23. The seismographs are installed at four positions on the dam foundation and at four positions on the dam body. The maximum accelerations are 246 gal (E-W component) at the dam body, E-W component of 28 gal and N-S component of 17 gal, both at the dam foundation (see Figures 3.24~3.27).

Table 3.1 General description of Iwaya Dam

Engineering	Water Resources Development Corp.
Year of completion	1977
River	Mase, tr. Kiso
Nearest city	Minokamo
Type	Rockfill
Height	128 m
Crest length	368 m
Volume content of dam	5,600,000 m ³
Gross capacity of reservoir	173,500,000 m ³
Purpose	Flood control, Water supply, Irrigation, Hydroelectric

Table 3.2 General description of Takane No.1 Dam

Year of completion	1969
River	Hida, tr. Kiso
Nearest city	Takayama
Type	Concrete Arch
Height	133 m
Crest length	277 m
Volume content of dam	330,000 m ³
Gross capacity of reservoir	43,600,000 m ³
Purpose	Hydroelectric
Engineering	Chube Electric Power Co.

Table 3.3 General description of Nagawado Dam and Midono Dam

	Nagawado Dam	Midono Dam
Year of completion	1969	1969
River	Azumi, tr. Shinano	Azumi, tr. Shinano
Nearest ciyt	Matsumoto	Matsumoto
Type	Concrete Arch	Concrete Arch
Height	155 m	96 m
Crest length	356 m	343 m
Volume content of dam	672,000 m ³	302,000 m ³
Gross capacity of reservoir	123,000,000 m ³	15,100,000 m ³
Purpose	Hydroelectric	Hydroelectric
Engineering	Tokyo Electric Power Co.	Tokyo Electric Power Co.

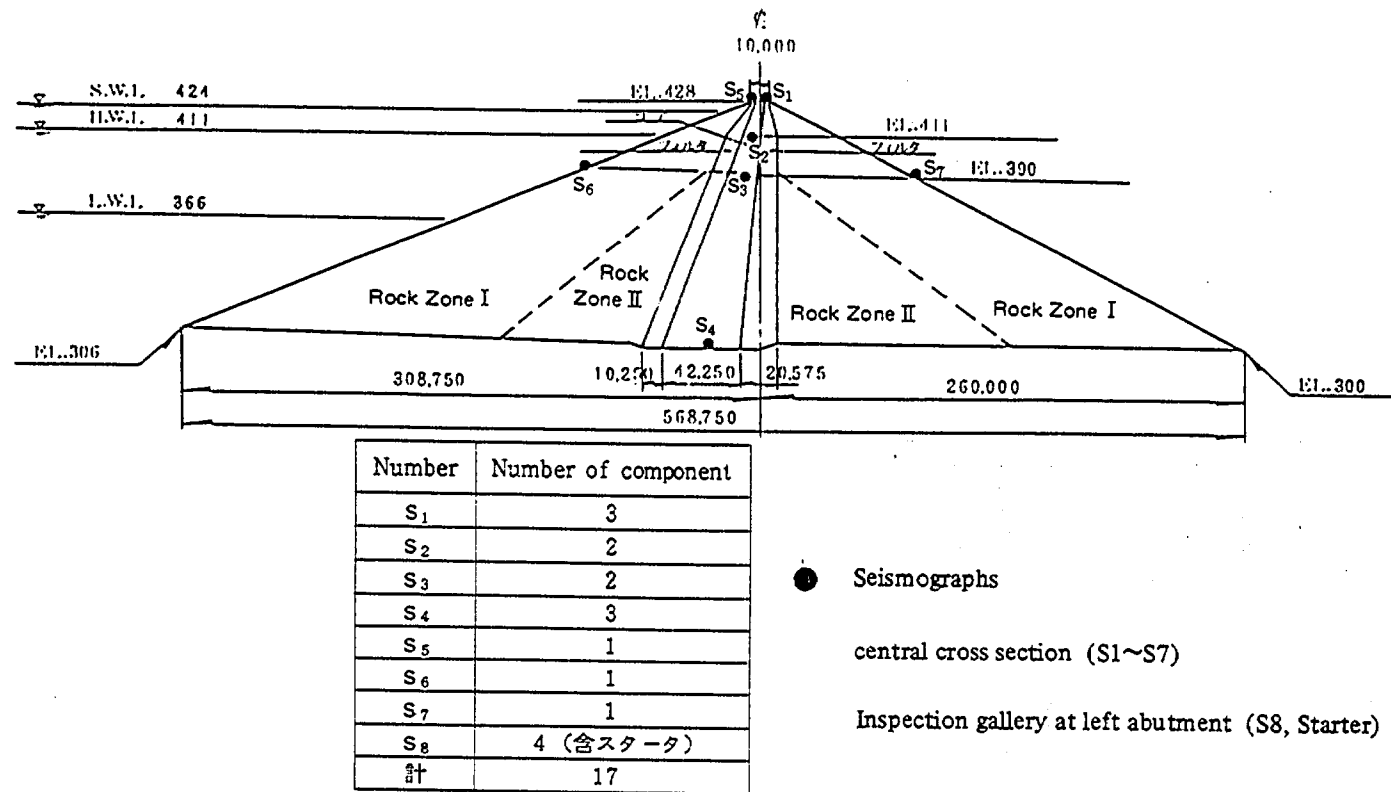


Fig. 3.16 Arrangement of seismographs (Iwaya Dam)

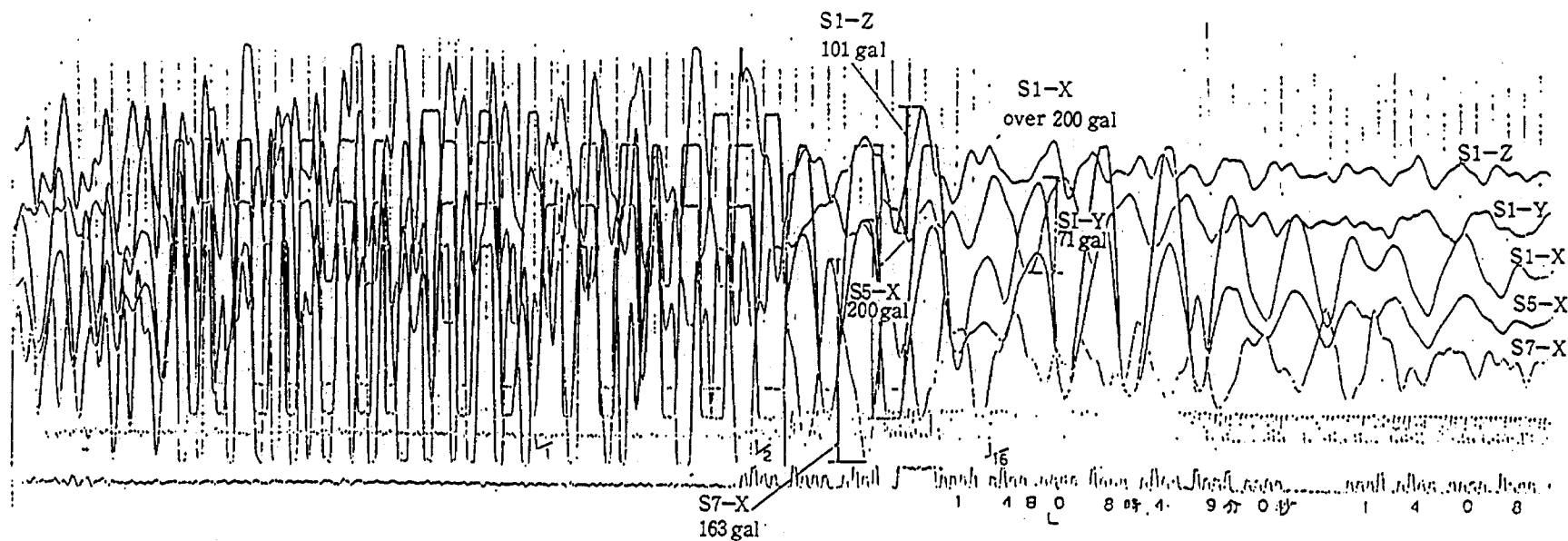
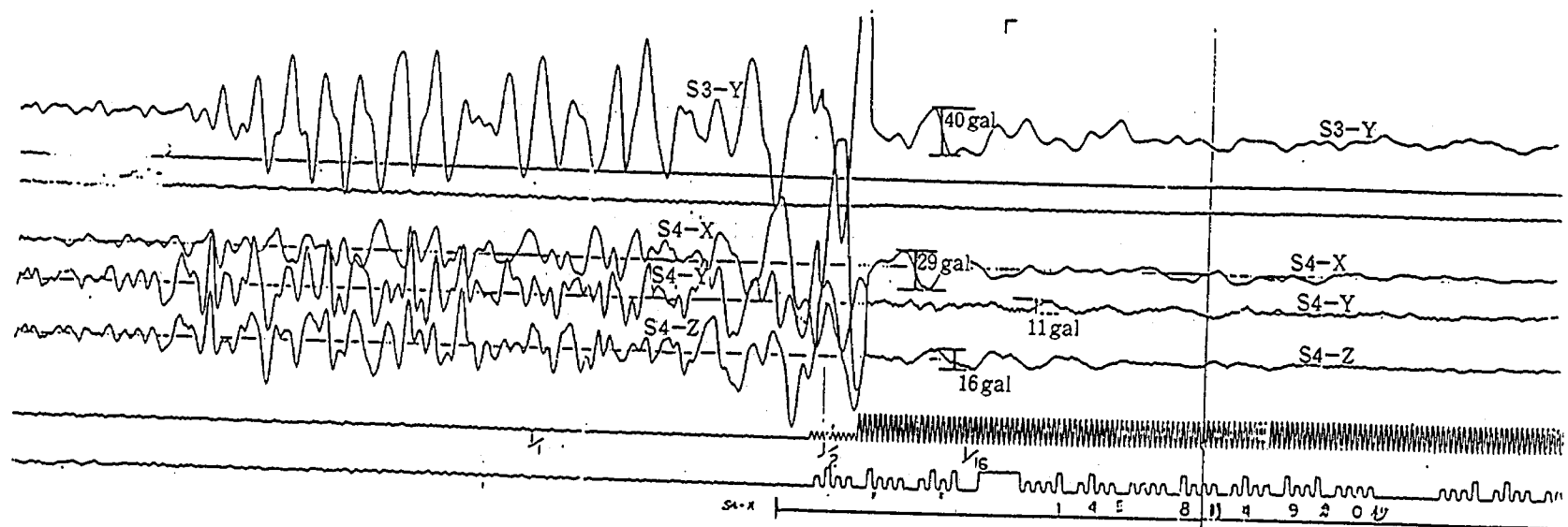
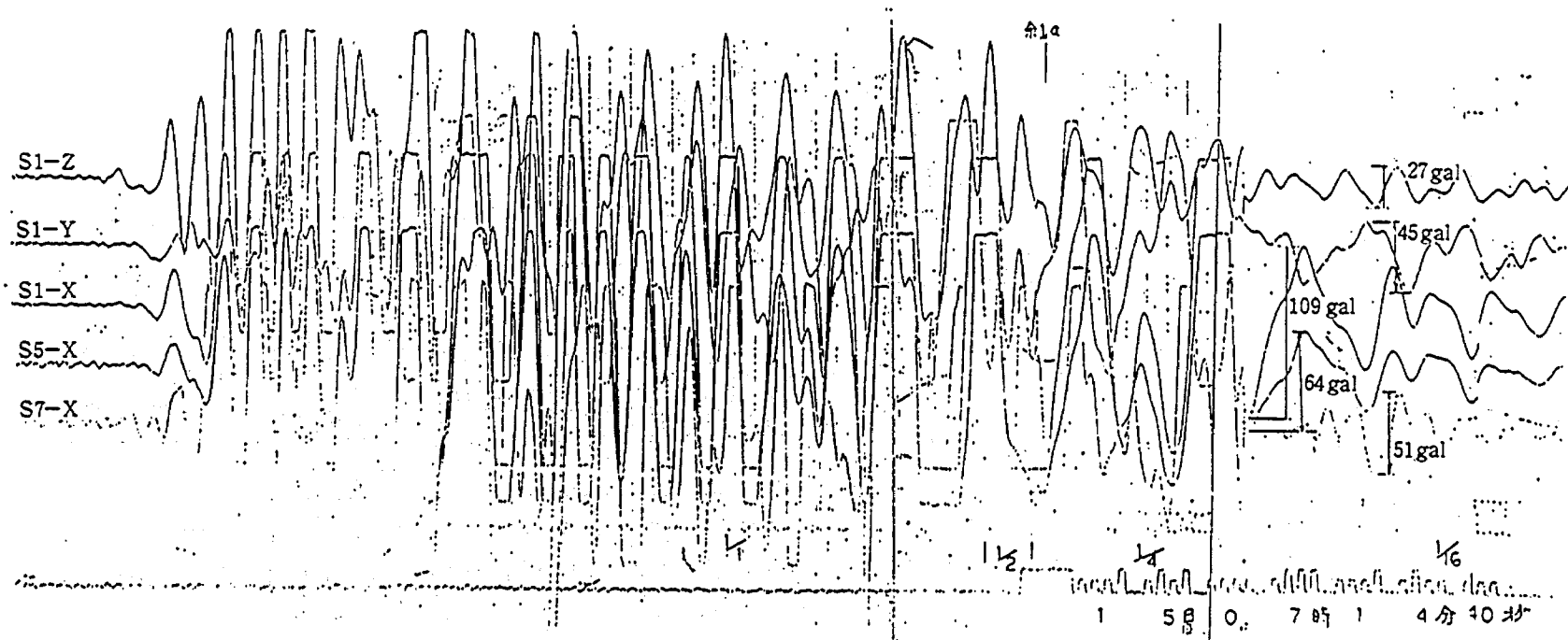


Fig. 3.17(a) Acceleration of the Western Nagano Earthquake at Iwaya Dam
(Courtesy of Water Resources Development Corp.)

**Fig. 3.17(b) Acceleration of the western Nagano Earthquake at Iwaya Dam
(Courtesy of water Resources Development Corp.)**





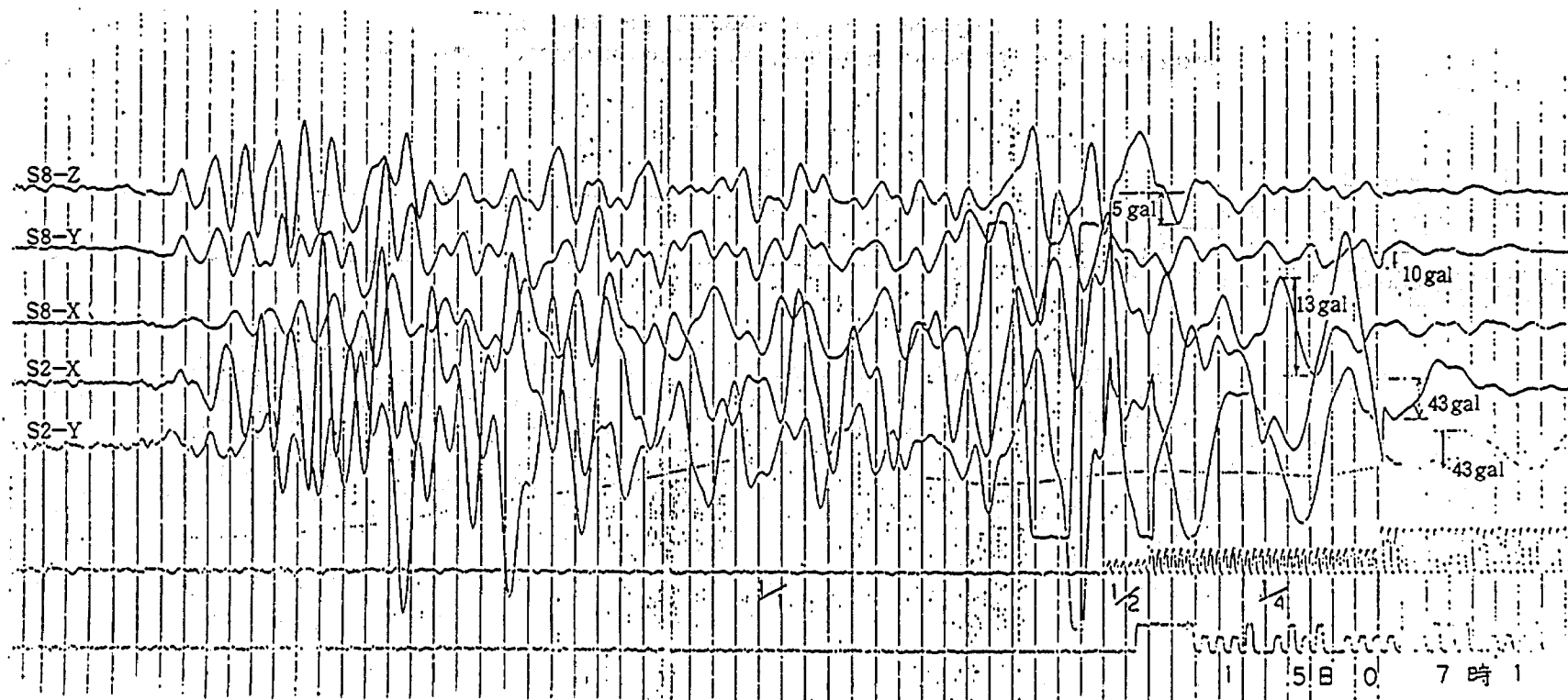


Fig. 3.18(b) Acceleration of the after shock of September 15, 1984 at Iwaya Dam
(Courtesy of Water Resources Development Corp.)

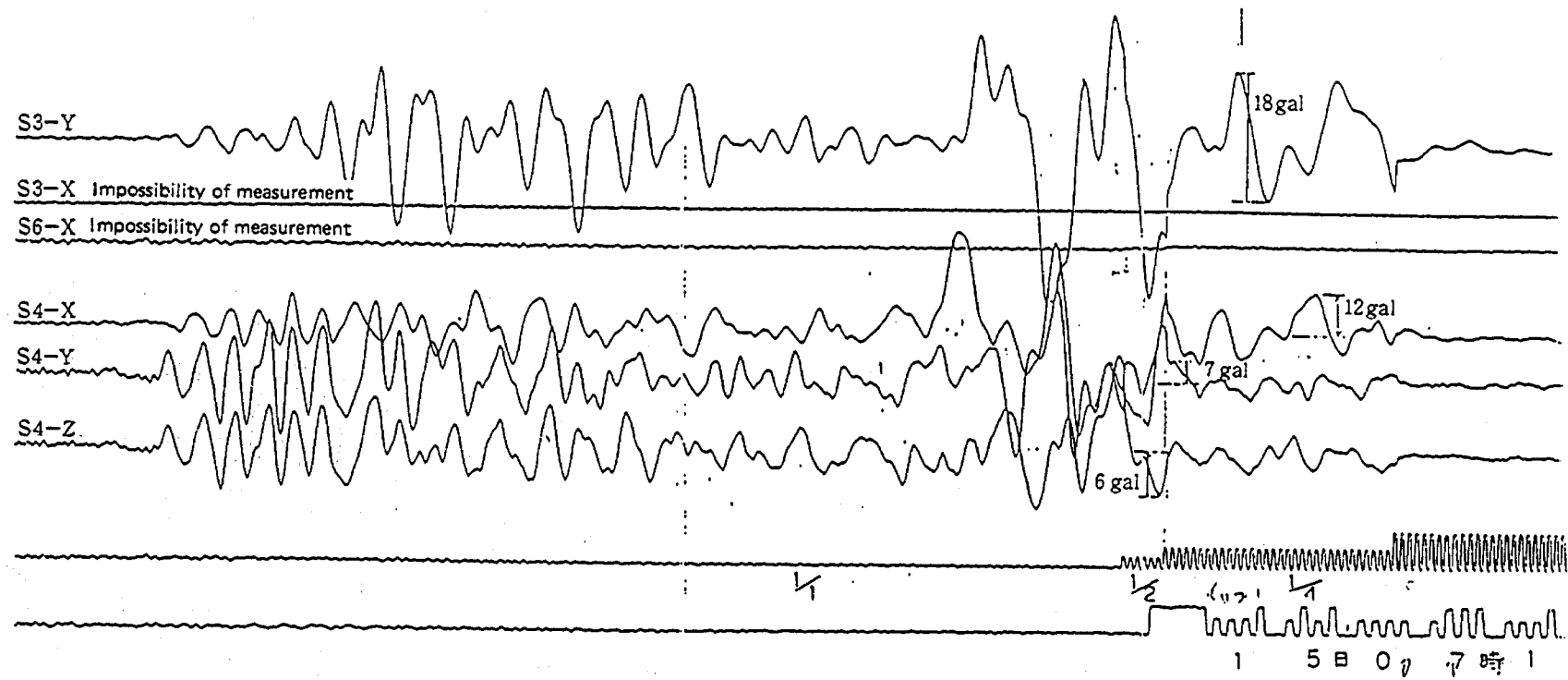


Fig. 3.18(c) Acceleration of the aftershock of September 15, 1984 at Iwaya Dam
(Courtesy of Water Resources Development Corp.)

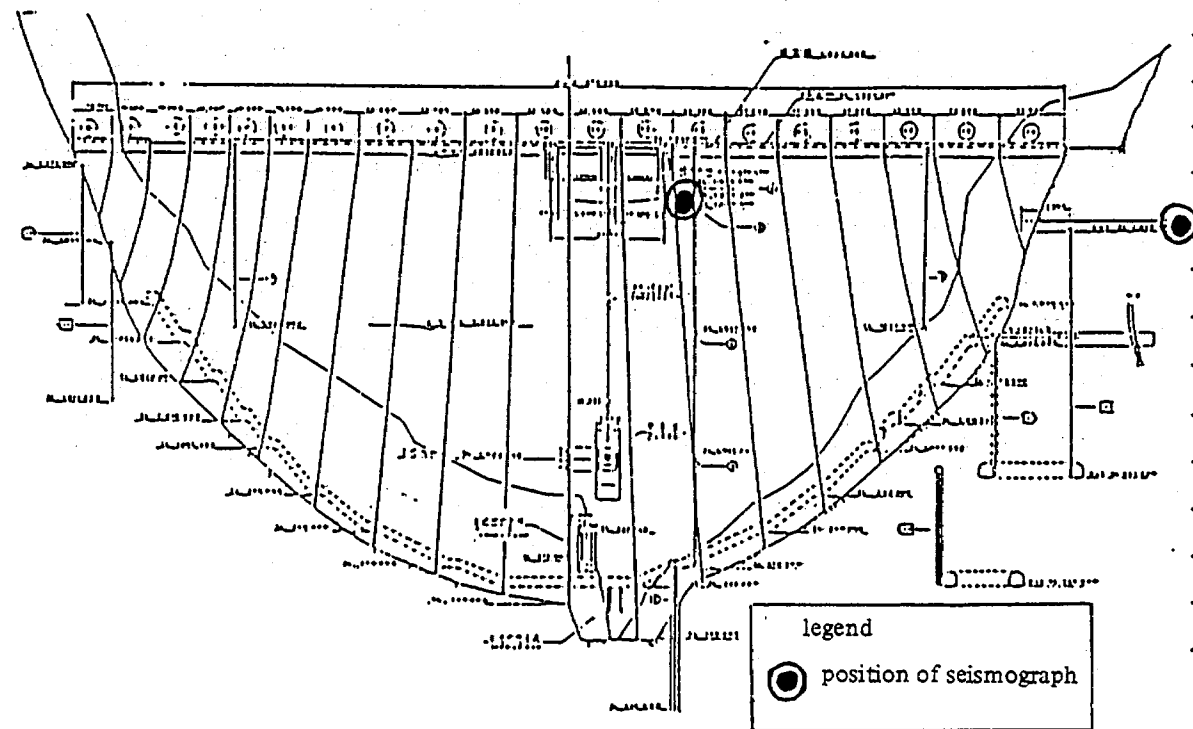


Fig. 3.19 Arrangement of seismographs (Takane No.1 Dam)

Water level is 1,057.21 m during earthquake

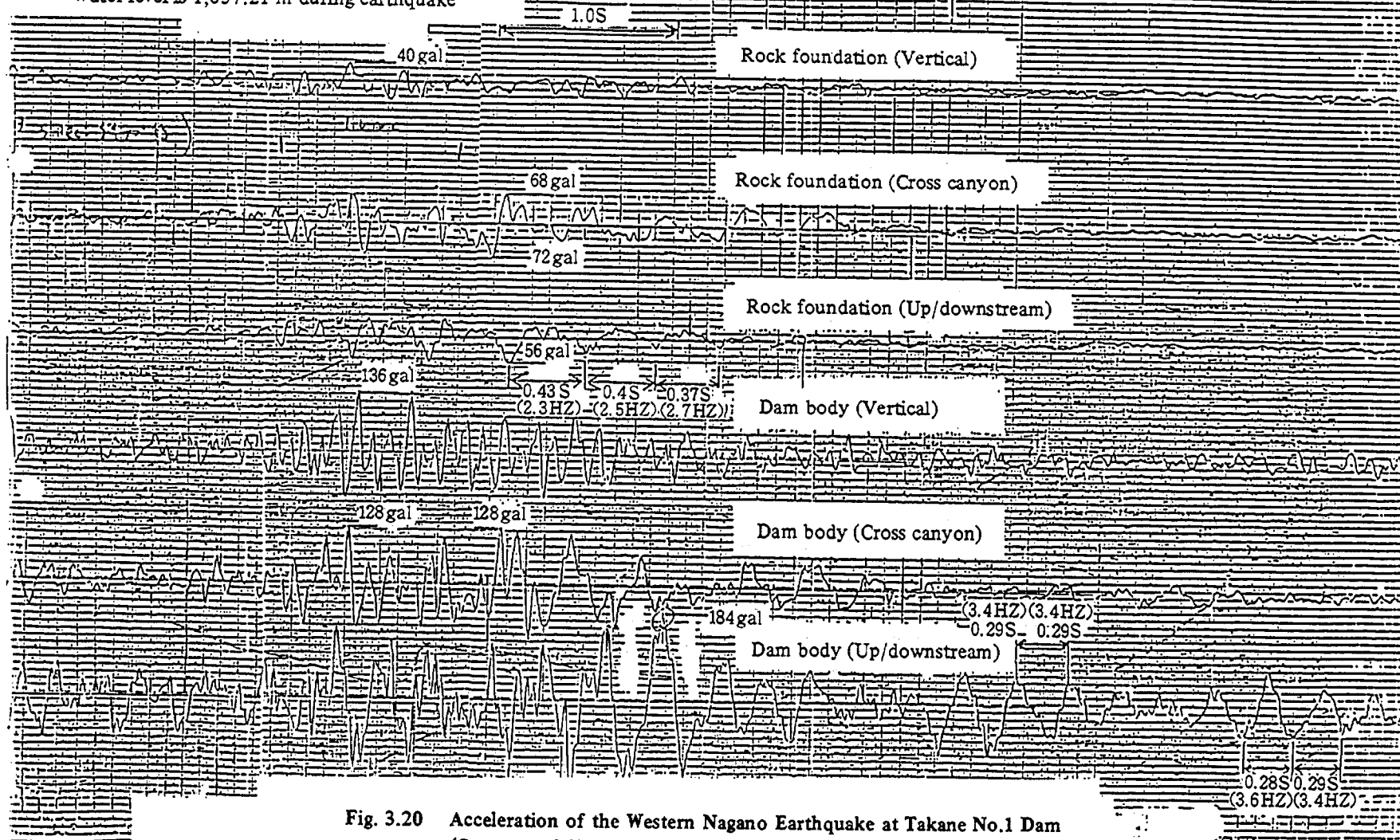


Fig. 3.20 Acceleration of the Western Nagano Earthquake at Takane No.1 Dam
(Courtesy of Chubu electric power Co.)

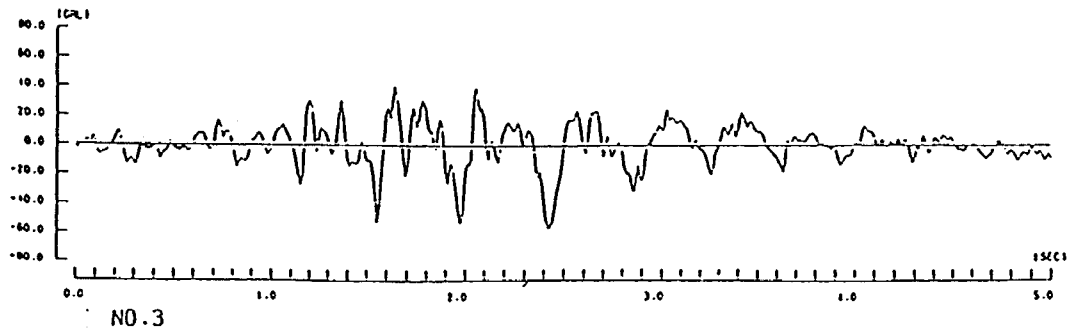


Fig. 3.21(a) Acceleration of the Western Nagano Earthquake at Takane No.1 Dam (Horizontal Up/downstream component at foundation) (Courtesy of Chubu electric power Co.)

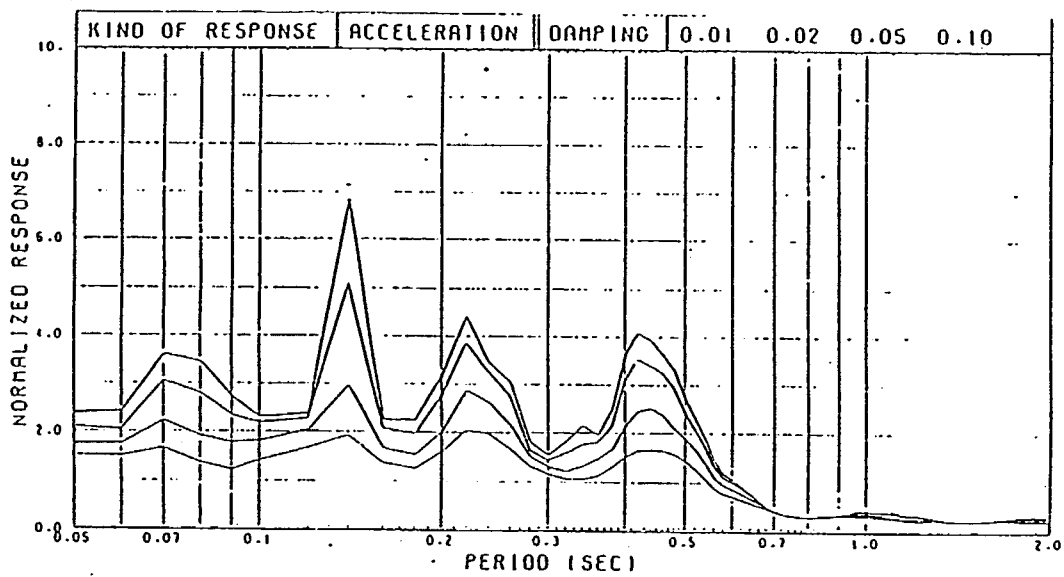


Fig. 3.21(b) Normalized response spectrum of the Western Nagano Earthquake at Takane No.1 Dam (Horizontal Up/downstream component at foundation) (Courtesy of Chubu electric power Co.)

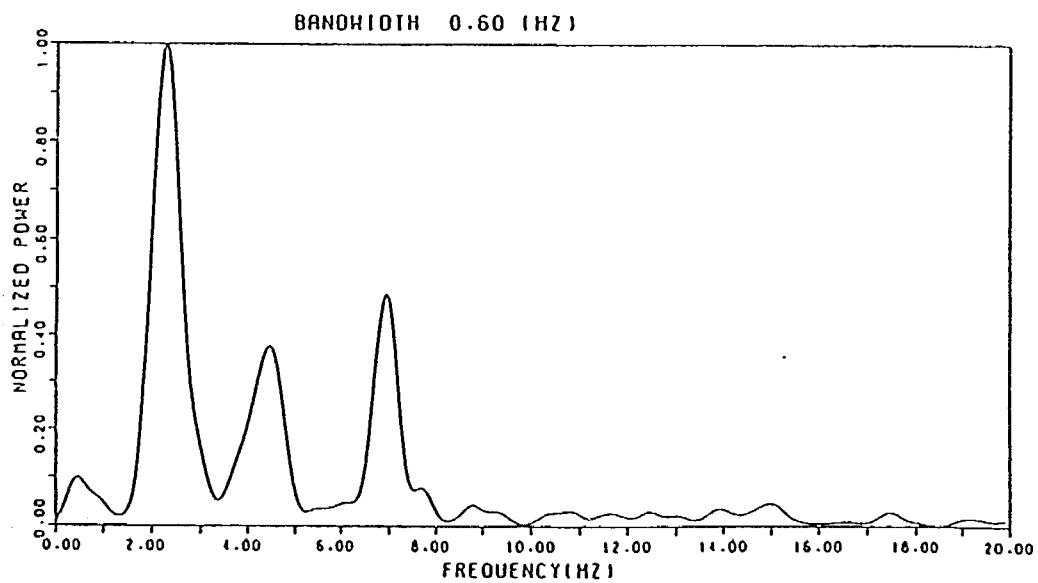


Fig. 3.21(c) Power spectrum of the Western Nagano Earthquake at Takane No.1 Dam (Horizontal Up/downstream component at foundation) (Courtesy of Chubu electric power Co.)

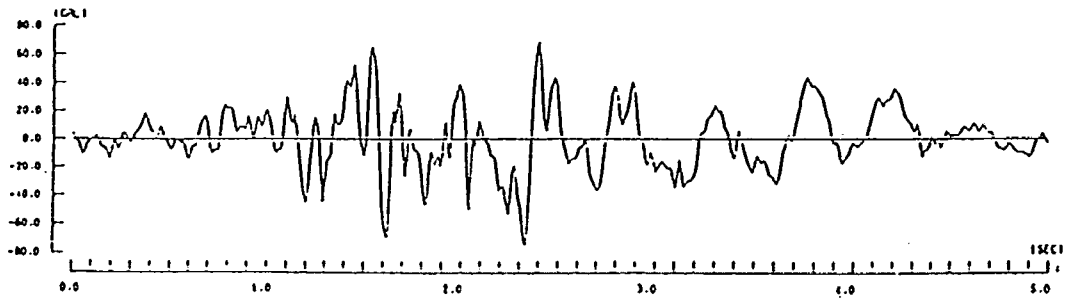


Fig. 3.21(d) Acceleration of the Western Nagano Earthquake at Takane No.1 Dam (Horizontal Cross canyon component at foundation) (Courtesy of Chubu electric power Co.)

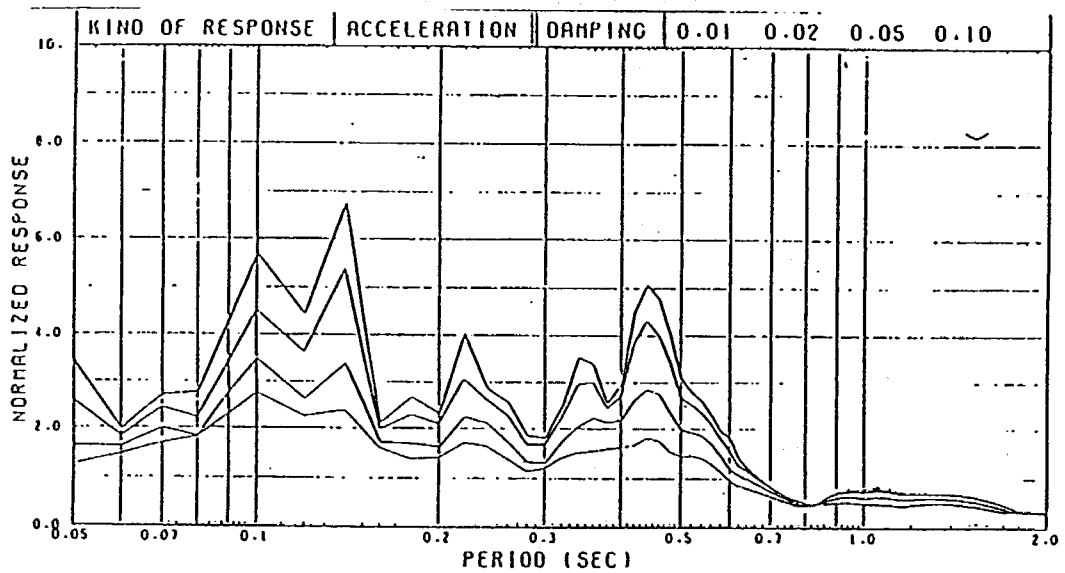


Fig. 3.21(e) Normalized response spectrum of the Western Nagano Earthquake at Takane No.1 Dam (Horizontal Cross canyon Component at foundation) (Courtesy of Chubu electric power Co.)

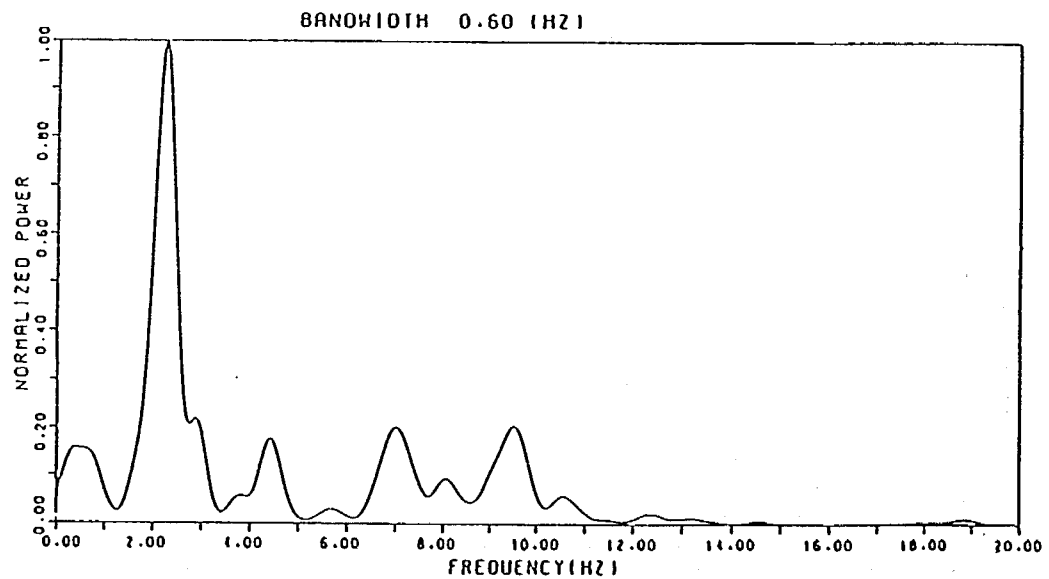


Fig. 3.21(f) Power spectrum of the Western Nagano Earthquake at Takane No.1 Dam (Horizontal Cross canyon component at foundation) (Courtesy of Chubu electric power Co.)

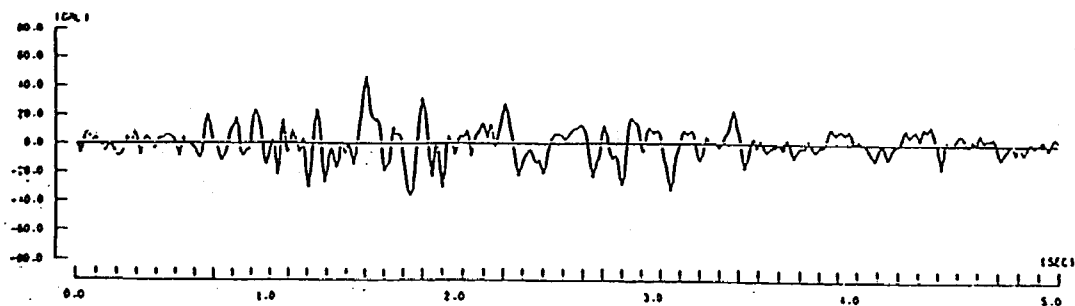


Fig. 3.21(g) Acceleration of the Western Nagano Earthquake at Takane No.1 Dam (Vertical component at foundation) (Courtesy of Chubu electric power Co.)

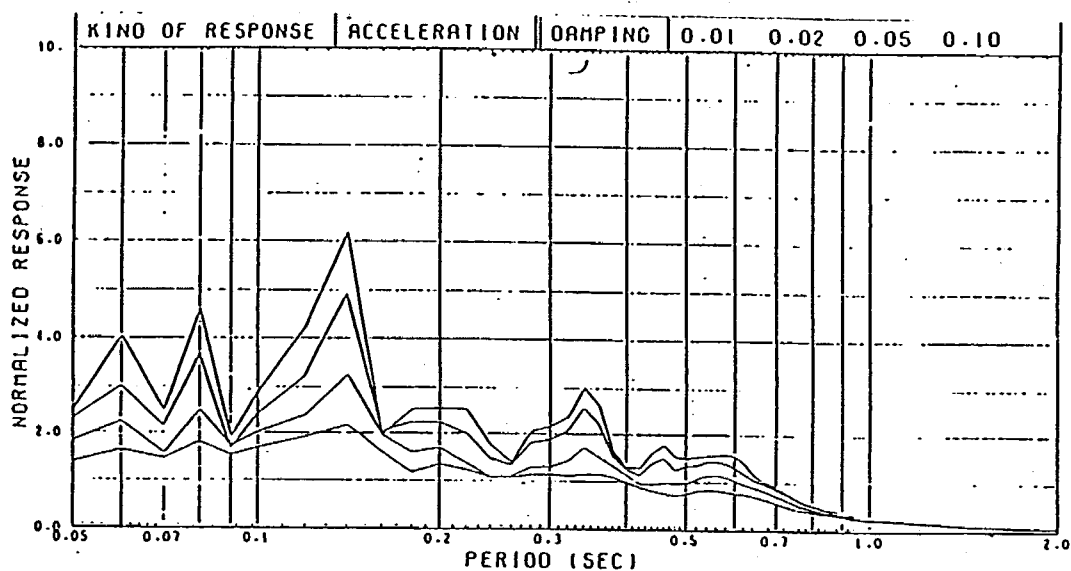


Fig. 3.21(h) Normalized response spectrum of the Western Nagano Earthquake at Takane No.1 Dam (Vertical component at foundation) (Courtesy of Chubu electric power Co.)

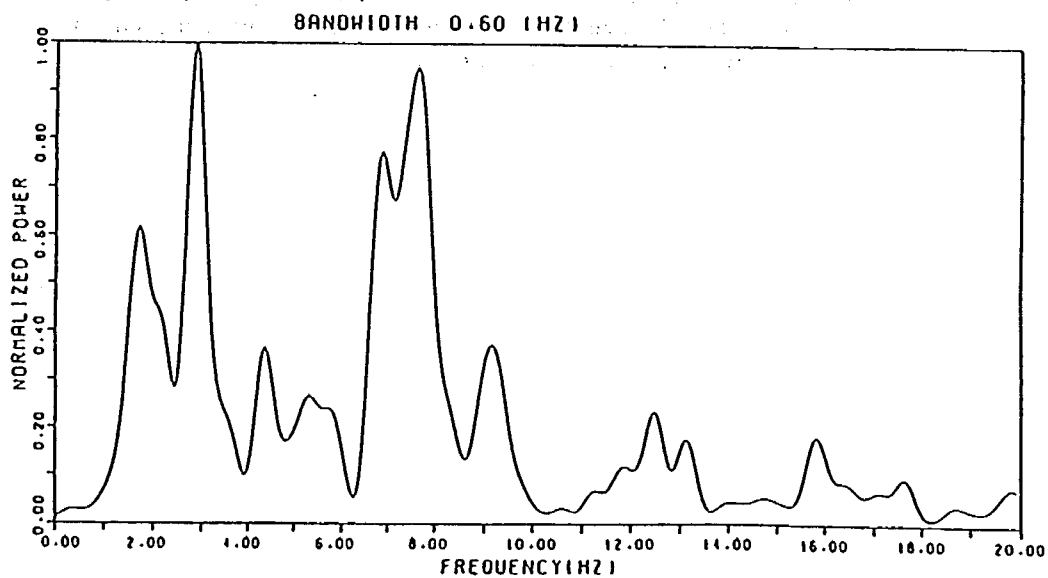


Fig. 3.21(i) Power spectrum of the Western Nagano Earthquake at Takane No.1 Dam (Vertical component at foundation) (Courtesy of Chubu electric power Co.)

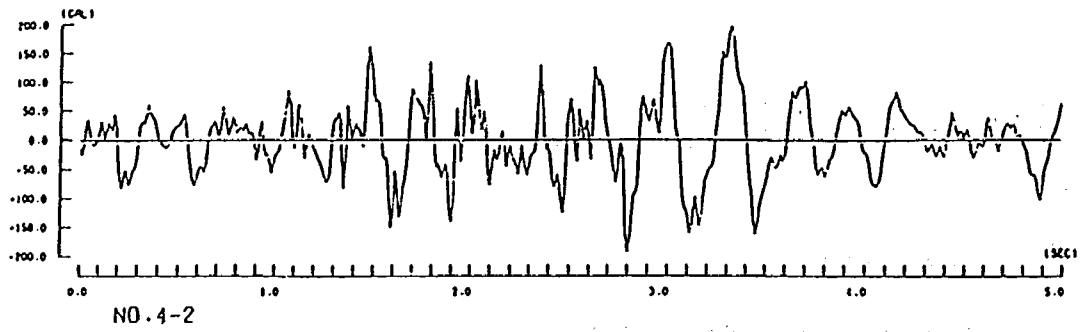


Fig. 3.21(j) Acceleration of the Western Nagano Earthquake at Takane No.1 Dam (Horizontal Up/downstream component at dam body)
(Courtesy of Chubu electric power Co.)

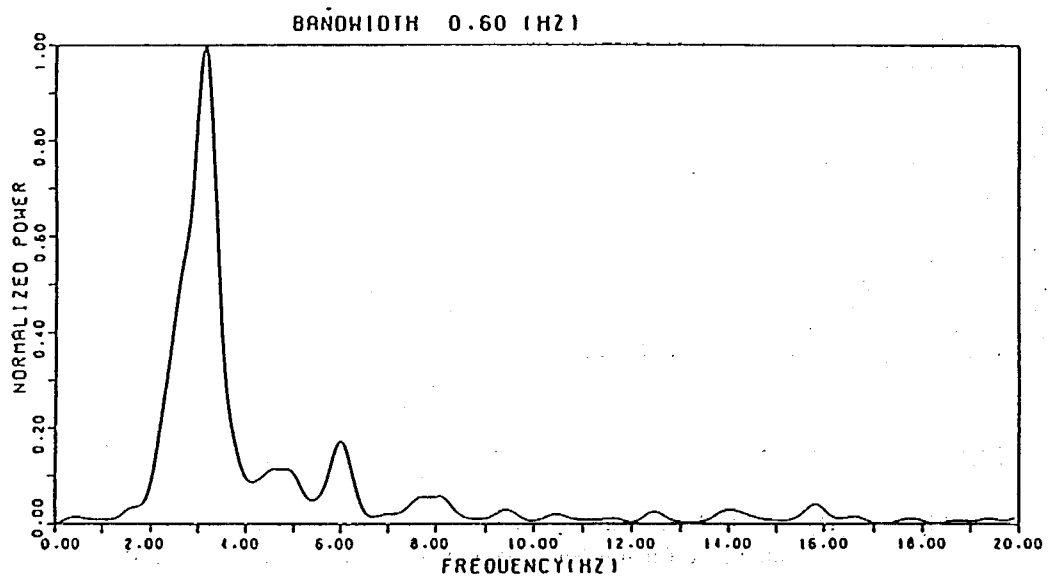


Fig. 3.21(k) Power spectrum of the Western Nagano Earthquake at Takane No.1 Dam (Horizontal Up/downstream component at dam body)
(Courtesy of Chubu electric power Co.)

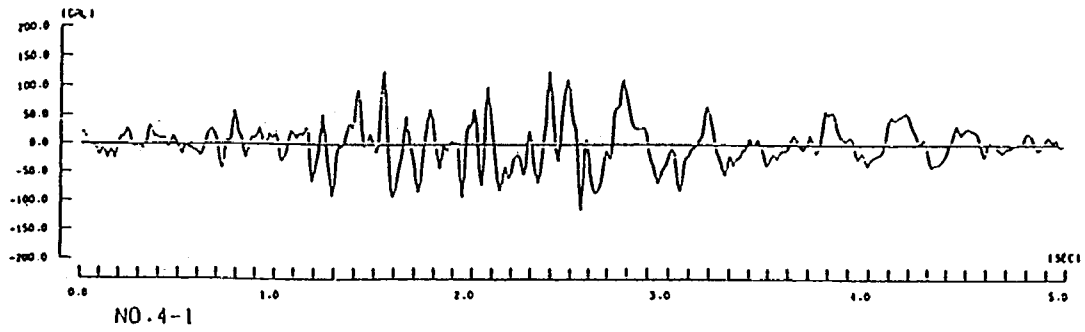


Fig. 3.21(l) Acceleration of the Western Nagano Earthquake at Takane No.1 Dam (Horizontal cross canyon component at dam body)
(Courtesy of Chubu electric power Co.)

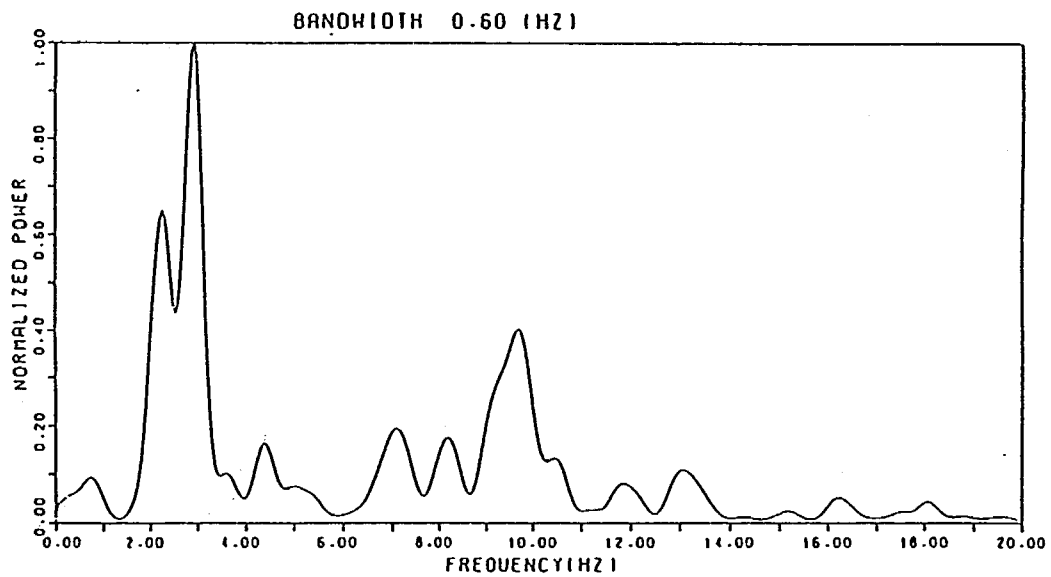


Fig. 3.21(m) Power spectrum of the Western Nagano Earthquake at Takane No.1 Dam (Horizontal cross canyon component at dam body)
(Courtesy of Chubu electric power Co.)

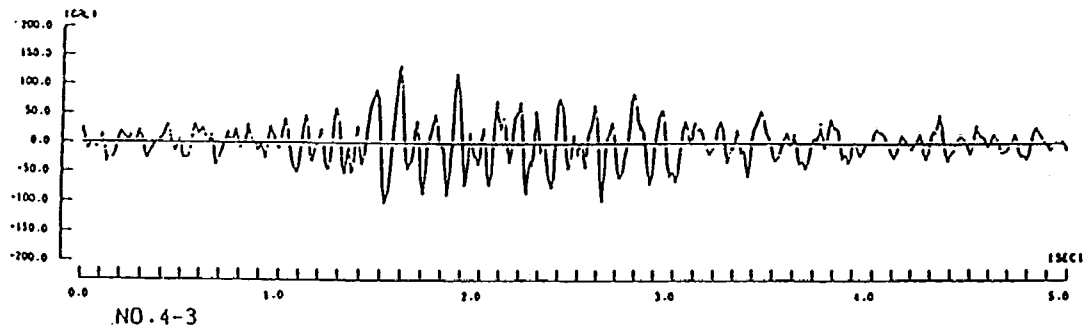


Fig. 3.21(n) Acceleration of the Western Nagano Earthquake at Takane No.1 Dam (Vertical component at dam body)
(Courtesy of Chubu electric power Co.)

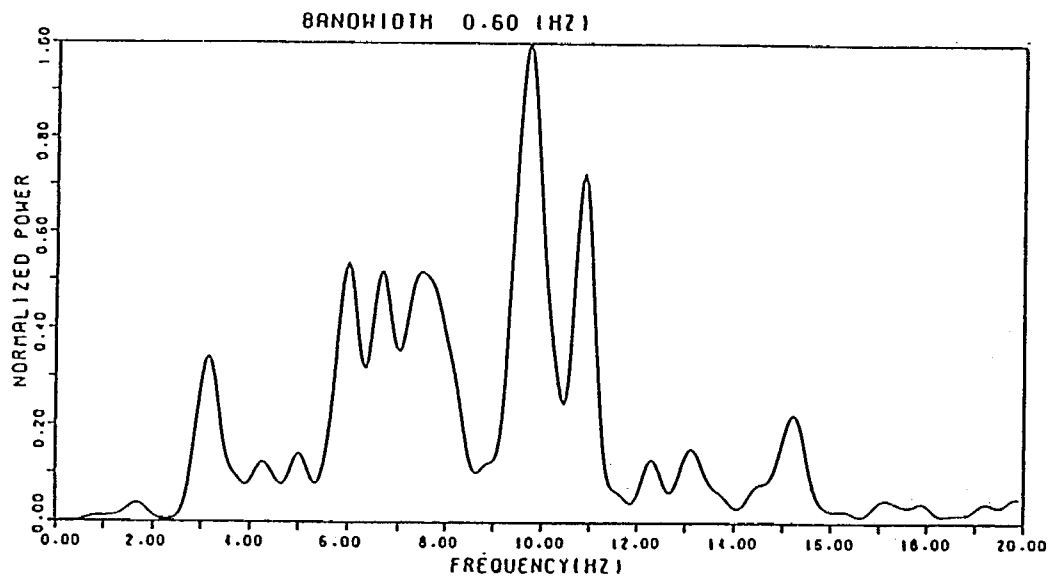


Fig. 3.21(o) Power spectrum of the Western Nagano Earthquake at Takane No.1 Dam (Vertical component at dam body)
(Courtesy of Chubu electric power Co.)

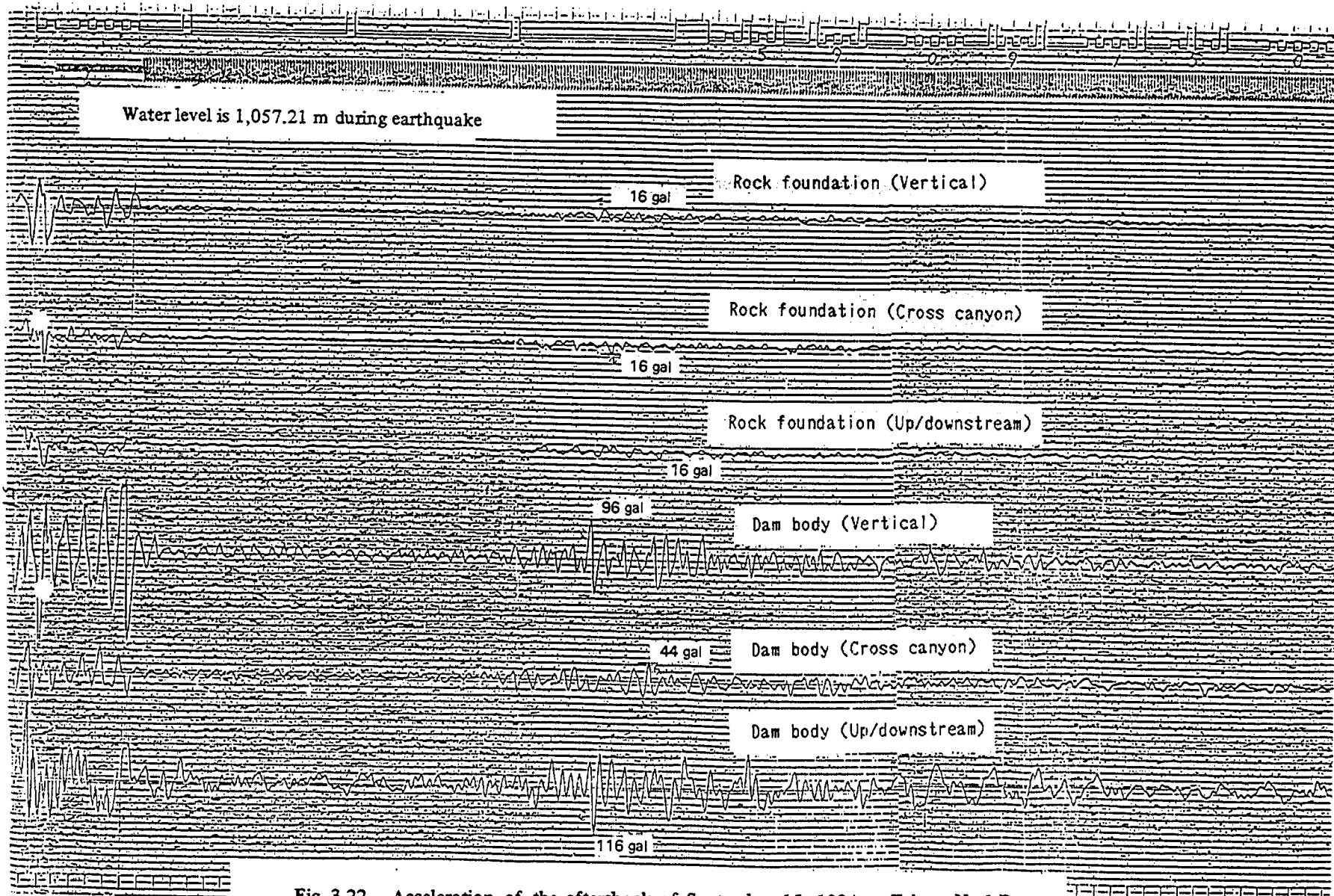


Fig. 3.22 Acceleration of the aftershock of September 15, 1984 at Takane No.1 Dam
(Courtesy of Chubu electric power Co.)

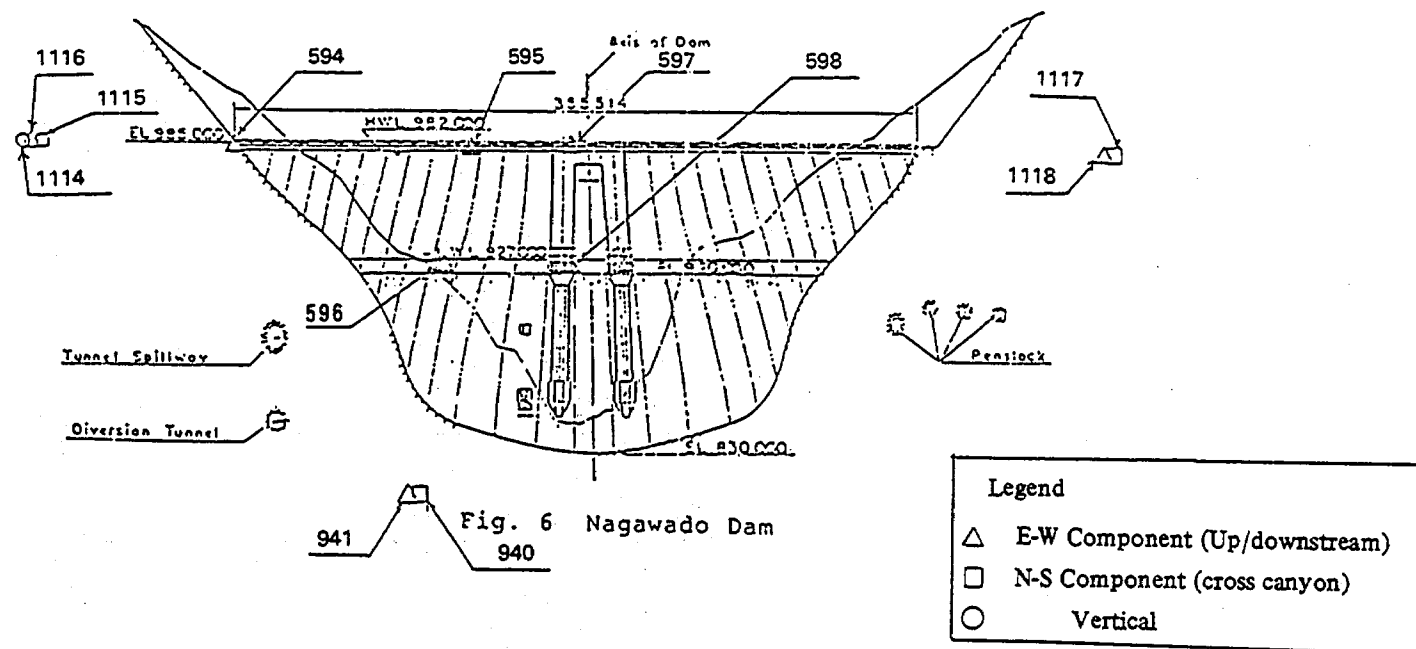
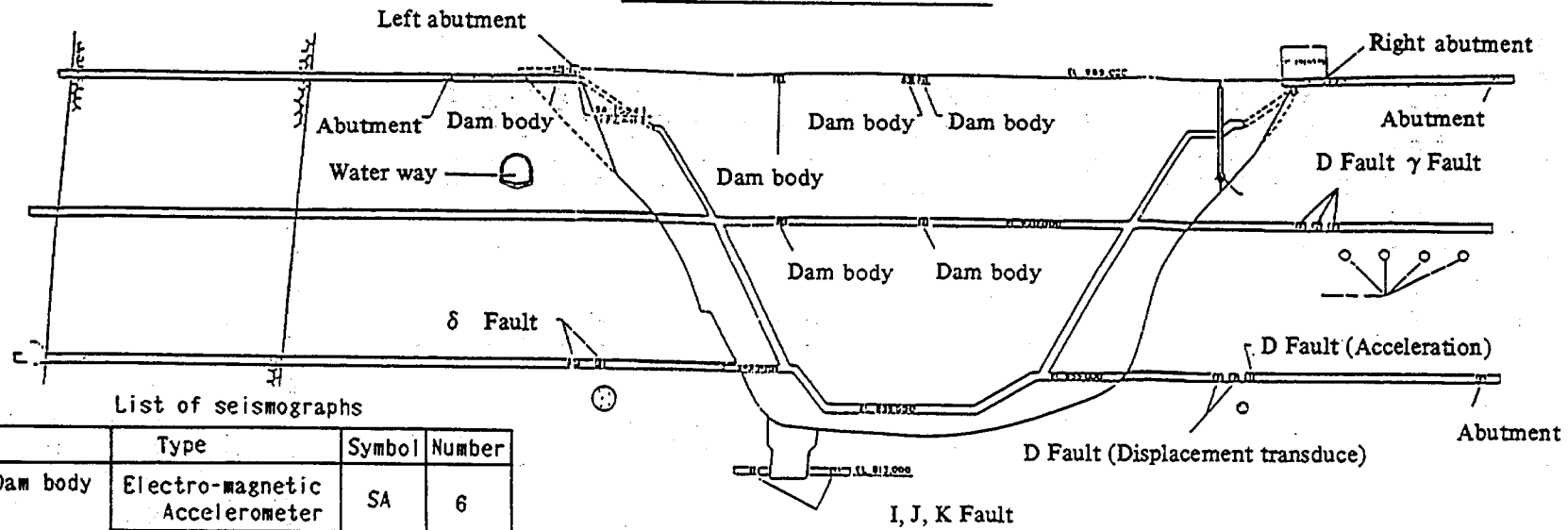


Fig. 3.23 Arrangement of seismographs (Nagawado Dam)

Upstream view, Development



List of seismographs

	Type	Symbol	Number
Dam body	Electro-magnetic Accelerometer	SA	6
	Electro-magnetic Accelerometer	SS	2
	total		8
Displaced part of Fault	Electro-magnetic Accelerometer	SA	16
	Electro-magnetic Displacement Transducer	SP	3
	total		19
Abutment	Electro-magnetic Accelerometer	SA	7
The sun total			34

Ground plan

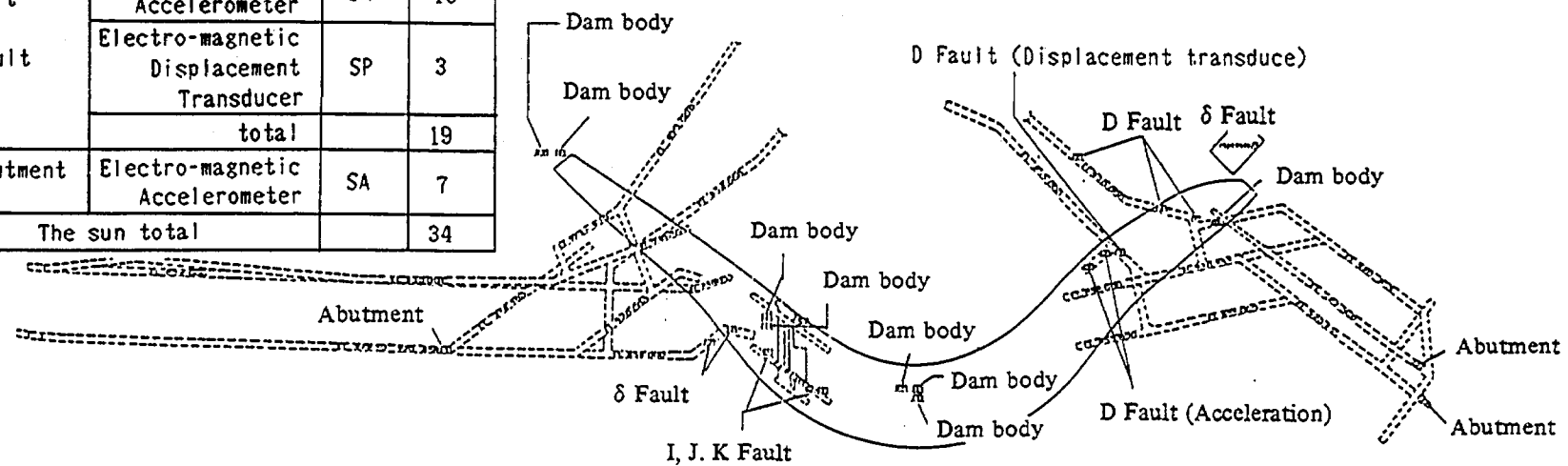


Fig. 3.24 Detail of distribution of earthquake monitoring device in Nagawado Dam

Table 3.4 Lists of the maximum acceleration of the Western Nagano Earthquake (Nagawado Dam, Courtesy of Tokyo Electric Power Co.)

NO.	Component	After Correction of sensitivity Acceleration: gal
594	R	39.9 (2.80)
595	R	246.4 (3.14)
596	R	55.2 (3.25)
597	R	199.3 (3.02)
598	R	68.4 (3.07)
599	R	36.2 (3.17)
936	N-S	21.7 (2.85)
938	N-S	20.3 (2.80)
939	E-W	24.1 (3.02)
940	N-S	16.8 (3.17)
941	E-W	28.3 (3.00)
942	N-S	39.6 (3.39)
943	E-W	30.8 (3.43)
944	N-S	28.5 (3.15)
946	N-S	27.3 (3.16)
947	E-W	22.7 (2.69)
948	N-S	23.7 (3.69)
949	E-W	23.7 (3.02)
950	N-S	21.6 (2.67)
951	E-W	22.4 (3.36)
1114	U-D	13.4 (3.19)
1115	N-S	26.8 (3.26)
1116	E-W	22.4 (2.80)
1117	N-S	28.1 (2.85)
1118	E-W	28.4 (3.81)
1119	N-S	25.6 (3.08)
1120	E-W	16.2 (2.95)

Table 3.5 Lists of the maximum acceleration of the aftershock of September 15, 1984 (Nagawado Dam, Courtesy of Tokyo Electric Power Co.)

NO.	Component	After Correction of sensitivity Acceleration: gal
594	R	11.9 (2.22)
595	R	97.0 (2.36)
596	R	18.7 (2.21)
597	R	58.1 (2.62)
598	R	25.9 (2.79)
599	R	9.9 (2.08)
936	N-S	8.7 (2.22)
938)	N-S	8.3 (2.17)
939	E-W	8.3 (2.36)
940	N-S	6.6 (2.20)
941	E-W	9.0 (2.36)
942	N-S	10.6 (2.36)
943	E-W	12.9 (1.63)
944	N-S	8.0 (2.03)
946	N-S	7.3 (2.03)
947	E-W	9.6 (2.09)
948	N-S	7.6 (2.47)
949	E-W	11.1 (2.36)
950	N-S	8.1 (2.39)
951	E-W	6.8 (2.07)
1114	U-D	6.1 (2.15)
1115	N-S	9.1 (2.16)
1116	E-W	6.1 (3.09)
1117	N-S	11.4 (2.13)
1118	E-W	9.5 (3.06)
1119	N-S	5.3 (1.98)
1120	E-W	8.9 (2.04)

Table 3.6 Lists of the maximum acceleration of the aftershock of September 15, 1984 (Midono Dam, Courtesy of Tokyo Electric Power Co.)

NO.	Component	After Correction of sensitivity Acceleration: gal
475	E-W	10.2 (0.10)
473	U-D	7.4 (0.41)
474	R	7.0 (0.63)
472	R	()

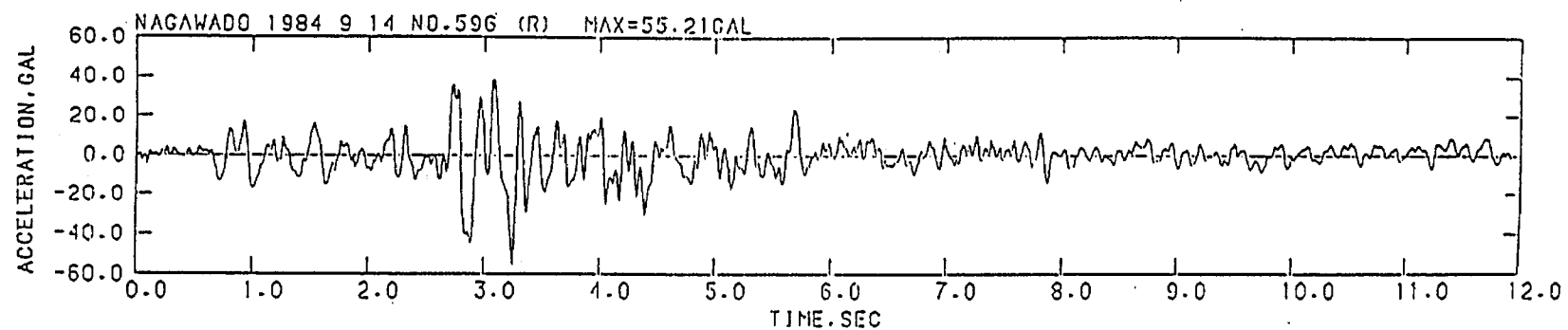
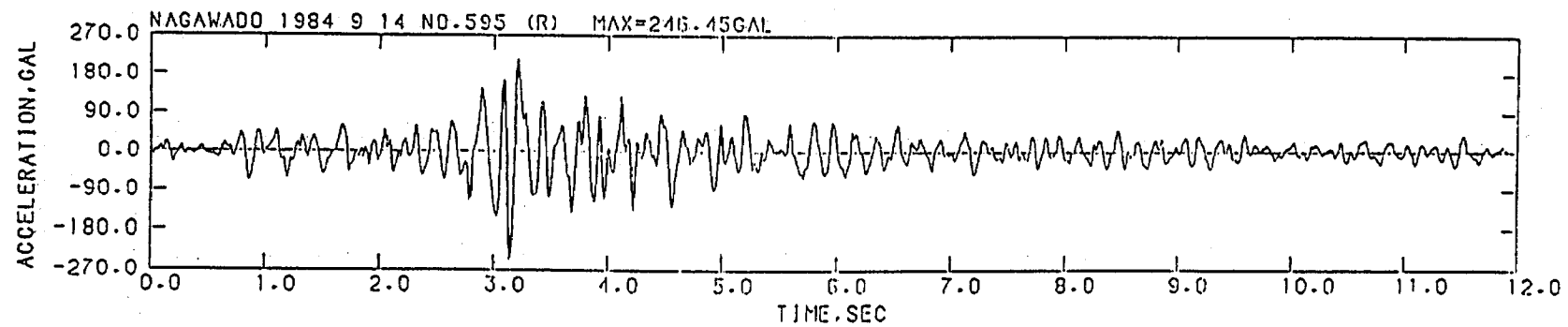
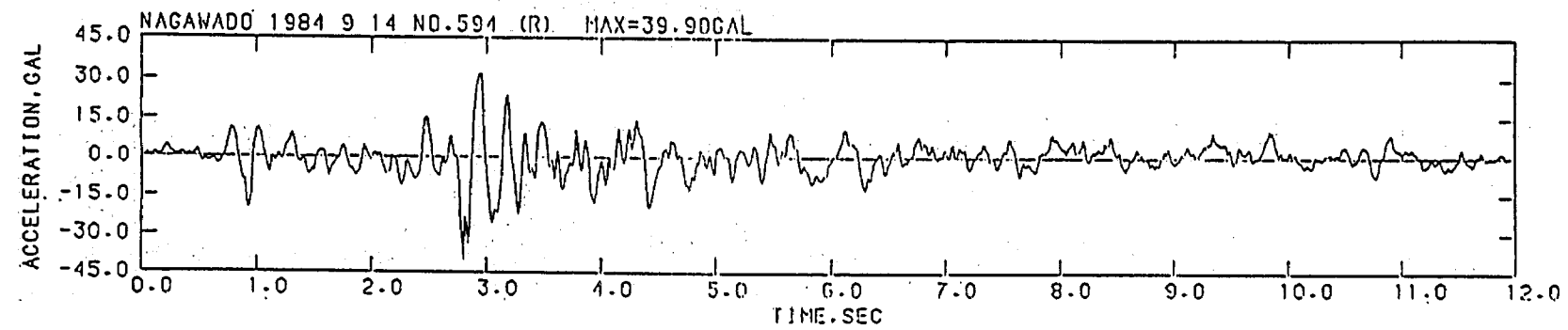


Fig. 3.25(a) Corrected acceleration of the Western Nagano Earthquake at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

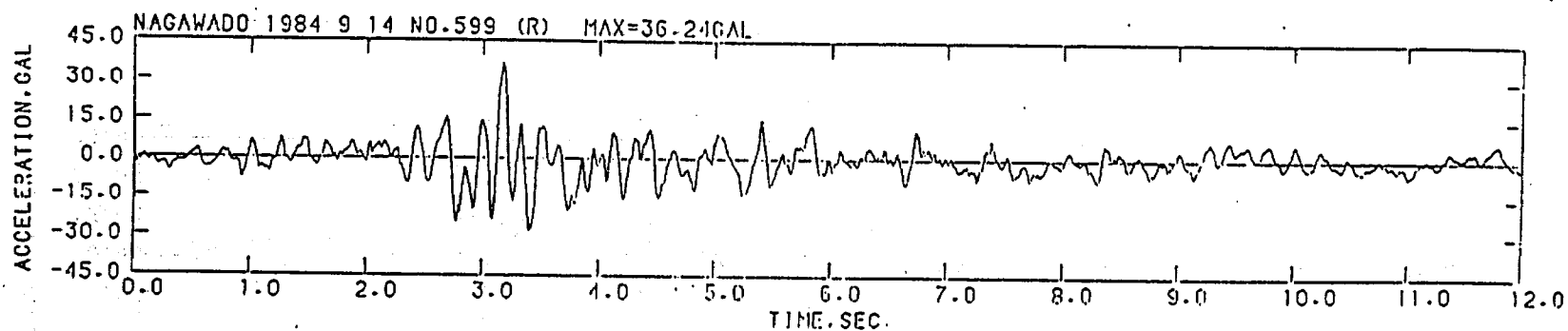
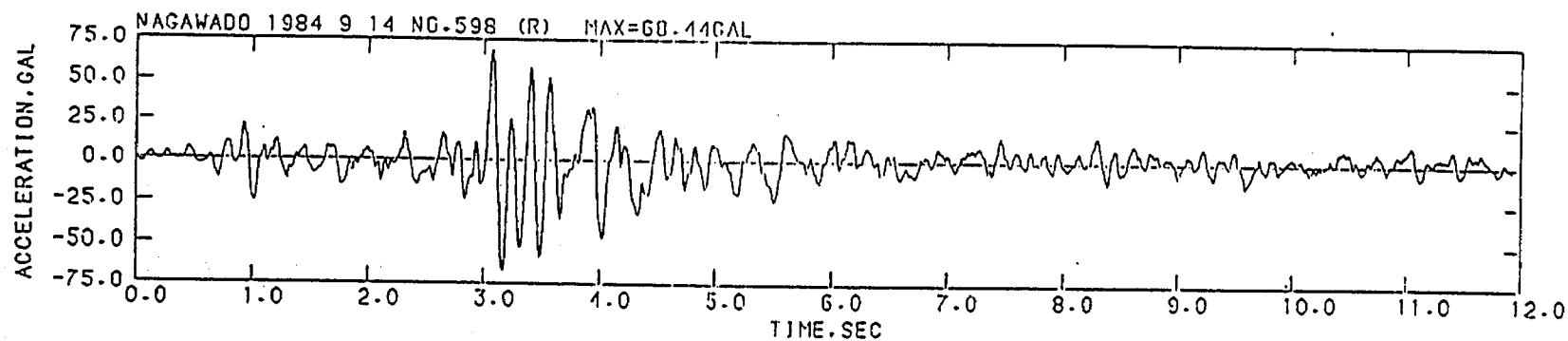
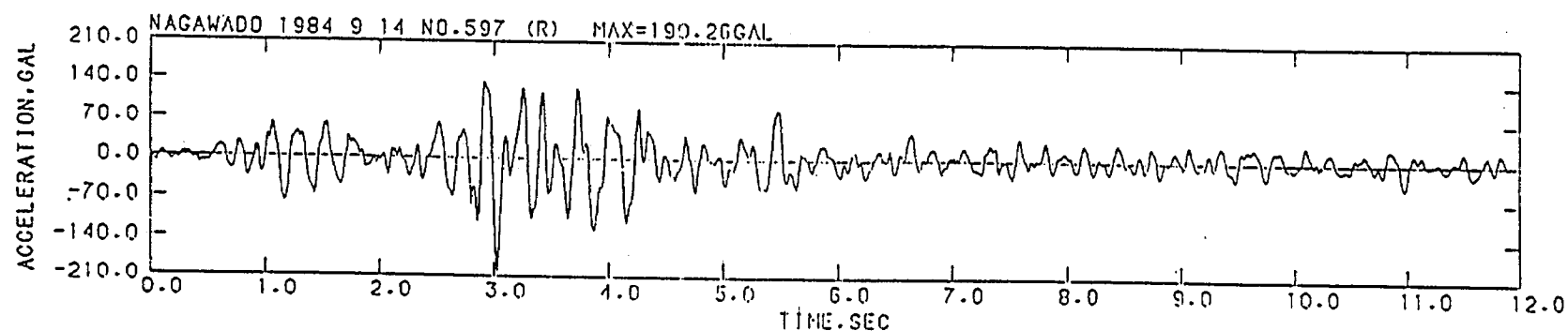


Fig. 3.25(b) Corrected acceleration of the Western Nagano Earthquake at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

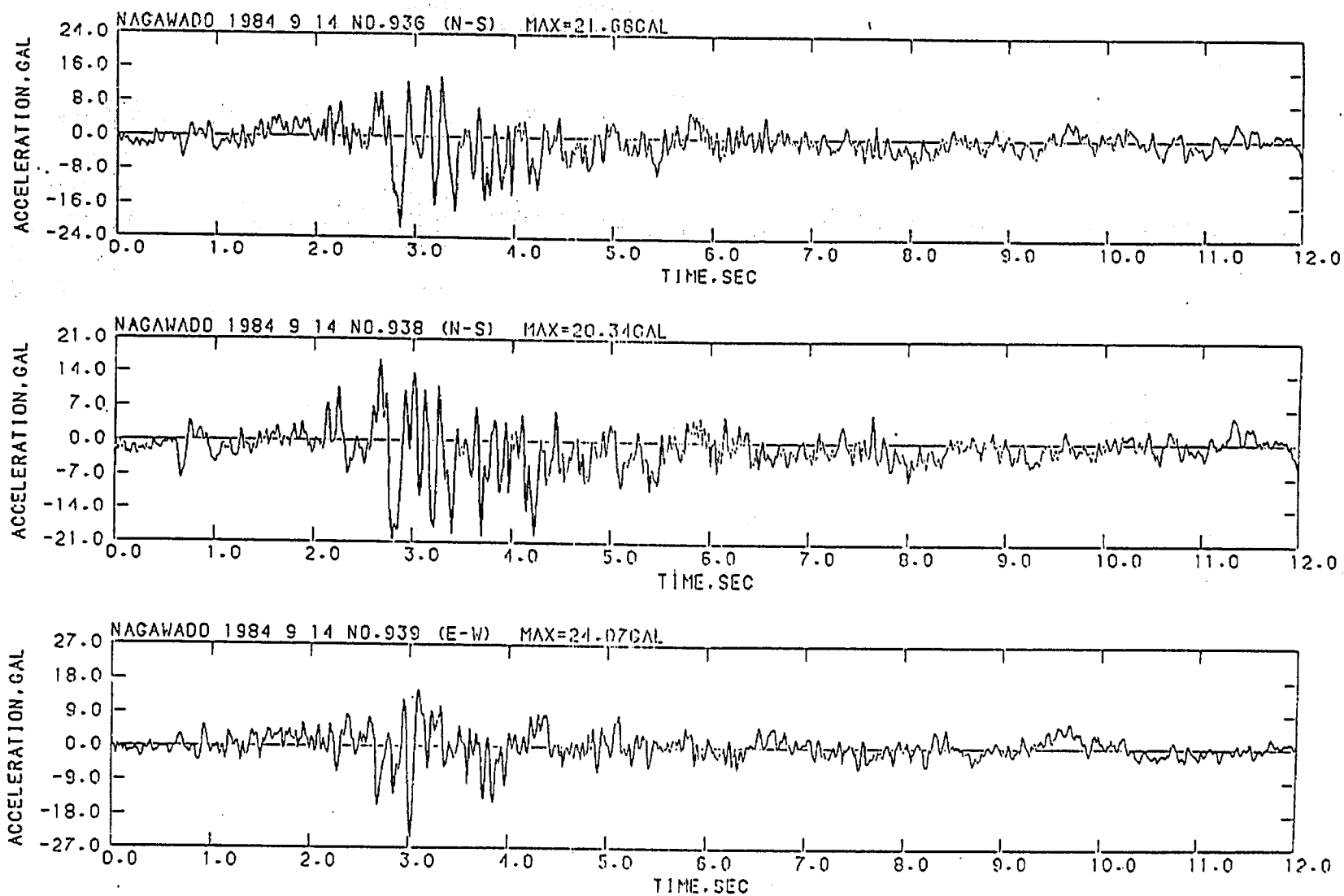


Fig. 3.25(c) Corrected acceleration of the Western Nagano Earthquake at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

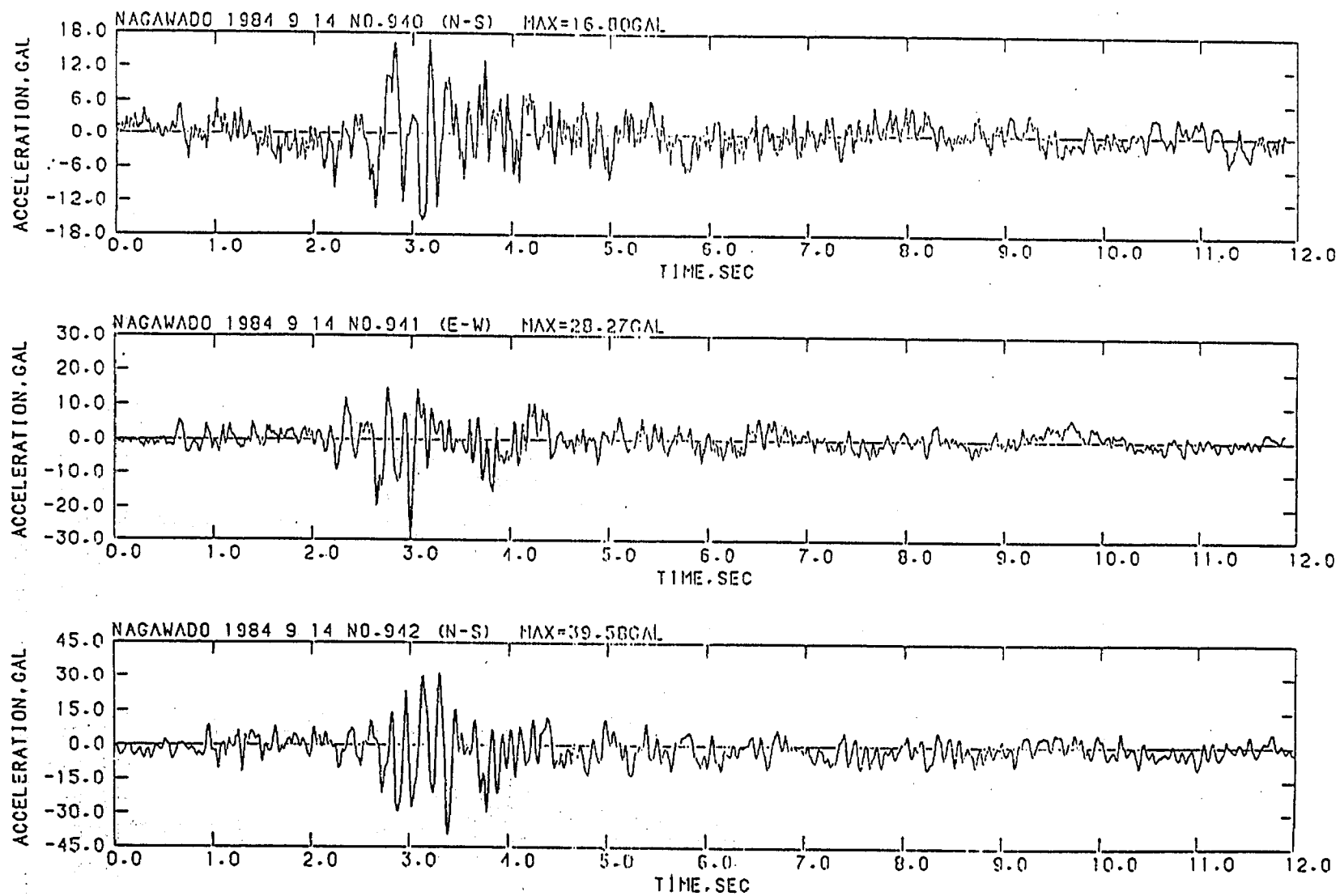


Fig. 3.25(d) Corrected acceleration of the Western Nagano Earthquake at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

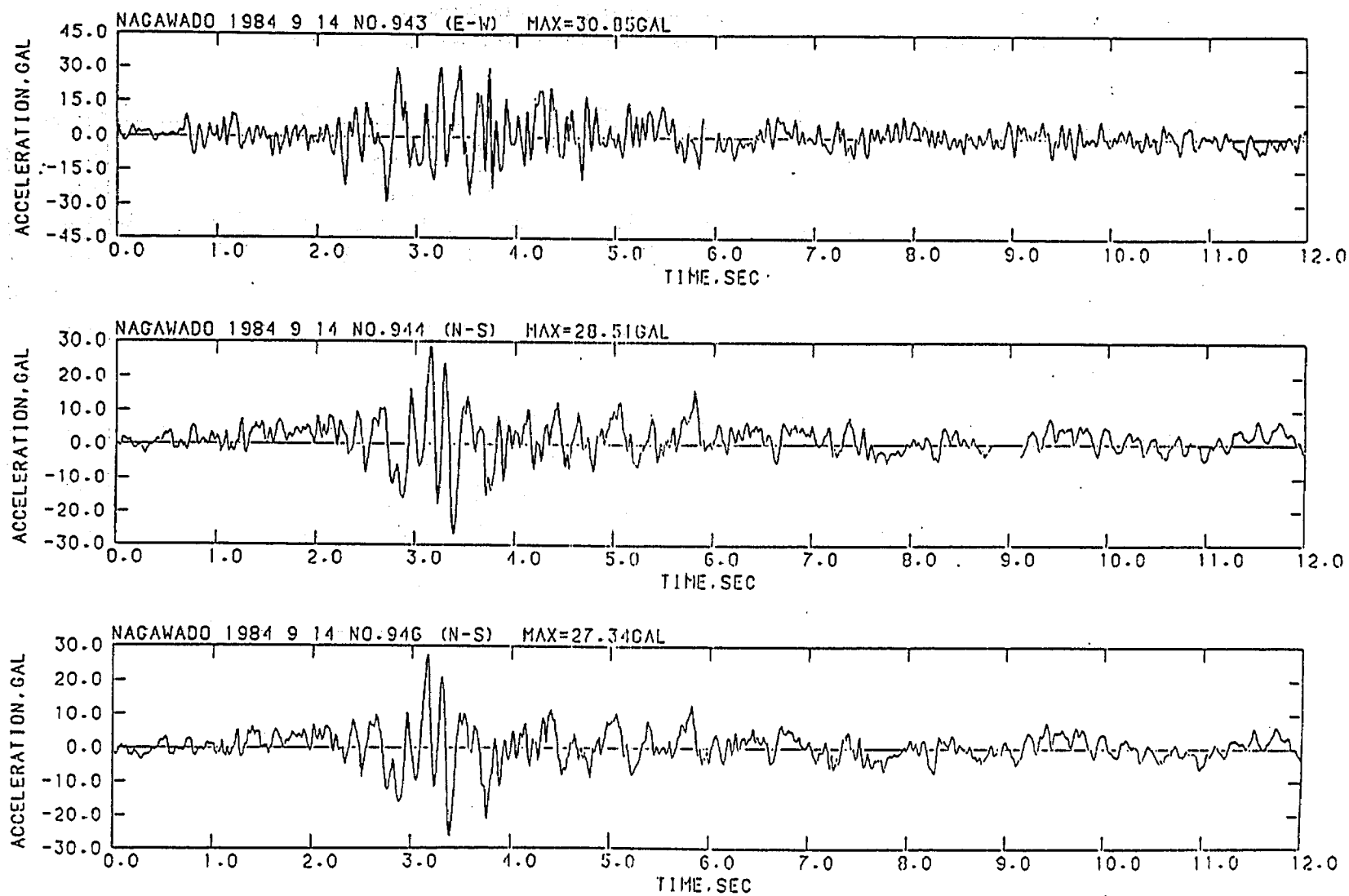


Fig. 3.25(e) Corrected acceleration of the Western Nagano Earthquake at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

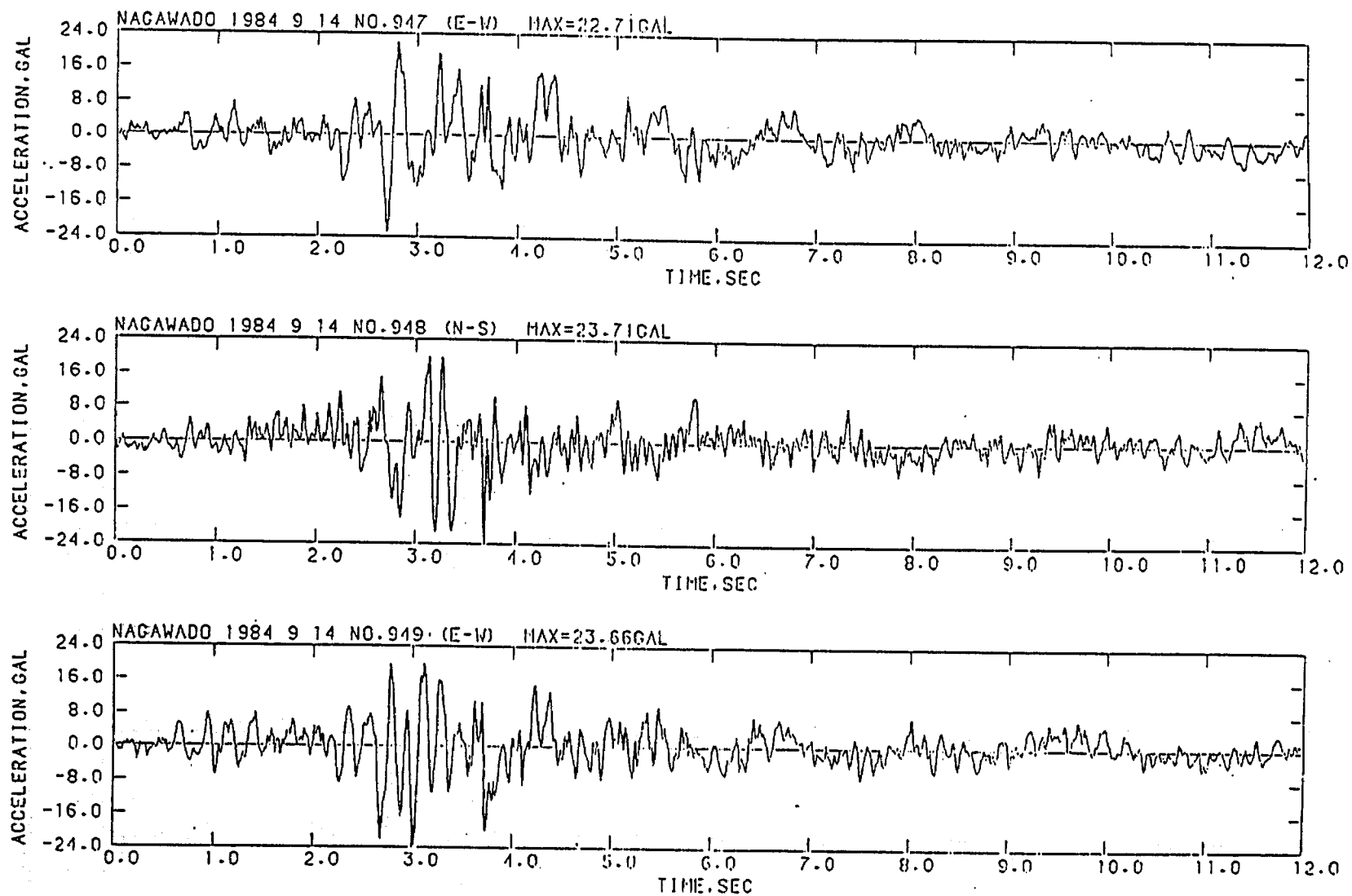


Fig. 3.25(f) Corrected acceleration of the Western Nagano Earthquake at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

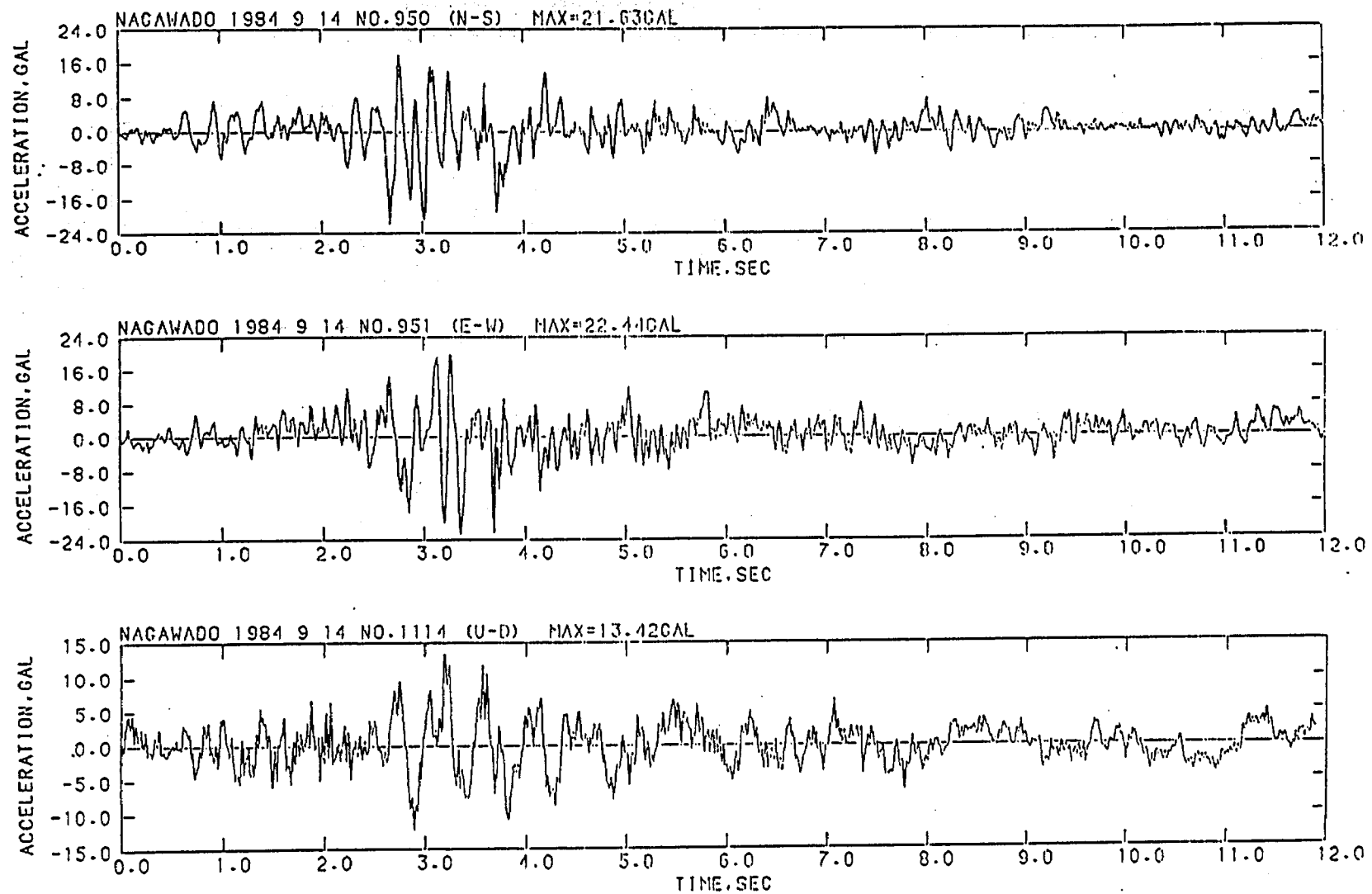


Fig. 3.25(g) Corrected acceleration of the Western Nagano Earthquake at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

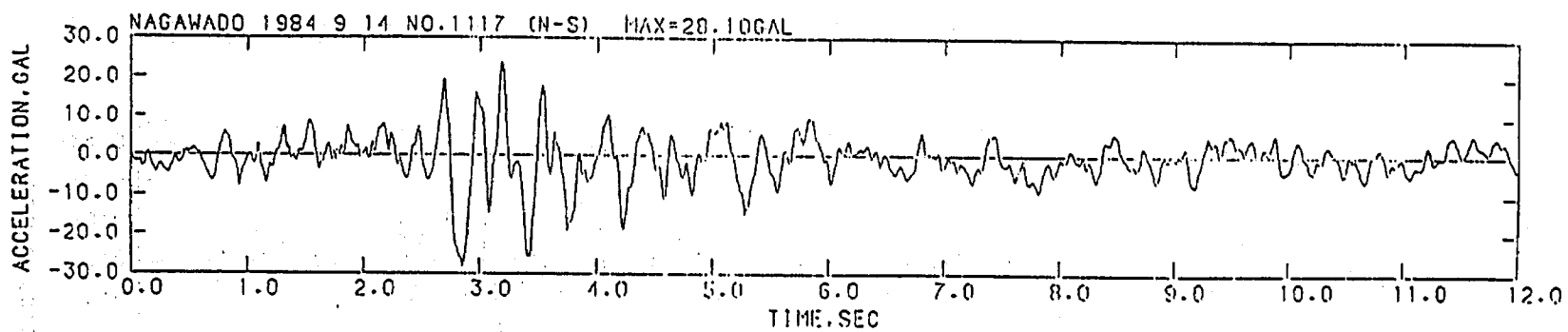
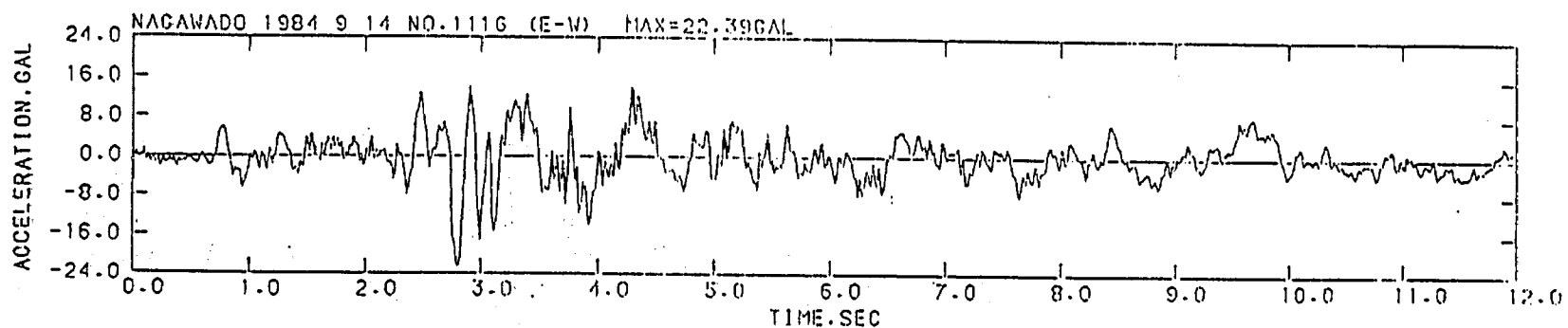
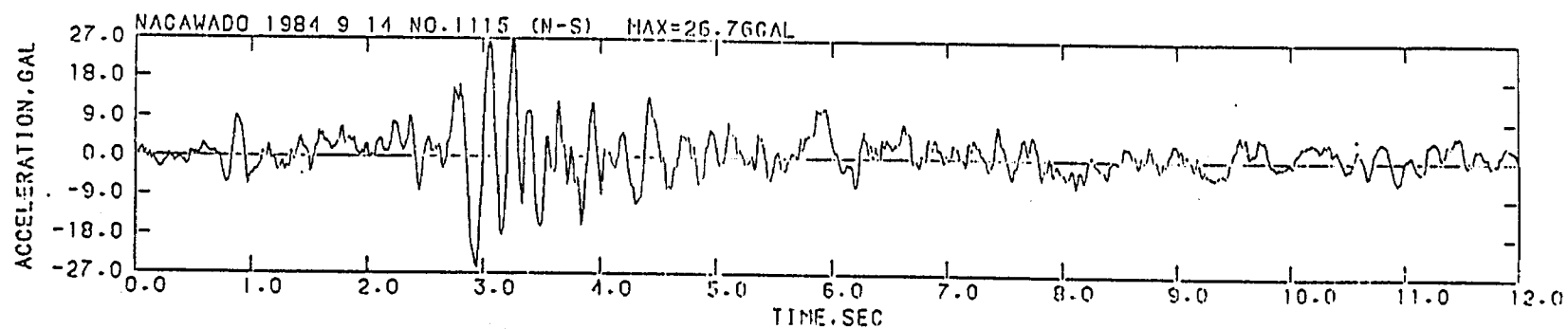


Fig. 3.25(h) Corrected acceleration of the Western Nagano Earthquake at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

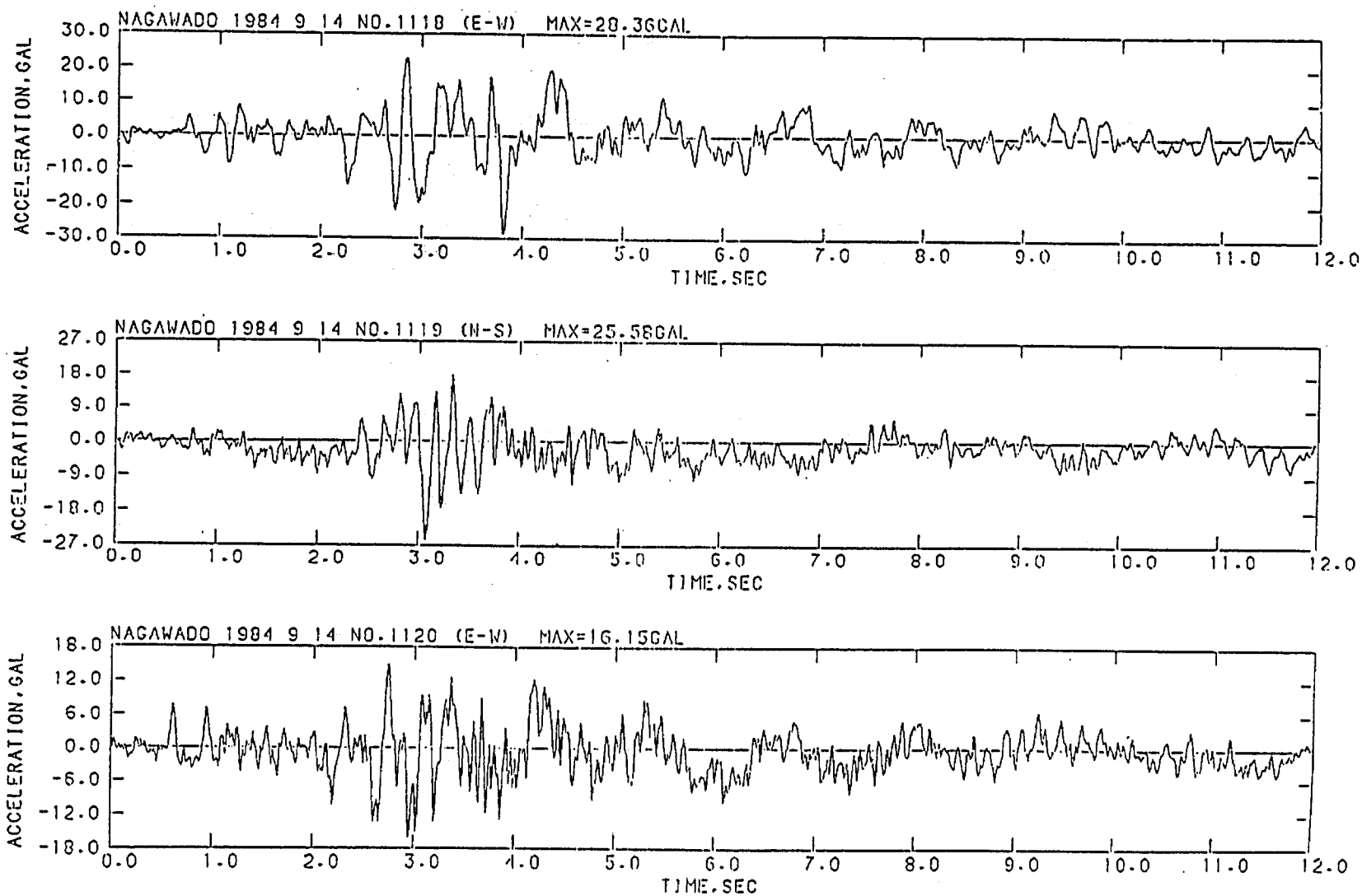


Fig. 3.25(i) Corrected acceleration of the Western Nagano Earthquake at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

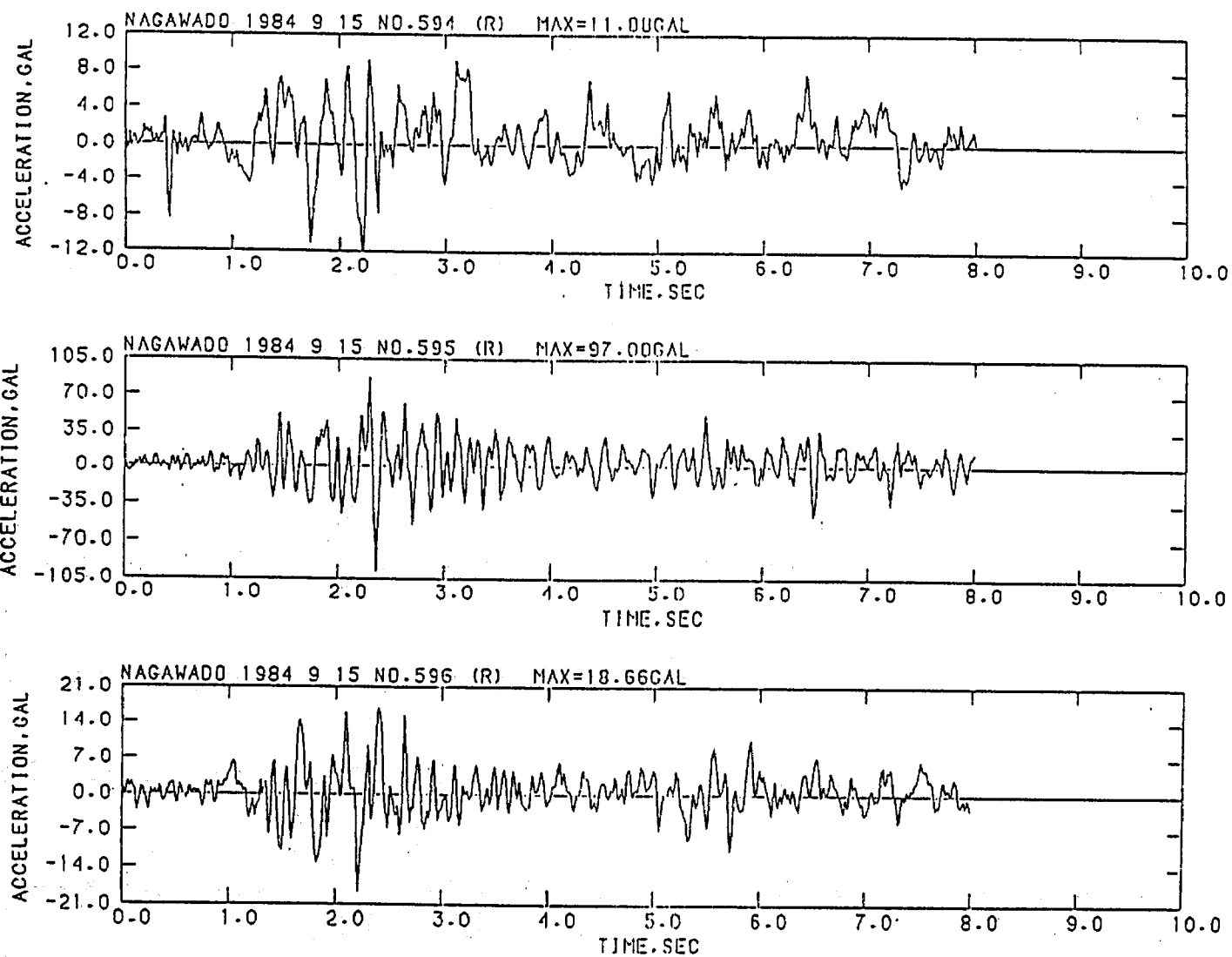


Fig. 3.26(a) Corrected acceleration of the aftershock of September 15, 1984 at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

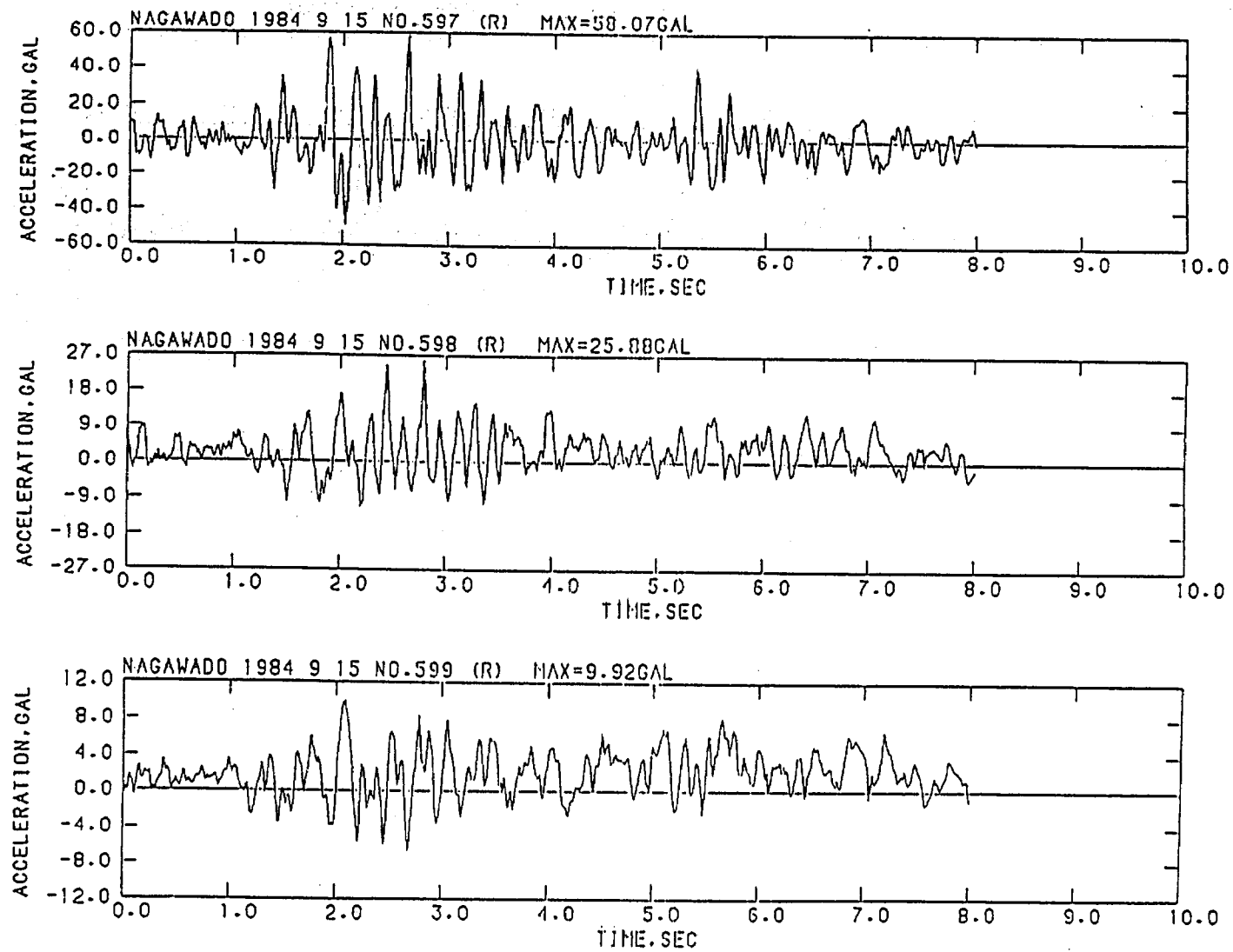


Fig. 3.26(b) Corrected acceleration of the aftershock of September 15, 1984 at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

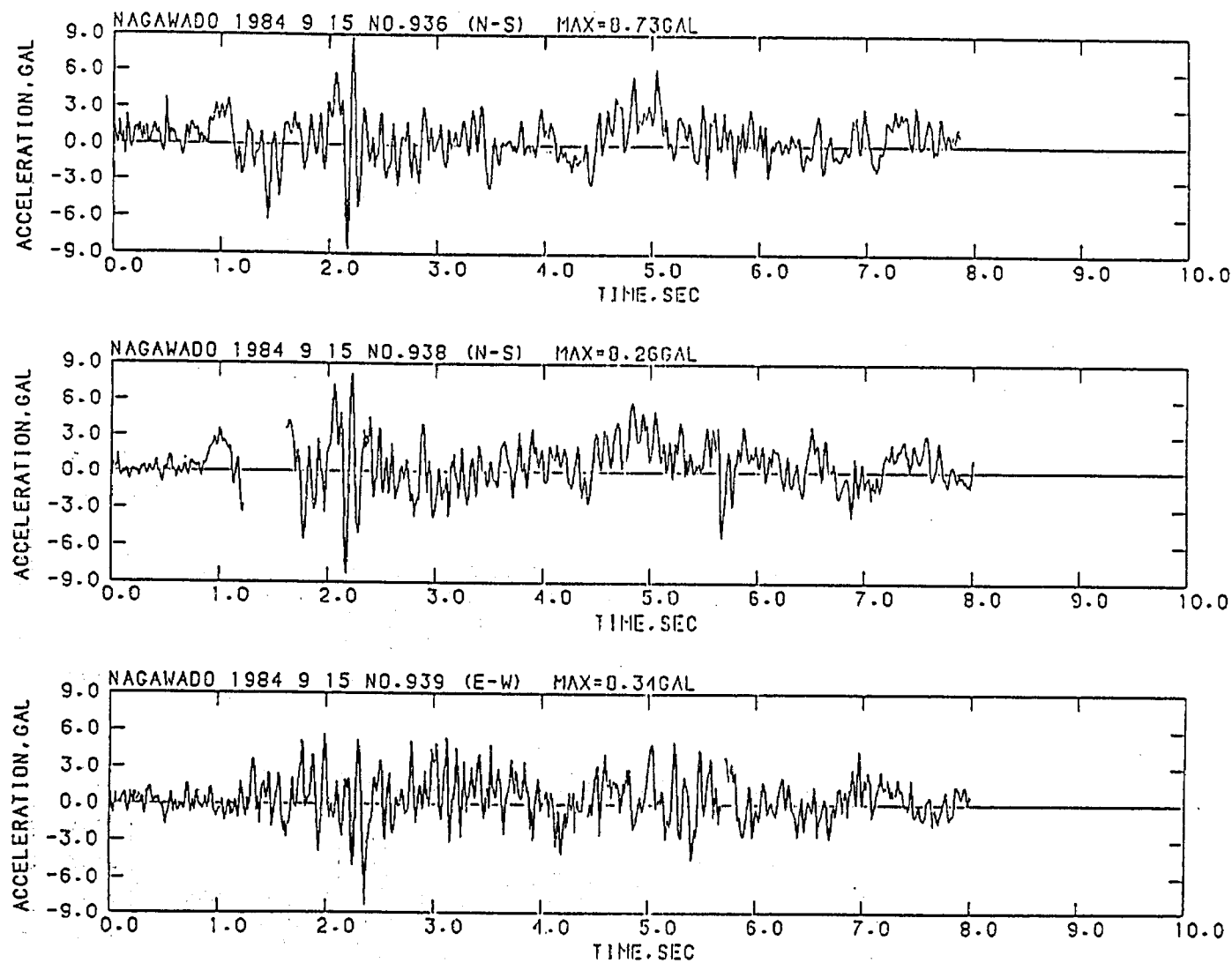


Fig. 3.26(c) Corrected acceleration of the aftershock of September 15, 1984 at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

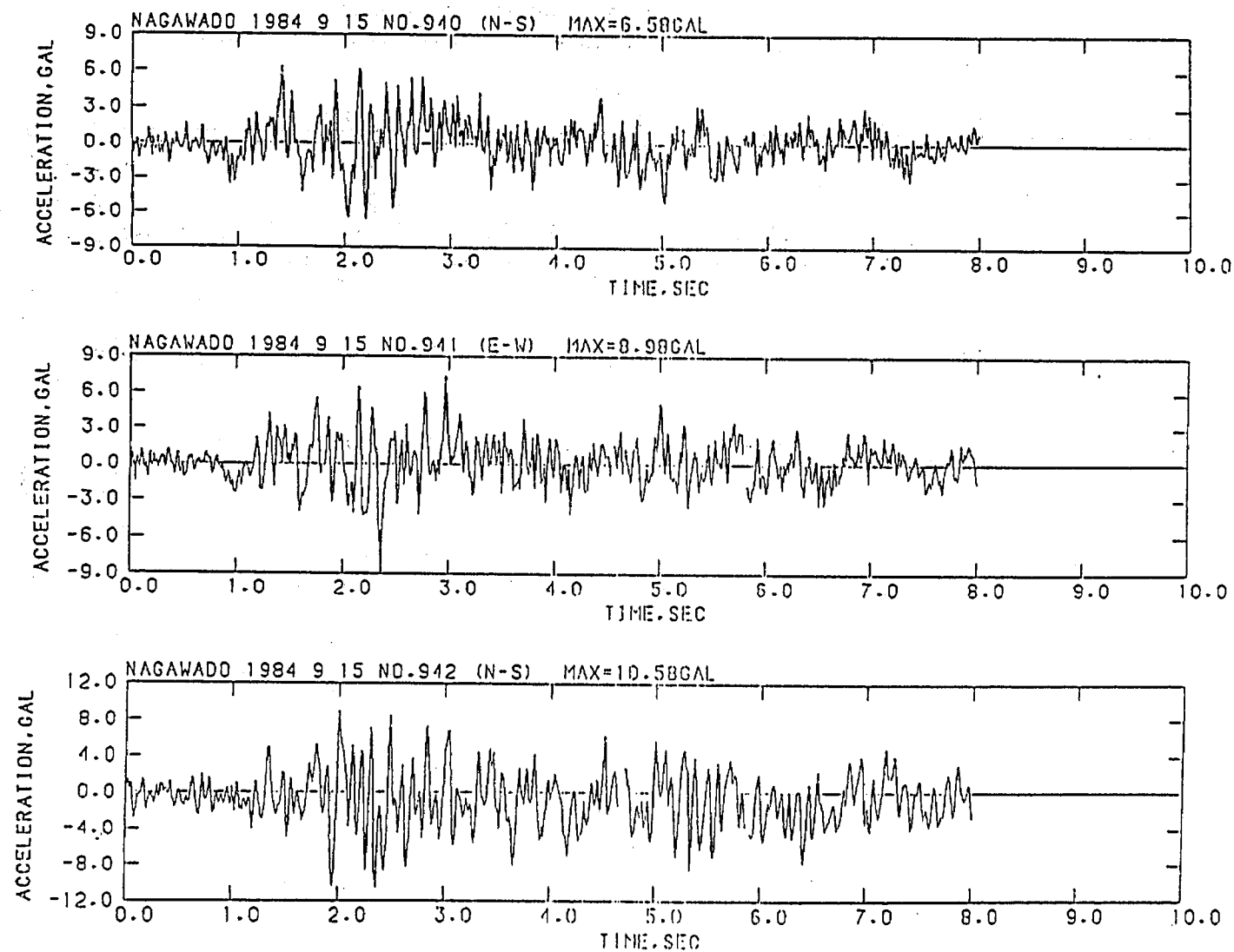


Fig. 3.26(d) Corrected acceleration of the aftershock of September 15, 1984 at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

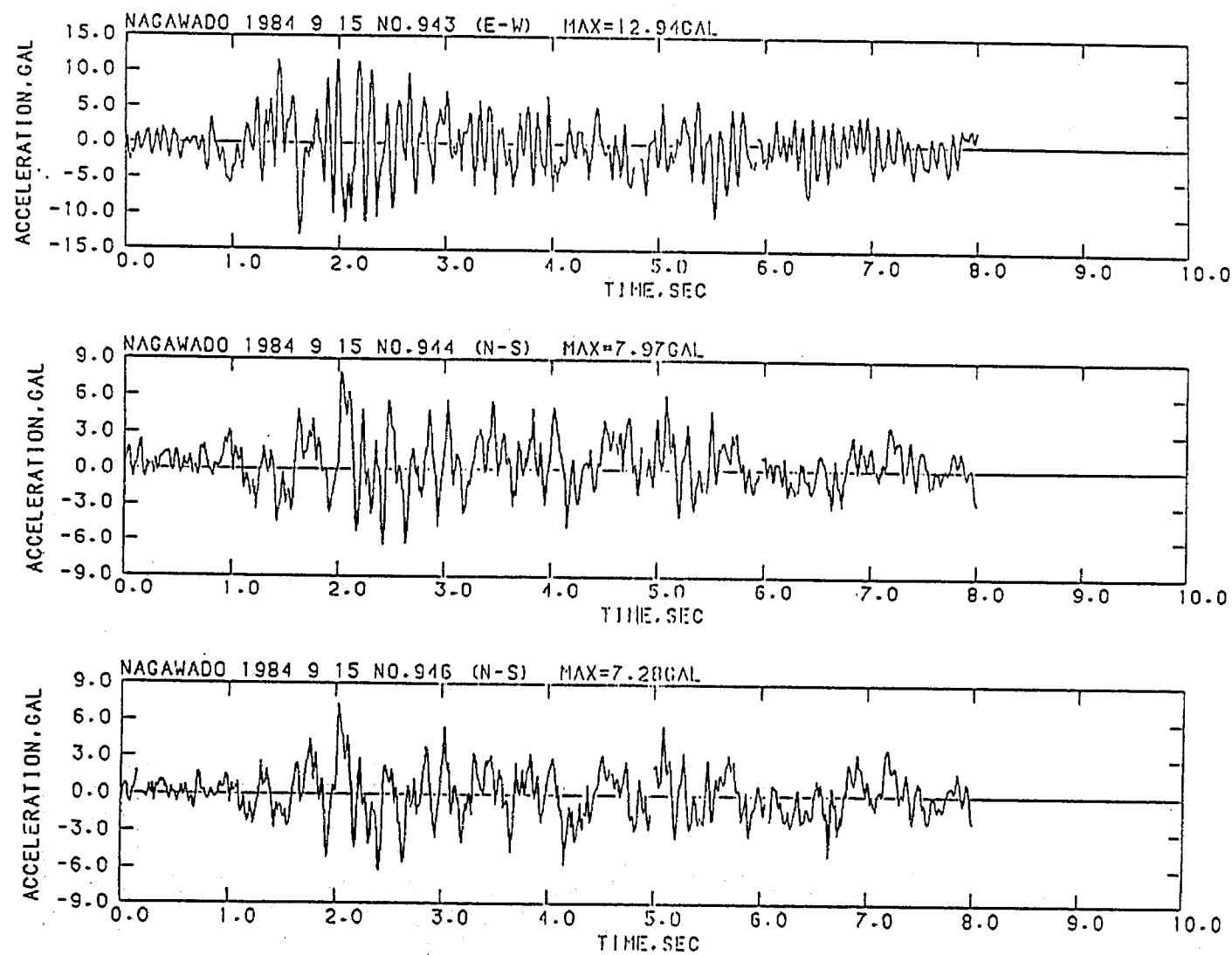


Fig. 3.26(e) Corrected acceleration of the aftershock of September 15, 1984 at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

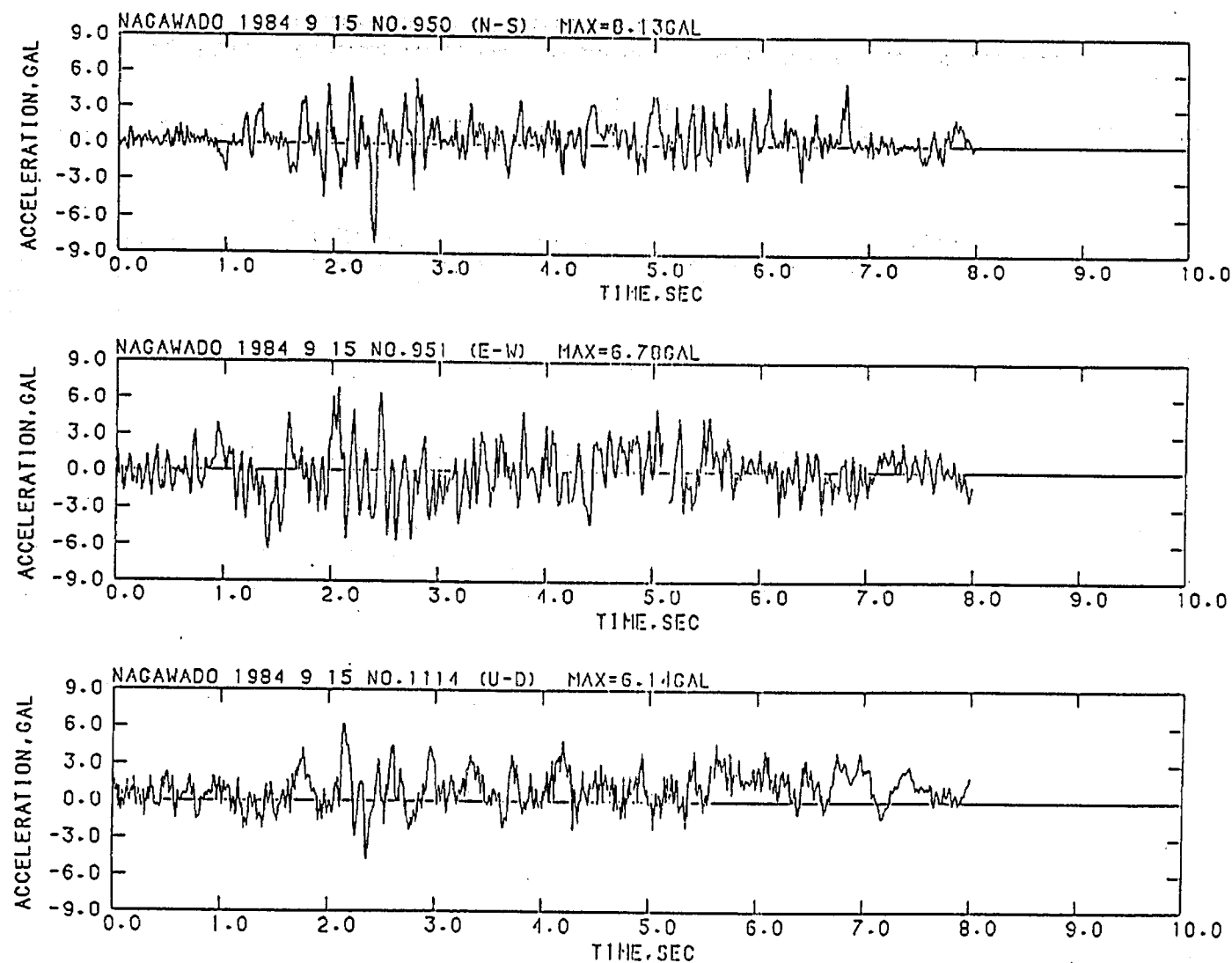


Fig. 3.26(f) Corrected acceleration of the aftershock of September 15, 1984 at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

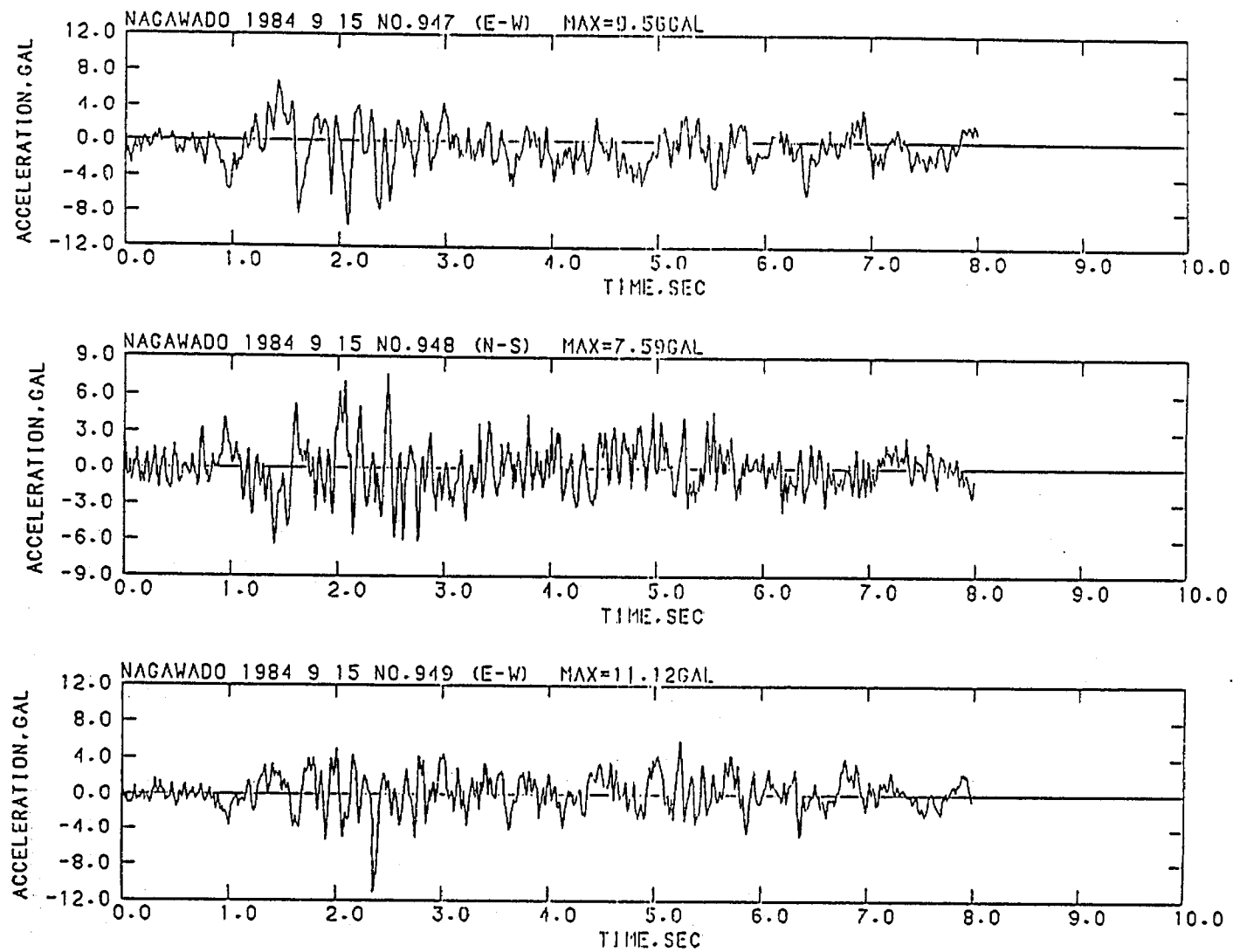


Fig. 3.26(g) Corrected acceleration of the aftershock of September 15, 1984 at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

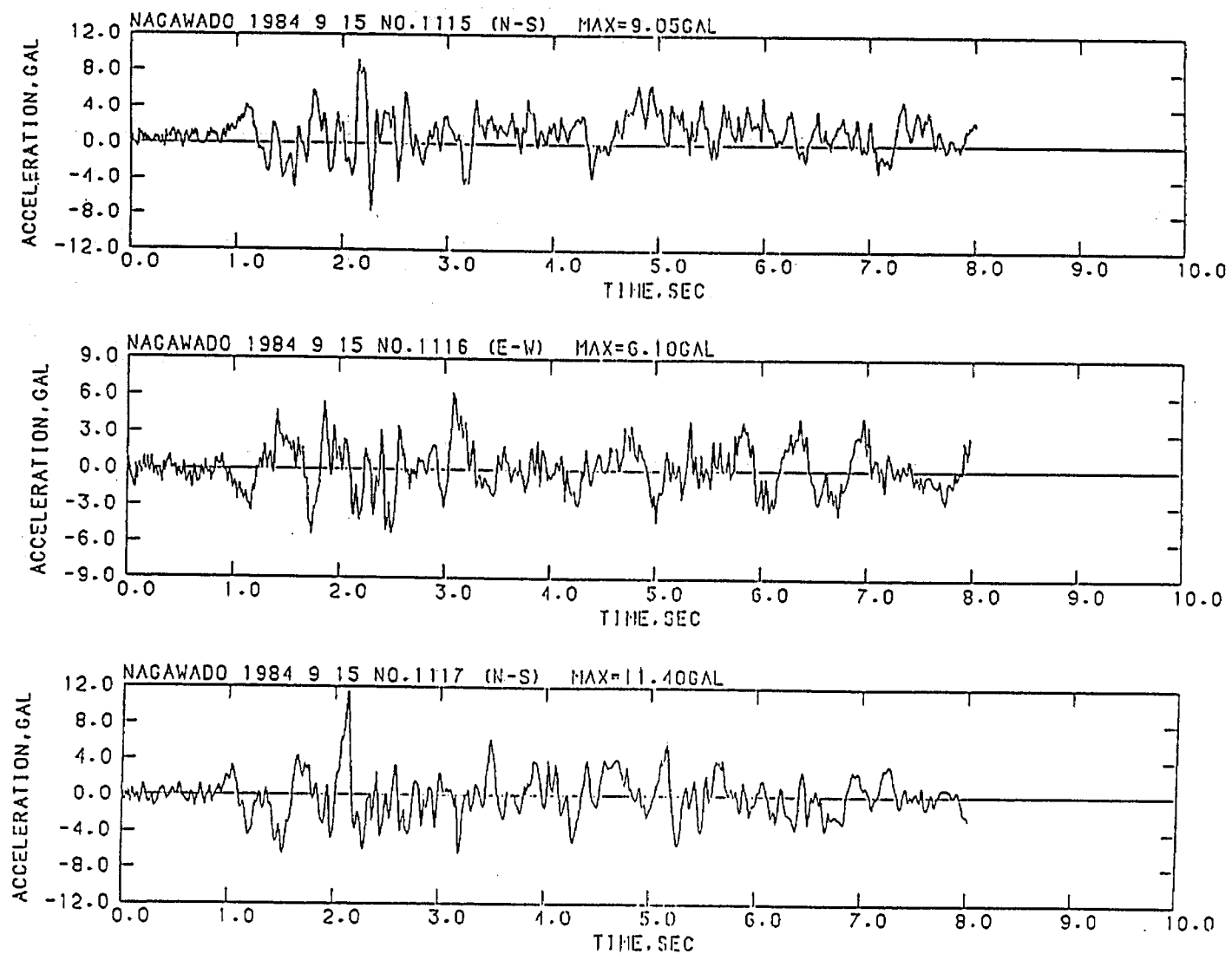


Fig. 3.26(h) Corrected acceleration of the aftershock of September 15, 1984 at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

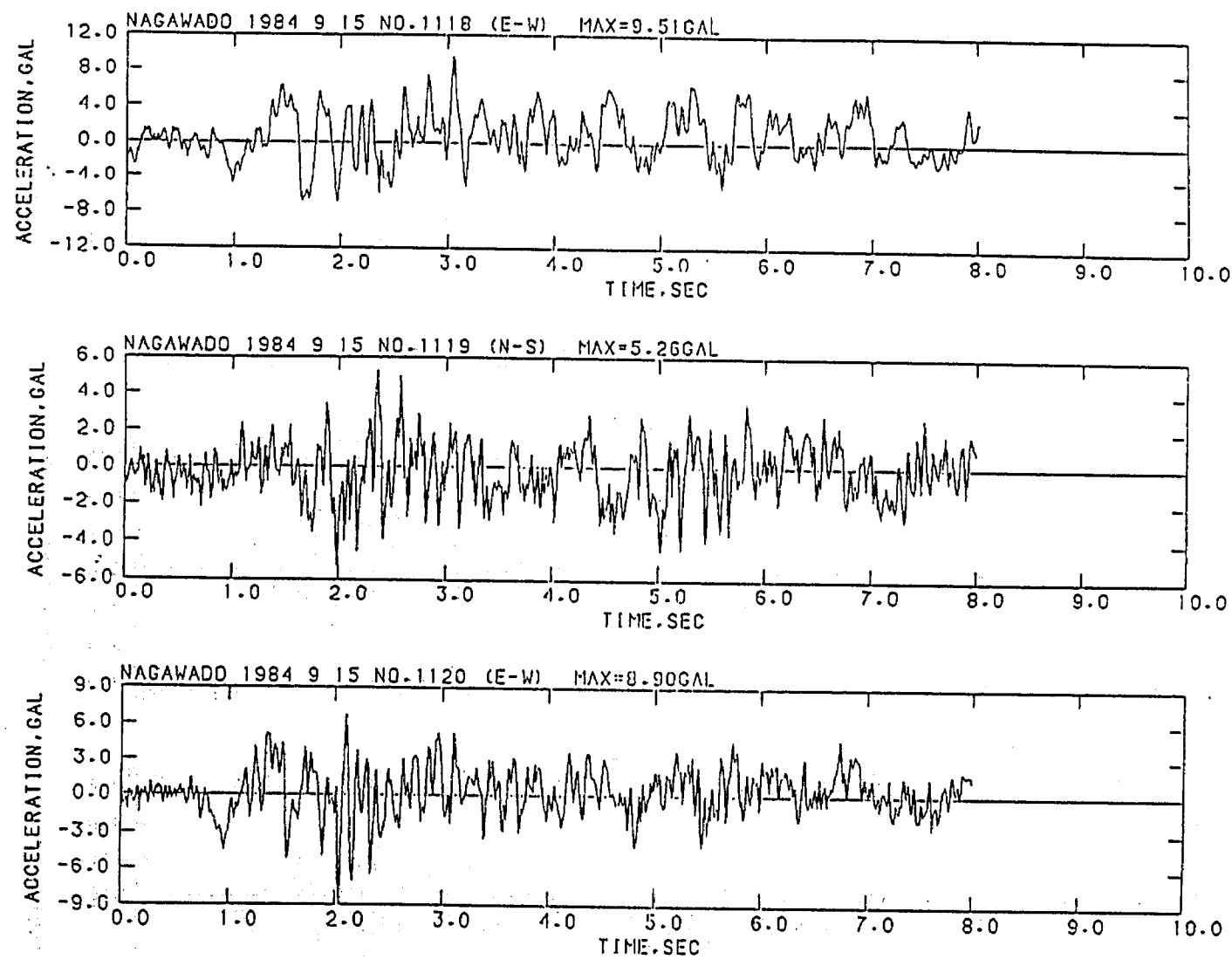


Fig. 3.26(i) Corrected acceleration of the aftershock of September 15, 1984 at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

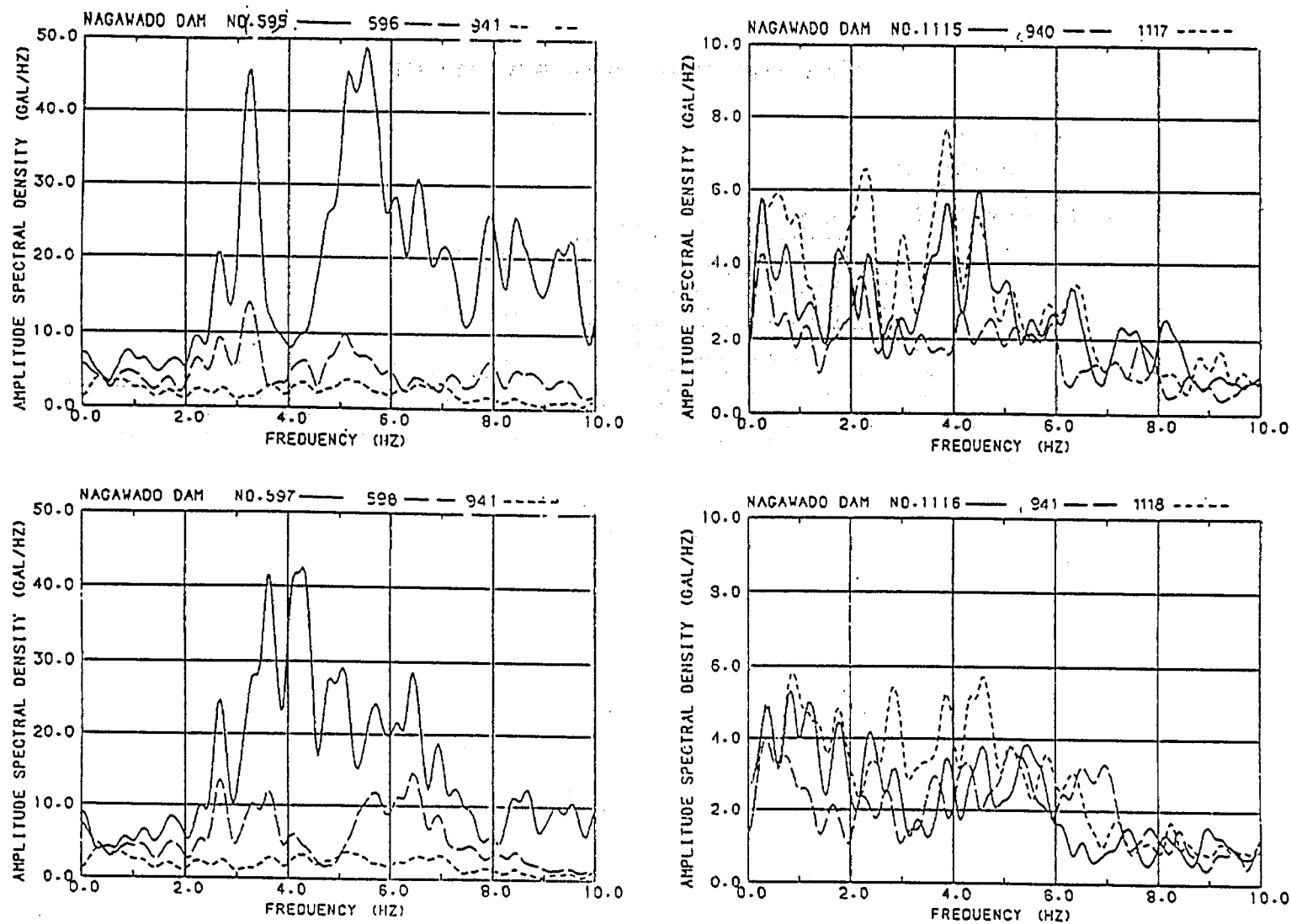


Fig. 3.27 Power spectrum of the Western Nagano Earthquake at Nagawado Dam
(Courtesy of Tokyo Electric Power Co.)

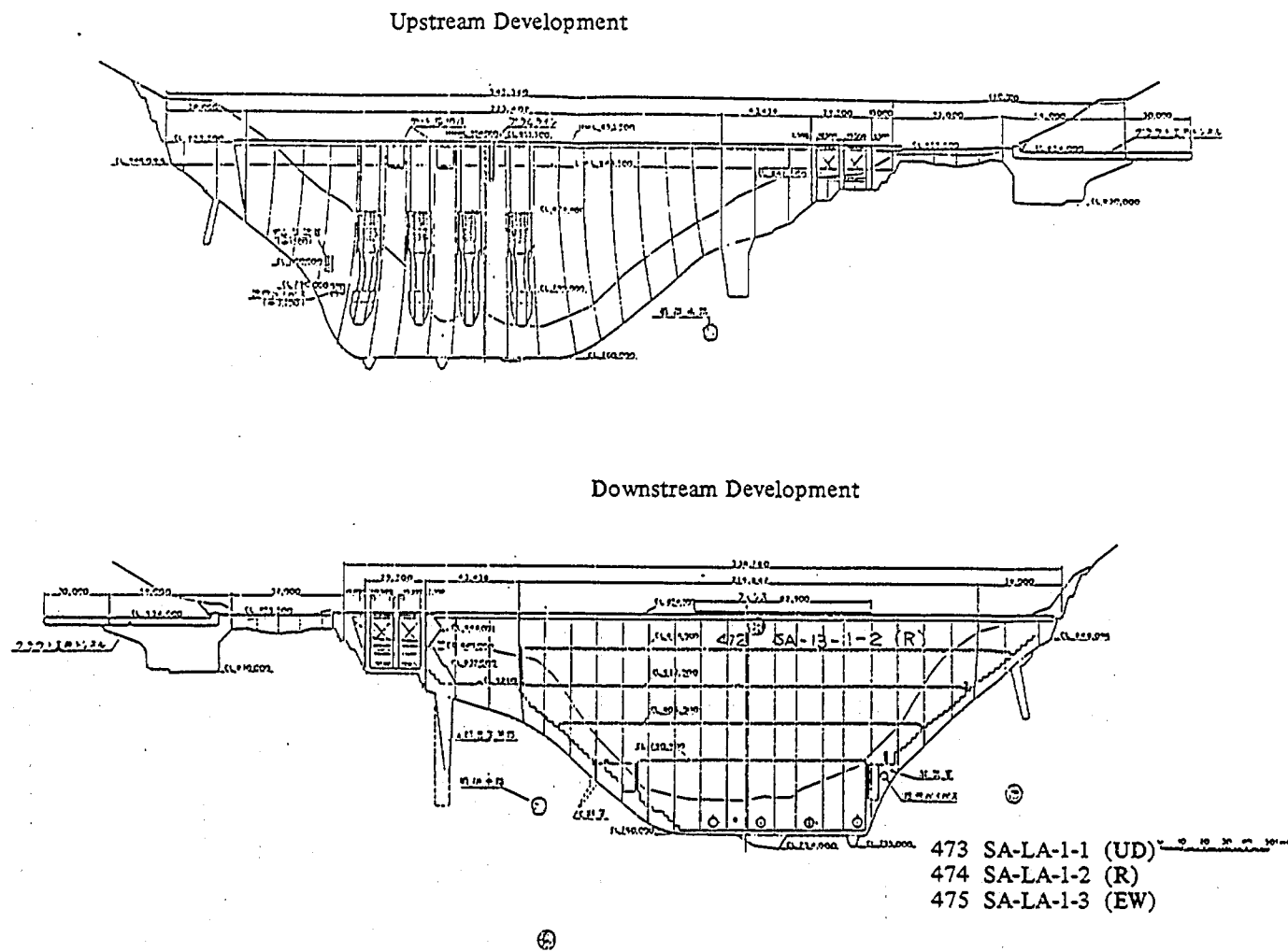


Fig. 3.28 Arrangement of seismographs of Midono Dam

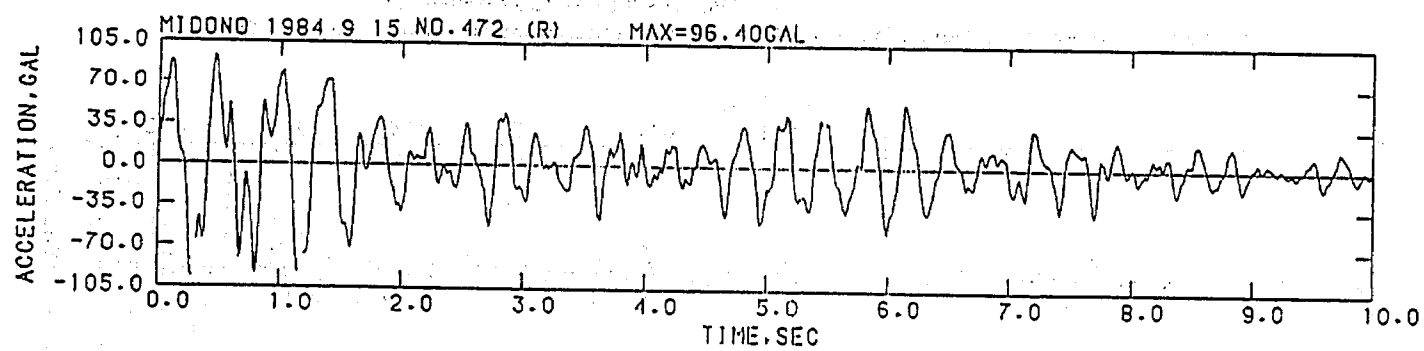


Fig. 3.29(a) Corrected acceleration of the aftershock of September 15, 1984 at Midono Dam
(Courtesy of Tokyo Electric Power Co.)

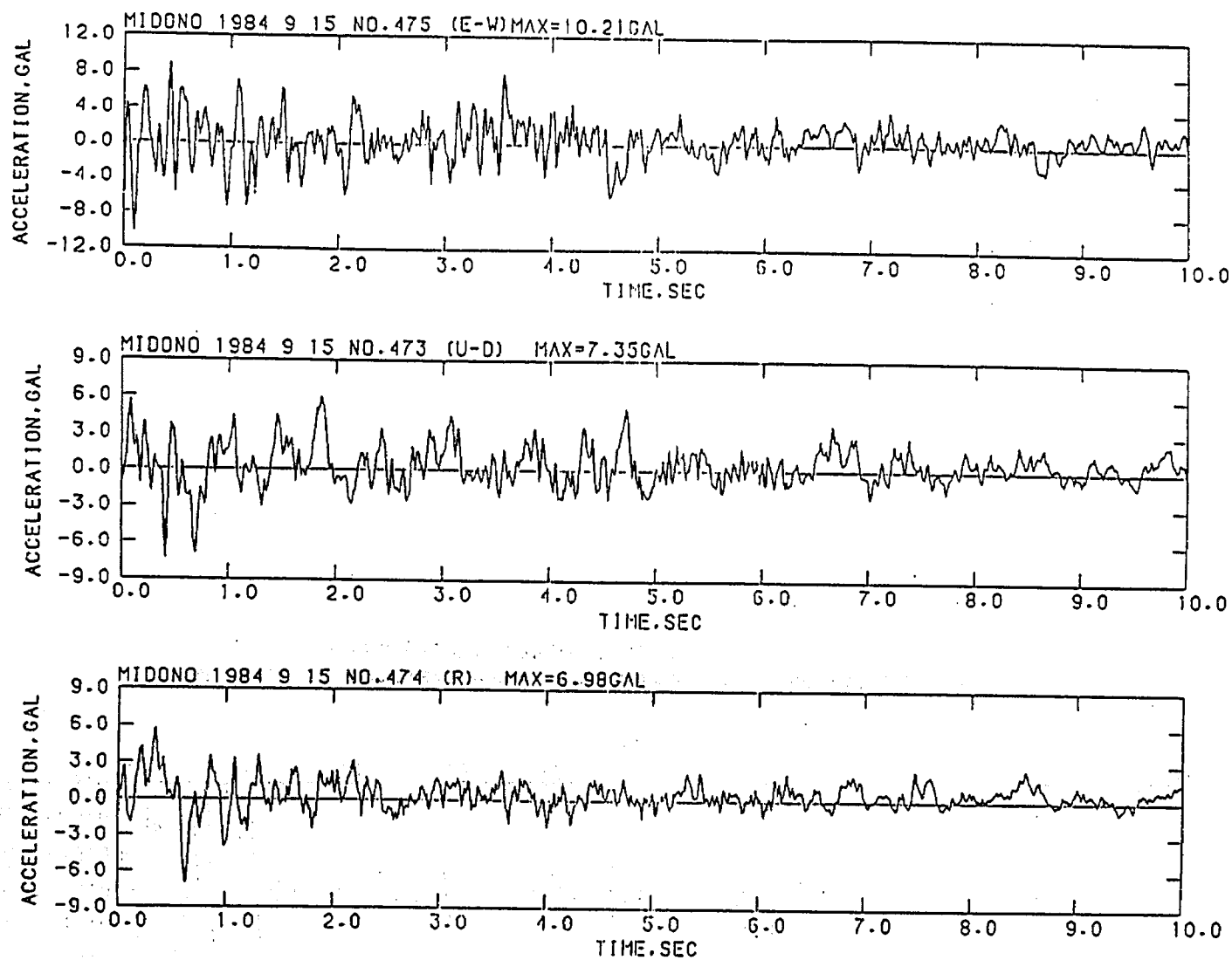


Fig. 3.29(b) Corrected acceleration of the aftershock of September 15, 1984 at Midono Dam
(Courtesy of Tokyo Electric Power Co.)

4. Behaviours of Dams during Earthquake

The locations of the major dams (dam height is more than 15 m) within the epicentral distance of 200 km is shown in Figure 4.1. Of these dams, the location of Makio Dam is the closest to the epicenter of the earthquake of September 14. This dam, however, had only very slight damage, and hence we will mainly describe the behaviour of Makio Dam.

4.1 Makio Dam

Construction work for Makio Dam began in November, 1957 and the dam was completed as a rockfill dam in March, 1961 by the Aichi Irrigation Public Corporation. The general description is given in Table 4.1 and the maximum cross section is shown in Figure 4.2.

(1) Estimation of the earthquake motion at Makio Dam

Accelerometers and displacement transducers have been installed at Makio Dam as previously stated in Figure 3.5. The accelerometer placed in the tunnel of right abutment, however, did not work well, and hence no accurate earthquake motions were observed at the dam foundation. Of the accelerometers in good order, the nearest ones to the foundation were No.8 and No.9. Accelerometers at dam crest, stopped monitoring probably due to the power failure when they were recording the high frequency motions (10~15 Hz) for the first 1.2 seconds. Some of the peaks of amplitudes were scaling off from the recording paper in the first 1.2 seconds record and therefore the motions recorded at this dam during the main earthquake are incomplete.

It is necessary to estimate the motions at the dam foundation during the main shock for the evaluation of the behaviour of dams which had only slight damage, against the big near-field event. The followings are the estimated reproduction of the main shock motions at Makio Dam foundation by using the motions recorded at other dams and the monitored aftershock motions at Makio Dam.

a. Duration

It seems to be reasonable to presume the duration of the motion at Makio Dam from the recorded motions at other dams. The considerations about the length of the earthquake fault, moving speed of fracture, transference velocity of elastic waves (P, S Wave, etc) and relative position between the above-mentioned fault and monitoring points should be taken into account, but duration was assumed from the records for the neighboring dams. From the motions recorded at Takane No.1 Dam and Nagawado Dam, the main motion lasted about 4 seconds after the arrival of S-wave and subsequently the earthquake wave continued about 8 seconds from the end of the main motion. It is then assumed that the duration of the motion at the foundation of Makio Dam is also 12~15 seconds.

b. Frequency characteristics

It is possible to analyze an initial short portion of the records at Makio Dam. The frequency of this part was 10 to 15 Hz. The predominant frequencies appeared in the wide range of frequencies of 0 to 6 Hz for Nagawado Dam, and as for Takane No.1 Dam the predominant frequency was 2.5 Hz in the main motion.

At Makio Dam, the comparatively large aftershocks were recorded at 12:51 p.m. on September 14, 7:14 a.m. on September 15, 7:16 a.m. on September 15, 9:12 a.m. on October 3 and 9:19 a.m. on October 9. The predominant frequencies of these motions were 15, 12, 9, 10 Hz respectively. The velocity of the earthquake recorded by Gifu University on October 3 had a predominant frequency of 8 Hz and the acceleration monitored by Fill Type Dam Division had a predominant frequency of about 20 Hz. Therefore, aftershocks had the predominant frequency of 10 Hz or higher. When we assume that the earthquake had the same predominant frequency with aftershocks, the estimated motions at the foundation of Makio Dam comes to have a higher predominant frequency than the motions at Nagawado Dam and Takane No.1 Dam. An earthquake motion having such a high frequency is probable because Makio Dam was located near the epicenter, and the S

Name	The western Nagano Prefecture Earthquake, 1984
Date	8:48 a.m. September 14, 1984
Location	N:35°49' E:137°33'
Depth	H=2 km, Magnitude 6.8 on the Richter scale

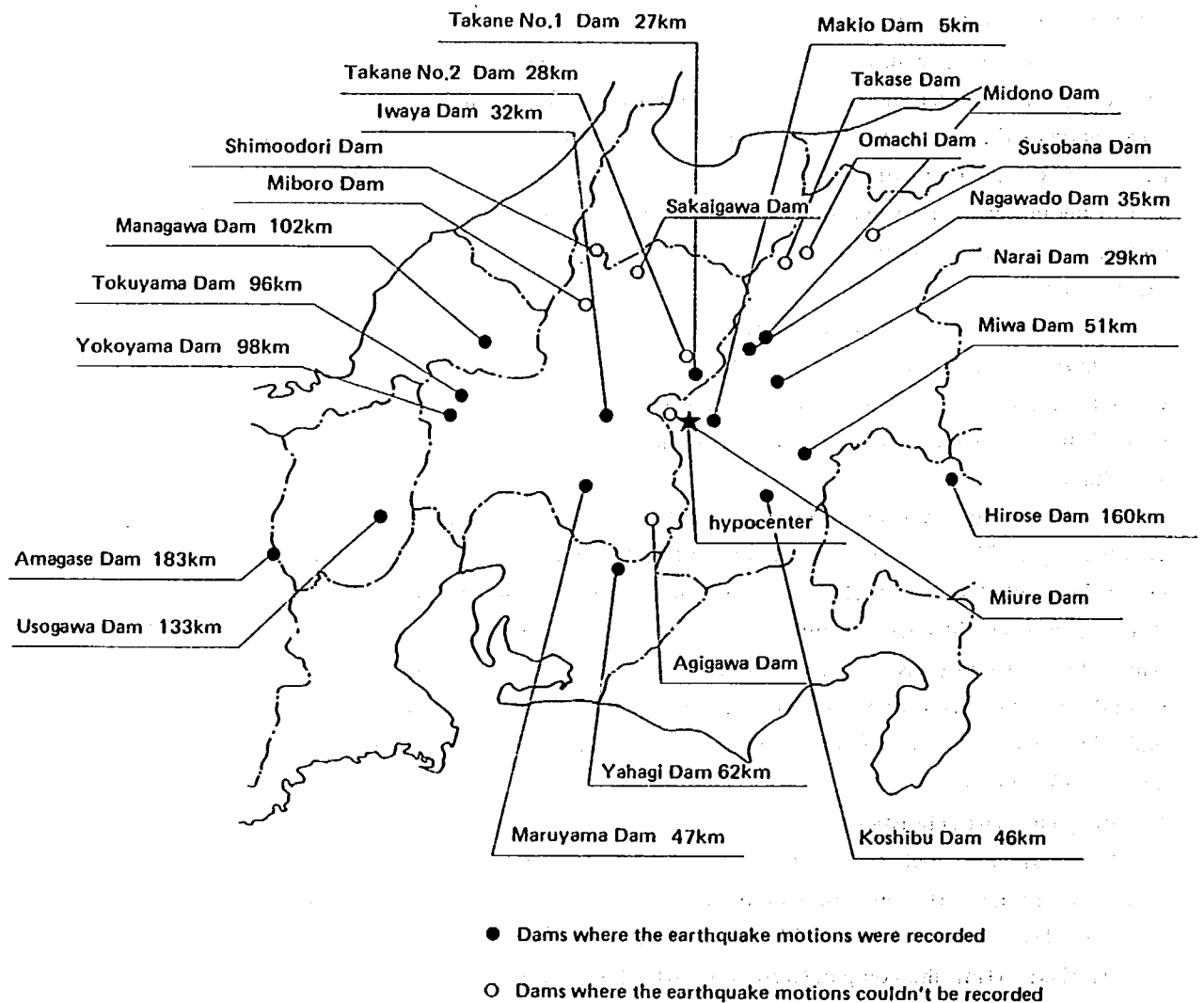


Fig. 4.1 Dams located within the epicentral distance of 200 km

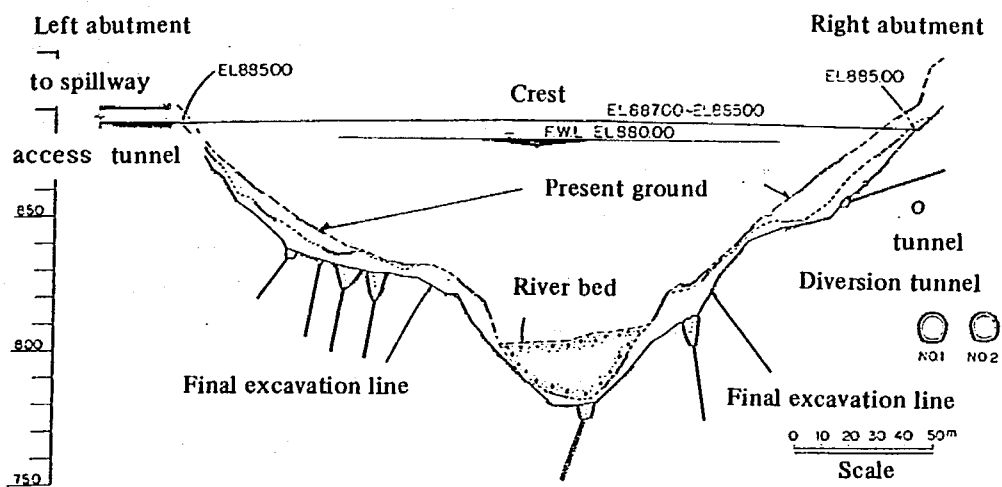
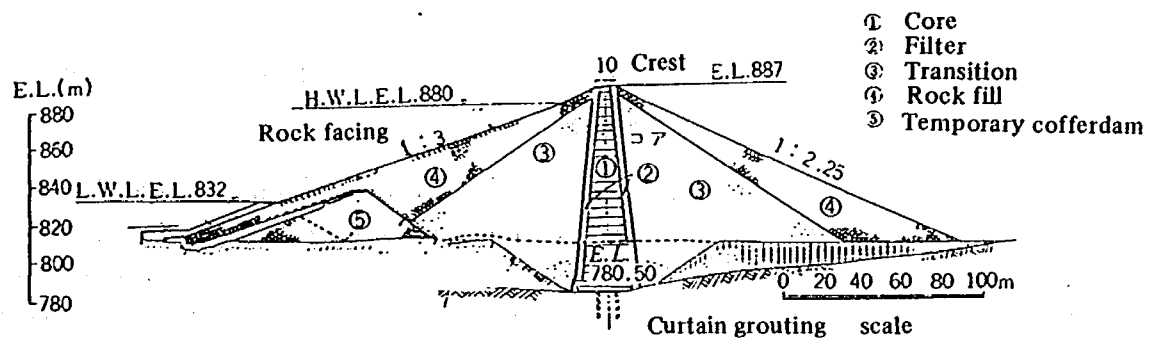


Fig. 4.2 Front view and cross section of Makio Dam

and P-wave reached the site almost at the same time. The earthquake motions recorded at other dam sites within the epicentral distance of 100 km during the Western Nagano Earthquake, were collected and analyzed by the Fill Type Dam Division, and some of them appear to have a predominant frequency of 10 Hz from the results of analyses.

The resonant frequency of Makio Dam was then assumed to be 2.0~2.1 Hz from the acceleration wave at the dam crest.

c. Maximum acceleration

There are not good grounds to estimate the maximum acceleration, as it is different in nature from the case of the time duration and the frequency characteristics. It is difficult to estimate the maximum acceleration from extrapolating the relationship between the maximum acceleration and the epicentral distance, even if that relationship was obtained from dams adjacent to Makio Dam. The records of the aftershocks monitored at Makio Dam are the most reliable, but the peak value of the motion is unreadable. As for the aftershock of October 9, the seismograph of P.W.R.I. indicated a maximum acceleration of 57 gal in the up/downstream, 84 gal in the dam axis direction and 27 gal in the vertical direction. An aftershock of the magnitude of 5.5 on the Richter scale occurred near Makio Dam on October 3. Although the magnitude of this aftershock was smaller than the main shock, the epicentral distance from the dam was closer than the main shock. According to the caretaker of the dam, this aftershock had almost the same shaking as the main earthquake at the dam control office. Moreover, the fact that the subsidence of the dam due to this aftershock was almost the same due to the main shock suggests the peak acceleration of the main motion would have been as the nearly same level as the aftershock. In the above description, seismographs of P.W.R.I. were installed on the crest of left abutment, and so the acceleration might be smaller at the lower level (50 %~ 70 % of accelerations at left abutment). Subsequently the maximum acceleration of the Western Nagano Earthquake at the site of Makio Dam was assumed to be 390~490 gal under the existing circumstances.

d. Vertical motion

As for the vertical component, we had to assume it from the acceleration recorded at Takane No. 1 Dam or the measurement of aftershocks at Makio Dam because the accelerographs at Makio Dam did not have a vertical component. The predominant frequency would be of about 10 Hz and the maximum acceleration would be 200~245 gal, as half of the horizontal component.

[Conclusions]

The horizontal motions of the Western Nagano Earthquake at the foundation of Makio Dam seems to have had a wide range of frequency (0 to 15 Hz), and especially high predominant frequencies of 8 to 10 Hz with the maximum acceleration of 0.4 to 0.5 g. The time duration was assumed to be 4 seconds during the main motion and about 15 seconds in total. As for the vertical component, the motion appeared to have the narrow range of frequency characteristics (8 to 12 Hz) and a predominant frequency of about 10 Hz with the maximum acceleration of 0.2 to 0.25 g.

(2) The behaviour of Makio Dam

Makio Dam suffered slight damage as shown in Figure 4.3, which indicates the cracks parallel to the dam axis at the crest, the settlement at the top of downstream slope, and the looseness and movement of the surface of the downstream slope. The dam was investigated by Water Resources Development Corporation and has been completely repaired. (Photo 1 to 4)

A crack such as that at crest is likely to be seen at earthfill dams subjected to heavy earthquakes and probably caused by extensional stresses during shaking. The settlement and loosening of downstream slope, were caused by the partial steep slope of the banking for the access road at downstream slope.

From the results of the survey, the maximum depth of the crack was 1.5 m, but there was no problem for the seepage because the cracks did not reach the designed upper level of the impervious core zone. Generally,

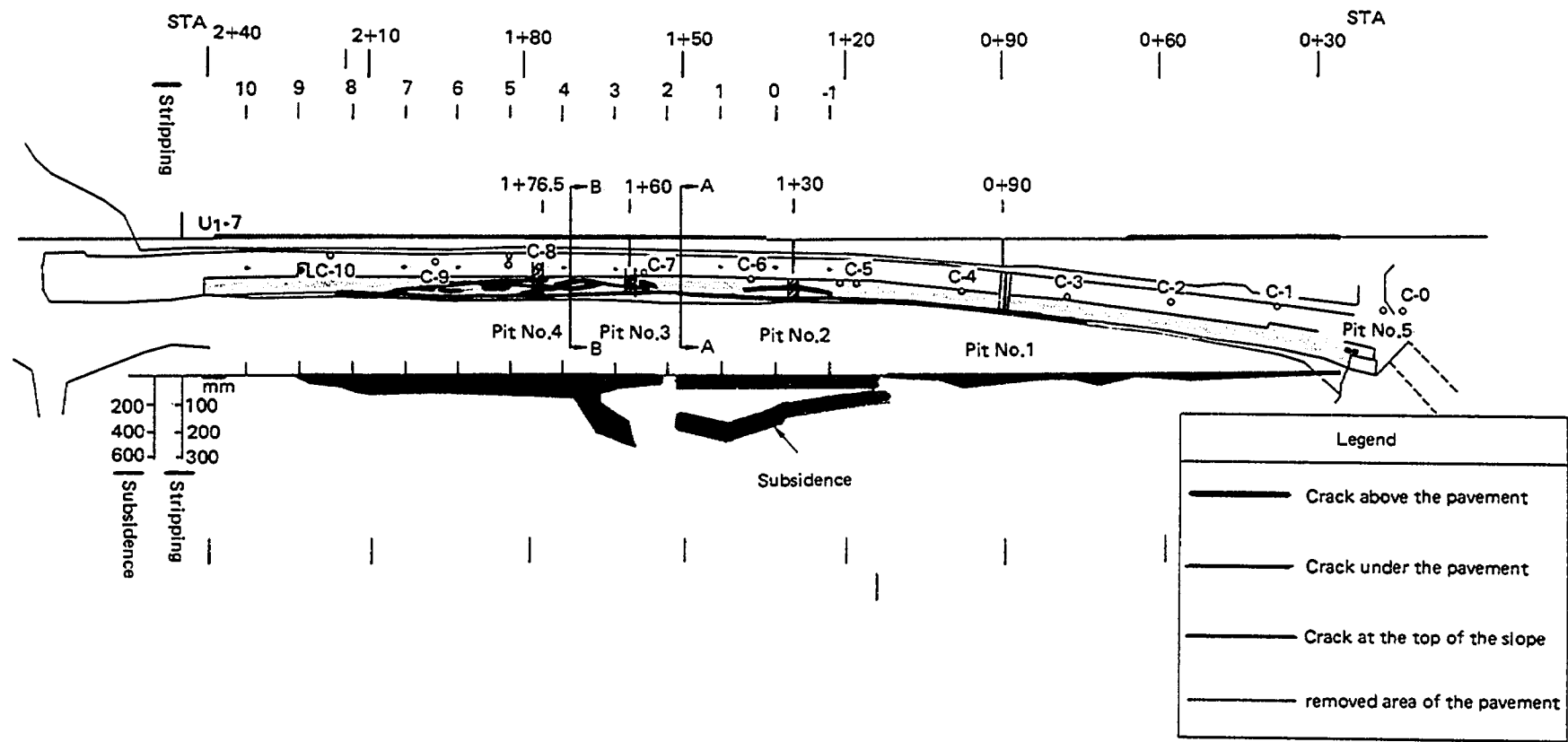


Fig. 4.3 Cracks at the crest of Makio Dam

the displacements of dam body including the movement of surface were about 50 mm toward the upstream direction and a settlement of 50~100 mm at the survey point of the upstream slope, and a settlement of about 50 mm at the downstream slope (horizontal movement is indistinct).

Survey points which were fixed at the center of crest just after the earthquake subsided about 10~15 mm due to the aftershock. Horizontal displacement was not found due to this aftershock according to the survey of October 3, but a downward movement of about 5 mm was surveyed on October 7. However, the error of ± 5 mm is considered to be unavoidable.

The reservoir water level during the earthquake was 850.0 m (N.W.L. is 880 m), and the reservoir level had been lowered for investigation and repairing. Re-filling of the reservoir have been planned with safety monitoring (especially leakage and deformation) when the repairing is completed.

4.2 The behaviour of other dams

Miure Dam, Ohtakigawa Dam, Narai Dam, Takane No.1 Dam, Takane No.2 Dam, Nagawado Dam (Midono Dam, Inakoki Dam) and Iwaya Dam are located near the epicenter of the Western Nagano Earthquake, and suffered no damage from the results according to an investigation by the Chubu Regional Construction Bureau, Ministry of Construcion. In the Takane No.1 Dam, the uplift pressure at the drainage holes of the foundation and the quantity of leakage increased by about 20 percent due to the main earthquake. This type of phenomenon is liable to appear at concrete dams during earthquakes. The increased leakage and uplift pressure usually decrease gradually and return to the former value after several months. In Narai Dam, the seepage flow from observation holes increased slightly but the amount is decreasing little by little.

The flowing are the results of investigation of other dams.

(1) Miure Dam

Miure Dam is located just upstream of Makio Dam and Ohtakigawa Dam and is concrete gravity type as shown in Figure 4.4. The general discription is given in Table 4.2. A shock of intensity 4 on the scale of Meteorological Agency (Japan) was felt at Miure Dam during the Western Nagano Earthquake. The reservoir level was 1,301.6 m (2.5 m below the normal water level). Emergency inspections of dam body, abutments and hydraulic structure were made immediately after, but nothing unusual was reported. For example, the leakage of 17.75 liters from dam body remained unchanged.

(2) Ohtakigawa Dam

Ohtakigawa Dam is a concrete gravity dam and is located between Miure Dam and Makio Dam. The general discription and the maximum cross section are given in Table 4.3 and Figure 4.5 respectively. Nothing unusual was found from the emergency inspection except for a hand-rail at crest, which sustained slight damage from waves during the earthquake.

(3) Narai Dam

Narai Dam is a rockfill dam with a central core and was completed in 1982. Its height is 60 m as shown in Figure 4.6. The general description is shown in Table 4.4. The reservoir water level was 1,056.6 m.

The leakage from dam body and uplift pressure have been monitored for safety control and increment in leakage observed after the main shock, took three days to return to the former quantity. However the leakage increased slightly due to the aftershock of October 3, but the amount is decreasing. (see Figure 4.7) As for the uplift pressure, no change was found before and after the main earthquake.

(4) Takane No.1 Dam

Leakage before the earthquake increased by 18 liters to about 130 liters, but increment has been gradually decreasing.

Table 4.1 General description of Makio Dam

Year of completion	1961
River	Kiso
Nearest city	Matsumoto
Type	Rockfill
Height	105 m
Crest length	260 m
Volume content of dam	2,616,000 m ³
Gross capacity of reservoir	75,000,000 m ³
Purpose	Irrigation, Hydroelectric Water supply
Engineering	Aichi Irrigation Public Corp.
Owner	Water Resources Development Corp.

Table 4.2 General description of Miure Dam

Year of completion	1943
River	Kiso
Nearest city	Kiso-fukushima
Type	Concrete gravity
Height	86 m
Crest length	290 m
Volume content of dam	507,000 m ³
Gross capacity of reservoir	61,100,000 m ³
Purpose	Hydroelectric
Owner	Kansai Electric Power Co.

Table 4.3 General description of Ohtakigawa Dam

Year of completion	1948
River	Kiso
Nearest city	Nagano
Type	Concrete gravity
Height	23 m
Crest length	75 m
Volume content of dam	9,000 m ³
Gross capacity of reservoir	484,000 m ³
Purpose	Hydroelectric
Owner	Kansai Electric Power Co.

Table 4.4 General description of Narai Dam

Year of completion	1982
River	Shinano
Nearest city	Shiojiri
Type	Rockfill
Height	60 m
Crest length	180.8 m
Volume content of dam	952,667 m ³
Gross capacity of reservoir	8,000,000 m ³
Purpose	Flood control Water supply
Engineering & Owner	Nagano Prefecture

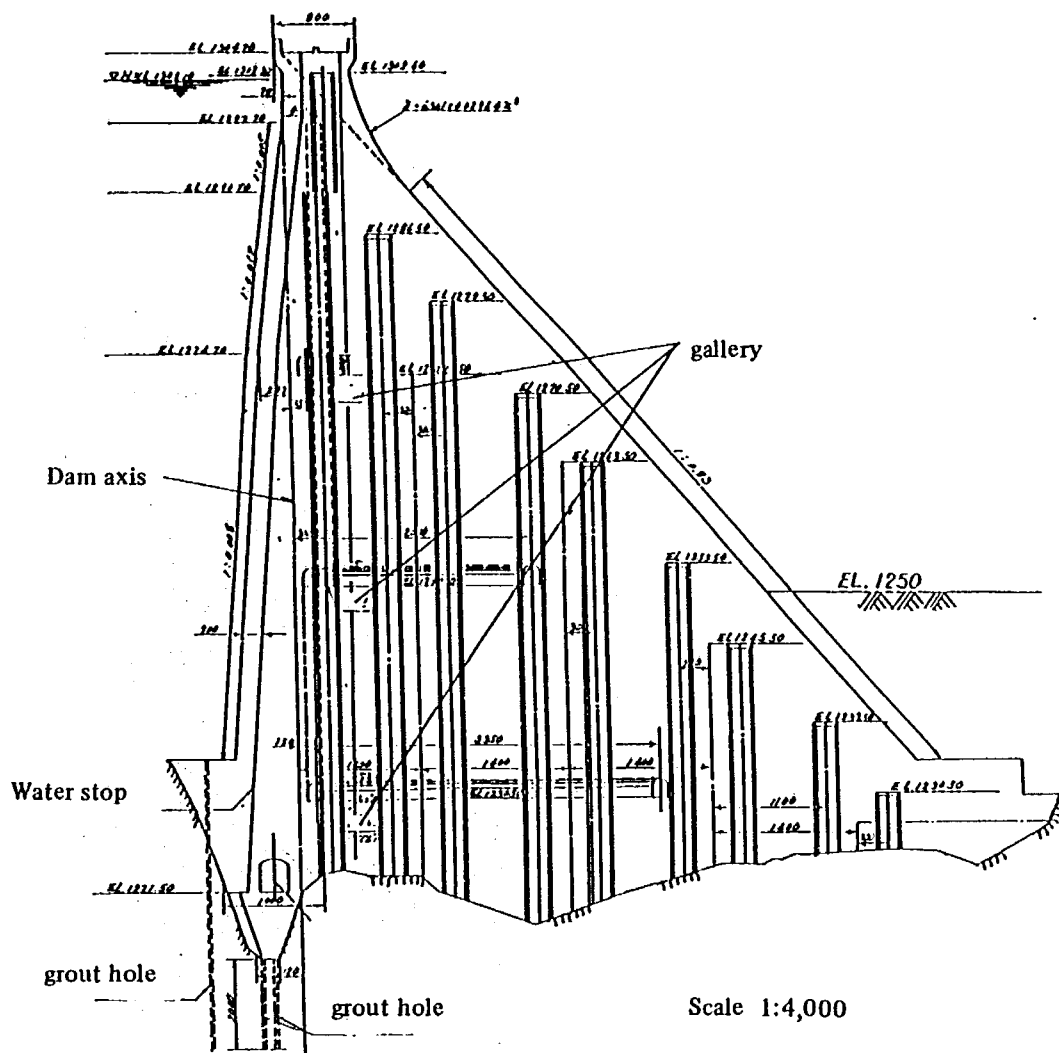
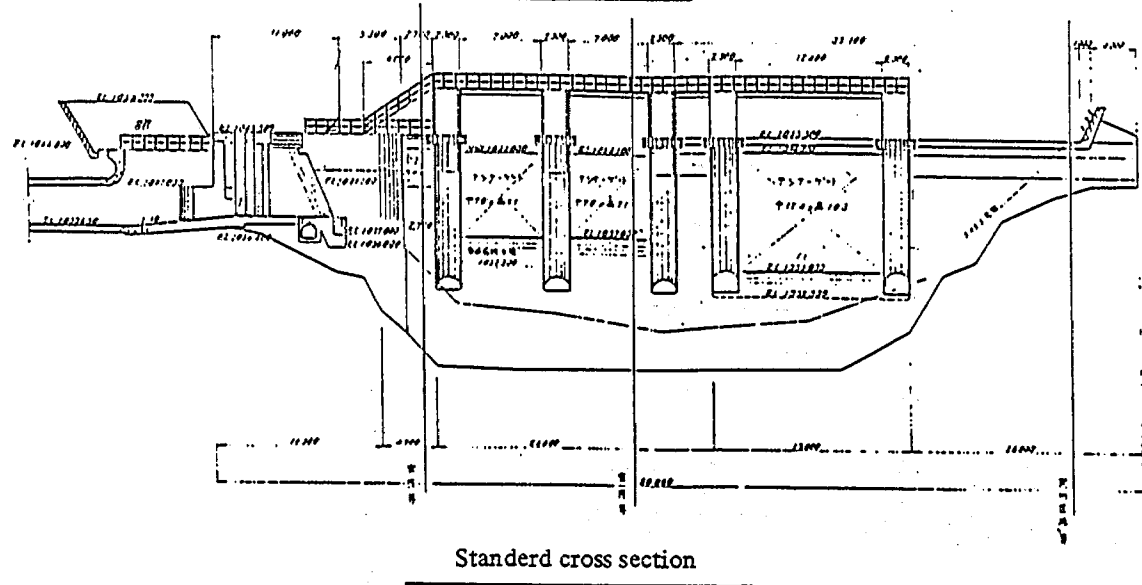


Fig. 4.4 Cross section of Miure Dam

Upstream view



Standard cross section

overflow section

non-overflow section

overflow section

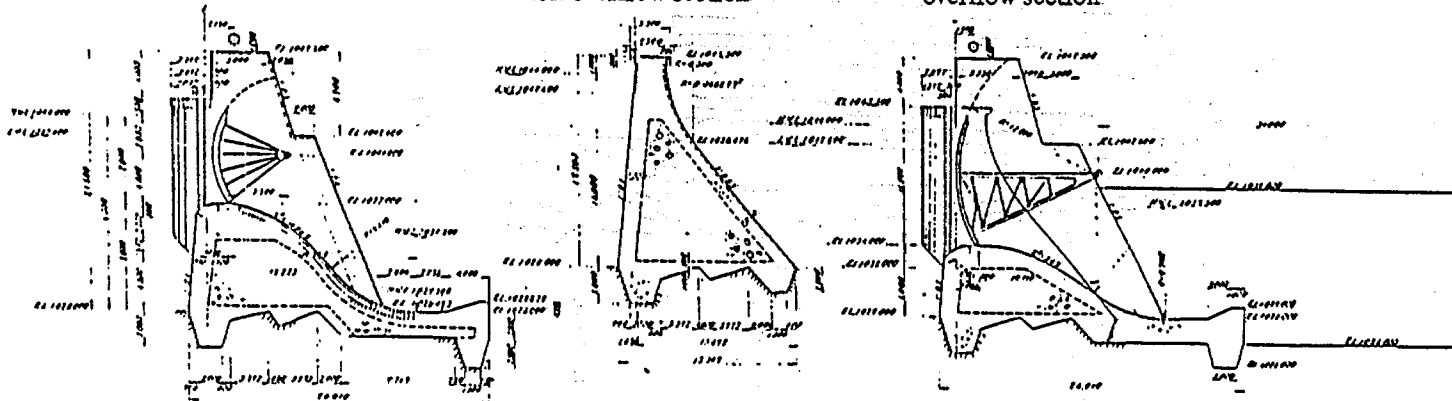


Fig. 4.5 Upstream view and cross sections of Ohtakigawa Dam

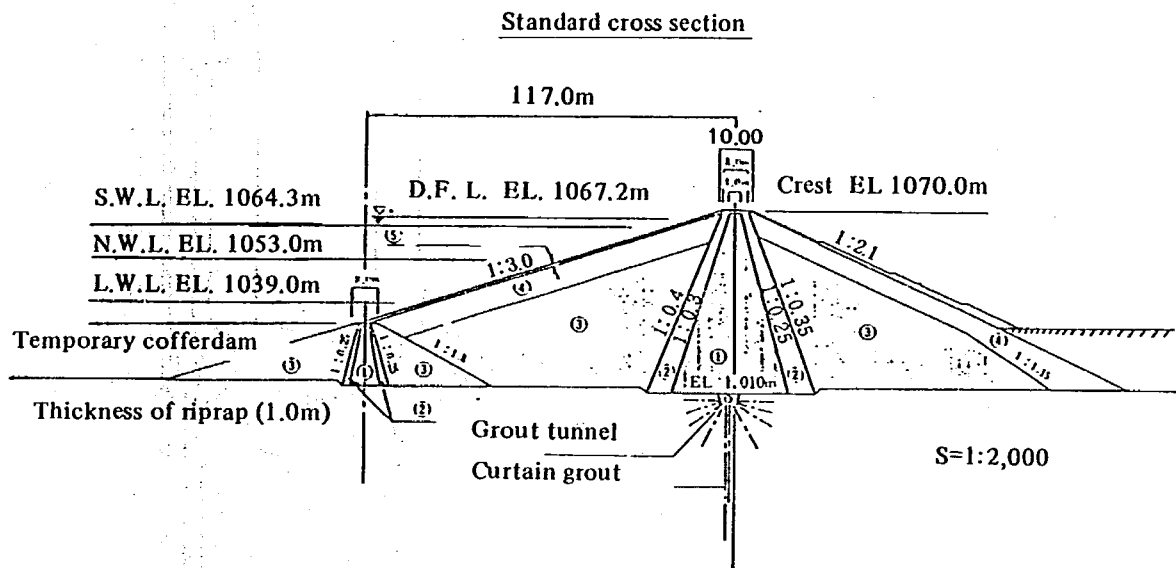


Fig. 4.6 Cross section of Narai Dam

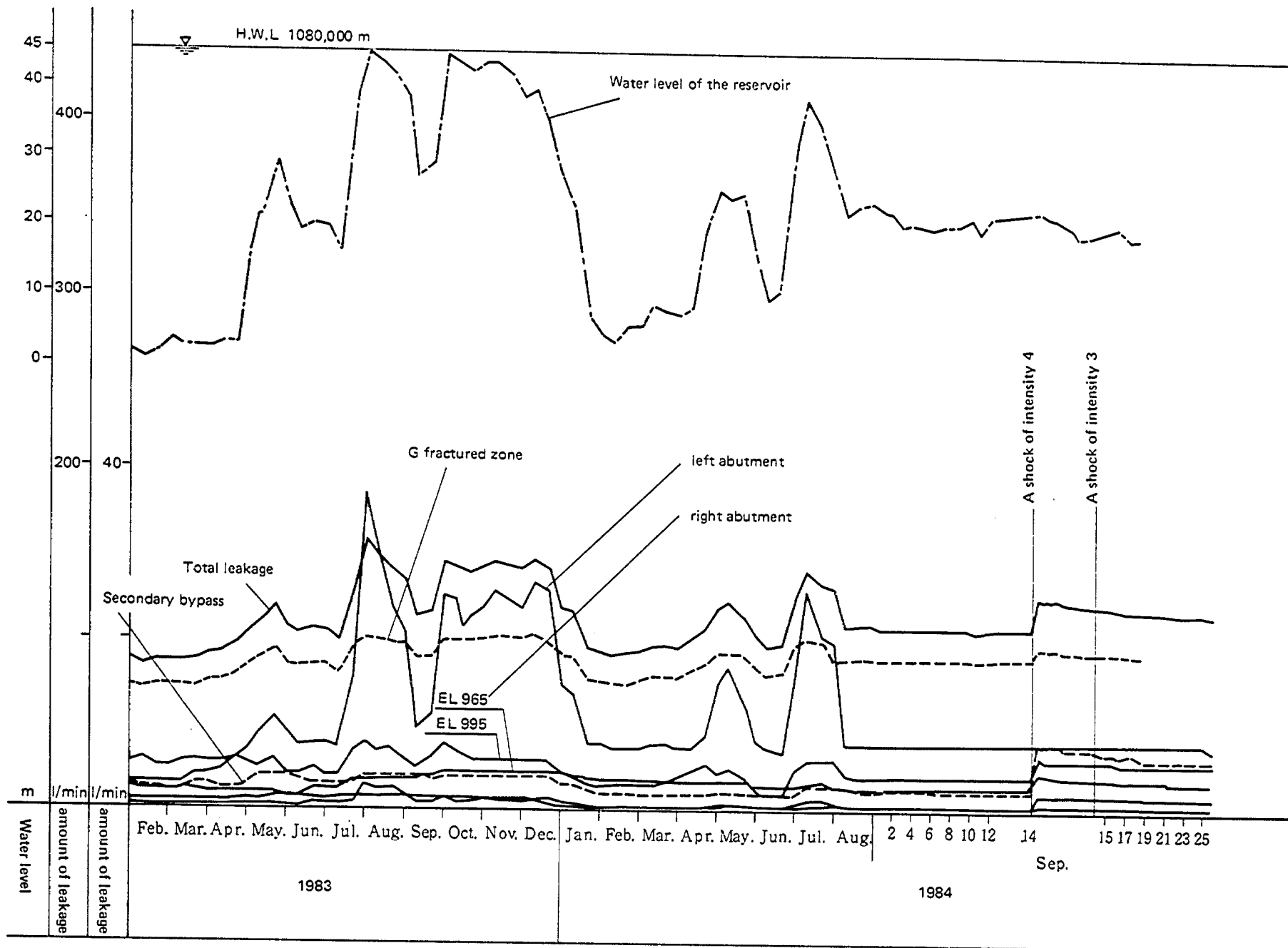


Fig. 4.7 Diagram of leakage (Takane No.1 Dam, Courtesy of Chubu Electric Power Co.)



Photo 1 Cracks parallel to dam axis (Makio Dam)



Photo 2 Cracks parallel to dam axis (Makio Dam)



Photo 3 Subsidence at the top of downstream slope (Makio Dam)

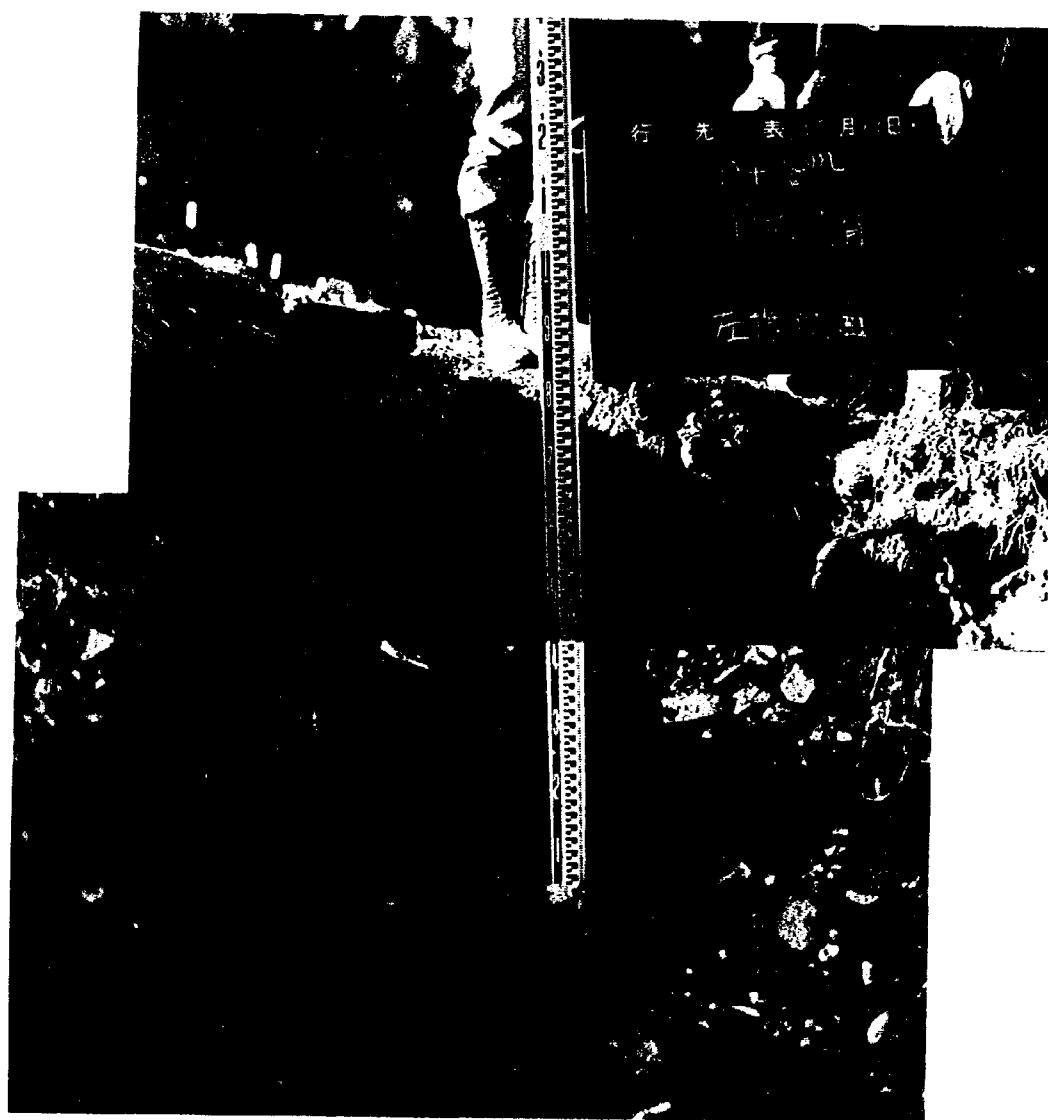


Photo 4 Movement of downstream slope (Makio Dam)

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Key Words: Earthquake, Aftershock, Rockfill Dam, Concrete Dam, Seismograph

"The Western Nagano Prefecture Earthquake, 1984" occurred near Ohtaki village, Nagano Prefecture at 8:48 a.m. September 14, 1984. Makio Dam was located about 5 km from the epicenter. In addition to Makio Dam, there were several high dams within the epicentral distance of 100 km and the earthquake motion were recorded at some of them.

In Makio Dam, a few cracks were found at crest, but the dam body suffered no major casualties. Satisfactory behaviours of dams during the earthquake indicate that the dams can withstand near-field earthquakes very well.



