EARTHQUAKE RECORDINGS ON AND NEAR DAMS

by

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USCOLD

Committee on Earthquakes
Panel on Instrumental Recordings at
Dams

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FOREWORD

This report presents data on earthquake recordings made on or near dams. The serious consequences of failure makes it imperative that dams in seismic regions be designed to resist earthquake shaking safely and economically. To achieve this, designers of dams must be provided with information about those dams that have been subjected to strong ground shaking, with or without damage. The most valuable of such information is provided by seismic recordings made on or near dams during strong shaking, as these show the nature of the earthquake shaking. Unfortunately there exist relatively few such recordings because only few dams are instrumented for this purpose. This report provides a collection of seismic records, ranging from very strong shaking to moderate shaking, which should be informative to engineers who design dams. There have been other cases where dams have been damaged by earthquakes but the shaking was not recorded by instruments. It is hoped that, in the future, all instances of earthquake damage to dams, or earthquake recordings on or near dams, will be described in publications so that the information is available to dam designers in all parts of the world.

Earlier reports issued by the Committee on Earthquakes are "Seismic Instrumentation of Dams" by B. A. Bolt and D. E. Hudson, April 1975; and "Evaluation of Seismicity at U.S. Reservoirs" by W. Daly, W. Judd, and R. Meade, May 1977.

G. W. Housner
Chairman
Committee on Earthquakes

The Committee on Earthquakes collects, analyzes and publishes data relevant to earthquake hazards and the design of dams, and identifies areas where additional research is needed. The project for preparing this report received partial support from the National Science Foundation. Any findings, opinions, conclusions or recommendations presented in this report are those of the authors and not of the National Science Foundation.

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2. INTRODUCTION

The Panel on Instrumental Recordings at Dams, appointed by the Committee on Earthquakes, of the United States Committee on Large Dams, has collected copies of the significant earthquake strong-motion accelerograms recorded on or near dams. This report gathers together some background information concerning each of these dams including, in general, a plan view and section showing the strong-motion instrument locations, and a copy of the significant records obtained. Information on site geology, a description of the dam, and the strong-motion instrumentation employed are also included. Each chapter, including this introduction, contains its own figures, tables and selected references.

No attempt has been made to include every recording from all dam installations, as these are far too numerous. The restriction to significant records (in the panel's estimation) has resulted in the inclusion of nine recordings from Los Angeles area dams during the San Fernando earthquake of February 9, 1971; the Oroville Dam recordings of August 1, 1975; and three recordings from dams outside the United States: Koyna Dam, India, December 11, 1967; Hsinfengkiang Dam, a magnitude 4.5 aftershock on December 18, 1972 (main shock, M=6.1, March 19, 1972); and El Infiernillo Dam, Mexico, July 3, 1973.

Two tables, arranged in chronological order of earthquake occurrence, describe the instrument location for strong-motion records obtained at the dams and the availability of plots of acceleration, velocity, displacement, the response spectrum (log-log plot), and the velocity spectrum. Also included are the range of peak values of acceleration recorded by the instruments and references where detailed descriptions of the records and their analyses may be found. Records numbered 2, 3, and 5-10, obtained during the San Fernando, California, earthquake of February 9, 1971, have been included in the digitizing project of the Earthquake Engineering Research Laboratory at the California Institute of Technology; the entry in the References column of Table 2 indicates to which part of this series the record belongs. For example, record no. 3, Pacoima Dam, belongs to Part C, and consequently, its corrected acceleration, velocity and displacement are included in Volume II, Part C, and its response spectrum and velocity spectrum in Volume III, Part C.

In addition to the collection of data on dams and recordings, which will be informative to engineers concerned with the seismic design of dams, this report brings into focus the wide variation in the methods of deploying strong-motion instruments on large dams. For example, the number of instrumented locations on the dams included in this report ranges from one to nine. It is interesting to note that an earlier publication of the USCOLD Subcommittee on Seismic Hazards and Effects on Dams (now the Committee on Earthquakes) entitled Seismic Instrumentation of Dams by Bruce A. Bolt and Donald E. Hudson, prescribes minimum strong-motion instrumentation for ordinary dams to include at least four instrumented locations, and that major dams should have more than four locations instrumented.

Note on recordings from Boulder Dam. Three accelerographs were installed at Boulder Dam (now, Hoover Dam) in April 1937 by the U.S. Bureau of Reclamation with the cooperation of the U.S. Coast and Geodetic Survey. They have subsequently recorded up to 20 earthquakes. The largest recording was on 25 March 1963, with 0.2 g recorded at both the 1215 gallery (a utility gallery within the dam near its top) and the top of the Nevada intake tower. The acceleration at ground level 600 m from the dam was 0.075 g. The records have not been digitized for analysis and are not included in this report.

3. ACKNOWLEDGEMENT

We are grateful to those individuals and agencies who allowed Panel members to inspect their files and to abstract and copy appropriate information and data. The Panel would especially like to thank Harry Kues of the Los Angeles County Flood Control District, Hank Mayeda of the Los Angeles Department of Water and Power, Chuck Orvis and Marty Carlassere of the Corps of Engineers, and Art Rezin of the Metropolitan Water District of Southern California.

4. List of Selected References Describing Strong-Motion Records Obtained from Large Dams

Koyna Dam, December 10, 1967

1. Gupta, Harsh K., B. K. Rastogi, and Hari Narain, 1971, The Koyna Earthquake of December 10, 1967: A Multiple Seismic Event, Bull. Seism. Soc. America, v. 61, no. 1, p. 167-176.
2. Krishna, Jai, A. R. Chandrasekaran, and S. S. Saini, 1969, Analysis of Koyna Accelerogram of December 11, 1967, Bull. Seism. Soc. America, v. 59, no. 4, p. 1719-1731 (plot, printout).
3. Guha, S. K., P. D. Gosavi, J. G. Padale, and S. C. Marwadi, 1966, Crustal Disturbance in the Shivaji/Sagar-Lake area of the Koyna Hydro-electric Project (Maharashtra, India), 3rd Symp. on Earthquake Eng'g., School of Research and Training in Earthquake eng'g., University of Roorkee, p. 399-416.
4. Housner, G. W., 1970, Seismic Events at Koyna Dam, Proceedings of Eleventh Symposium on Rock Mechanics, 1970.

Pacoima Dam, February 9, 1971; Abutment

5. Trifunac, M. D., and D. E. Hudson, 1971, Analysis of the Pacoima Dam Accelerogram, Bull. Seism. Soc. America, v. 61, no. 5, p. 1393-1411.
6. Perez, V., 1973, Velocity Response Envelope Spectrum as a Function of Time for the Pacoima Dam Accelerogram, San Fernando Earthquake, Feb. 9, 1971, Bull. Seism. Soc. America, v. 63, no. 1. p. 299-313.
7. Boore, D. M., 1973, The Effect of Simple Topography on Seismic Waves: Implications for the Accelerations Recorded at Pacoima Dam, San Fernando Valley, California, Bull. Seism. Soc. America, v. 63, no. 5, p. 1603-1609.

8. Bolt, B. A., 1972, San Fernando Rupture Mechanism and the Pacoima Strong-Motion Record, Bull. Seism. Soc. America, v. 62, no. 4, p. 1053-1061.

Lower San Fernando Dam, February 9, 1971

9. Scott, R. F., 1972, The Calculation of Horizontal Accelerations from Seismoscope Records, Bull. Seism. Soc. America, v. 63, no. 5, p. 1637-1661.

Hsinfengkiang Dam, China, December 18, 1972

10. Bolt, Bruce A., and W. K. Cloud, 1974, Recorded Strong Motion on the Hsinfengkiang Dam, China, Letters to the Editor, Bull. Seism. Soc. America, v. 64, no. 4, p. 1337-1342.

11. Shen Chung-kang, Chen Hou-chun, Chang Chu-Han, Huang Li-sheng, Li Tzu-chiang, Yang Cheng-jung, Wang Ta-chun, and Lo Hsueh-hai, 1973, Earthquakes Induced by Reservoir Impounding and Their Effect on the Hsinfenkiang Dam, Proc. 11th Int. Cong. Large Dams, Madrid.

Data Reports on the San Fernando Earthquake, February 9, 1971

12. Hudson, D. E. (Ed.), 1971, Strong Motion Instrumental Data on the San Fernando Earthquake of Feb. 9, 1971, Joint report by the Earthquake Engineering Research Laboratory at the California Institute of Technology and the Seismological Field Survey, National Oceanic and Atmospheric Administration.

13. Jennings, P. C. (Ed.), 1971, Engineering Features of the San Fernando Earthquake, Feb. 9, 1971, Earthquake Engineering Research Laboratory Report No. EERL 71-02, California Institute of Technology, Pasadena, California.

14. Earthquake Engineering Research Laboratory, California Institute of Technology, Strong Motion Earthquake Accelerograms, Volume I,

Uncorrected Accelerograms, Parts C through S.

15. Earthquake Engineering Research Laboratory, California Institute of Technology, Strong Motion Earthquake Accelerograms, Volume II, Corrected Acceleration, Velocity and Displacement, Parts C through S.

16. Earthquake Engineering Research Laboratory, California Institute of Technology, Analyses of Strong Motion Earthquakes Accelerograms, Volume III, Response Spectra, Parts C through S.

<u>Oroville Dam, California, August 1, 1975</u>

17. Richard P. Maley, Virgilio Perez, and B. J. Morrill, Strong-Motion Seismograph Results from the Oroville Earthquake of 1 August 1975, *in* Oroville, California Earthquake 1 August 1975, Special Report 124 of California Division of Mines and Geology.

18. Special Papers on the Oroville California Earthquakes of August, 1975, *in* Bull. Seis. Soc. America, v. 66, no. 4, August, 1976.

<u>Arvin-Tehachapi Earthquake, 21 July 1952</u>

19. E.E. Esmiol, Rational Earthquake Design Criteria for Earth Dams, U.S. Bureau of Reclamation, Division of Design, Denver, Colorado, March 1965.

TABLE 1

5. LIST OF SIGNIFICANT STRONG-MOTION RECORDS OBTAINED AT AND NEAR DAMS

Record No	Station Description
1	Koyna Dam, India; in the gallery at about midheight in block 1A
2	Santa Felicia Dam, Piru, California; two stations: one at the outlet works and the other on the crest
3	Pacoima Dam, California; on a steep-sided ridge forming the left abutment
4	Lower San Fernando Dam, California; the seismoscope on the east abutment provided sufficient information for approximate calculations of the two horizontal acceleration components
5	Carbon Canyon Dam, Brea, California; on the crest
6	Whittier Narrows Dam, Whittier, California; on the crest
7	San Antonio Dam, Upland, California; on the crest
8	Fairmont Reservoir, Fairmont, California; abutment
9	Santa Anita Reservoir, Arcadia, California; abutment
10	Puddingstone Reservoir, San Dimas, California; abutment
11	Hsinfengkiang Dam, China; 12 accelerometers at 9 locations in the dam
12	El Infiernillo Dam, Mexico; at the center of the crest
13	Oroville Dam, California; on the crest and at the seismograph station adjacent to the dam.

TABLE 2. AVAILABILITY OF PLOTS

Record No.	Instrument Location	Date	Accelerometer Locations	Total Components	Plots of Acceleration	Velocity & Displacement	Response Spectrum, Log plot	Velocity Spectra	References	Range of Peak Accelerations, (g)
1	Koyna Dam	12-11-67	1	3	x	x	x	x	1,2,3,4	0.3-0.6
2	Santa Felicia Dam	2-09-71	2	6	x	x	x	x	Part E, 12-16	0.06-0.2
3	Pacoima Dam	2-09-71	1	3	x	x	x	x	Part C 5-8,12-16	0.7-1.1
4	Lower San Fernando Dam	2-09-71	1	2	x	x	-	x	9	0.6-0.8
5	Carbon Canyon Dam	2-09-71	1	3	x	x	x	x	Part N, 12-16	0.04-0.07
6	Whittier Narrows Dam	2-09-71	1	3	x	x	x	x	Part N, 12-16	0.06-0.1
7	San Antonio Dam	2-09-71	1	3	x	x	x	x	Part N, 12-16	0.03-0.08
8	Fairmont Reservoir	2-09-71	1	3	x	x	x	x	Part O, 12-16	0.03-0.1
9	Santa Anita Reservoir	2-09-71	1	3	x	x	x	x	Part P, 12-16	0.05-0.16
10	Puddingstone Reservoir	2-09-71	1	3	x	x	x	x	Part P, 12-16	0.04-0.07
11	Hsinfengkiang Dam	12-18-72	9	12	x	-	-	-	10,11	0.02-0.5
12	El Infiernillo Dam	7-03-73	1	3	x	x	-	-	-	0.05-0.1
13	Oroville Dam	8-01-75	2	6	x	x	x	x	17,18	0.09-0.13

7. KOYNA DAM

Introduction

Koyna Dam and its reservoir, Shivajisagar Lake, are located on the Peninsula of India at 17.38°N and 73.75°E, about 64 km inland from the Arabian Sea. The Koyna River flows primarily due south from its source for a distance of about 61 km and then makes an abrupt turn to the east and flows 773 km into the bay of Bengal. Koyna Dam is about 5 km north of this turn. The approximately north-south trending continental divide is several km west of Koyna. Figure 1 (Berg and others, 1969) shows the Koyna site relative to the Indian seismic zones.

Soon after the impounding of the reservoir in 1962, earth tremors near the dam became increasingly evident, even though the Peninsular Shield of India was thought to be nearly aseismic. In 1963, a seismographic network was established with four stations positioned around and within a few tens of kilometers of the reservoir, and two accelerographs were installed in the dam. Computed hypocenters were very shallow and clustered near the reservoir. On September 13, 1967 two moderate shocks occurred, magnitudes approximately 5.0 and 5.5, with epicenters estimated to be in the vicinity of the dam. On December 11, 1967 a magnitude 6.5 earthquake occurred near the reservoir causing considerable damage to the dam and the nearby township of Koynanagar. A horizontal crack developed through the dam at elevation 628 m (2060 feet) (Figure 2).

A downstream view of the dam is shown in Figure 3. Figure 4 shows damage sustained by the guard rail on the crest of the dam.

Geology

Koyna Dam and Reservoir are situated in Deccan Trap (volcanic) terrain -- a broadly aseismic pre-cambrian block. Deccan Trap, mainly basaltic in composition, resulted from extensive lava flows in the Cretaceous-Tertiary

(Eocene) periods and occupy about 518,000 square kms in the western and central parts of Peninsular India.

There is evidence of tectonic movements and crustal adjustments in the Deccan Trap. The west coast of India is of tectonic origin. The land mass formerly to the west of the present coastline is thought to have been faulted down and covered by the Arabian Sea. This Miocene fault (the Malabar Fault) trends almost N-S and is part of a major structural feature. Faults parallel to the coast are indicated by several warm springs that lie near and parallel to the west coast. This system of N-S trending faults in the trap region resulted from tectonic activity that occurred during the formation of the west coast. The N-S trend of the Koyna River above Koyna is believed by many geologists to be the result of faulting (Housner, 1970).

Seismicity

Historically, (since 1594) none of the reported earthquakes that occurred on the eastern Indian Peninsular Shield would have been felt strongly at Koyna (Committee of Experts, 1968). Infrequent low magnitude earthquakes had occurred in the Koyna Dam site area before construction of the dam, as confirmed by Benioff seismograms recorded at Poona (120 km to the north) beginning in the early 1950's.

The seismic zoning map (Figure 1) divides India into seven seismic zones with Koyna in Zone No. 0. The seismic design coefficients for the seven zones are given in the table below (Housner, 1970).

Seismic Design Coefficients for Seismic Zones
Shown in Figure 1

Zone No.	Hard Soil	Average Soil	Soft Soil
0	0	0	0
I	0	0.01	0.02
II	0.02	0.03	0.04
III	0.04	0.05	0.06
IV	0.05	0.06	0.08
V	0.06	0.08	0.10
VI	0.08	0.10	0.12

Description of the Dam

Koyna Dam is a concrete gravity dam 853 m long and 103 m high. Reservoir capacity is $2{,}780 \times 10^6$ cubic meters (2,260,000 acre-feet) with a maximum reservoir water depth of 100 m. The dam is constructed of rubble concrete with a 1.8 m thickness of conventional concrete on the upstream face. Figure 2 shows a cross-section of the highest monolith of the dam. Figure 5 shows the dam and its foundation as viewed from downstream. The monoliths are each more than 15 m thick. Note the AR-240 accelerographs in Monoliths 1A and 13.

Besides the two accelerographs, the four seismograph stations previously noted were installed around the dam, including one at the dam. The station at the dam included a Wood-Anderson seismograph, a Benioff vertical seismograph, and three tiltmeters. The three outlying stations each had a Wood-Anderson and a Benioff seismograph. The instruments were installed during the period November 1963 to January 1965.

Strong-Motion Recordings

Earthquakes occurring on September 13 (magnitude 5.5) and December 11 (magnitude 6.5) triggered the accelerographs in Monoliths 13 and 1A, respectively.

The December accelerogram was in some parts too faint to reproduce photographically, so a tracing was made (Figure 6). However, because of the tracing, there is some doubt as to the correct value of the peak acceleration. The maximum acceleration (0.45 *g*) shown in Figure 6 occurs on the horizontal component aligned with the longitudinal axis of the dam.

Spectral analyses of both the September and December strong-motion recordings are discussed in Berg, and others (1969). Analysis of the December accelerogram is also presented in Krishna, and others (1969).

Berg tabulated some of the significant properties of the two earthquakes:

		September 13	December 11
Peak acceleration	Vertical	.08 g	.36 g
	Longitudinal	.11 g	.45 g
	Transverse	.11 g	.39 g
Undamped response, transverse	Peak velocity (at period)	.26 ft/sec (.1 sec.)	2.5 ft/sec (.6 sec)
Undamped spectral intensity		.23 ft	4.0 ft

"Spectral intensity is defined as the area under the undamped velocity spectrum curve between 0.1 and 2.5 second period. It provides an objective measure of the destructiveness of the earthquake at the recording station. For comparison, the spectral intensity of the S69E component of the Taft, California, earthquake of July 21, 1952, was 4.8 feet, and the N-S component of the El Centro, California, earthquake of May 18, 1940, had a spectral intensity of 8.9 feet..." (Berg, and others, 1969).

References

Berg, and others, 1969, The Koyna, India, Earthquakes: Proceedings of the Fourth World Conference on Earthquake Engineering, V. 3.

Committee of Experts, 1968. Report on Koyna Earthquake of December 11, 1967, 1 and 2: Gov. of India Press, New Delhi, 75 pp.

Guha, S. K., and others, 1968; Recent Seismic Disturbances in the Shivajisager Lake Area of the Koyna Hydroelectric Project Maharashtra, India: Central Water and Power Research Station, Khadakwasla (South), Poona 24 (India).

Housner, G. W., 1970, Seismic Events at Koyna Dam: Proc. 11th Symposium on Rock Mechanics.

Krishna, J., 1969, Analysis of Koyna Accelerogram of December 11, 1967: Bull. Seism. Soc. Am., V 59, 4, p. 1720.

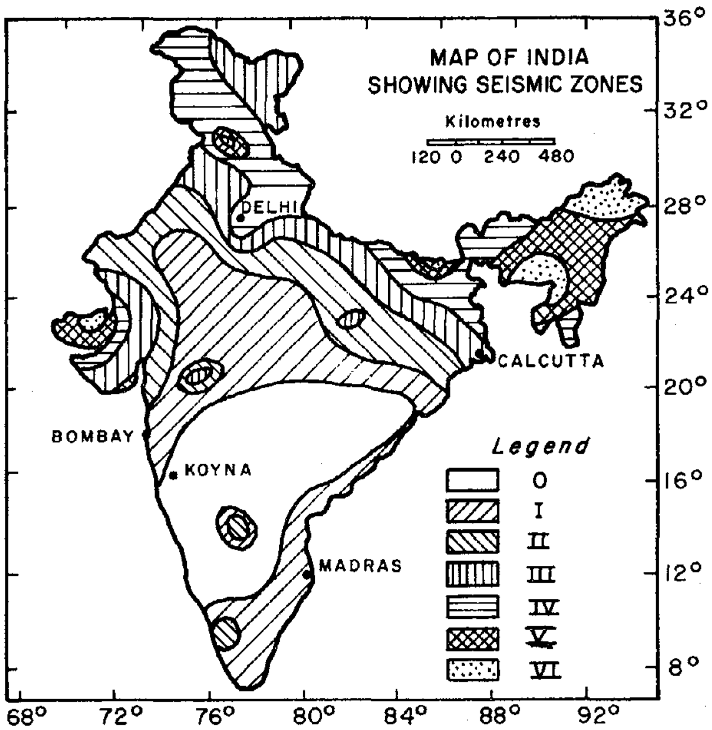


Figure 1. The Inian Seismic Zones as assessed prior to the earthquake. (Berg et al, 1969)

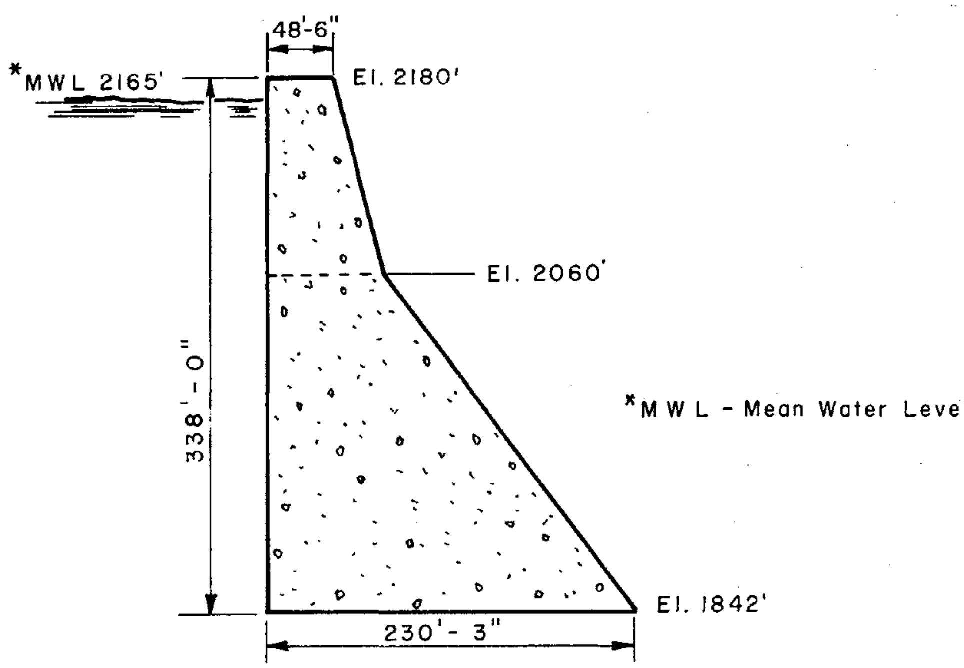


Figure 2. Section through highest monolith of Koyna Dam. The main crack produced by the earthquake of December 11, 1967 passed horizontally through the monolith at elevation approximately 2060 ft. (After Housner, 1970)

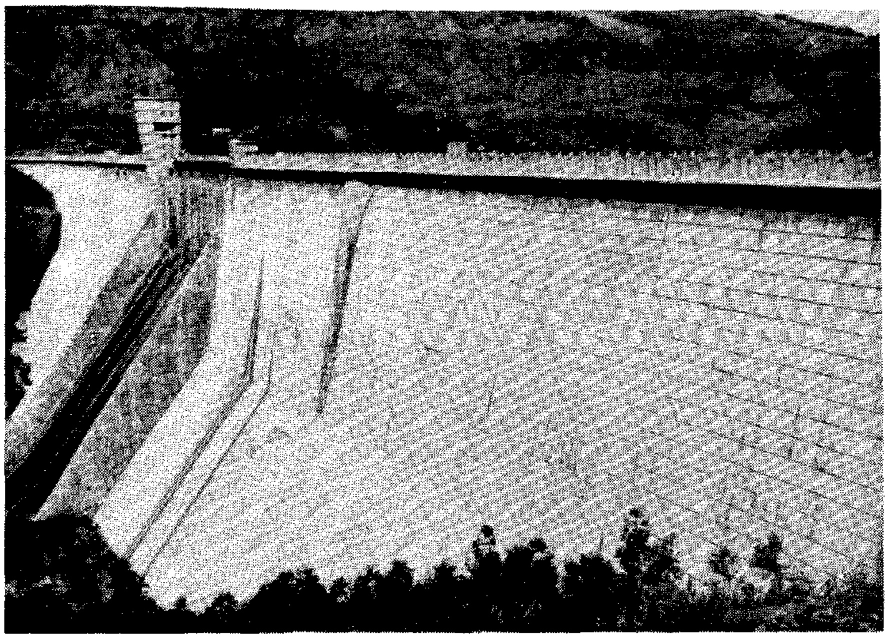


Figure 3. Koyna Dam. View of downstream face following the earthquake.
(Photo by G.V. Berg)

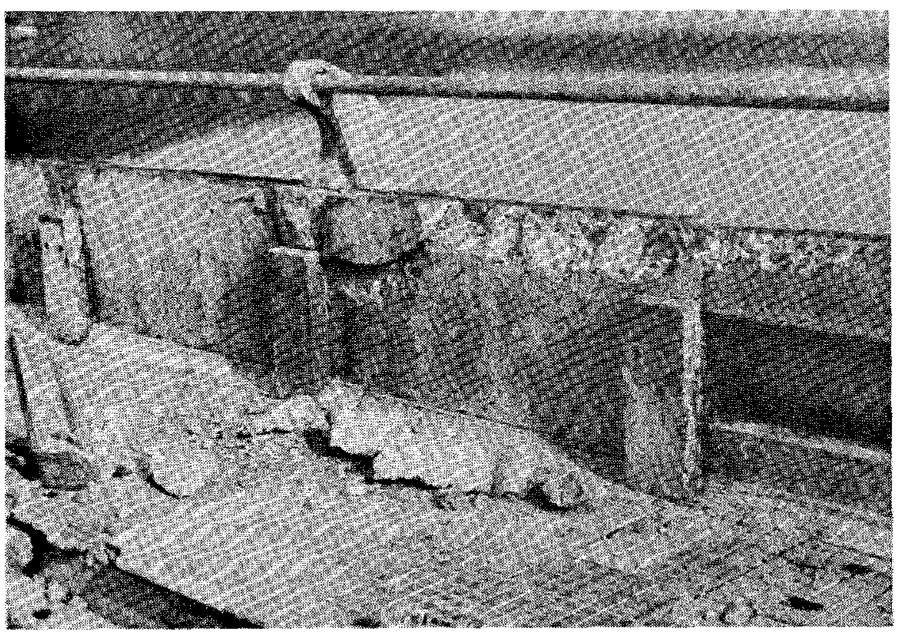


Figure 4. Damage sustained by guard rail on crest of dam.(Photo by G.V.Berg)

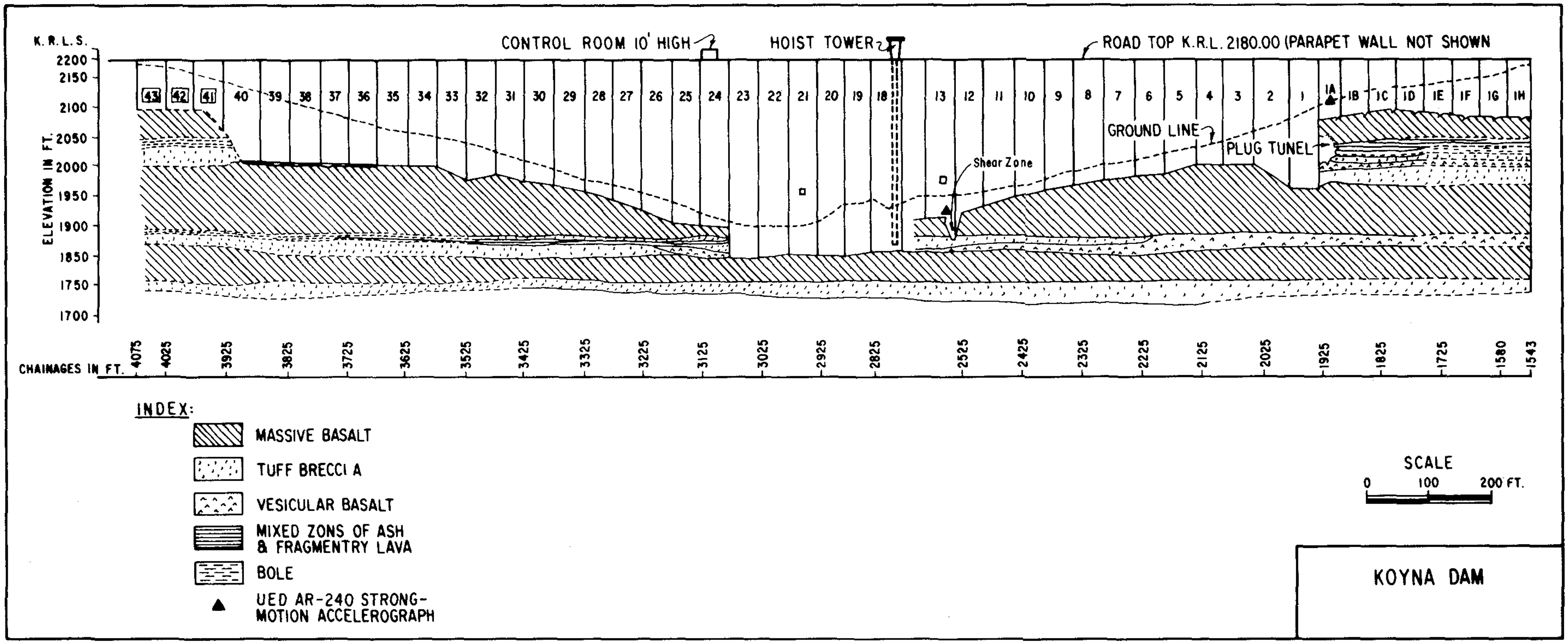


FIGURE 5. KOYNA DAM FOUNDATION GEOLOGY (AFTER COMMITTEE OF EXPERTS, 1968)

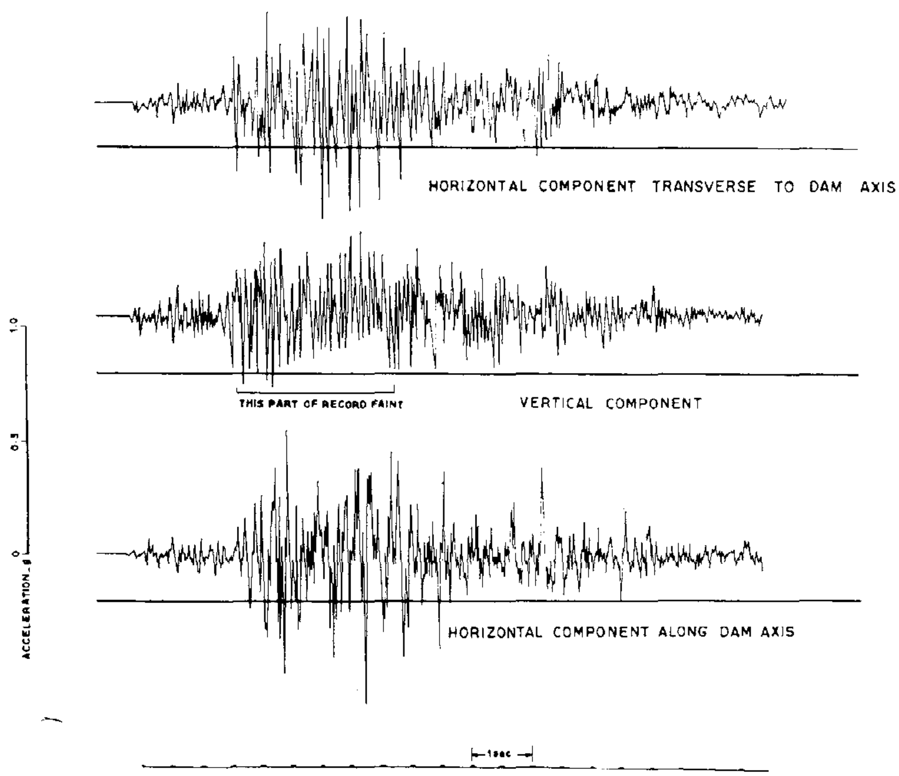


Figure 6. Accelerogram recorded in Block 1-A of Koyna Dam during the earthquake of December 11, 1967. (After Krishna et al, BSSA vol 59, no. 4, August 1969)

8. SANTA FELICIA DAM

Introduction

Santa Felicia Dam, located 65 km northwest of downtown Los Angeles (Figure 1), was constructed by the United Water Conservation District to provide irrigation and ground water recharge throughout the Santa Clara River Valley and Oxnard flood plain. The crest of the dam extends east-west across Piru Canyon, a north-south channel cutting through the Transverse Ranges. The base of the dam is located at an elevation of 265 m while nearby mountains rise to more than 900 m.

Geology

Santa Felicia Dam is located in the Piru Mountains, a segment of the Transverse Ranges in eastern Ventura County, 30 km southwest of the San Andreas fault zone.

The damsite lies within Miocene sandstones and shales that locally dip approximately 70° south and strike nearly east-west and cross Piru Creek in a normal direction (Rhoades, 1954). The sandstones are generally poorly cemented and range in thickness from a few cm to several meters. The thinner bedded shales vary from relatively hard fissile zones to compacted but uncemented softer layers. Minor faulting is indicated by the existence of slickensides in the sandstone strata located near the spillway on the right bank, 6 m west of the outlet works accelerograph site.

Approximately 23 m of alluvial stream fill was removed from the creek bed beneath the axis of the dam to expose the native shale and sandstone. The rock floor was relatively flat and is predominantly shale under the upstream half of the dam and predominantly sandstone under the downstream half.

Description of the Dam

Santa Felicia Dam, completed in 1955, is a zoned earth fill structure with a crest length of 388 m, height of 60 m and a crest width of 9 m (Figures 2 and 3). A total volume of 2.83×10^6 m^3 was required for the embankment. Maximum capacity of the reservoir is 1.23×10^8 m^3 (100,000 acre-feet). The direction of the longitudinal axis of the dam is S78.6W

Strong-Motion Recordings

Two accelerographs and 6 seismoscopes were installed at Santa Felicia Dam at the time of the San Fernando earthquake (Figure 4). The accelerographs were located at center crest and at the outlet works on abutment bedrock (right bank) near the toe of the dam. The 6 seismoscopes were located at center crest, right crest, right and left abutments, downstream on spoil material, and at the outlet works. Figures 5 through 10 show the corrected accelerograms and the integrated velocity and displacement curves from the San Fernando earthquake of 1971 (reference 15, Introduction). The instrument on the abutment was installed on the valve house floor that was apparently supported by pipes vertically embedded in the ground. Consequently there is a high frequency vibration in the horizontal components of acceleration which represents structural vibrations and not earthquake ground motion. The accelerographs were not connected for simultaneous starting and the abutment instrument record began a few seconds after the crest instrument. Figures 11-16 show the corresponding response spectra. The spectral peaks in the neighborhood of 0.12 secs in Figures 11-13 represent the vibrations of the valve house. The peaks in the neighboehood of 0.7 secs in Figures 14-15 represent the vibrations of the fundamental modes of the dam.

References

Rhoades, R., Geology of the Santa Felicia Dam Site, Ventura County California United Conservation District, Santa Paula, California, 8 p.

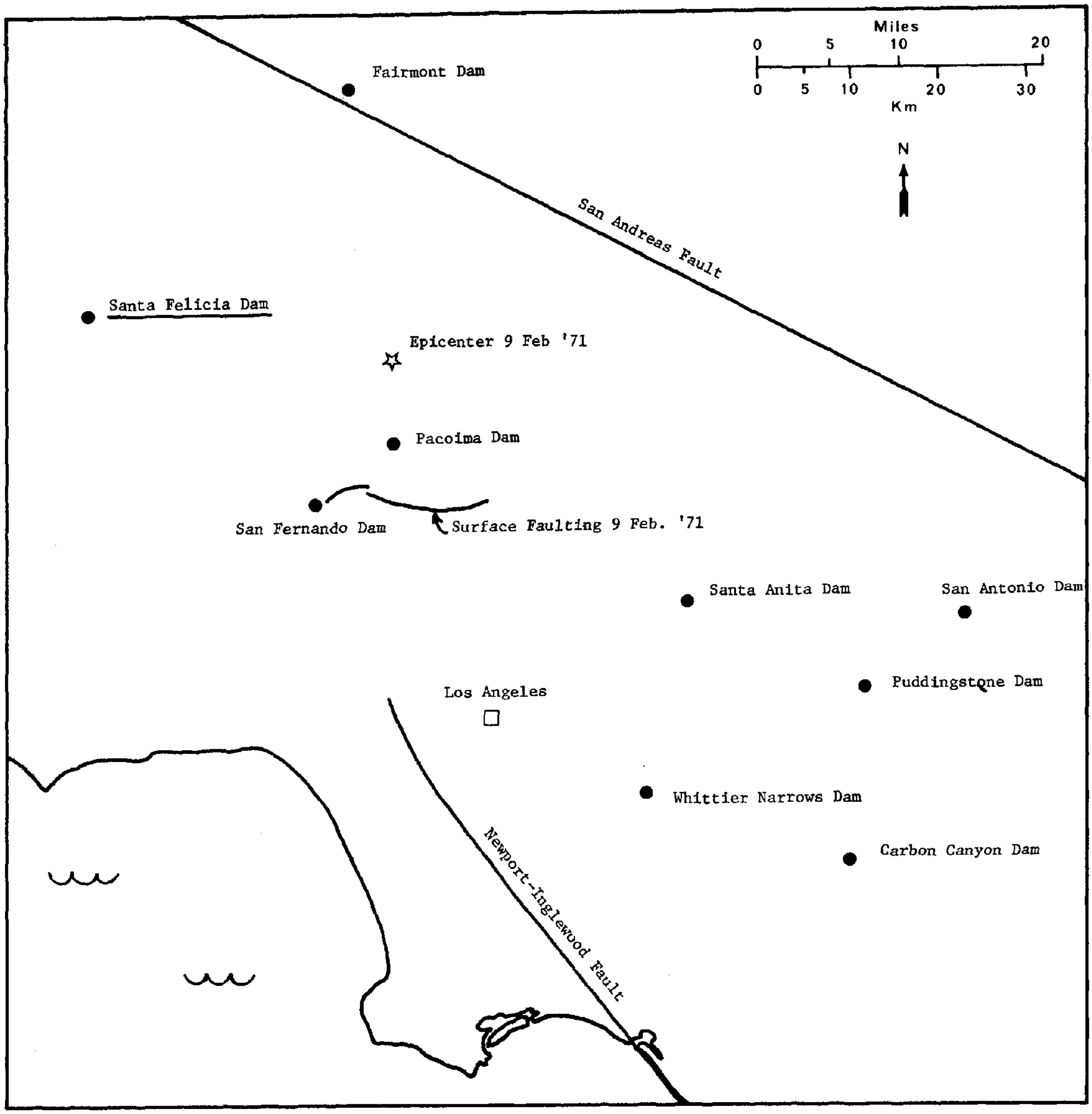


Figure 1. Location of dams where significant strong-motion records were obtained from the San Fernando earthquake of 9 February 1971.

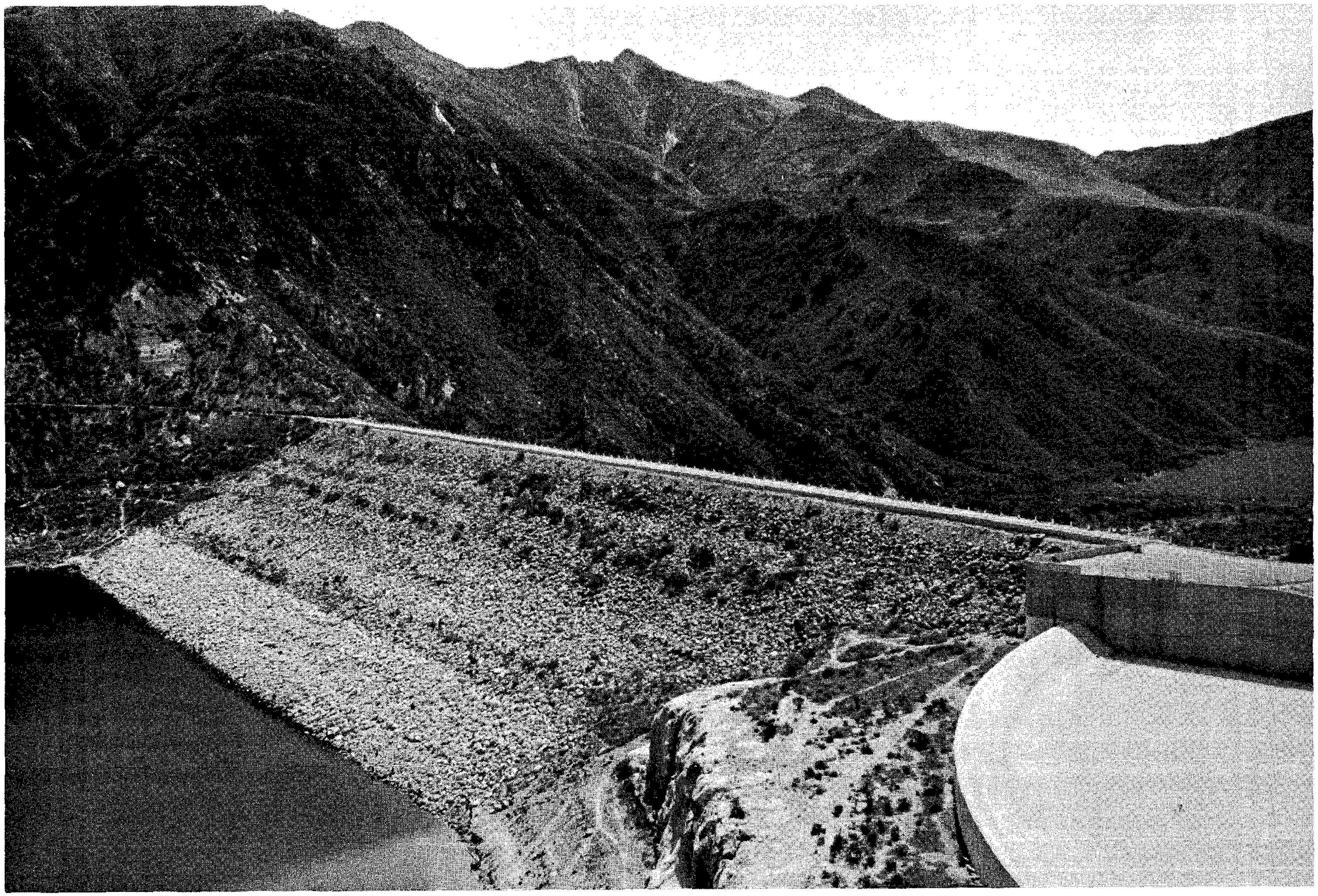


FIGURE 2. Santa Felicia Dam.

(Photo: California Istitute of Technology, EERL)

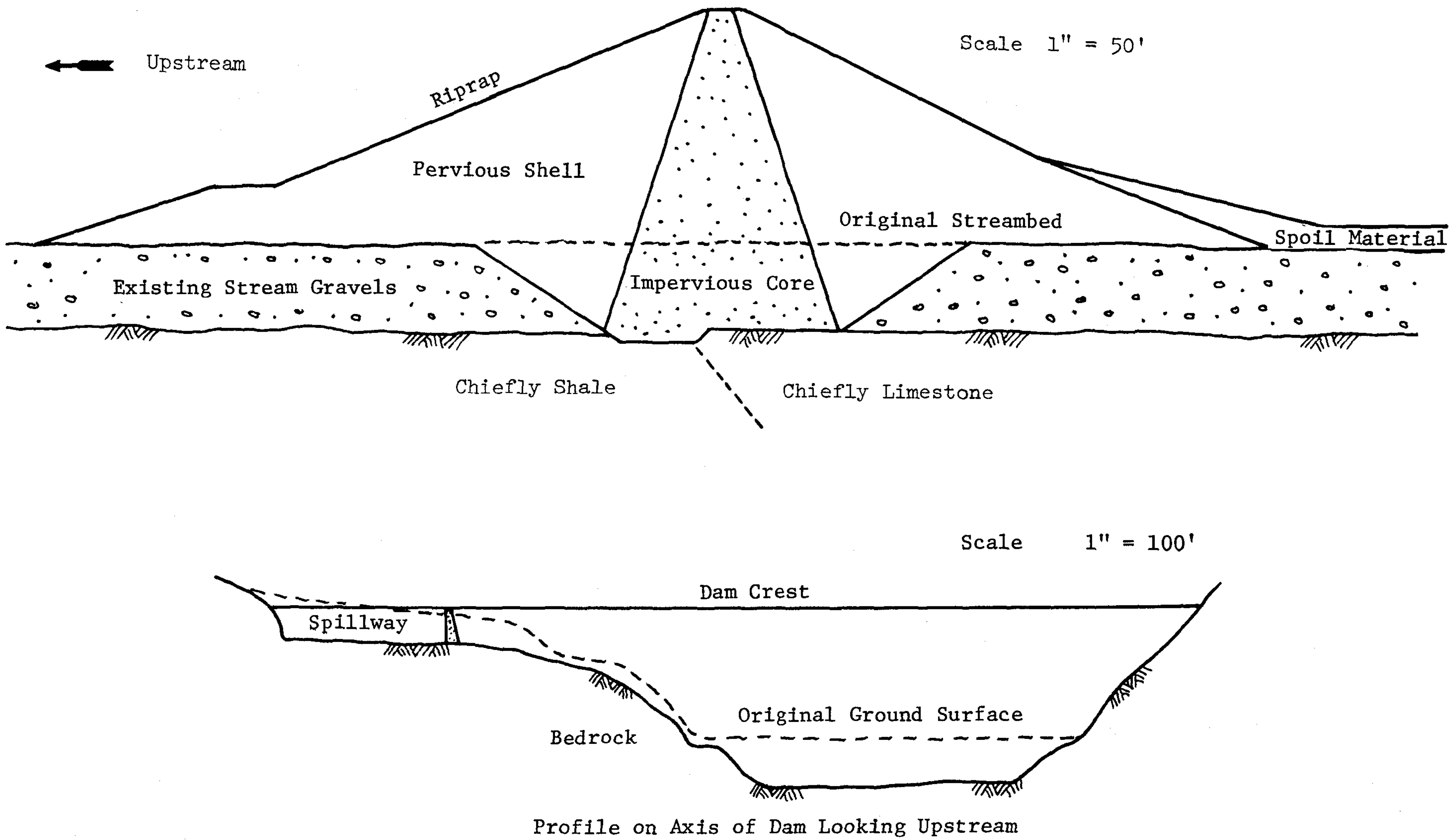


Figure 3. Cross-section and profile of Santa Felicia Dam.

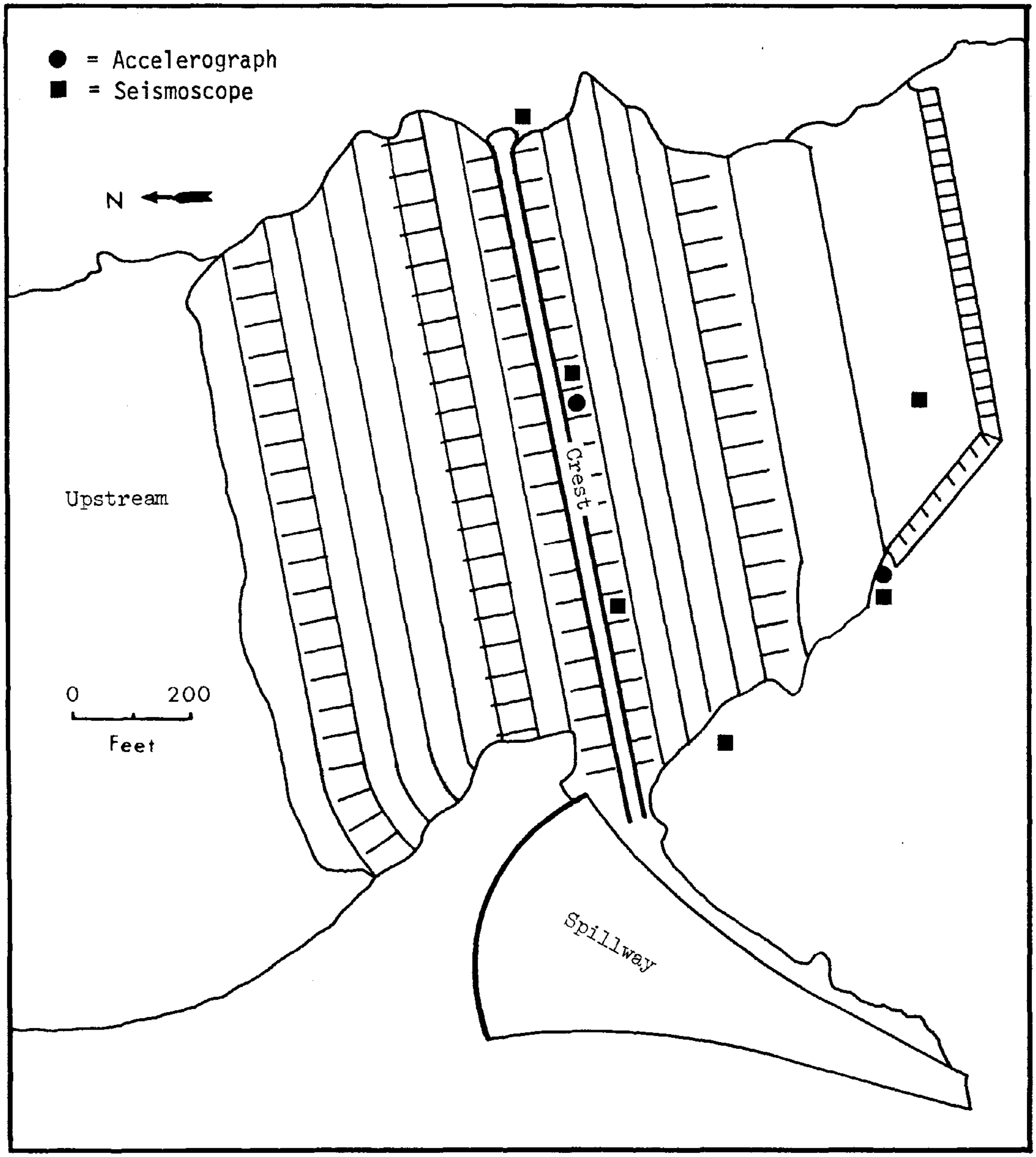


FIGURE 4. Location of strong-motion instruments at Santa Felicia Dam in 1971.

FIGURE 5.

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST
IIE082 71.063.0 SANTA FELICIA DAM, CAL., CREST COMP S15E
⊙ PEAK VALUES : ACCEL = -203.3 CM/SEC/SEC VELOCITY = 22.2 CM/SEC DISPL = -7.1 CM

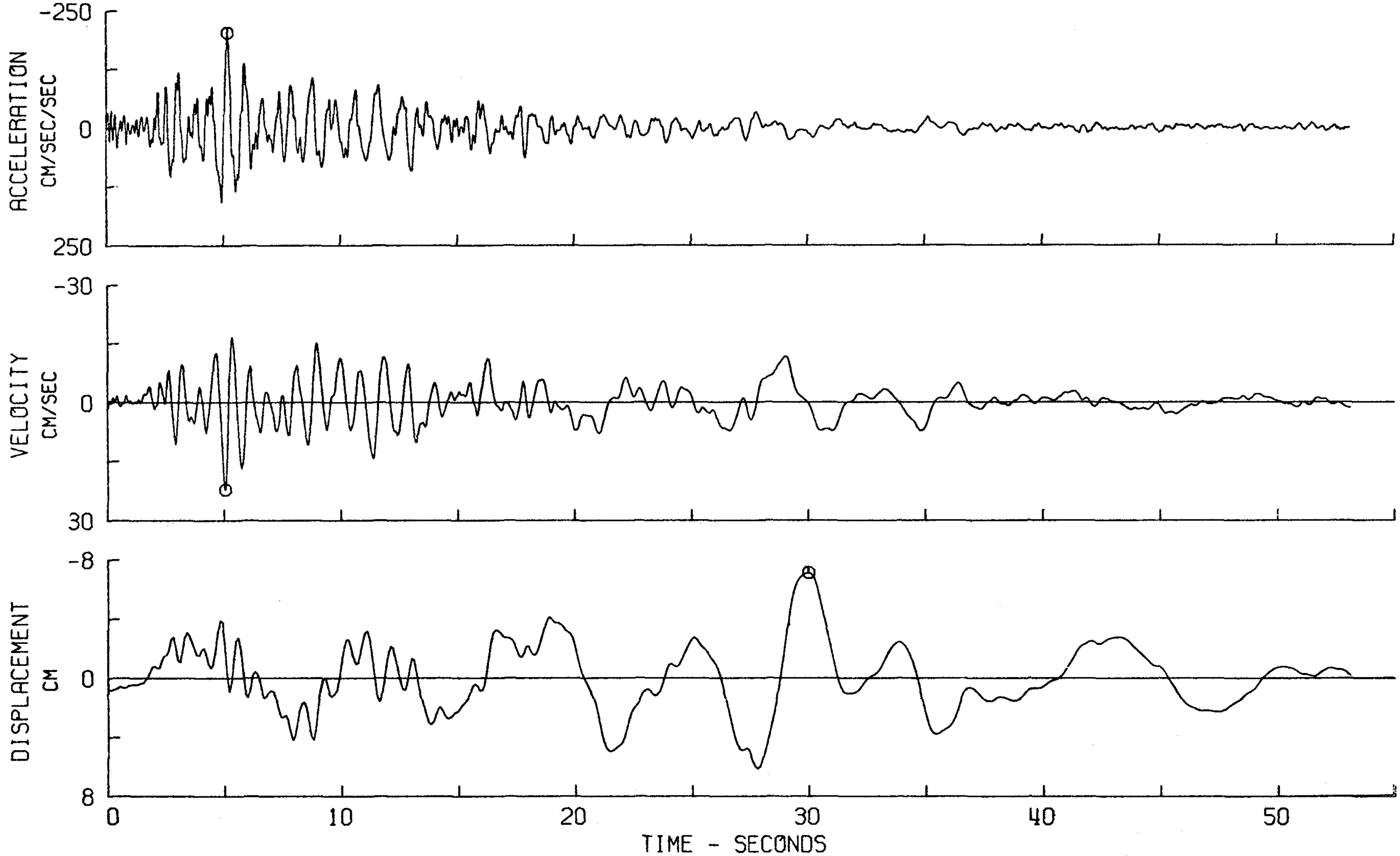


FIGURE 6.

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIE082 71.063.0 SANTA FELICIA DAM, CAL., CREST COMP S75W

⊙ PEAK VALUES : ACCEL = 174.0 CM/SEC/SEC VELOCITY = -18.1 CM/SEC DISPL = -5.3 CM

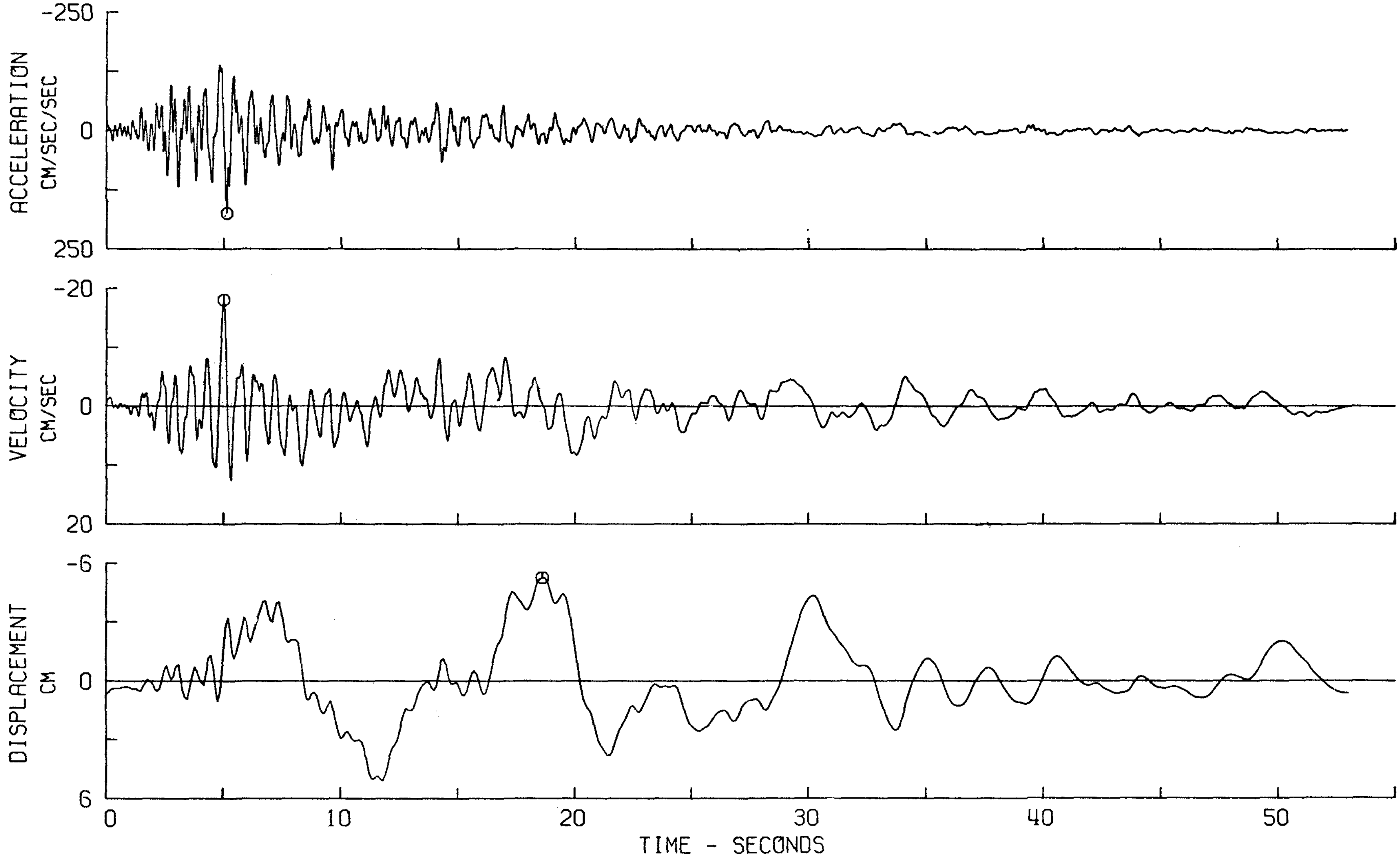
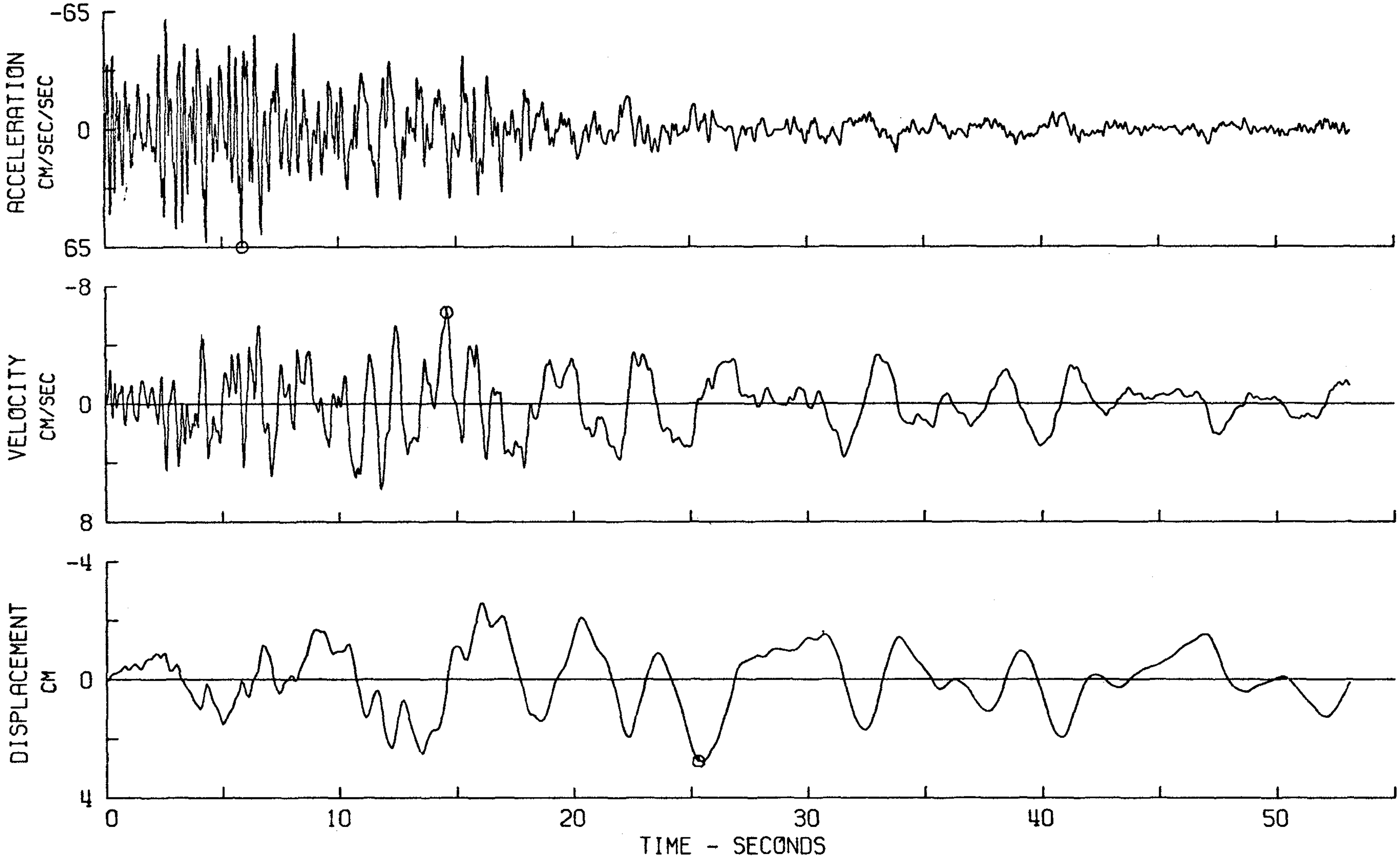


FIGURE 7.

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIE082 71.063.0 SANTA FELICIA DAM, CAL., CREST COMP DOWN

⊙ PEAK VALUES : ACCEL = 65.0 CM/SEC/SEC VELOCITY = -6.2 CM/SEC DISPL = 2.8 CM



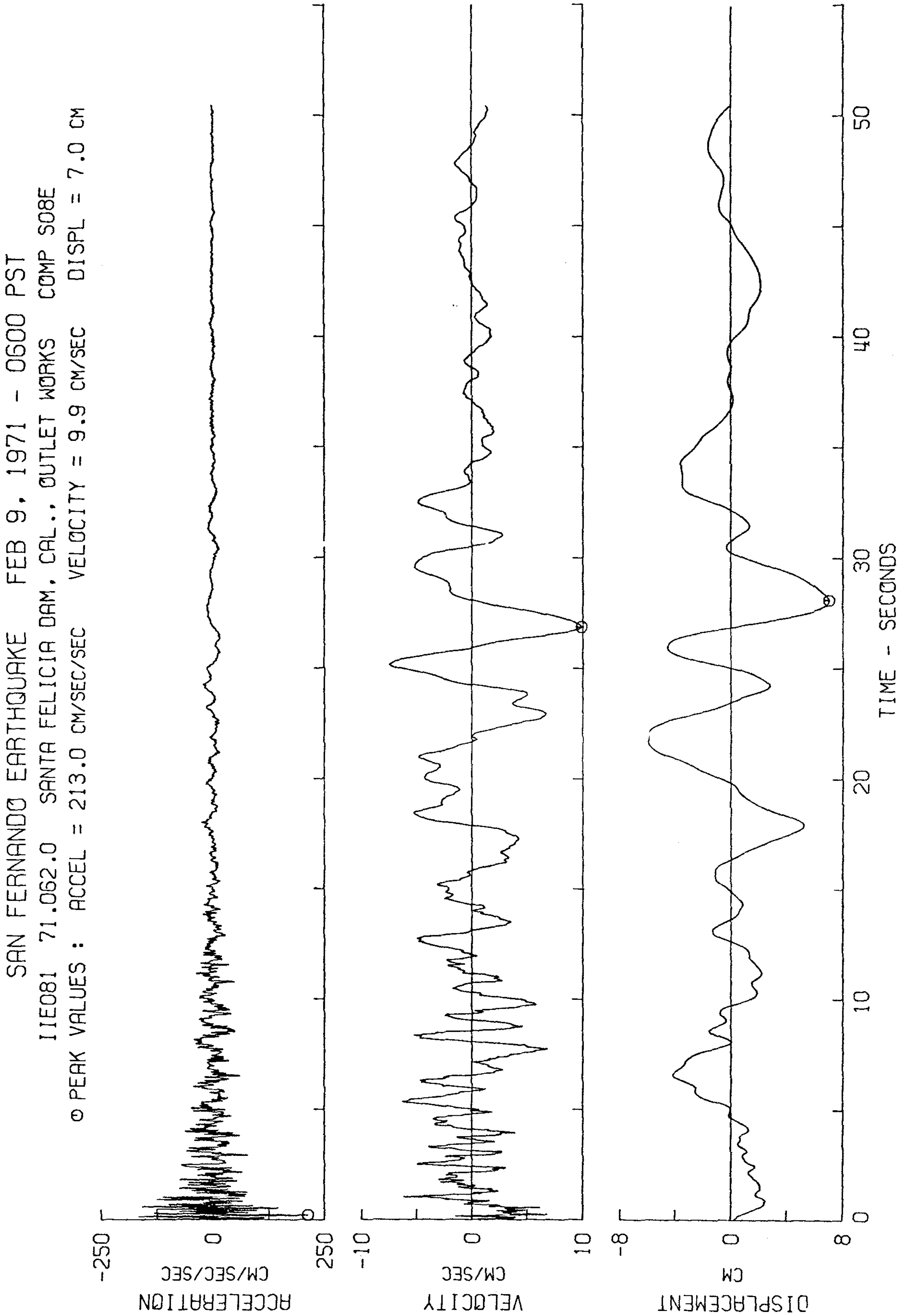


Figure 8. Santa Felicia Dam Outlet Works Accelerogream, Component S08E

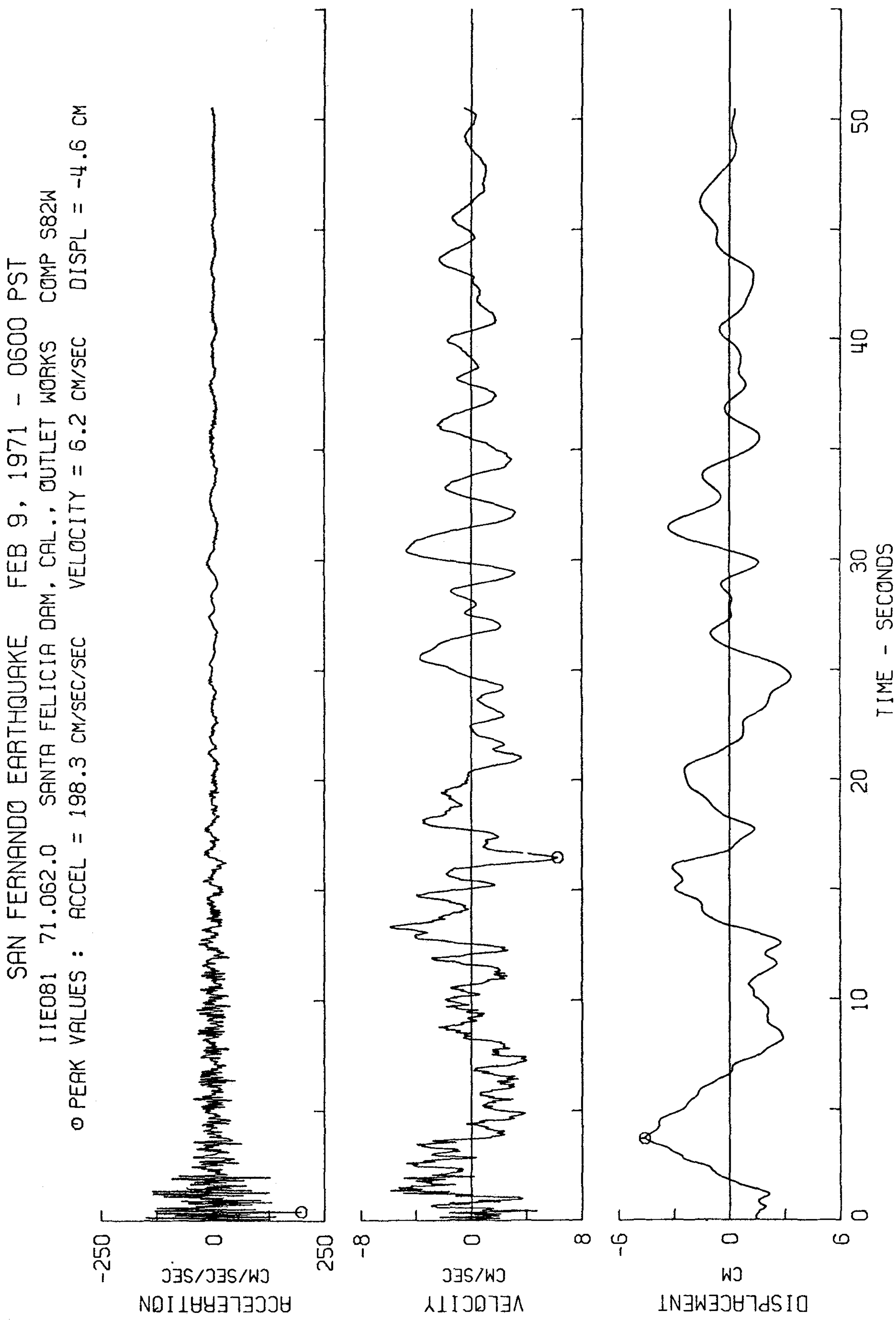


Figure 9. Santa Felicia Dam Outlet Works Accelerogram, Component S82W

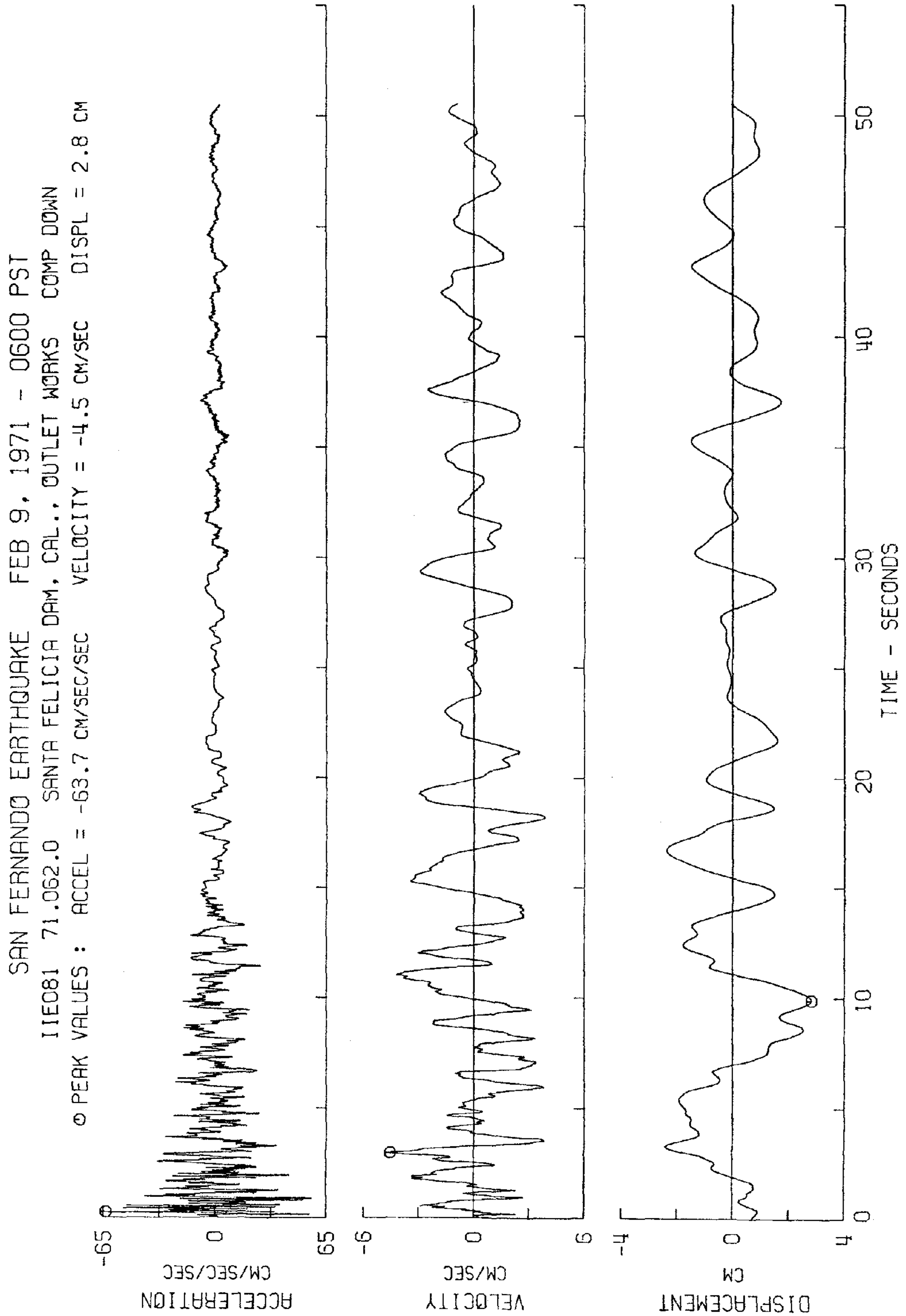


Figure 10. Santa Felicia Dam Outlet Works Accelerogram, Component Vertical.

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIIE081 71.062.0 SANTA FELICIA DAM, CAL., OUTLET WORKS COMP S08E

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL

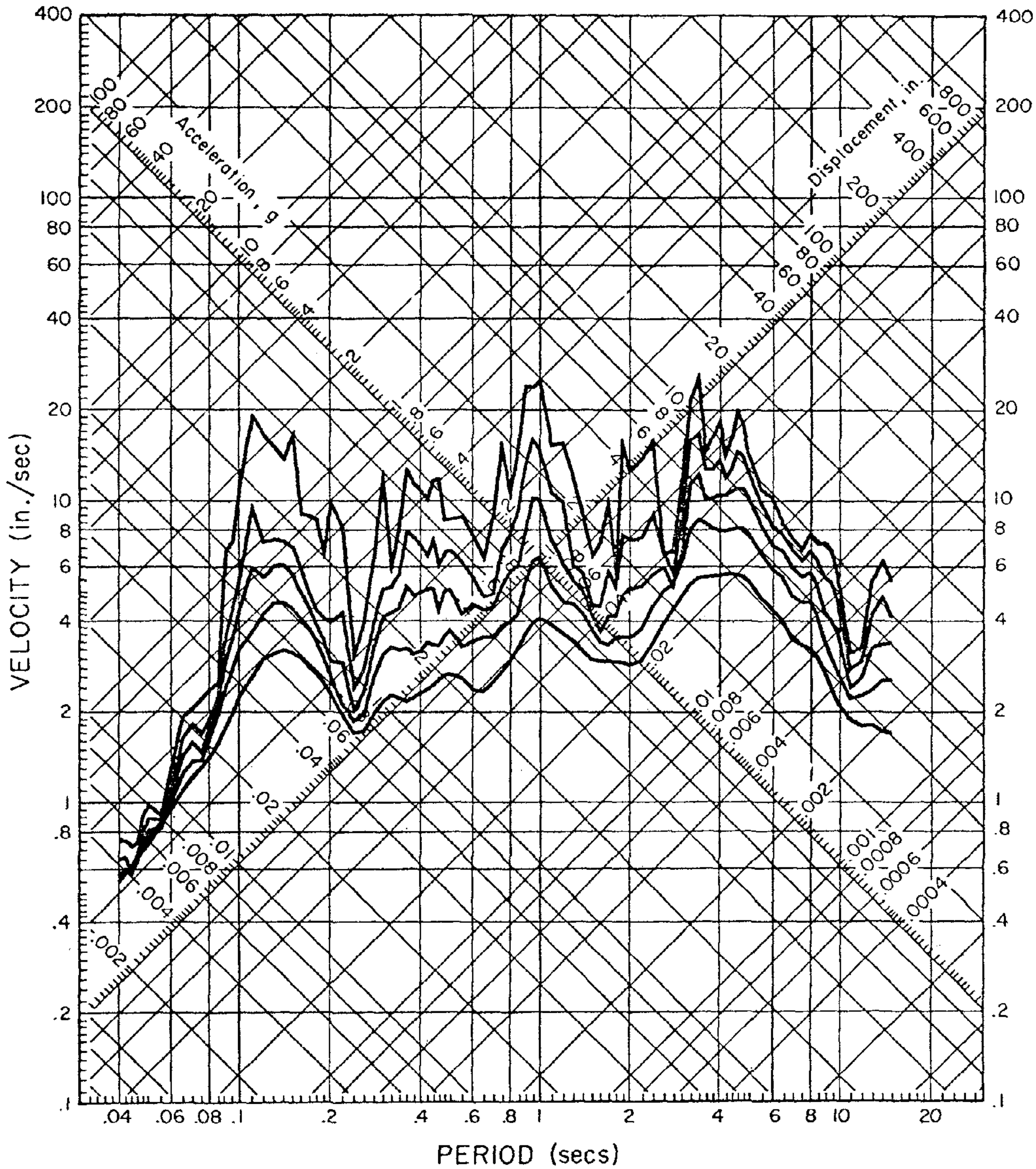


Figure 11. Response Spectrum Santa Felicia Dam Outlet Works-S08E (From Calif. Inst. Tech. Data Reports)

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIIE081 71.062.0 SANTA FELICIA DAM, CAL., OUTLET WORKS COMP S82W

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL

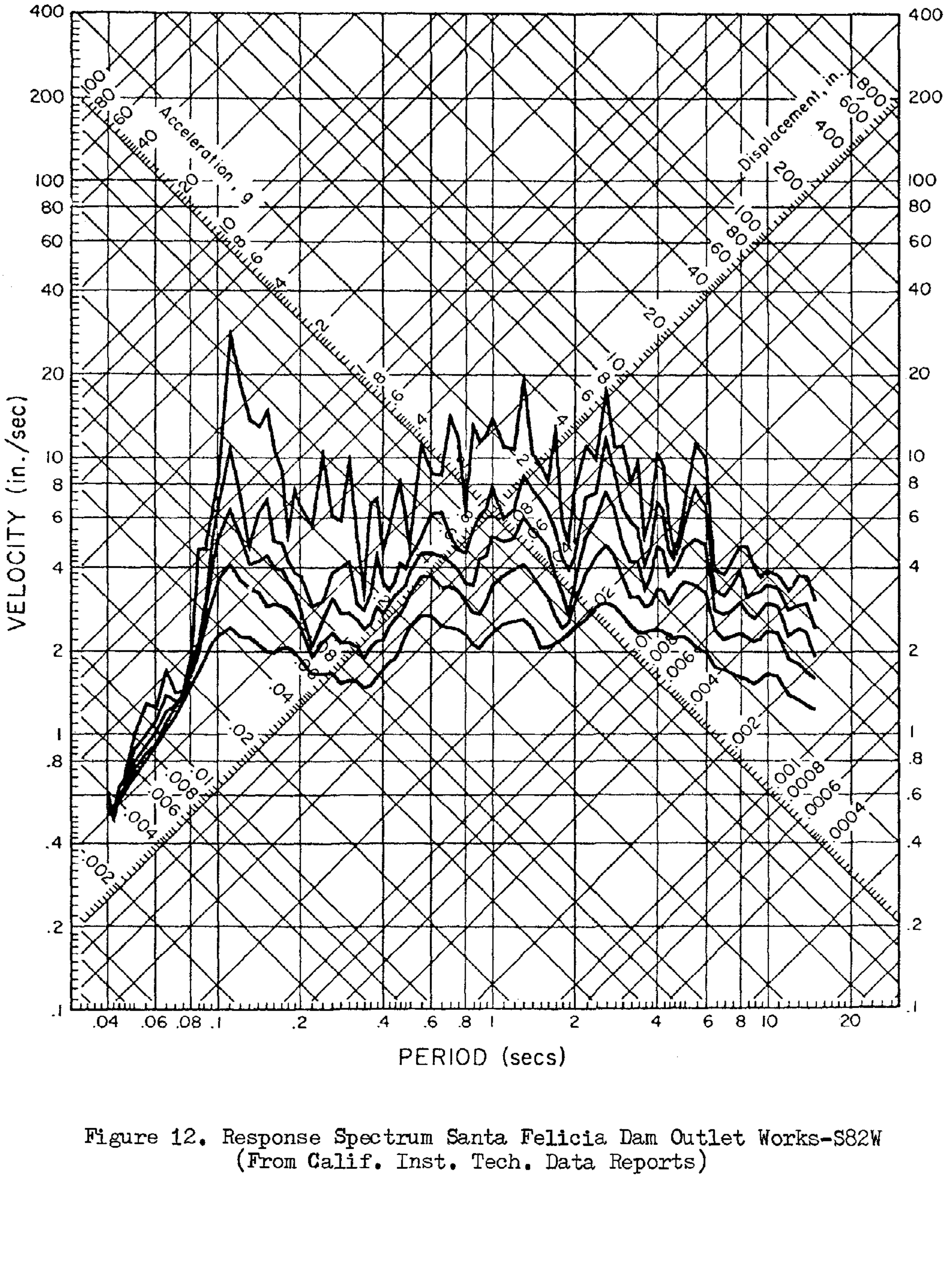


Figure 12. Response Spectrum Santa Felicia Dam Outlet Works-S82W
(From Calif. Inst. Tech. Data Reports)

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIIE081 71.062.0 SANTA FELICIA DAM, CAL., OUTLET WORKS COMP DOWN

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL

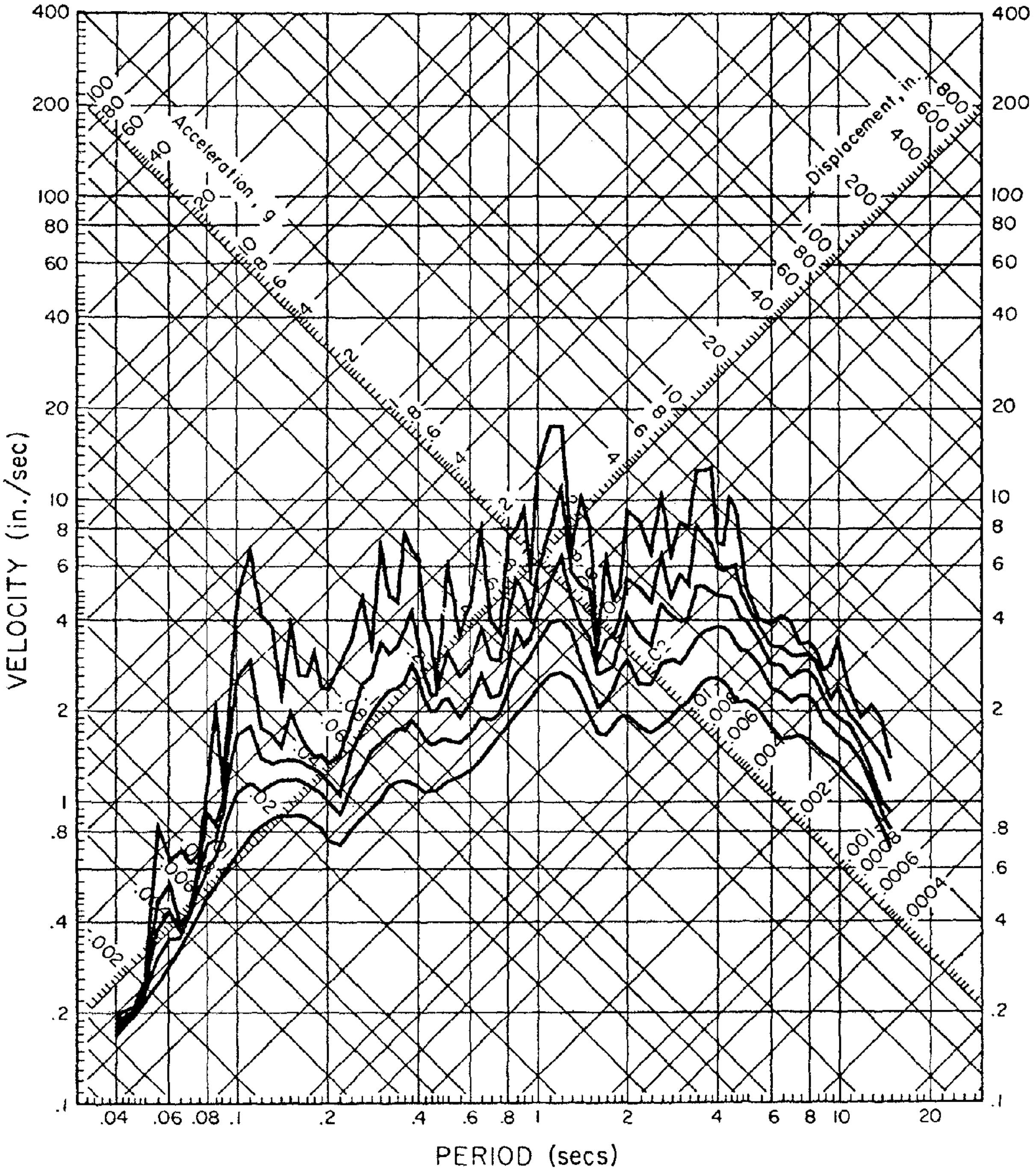


Figure 13. Response Spectrum Santa Felicia Dam Outlet Works-vertical. (From Calif. Inst. Tech. Data Reports)

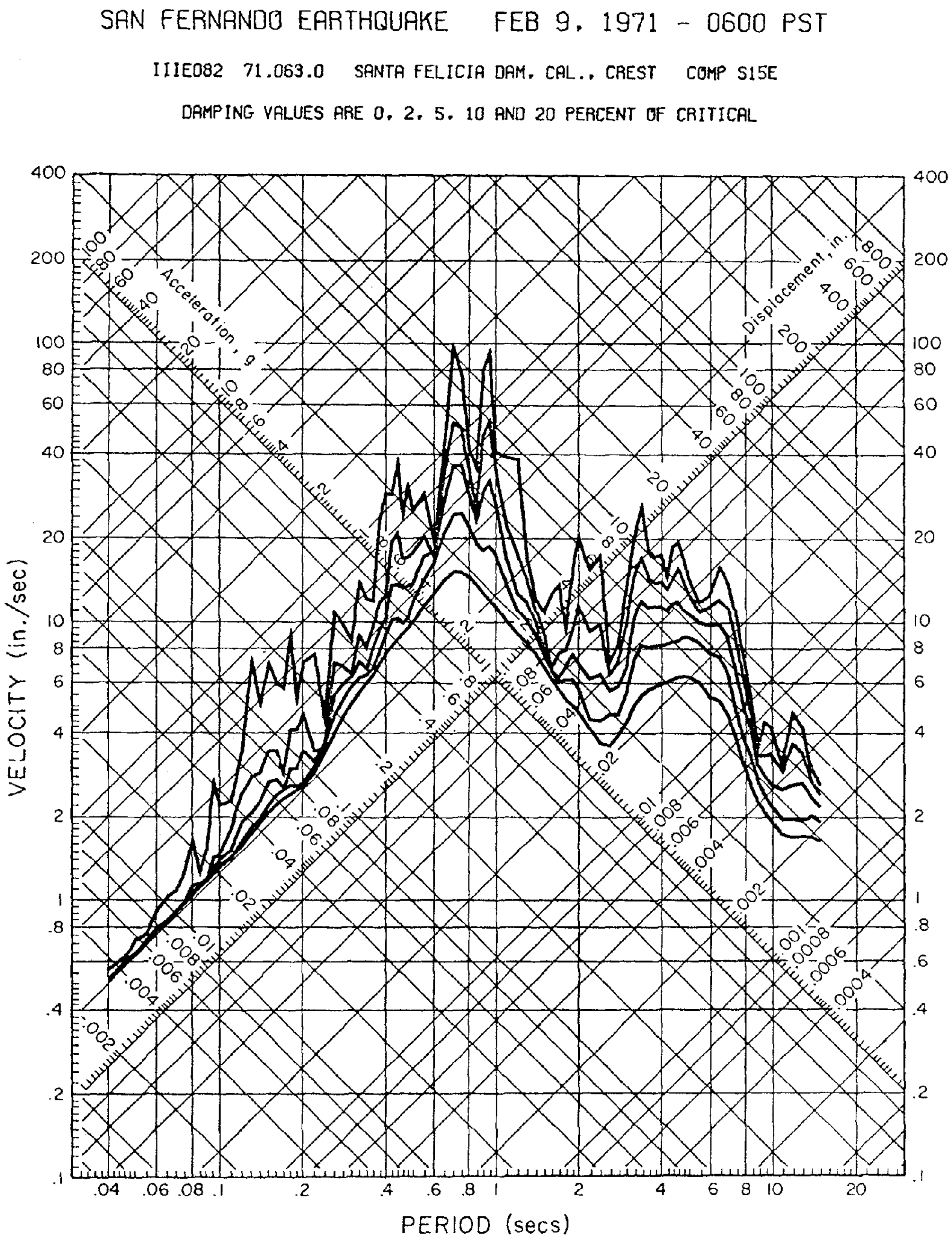


Figure 14. Response Spectrum Santa Felicia Dam Crest-S15E.
(From Calif. Inst. Tech. Data Reports)

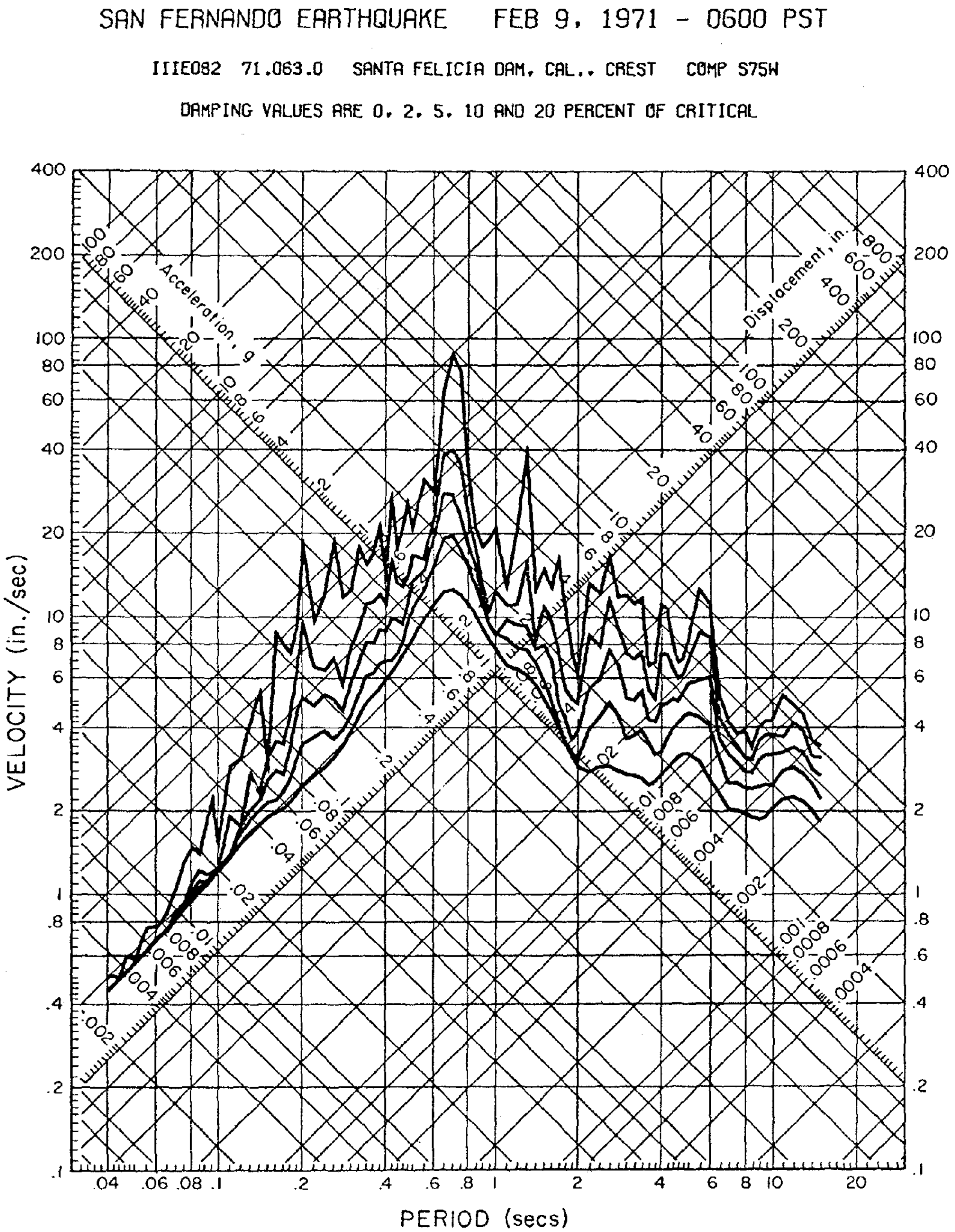


Figure 15. Response Spectrum Santa Felicia Dam Crest-S75W.
(from Calif. Inst. Tech. Data Reports)

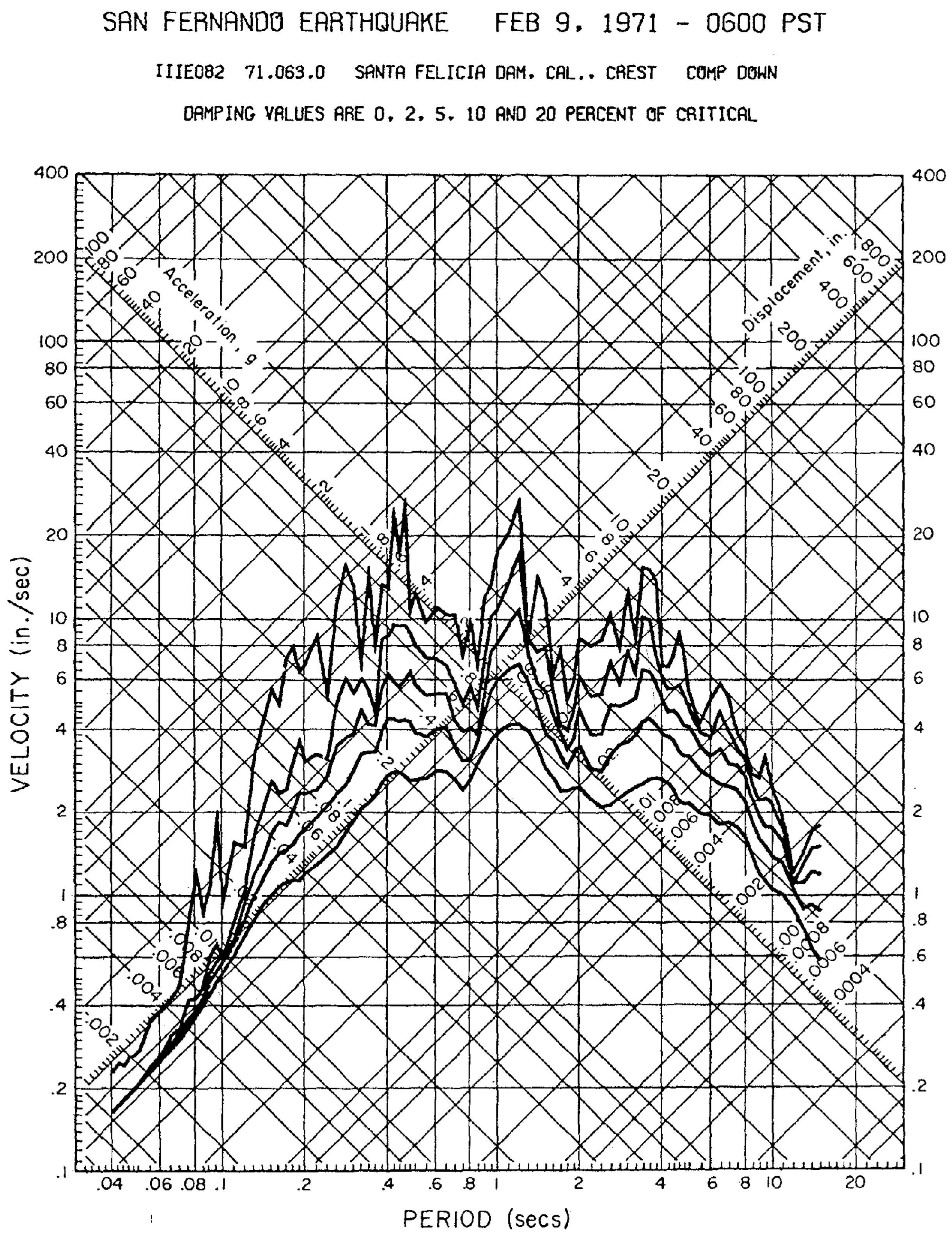


Figure 16. Response Spectrum Santa Felicia Dam Crest-Vertical. (From Calif. Inst. Tech. Data Reports)

9. PACOIMA DAM

Introduction

Pacoima Dam is located in Pacoima Canyon 6 km northeast of San Fernando on the southern edge of the San Gabriel Mountains (see Santa Felicia Dam, Figure 1). The facility was constructed by the Los Angeles County Flood Control District for the dual purpose of flood control and water conservation and serves to protect a large portion of the low-lying San Fernando Valley. The dam was located directly over the thrust fault that generated the February 9, 1971 earthquake.

Geology

The dam is located in a steep-walled canyon carved into diorite that has been extensively fractured, resulting in numerous rockslides particularly during and after the San Fernando earthquake. Most abutment rock has been stabilized through the emplacement of rock bolts and by the application of a gunite covering where slides would present a hazard to personnel and facilities (NOAA/EERI Earthquake Investigation Committee, 1973). The fractured nature of the diorite and the orientation of the fracture planes relative to the canyon walls are considered to be more important than the nature of the rock. In the right abutment, the fracture planes dip into the canyon wall presenting a relatively stable situation. By contrast, the left abutment displays a prominent system of joints that are nearly vertical as well as a secondary set that dips 40° to 50°N. Because of these fracture systems considerable grouting was carried out to stabilize the upper 23 m of the left abutment, a semi-weathered zone that has undergone some rock creep. A total of 1281 m^3 of grout had been injected into the abutment through 1965.

Description of the Dam

Pacoima Dam, constructed between 1925 and 1928, is a constant angle concrete arch structure with a height of 114 m and a crest length of 180 m

(Figures 1, 2 and 3). The crest width is 3 m at its narrowest point. The maximum reservoir capacity is 1.23×10^7 m^3(10,000 acre-feet) at the upper spillway. The facility has dual spillways consisting of two tunnels at different elevations in the left abutment that join near a common exit. It is reported that the occurrence of the 1925 Santa Barbara earthquake caused the engineers to reconsider the design of the dam for earthquake resistance.

Strong-Motion Recordings

In 1965 a Teledyne AR-240 accelerograph was installed in a small steel building on a sharp ridge of the left abutment approximately 15 m above crest level of the dam (Figure 2). A Wilmot seismoscope was also installed on the downstream parapet near the center of the crest. During the 1971 San Fernando earthquake cracks in the rock beneath the accelerograph station were enlarged and some displacement and shifting occurred causing the instrument housing to tilt slightly. Consequently, the horizontal starting pendulum in the accelerograph produced a continuous electrical contact; this depleted the supply of recording paper while recording some additional 30 aftershocks (reference 5, Introduction). Corrected accelerograms and integrated velocity and displacement curves of the main San Fernando shock are shown in Figures 4, 5, and 6 (reference 15, Introduction). An incomplete record was obtained from the seismoscope when the recording plate was thrown off the instrument at the beginning of the earthquake.

References

NOAA/EERI Earthquake Investigation Committee, 1973, Earthquake Damage to Water and Sewerage Facilities (Pacoima Dam section), San Fernando, California, Earthquake of February 9, 1971, U.S. Dept. of Commerce, NOAA, Vol. II, p. 87-100.

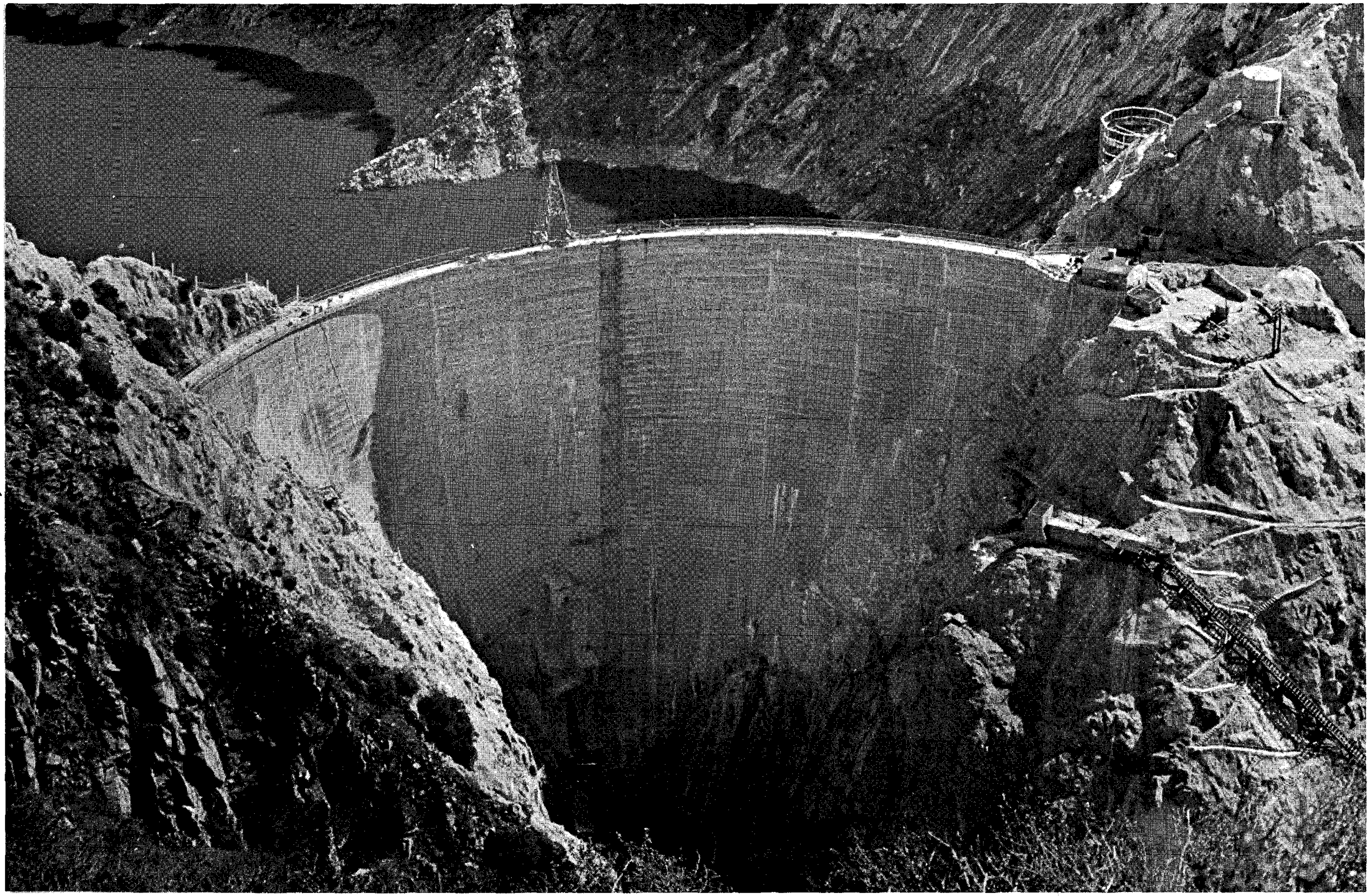


Figure 1. Photograph of Pacoima Dam. The accelerograph was installed in a small metal hut a few meters below the large white water tank shown in upper right of photo.

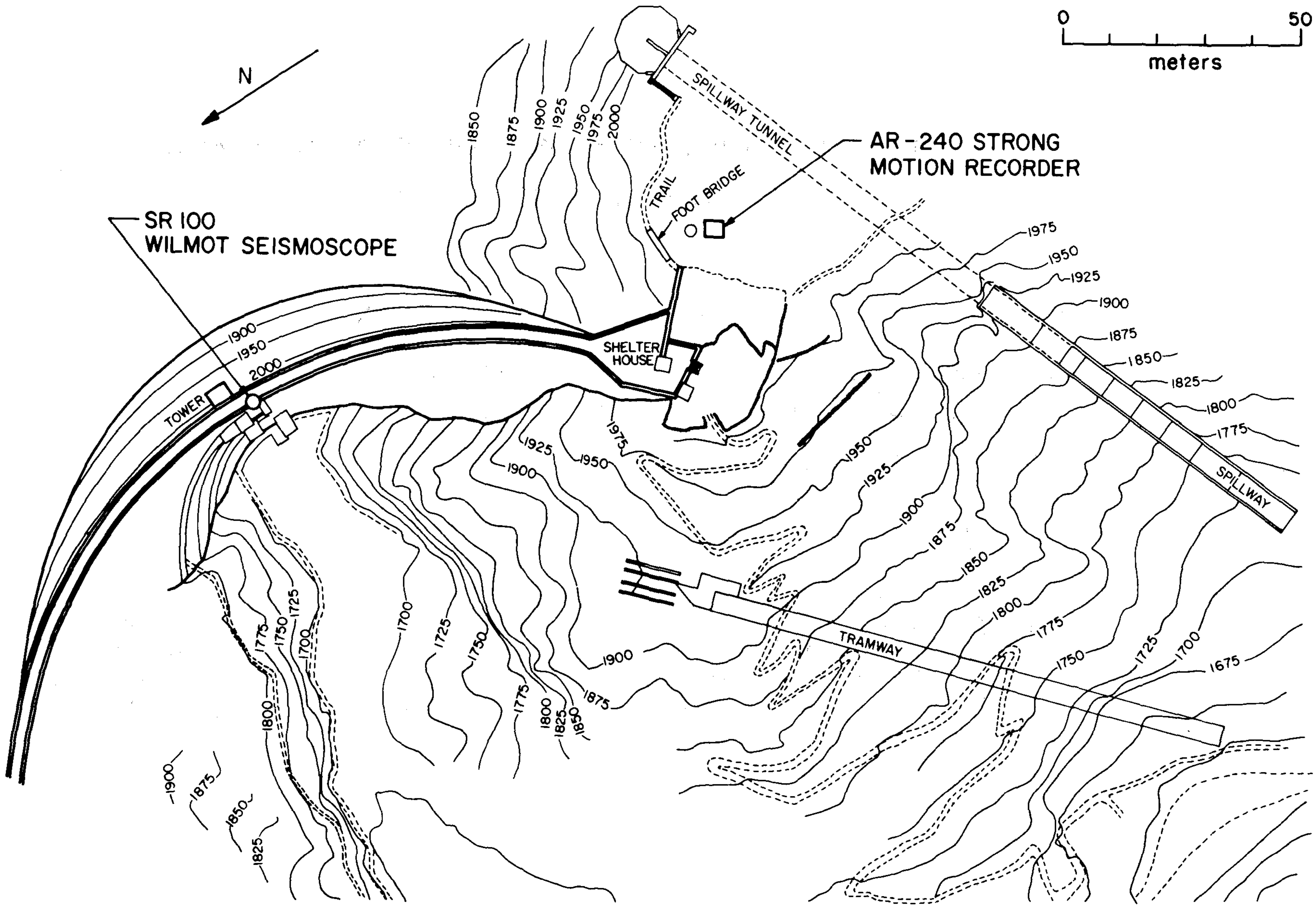


FIGURE 2. Location of strong-motion instruments at Pacoima Dam (Trifunac and Hudson, 1971).

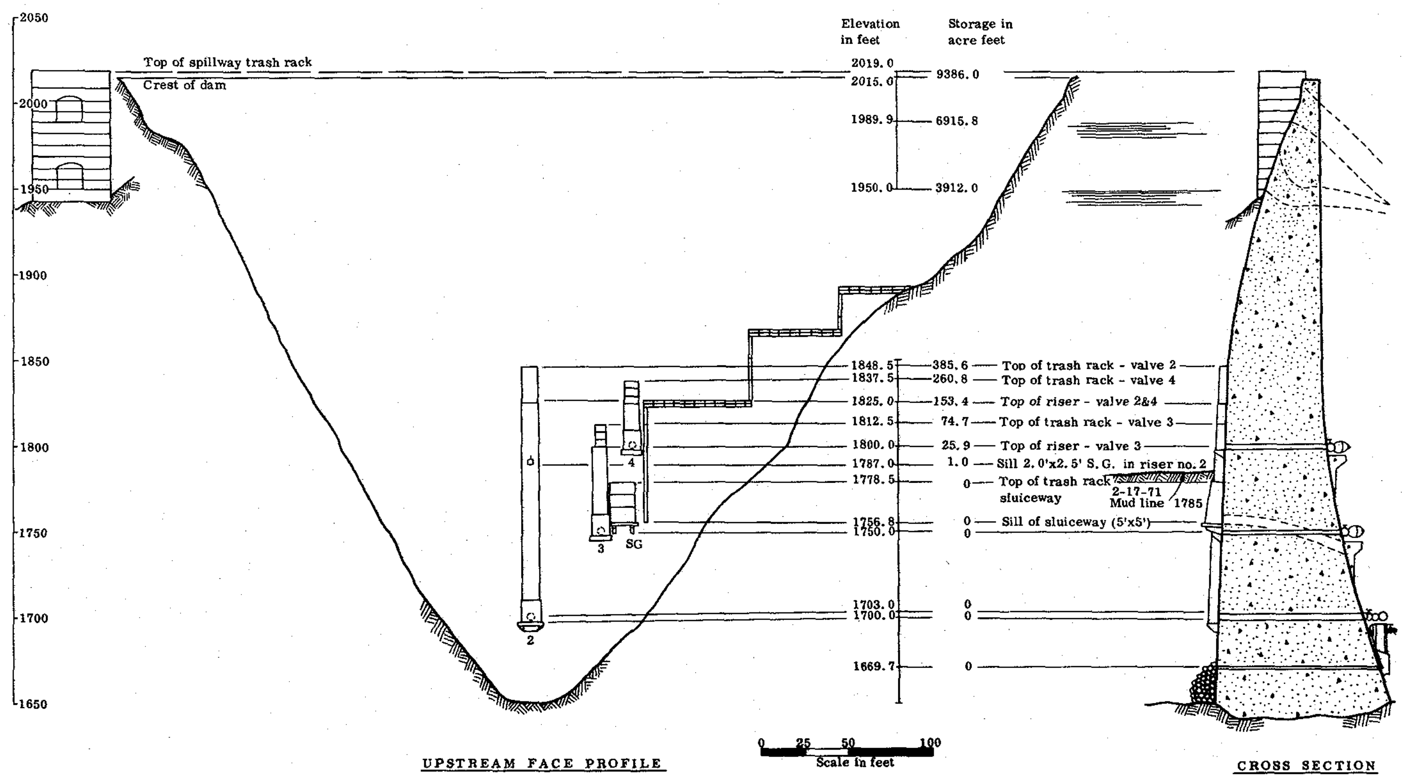


FIGURE 3. Pacoima Dam profile and section (Phillips and others, 1971).

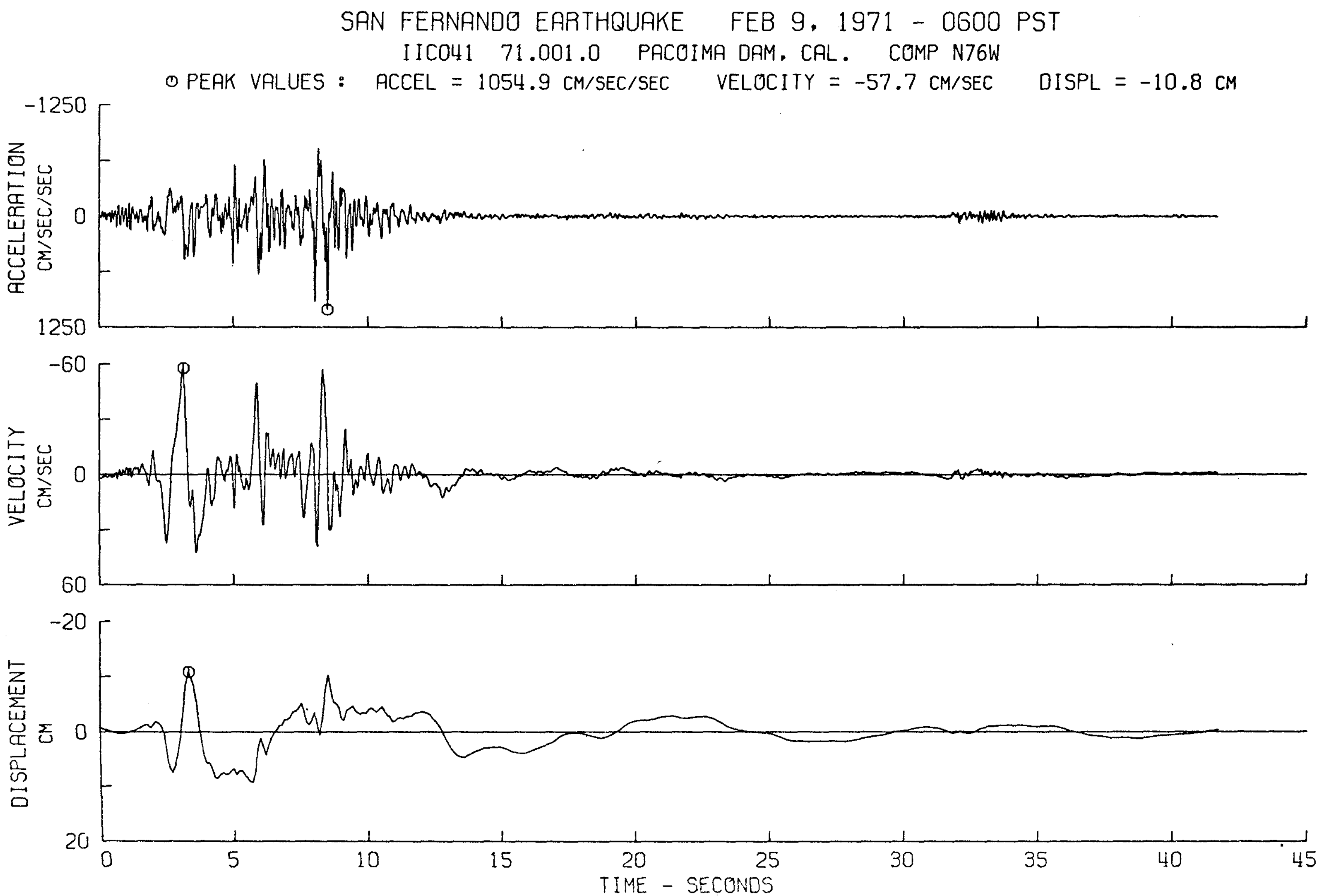


Figure 4. Pacoima Dam accelerogram, component N76W.

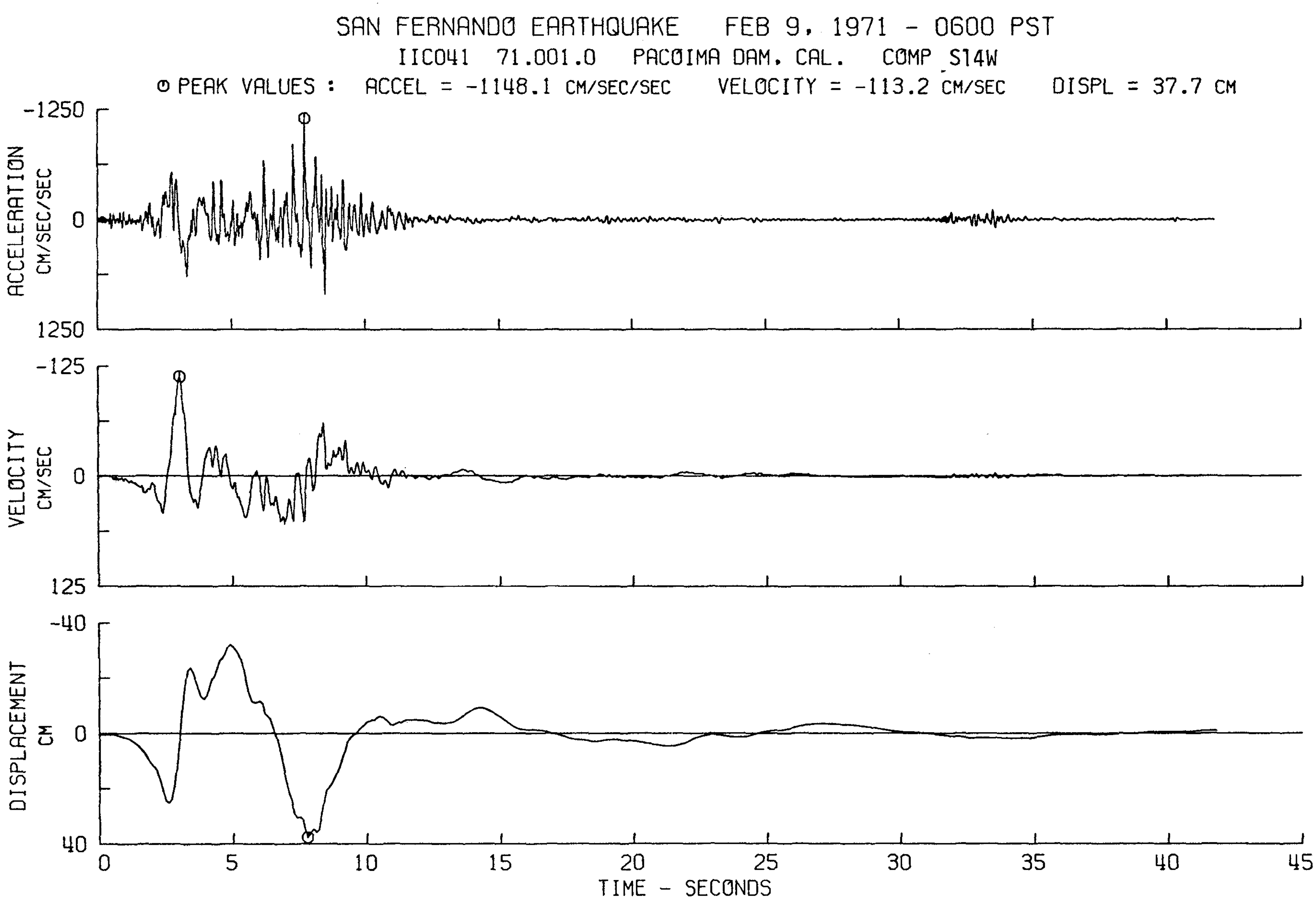


Figure 5. Pacoima Dam accelerogram, component S14W.

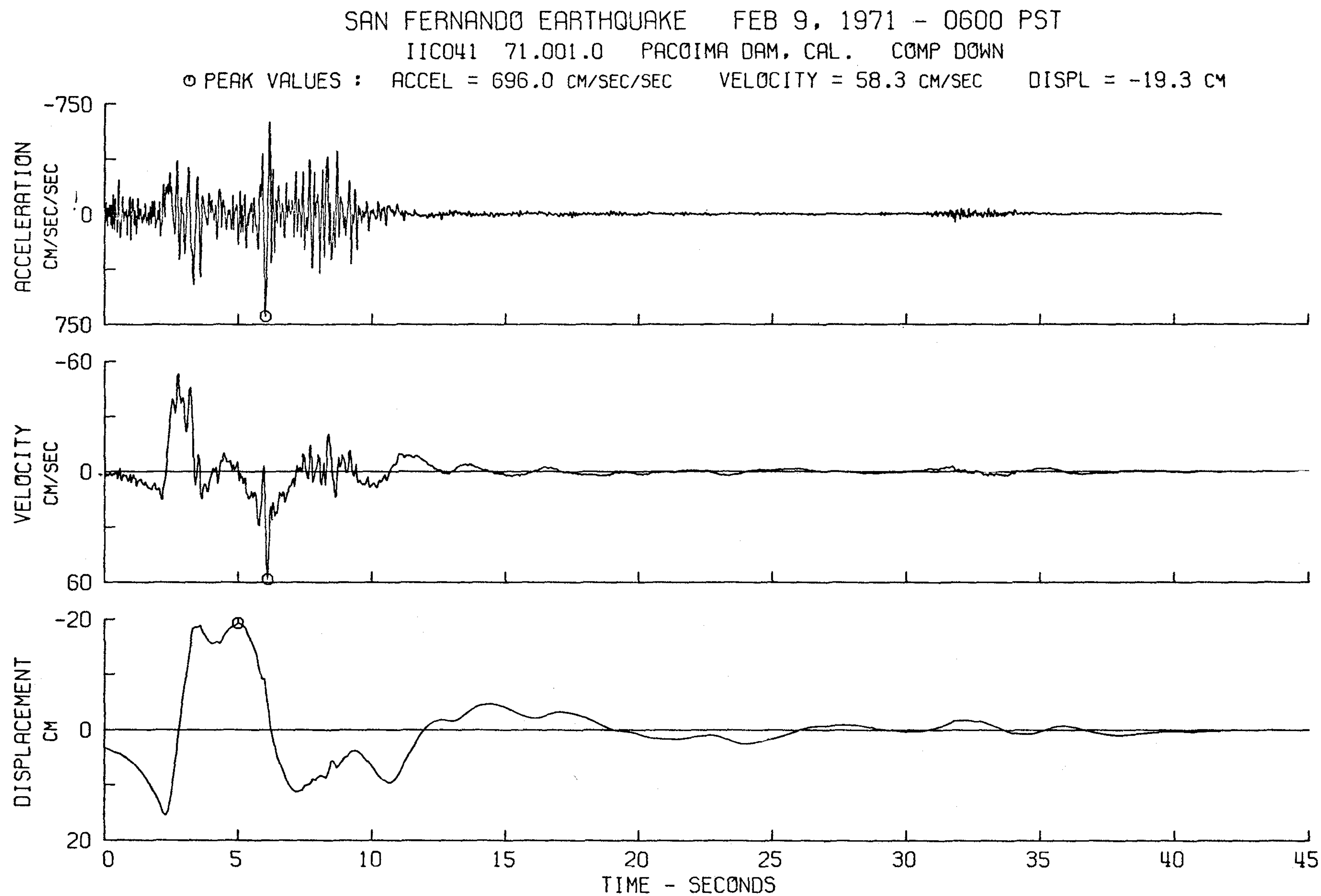


Figure 6. Pacoima Dam accelerogram, component vertical.

10. LOWER SAN FERNANDO DAM

Introduction

The Lower San Fernando Dam and reservoir were located in northern San Fernando Valley near the base of the western San Gabriel Mountains, approximately 3 km north of the city of San Fernando and approximately 35 km northwest of downtown Los Angeles (see Santa Felicia Dam, Figure 1). The reservoir was situated at the southern terminus of the Los Angeles Aqueduct system, and was constructed by the Los Angeles Department of Water and Power to provide local storage of a domestic water supply for delivery into the city distribution system.

Geology

The dam site is located in the northern-most portion of the San Fernando Valley, a broad elliptical plain 35 km long (east-west) by 18 km wide. This valley is situated in the central part of the east-west trending Transverse Ranges structural province of southern California, which includes the generally north-dipping reverse (or thrust) faults of the Sierra Madre, San Fernando, and Santa Susana fault zones.

Three marine sedimentary formations of Upper Miocene to Middle Pliocene age comprise the bedrock at the abutments and beneath the dam embankment (NOAA/EERI San Fernando Earthquake Investigation Committee, 1973). The dam embankment in the channel section and the lowermost portions of the abutments rest on Recent alluvium that attains a maximum thickness of 12 m beneath the dam. The right abutment consists of a massive sandstone member of the Pico Formation. This unit extends to the east beneath the dam and is in normal depositional contact with the underlying Repetto Formation. Locally, the Repetto consists of clay, siltstone and shale and extends beneath much of the embankment foundation. The Modelo Formation is a thinly stratified shale and siltstone that comprises the entire left abutment and extends a short distance beneath the dam.

Description of the Dam

The dam, completed in 1918, was a hydraulic and dry earthfill embankment with three cutoff trenches extending from the underlying alluvium into bedrock foundation of sandstone, shale and conglomerate (California Dept. of Water Resources, 1971). The crest had a total length of 654 m, an average width of 6 m, and a maximum height of 42.6 m (Figures 1 and 2). More than 2.5×10^6 m^3 of fill were used in the construction of the embankment. The reservoir covered an area of 1.81 km^2 and had a storage capacity of more than 2.5×10^7 m^3 (20,500 acre-feet). Earthquake forces were, presumably, not considered in the design. The ground shaking produced by the July 21, 1952, Tehachapi earthquake (magnitude 7.2), approximately 80 km north of the dam, caused some cracking and evidence of distress to Lower San Fernando Dam and to 2 similar dams, Haiwee Dam and Dry Canyon Dam. After the earthquake additional earth buttressing was placed on the downstream face of the dam. This strengthening probably prevented the dam from failing in the downstream direction during the 1971 earthquake; it collapsed partially in the upstream direction.

Strong-Motion Recordings

A Wilmot seismoscope and a Teledyne peak recording accelerograph (PRA) were located on the crest near the center of the dam at the time of the February 9, 1971 San Fernando earthquake. In addition, another seismoscope was located on the east abutment (Figure 3). The instruments on the crest were located opposite the central outlet tower, and were temporarily lost when the upstream face of the dam slid into the reservoir. When the instruments were recovered several days later, their records were still legible. The PRA record showed a maximum horizontal acceleration of approximately 0.5 g and a maximum vertical acceleration of more than 0.1 g. The fraction of these readings that was caused by tilt is unknown. The seismoscope record from the abutment station showed a maximum relative displacement of 6.79 cm. This record provided sufficient information for the calculation of the two horizontal components of acceleration (reference 9, Introduction). The results of these analyses are shown in Figures 4 and 5.

References

NOAA/EERI San Fernando Earthquake Investigation Committee, 1973, Earthquake Damage to Water and Sewerage Facilities in Benfer, N. A. and Coffman, J. L., Editors, San Fernando, California Earthquake of February 9, 1971: U.S. Dept. of Comm., NOAA Spec. Rpt., V. II, p. 75-87.

California Dept. of Water Resources, Division of Safety of Dams, 1971, Interim Report on the Effects of the San Fernando Earthquake on the Van Norman Reservoir Complex: Memorandum Rpt., 27p., 2 appendices, 2 plates.

Scott, R. F., 1973, The Calculation of Horizontal Acceleration Components from Seismoscope Records, Bull. Seism. So. Amer., v 63, 5, p. 1637-1661.

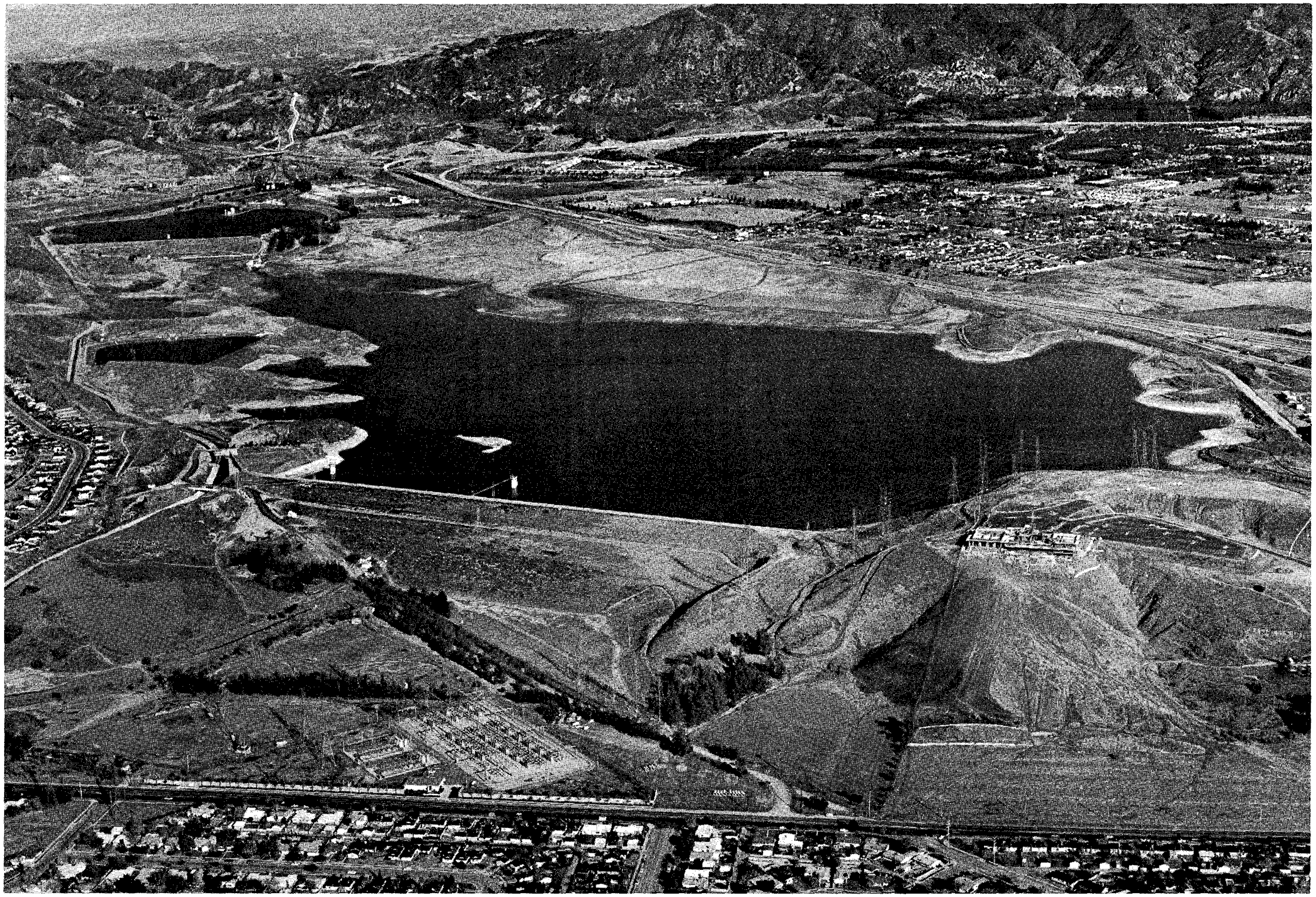


FIGURE 1. Lower San Fernando Dam. The abutment seismoscope is located on the right near the transmission towers. (LADWP photograph taken before the earthquake.)

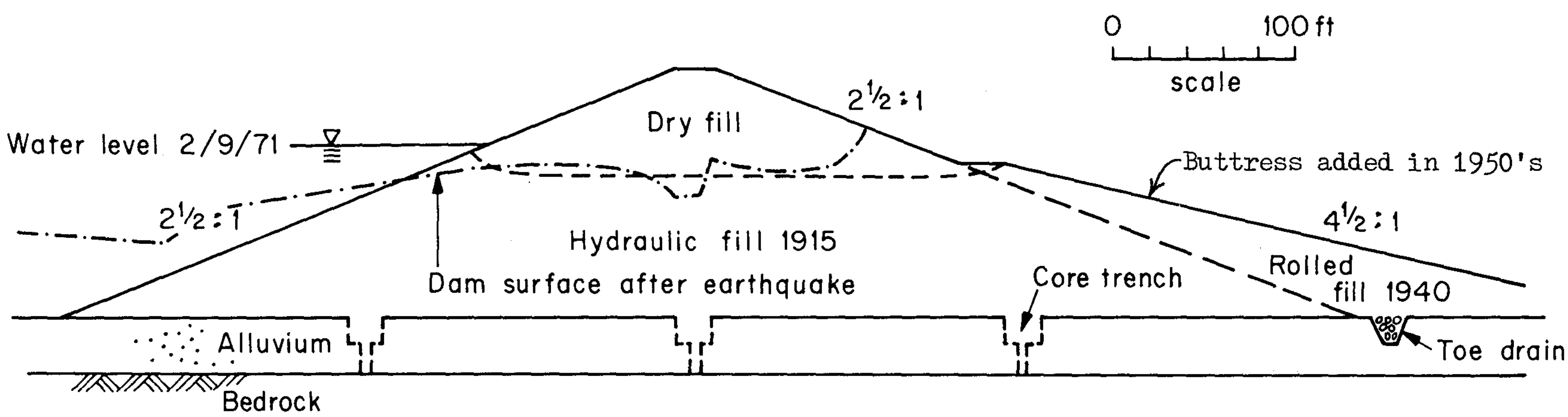


FIGURE 2. Cross-section of Lower San Fernando Dam.

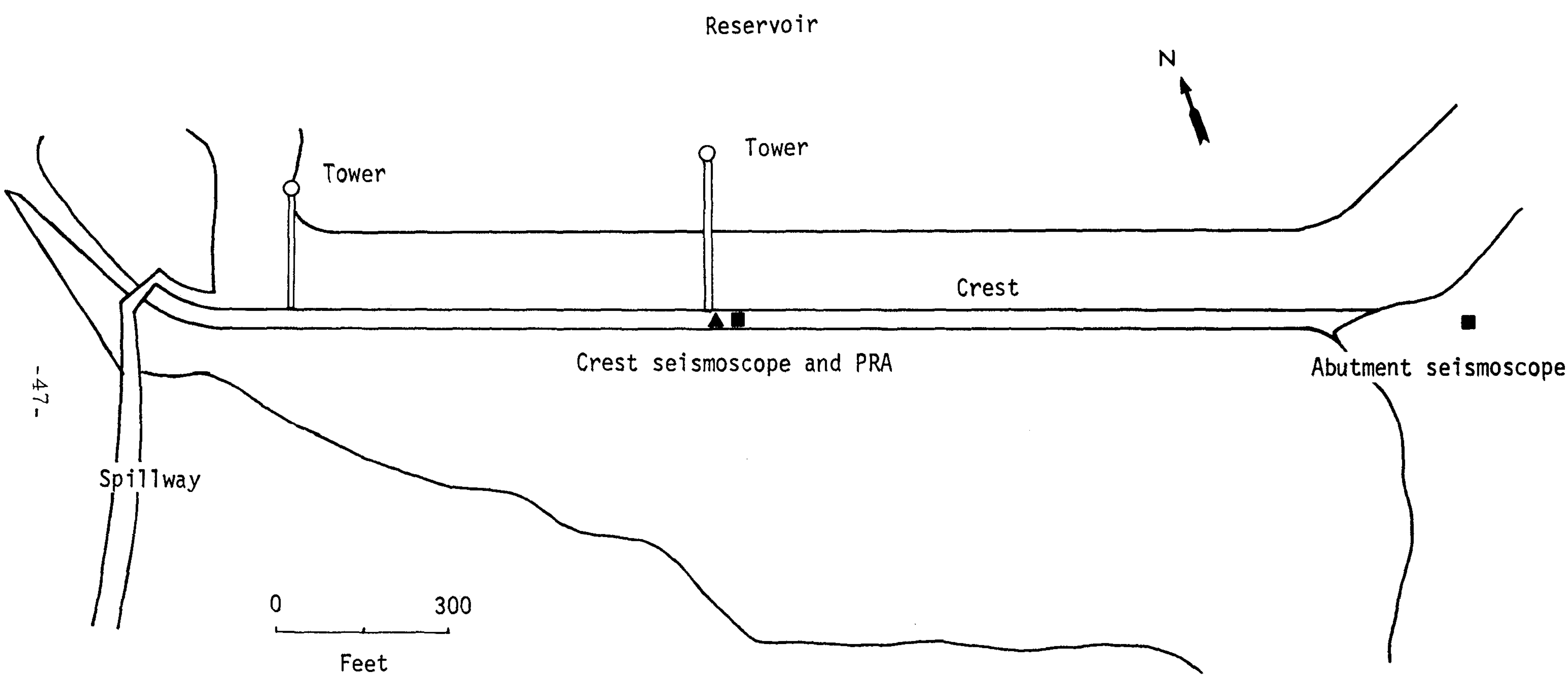


FIGURE 3. Plan view of Lower San Fernando Dam showing the locations of the seismoscopes and the PRA.

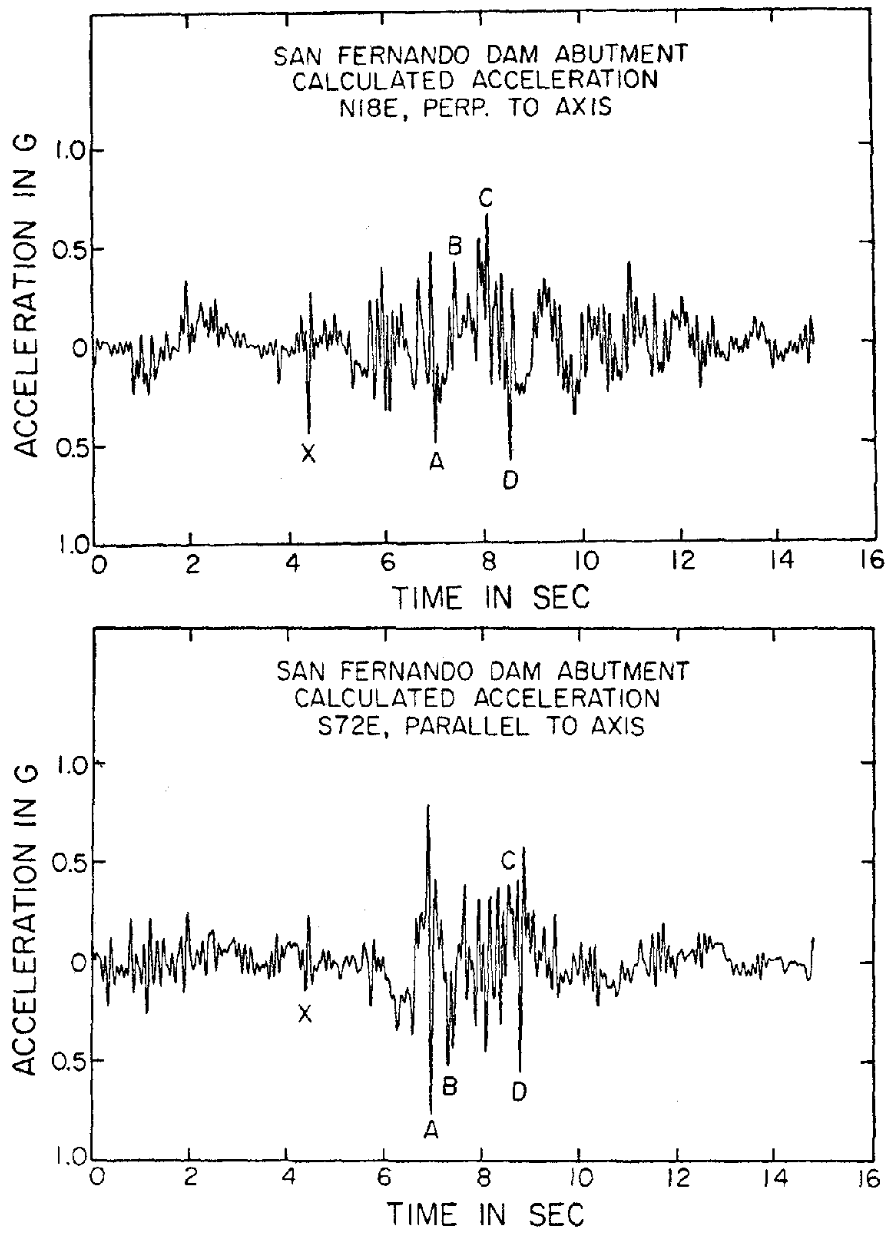


Figure 4. Horizontal acceleration-time history as computed from the abutment seismoscope record (Scott, 1971)

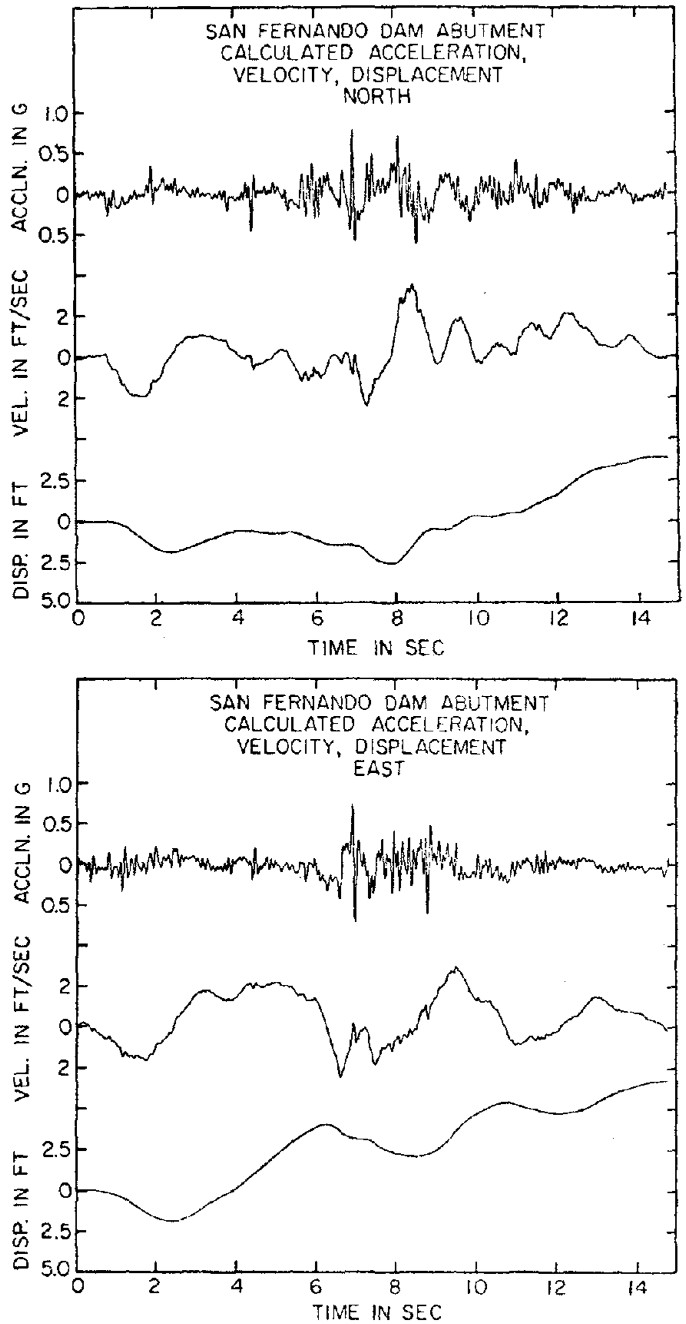


Figure 5. Calculated acceleration, velocity and displacement curves.
(Scott, 1971)

11. CARBON CANYON DAM

Introduction

Carbon Canyon Dam was constructed by the Army Corps of Engineers as a flood-control structure across Carbon Canyon Creek in Orange County, California, approximately 7 km east of Brea and 40 km southeast of Los Angeles (see Santa Felicia Dam, Figure 1). The unit, completed in 1961, is part of the comprehensive plan for the Santa Ana River Basin in Orange County and is designed to protect large parts of the cities of Anaheim and Los Alamitos.

Geology

Carbon Canyon Dam is situated near the southern boundary of the Puente Hills, a region of soft sedimentary Cenozoic rocks. The dominant structural feature in this region is the northwest trending Whittier fault zone, that passes within 1.5 km (to the north) of Carbon Canyon Dam (Jenkins & Rogers, 1965, and Yerkes and others, 1965).

The dam was constructed across the downstream narrows of Carbon Canyon, and rests on approximately 30 m of Recent silt, sand and gravel. The valley floor is nearly flat, except for the steep-walled gully that contains the present stream channel. The abutments consist of Upper Pleistocene terrace deposits and the Pico and Repetto formations, chiefly siltstones and sandstones, that locally dip 30-40° to the southwest (Troxel, 1954).

Description of the Dam

The dam is a random earthfill structure (Figure 1) 587 m long, with a crest width of 6 m and a maximum height of 30 m above the main streambed (Corps of Engineers, 1957 and 1969). The crest of the dam continues across a saddle fill at the right abutment for an additional length of 210 m. The dam contains over 1.1×10^6 m^3 of embankment material and has a reservoir capacity of 8.15×10^6 m^3 (6615 acre-feet) at maximum pool elevation.

Strong-Motion Recordings

A Teledyne RFT-250 accelerograph was installed on the crest of the dam in the standby generator house in 1968 (Figure 2). Corrected accelerograms and the calculated velocity and displacement curves from the San Fernando earthquake are shown in Figures 3, 4, and 5 (reference 15, Introduction).

References

Corps of Engineers, Los Angeles, California, 1957, General Design for Carbon Canyon Dam and Channel: p. 1-2, two figures, one table.

_____, 1969, Periodic Inspection and Continuing Evaluation Report No. 1: p. 1-6.

Jenkins, O. P., and Rogers, T. H., 1965, Geologic Map of California: California Div. of Mines and Geology, Santa Ana Sheet and source data.

Troxel, B. W., 1954, Geologic Guide for the Los Angeles Basin, Southern California: Geol. So. California, Bull. 170, p. 15-16, one figure.

Yerkes, R. F., McColloh, T. H., Schoellhamer, J. E., and Vedder, J. C., 1965, Geology of the Los Angeles Basin - An Introduction: U.S. Geol. Survey Prof. Paper 420-A, 57 p.

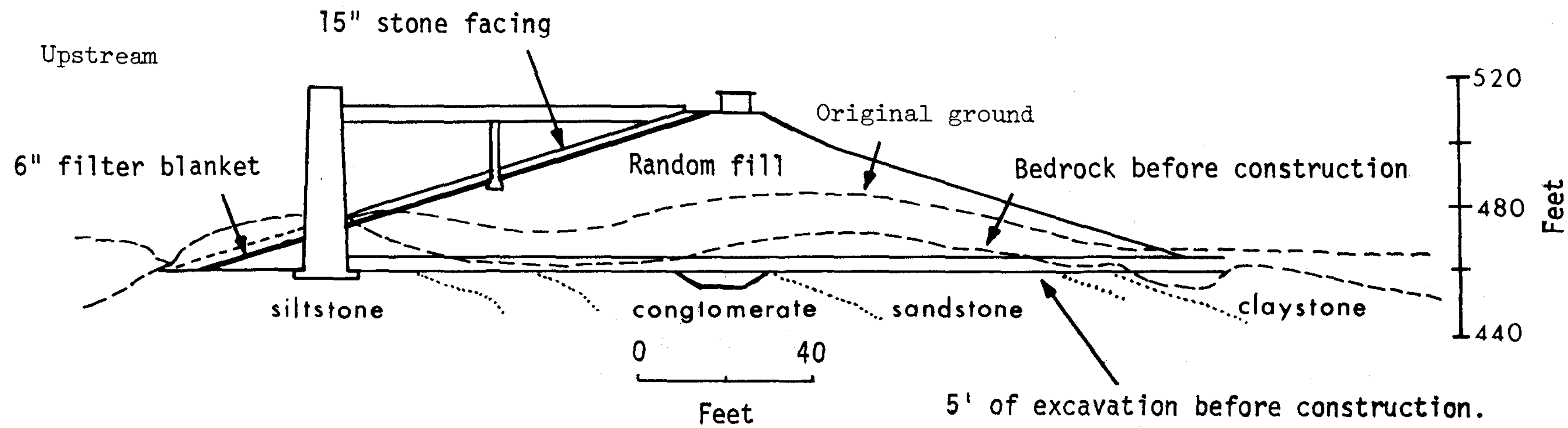


Figure 1. Cross-section of Carbon Canyon Dam.

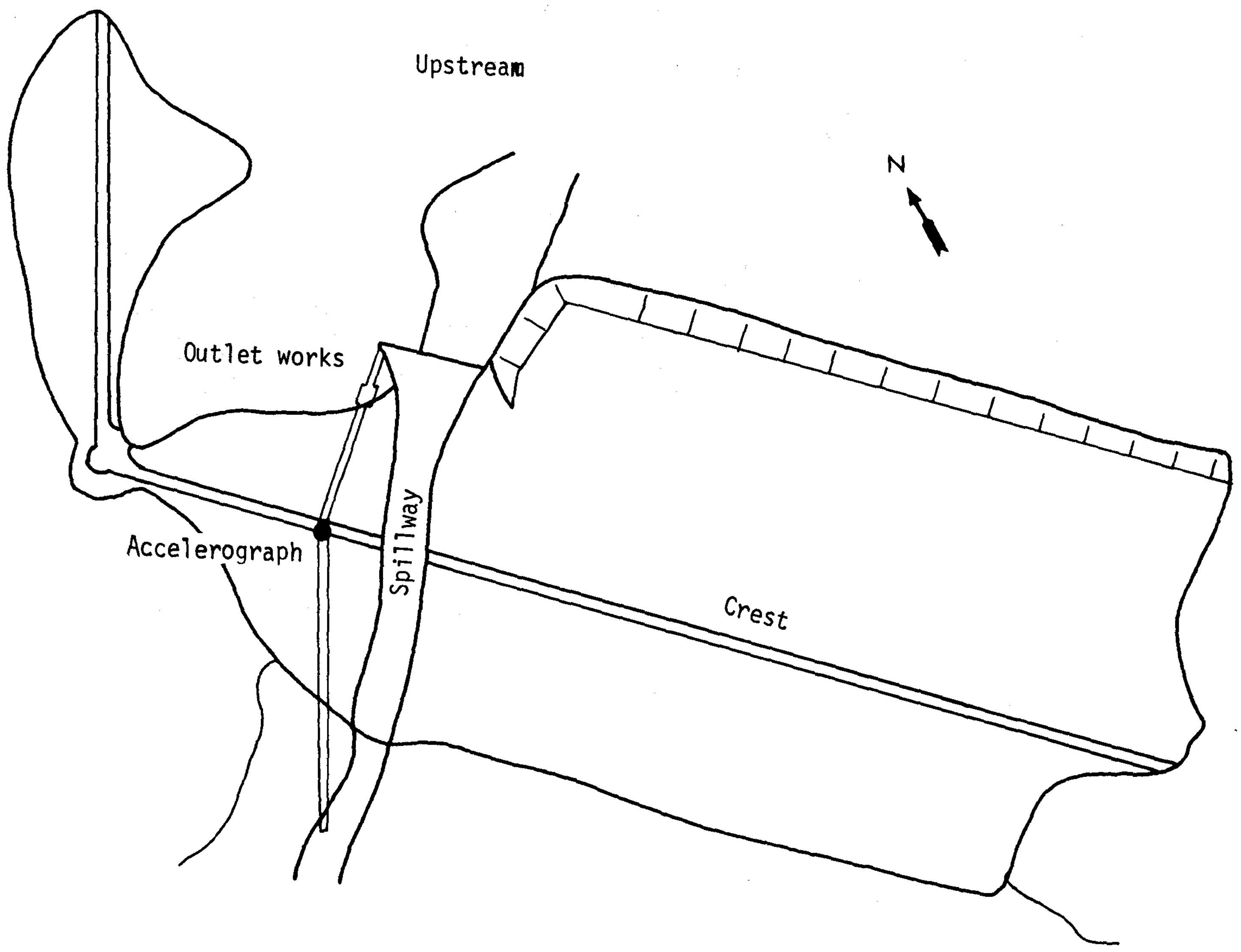


Figure 2. Location of the accelerograph on Carbon Canyon Dam.

FIGURE 3.

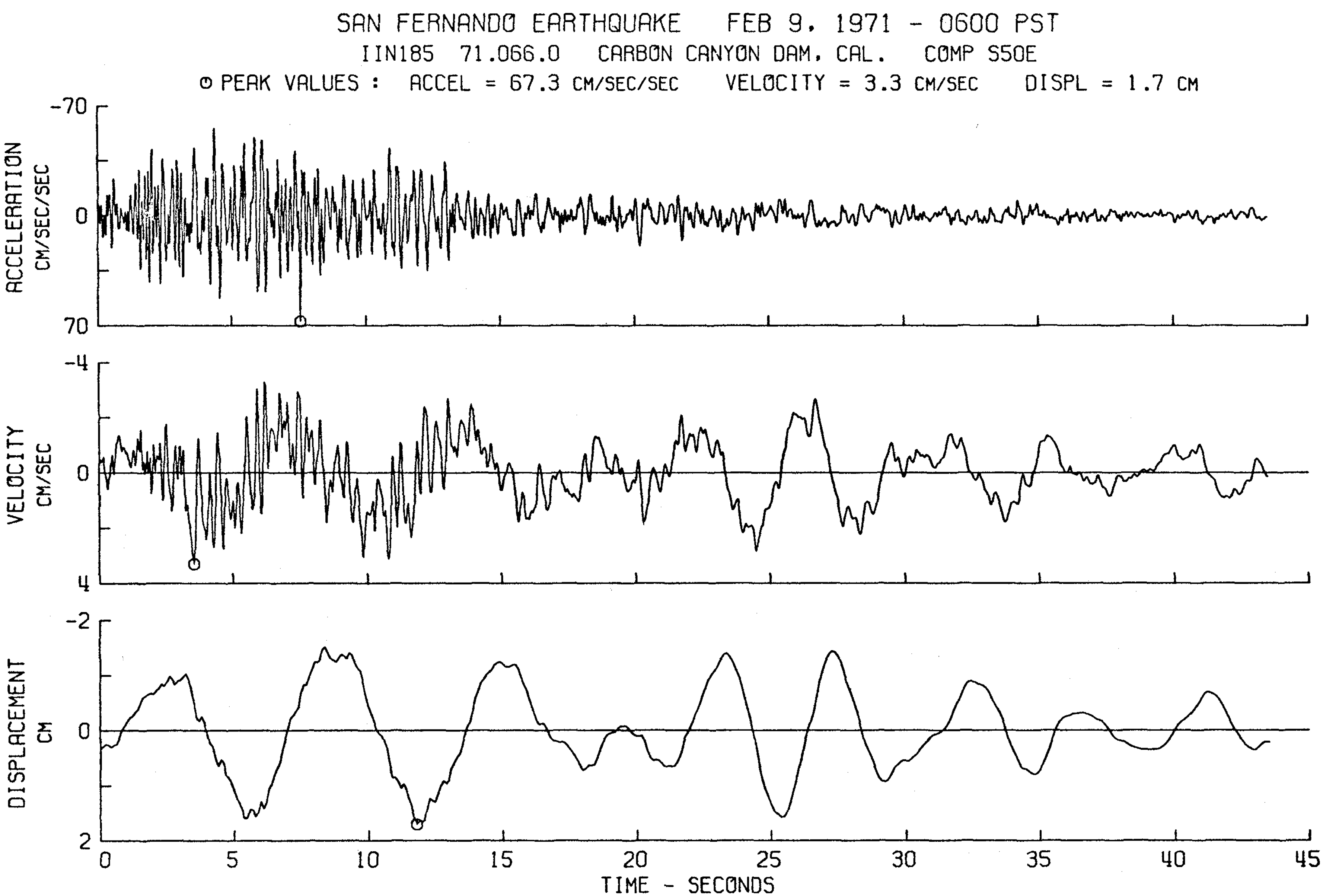


Figure 3. Carbon Canyon Dam accelerogram, component S50E

FIGURE 4.

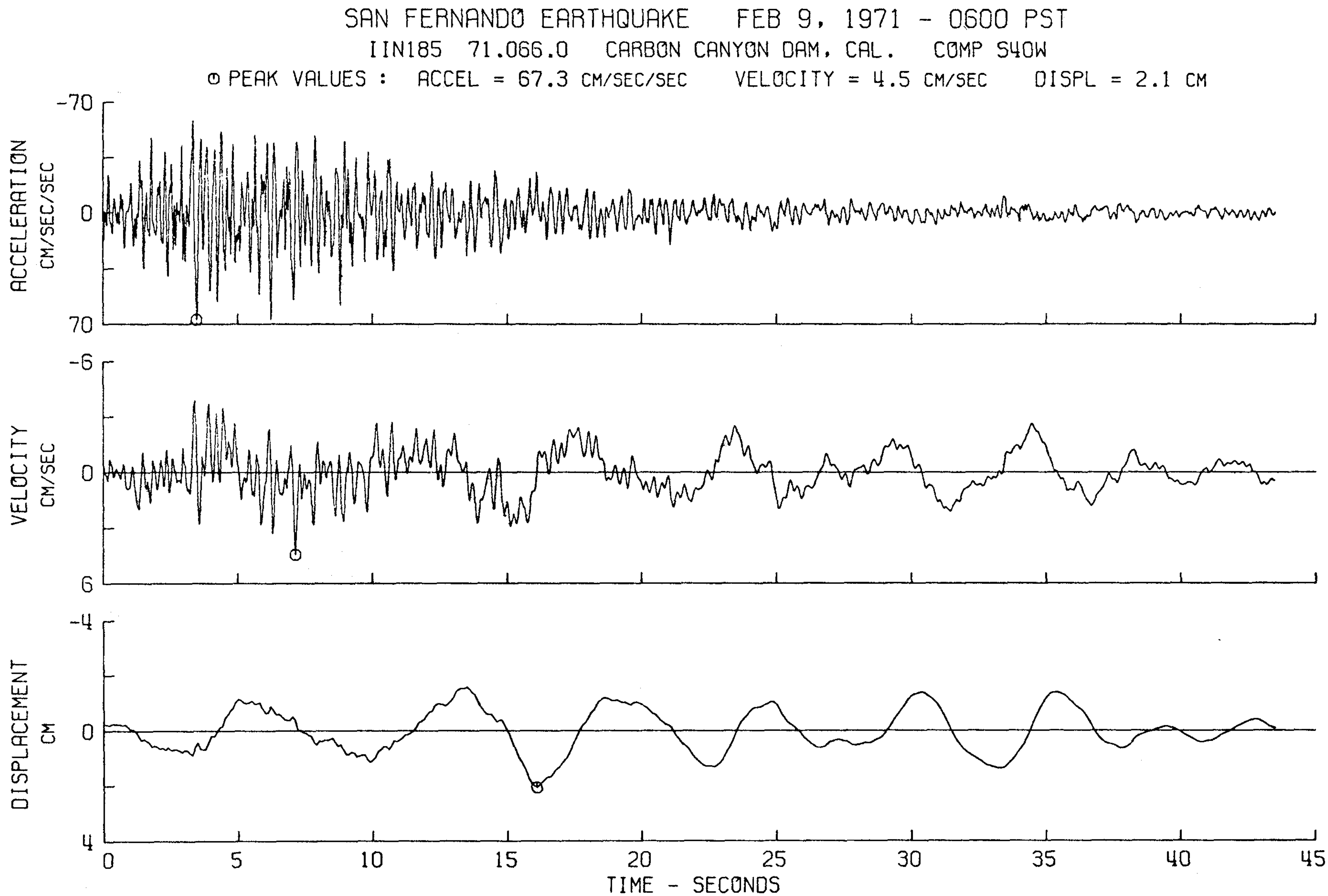


Figure 4. Carbon Canyon Dam accelerogram, component S40W

FIGURE 5

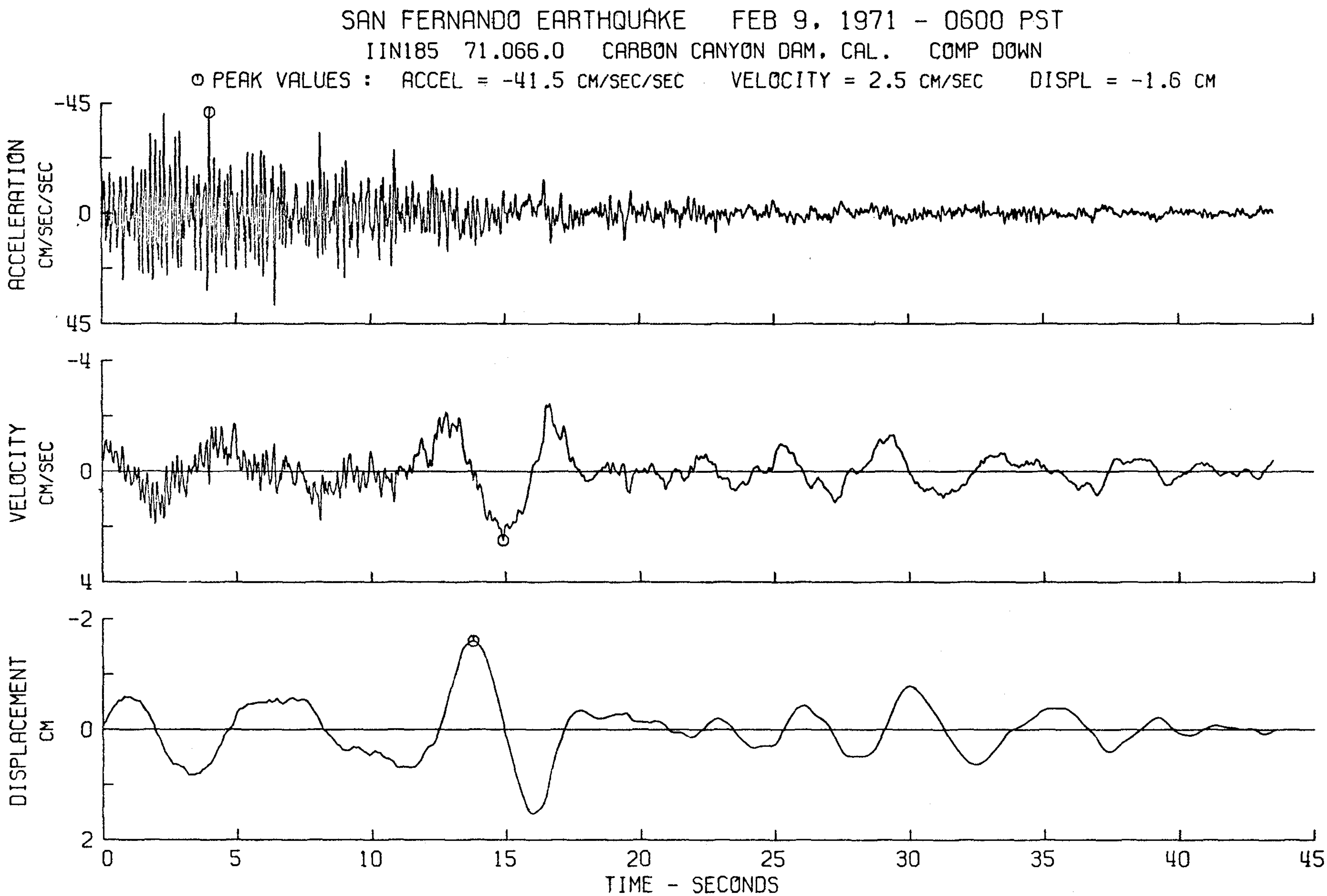


Figure 5. Carbon Canyon Dam accelerogram, component vertical.

12. WHITTIER NARROWS DAM

Introduction

The descriptive information in this report was largely obtained from the pre-construction data gathered by the Corps of Engineers and presented in the Definite Project Report on Whittier Narrows Flood-Control Basin (1945). Subsequently the proposed location of the dam was changed and although it was constructed in the Whittier gap, the eastern end of the dam is approximately 1.6 km (one mile) south of the first planned site. The western end of the dam terminates near the originally intended location. Nevertheless, the geologic data contained in the first Corps of Engineers report is about equally applicable to either location. The minimal design features presented here have been obtained from subsequent plans and are of the existing dam (Corps of Engineers, 1972).

Whittier Narrows Dam, constructed primarily as a flood control unit, is located on the main channels of the Rio Hondo and San Gabriel Rivers 16 km southeast of Los Angeles (see Santa Felicia Dam, Figure 1). The crest of the dam extends essentially east-west cutting off uncontrolled stream flow through a relatively narrow gap that is restricted by the Montebello Hills* on the west and the Puente Hills on the east.

Geology

The dam is 23 km northeast of the Newport-Inglewood fault zone, 16 km south of the San Gabriel frontal fault system (source of the San Fernando earthquake) and 47 km southwest of the San Andreas fault. According to the Corps of Engineers, the East Montebello fault passes southeast through the Narrows and by implication directly beneath a central portion of the present dam. Whittier Narrows Dam is underlain by 45 to 215 m of pervious unconsolidated sediments including clay, silt, sand and gravel. Because of

*Called La Merced Hills in Corps of Engineers reports.

the depth of these unconsolidated materials the dam foundation was emplaced entirely on alluvium. Bedrock below the alluvium consists of 600m to 1500 m of shale and siltstones with some interbedded sandstone and conglomerates, all similar to that found in the adjacent hills. Basement rock is estimated to be at 1800 to 4000 m, dependent upon an unknown amount of vertical fault offset.

During the entire year, practically all of the alluvium beneath the dam is saturated with moving ground water.

Description of the Dam

Whittier Narrows Dam, completed in 1957, is an earth fill structure with a crest length of 5170 m, a maximum height of 17 m, and a crest width of 10 m (Figures 1, 2 and 3). A total volume of 2.1×10^6 m^3 was required for the embankment. Approximately 1.5 m of alluvium was excavated below the central impervious portion of the dam. The flood control basin formed by the dam has a capacity of 4.45×10^7 m^3 (36,000 acre-feet).

Strong-Motion Recordings

A Teledyne RFT-250 accelerograph was installed in the control house 3.5 m east of the spillway in April 1968 (Figure 3). Corrected accelerograms and the calculated velocity and displacement curves from the San Fernando earthquake are shown in Figures 4, 5 and 6 (reference 15, Introduction).

References

Corps of Engineers, 1945, Definite Project Report on Whittier Narrows Floor Control Basin, Los Angeles, California: 13 p. and 8 appendices.

Corps of Engineers, 1972, Whittier Narrows Dam, Outlet Works and Spillway: Periodic Inspection and Continuing Evaluation Report No. 1., 27 p. and appendix.

FIGURE 1. Whittier Narrows Dam.

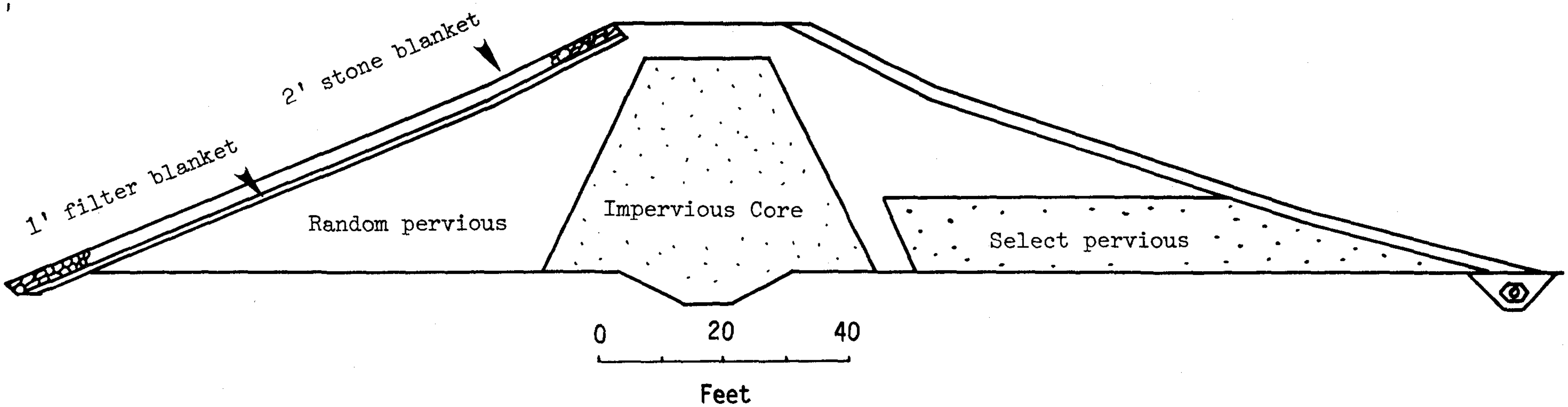


FIGURE 2. Typical section of the east and central embankment of Whittier Narrows Dam.

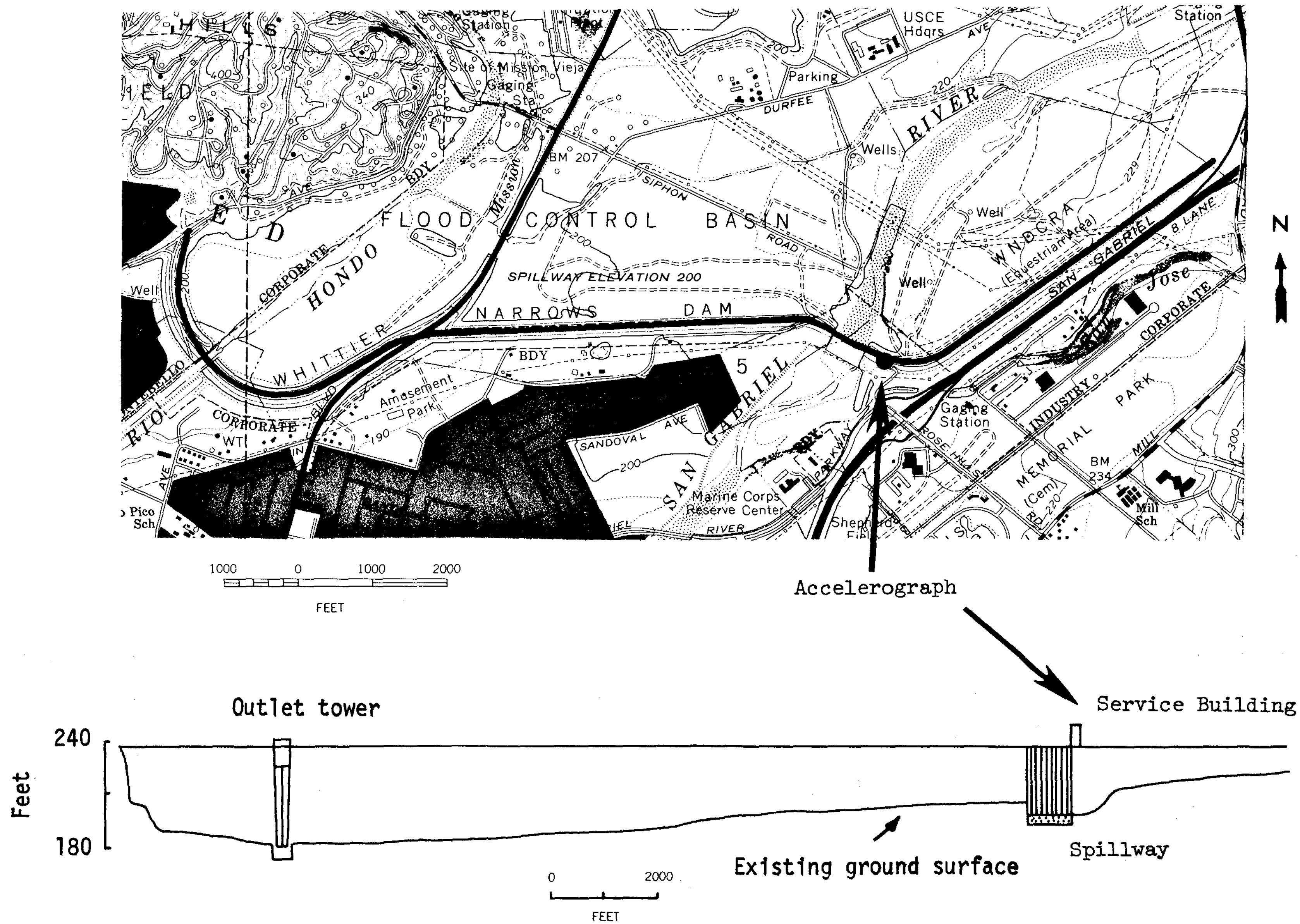


FIGURE 3. Plan view and profile of Whittier Narrows Dam showing the accelerograph location.

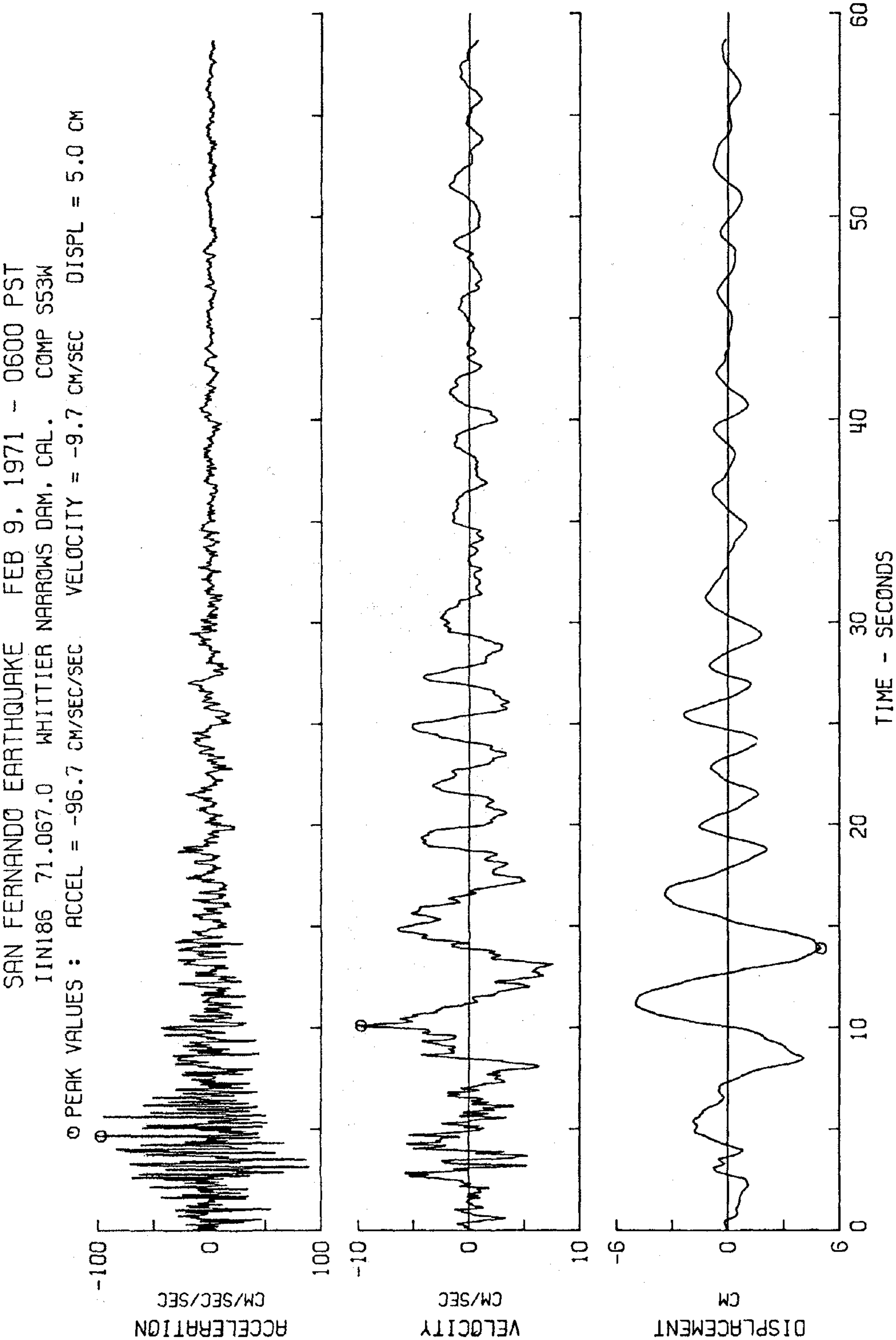


Figure 4. Whittier Narrows Dam Accelerogram, Component S53W.

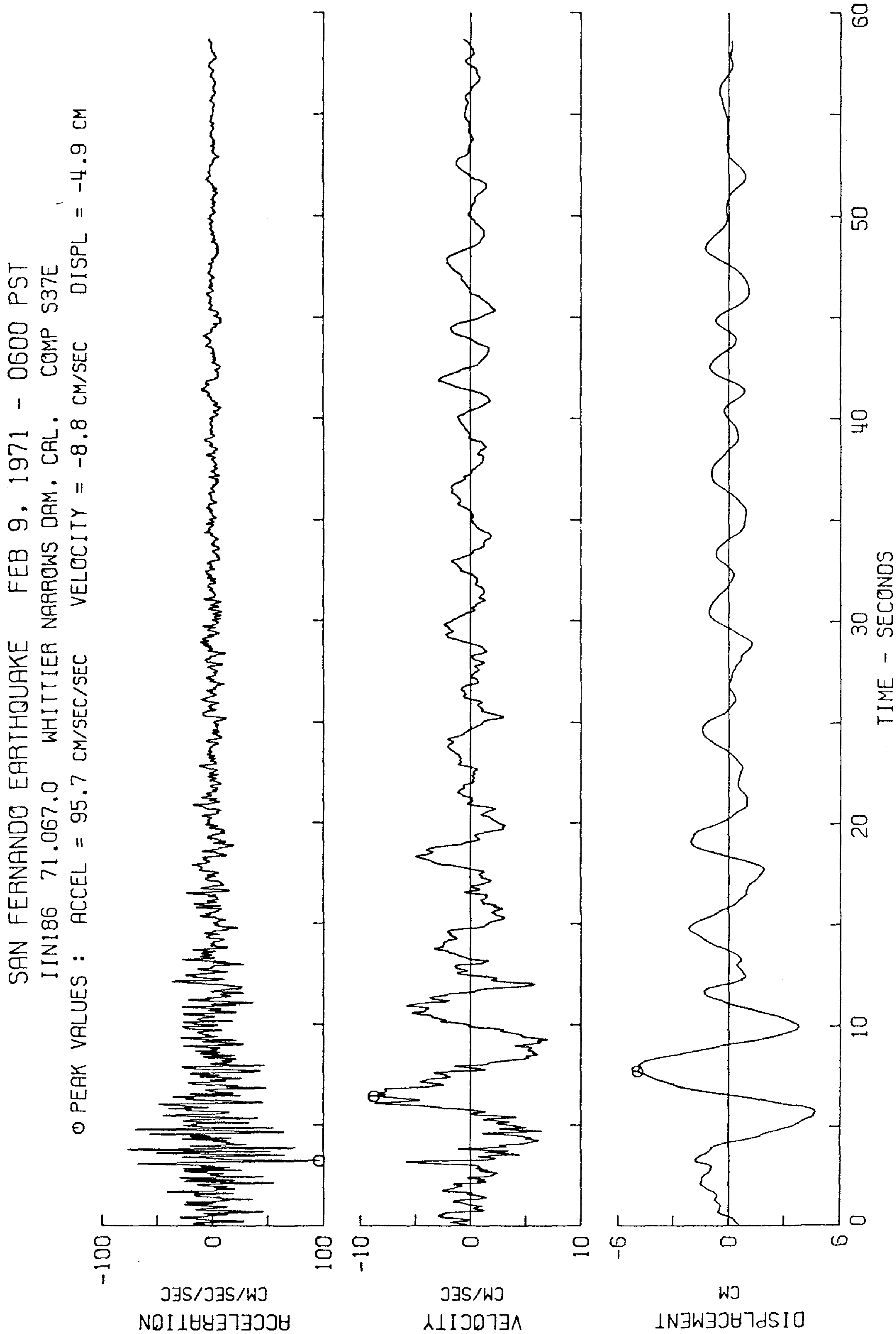


Figure 5. Whittier Narrows Dam Accelerogram, Component S37E.

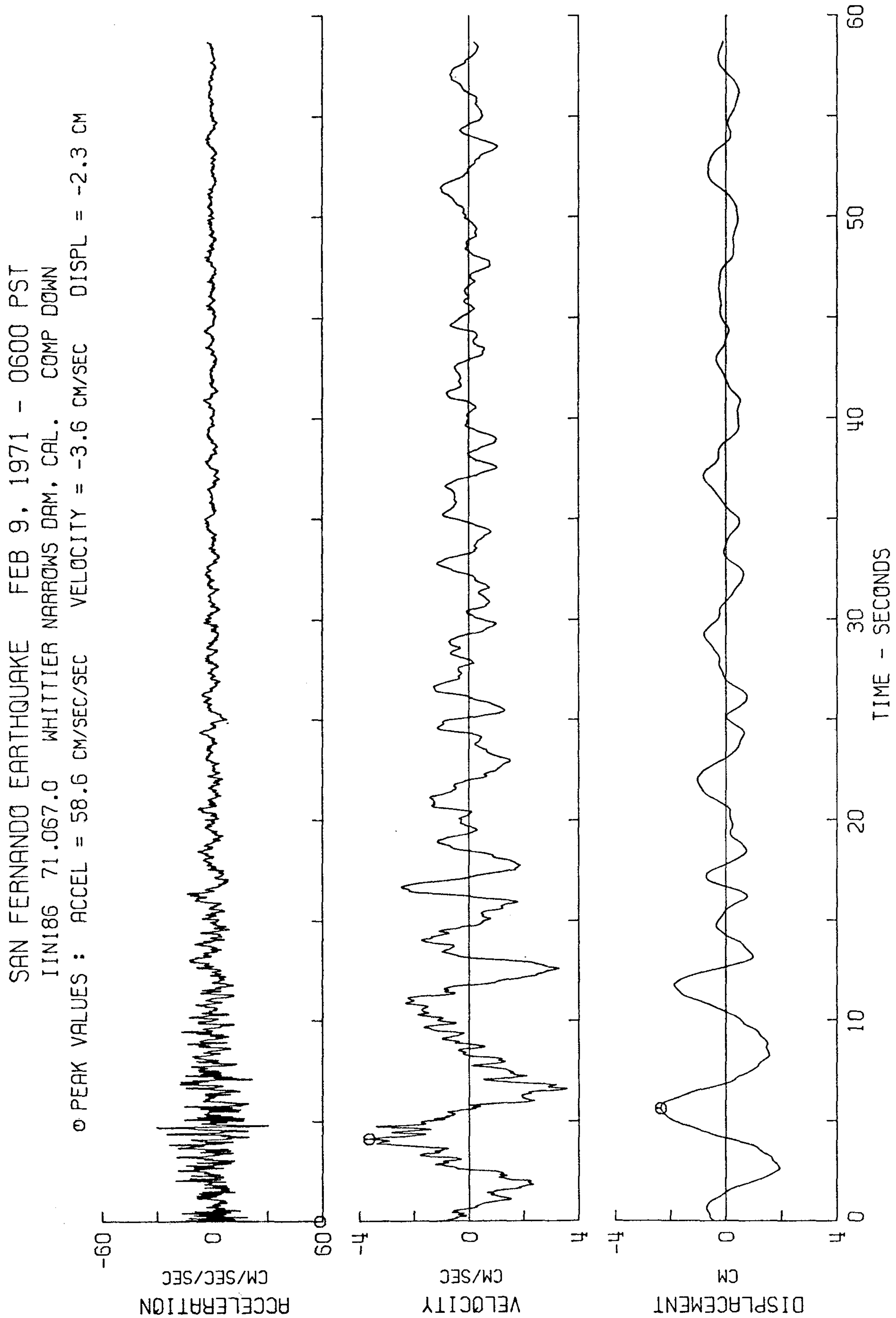


Figure 6. Whittier Narrows Dam Accelerogram, Component Vertical

13. SAN ANTONIO DAM

Introduction

San Antonio Dam was constructed by the Army Corps of Engineers in 1965 as a flood and debris control reservoir for the purpose of providing protection against floods in the broad alluvial plain of the upper Santa Ana Valley. The dam is located on San Antonio Creek approximately 16 km above its junction with Chino Creek. The site is 7 km northeast of the city of Claremont and approximately 64 km east of downtown Los Angeles (see Santa Felicia Dam Figure 1).

Geology

Tightly folded Paleozoic metasedimentary rocks and Cretaceous granites, primarily quartz diorite, are most prevalent in the area of the dam site (Jenkins and Rogers, 1967). The left abutment is founded on metasedimentary rock consisting of gneiss and mylonite while the right abutment rests on gneiss and granite. The embankment was constructed across the valley floor on Recent alluvium consisting of sand, gravel and boulders as large as 3 m in diameter. The alluvium beneath the embankment has a known maximum thickness of 65 m (Corps of Engineers, 1971). Ground water is at a minimum depth of 18.5 m (Corps of Engineers, 1954). The spillway is founded on terrace deposits of older alluvium, that overlie an earlier surface of decomposed metasediments and granite.

Description of the Dam

Principal features of the dam are an earthfill embankment, outlet works and spillway. The crest of the dam is 1168 m long, 9 m wide and 49 m above the original streambed (Figures 1, 2 and 3). While the reservoir is normally dry, it has a maximum capacity of 1.14×10^7 m^3 (9,285 acre-feet).

Strong-Motion Recordings

A Teledyne RFT-250 accelerograph was installed in a small building on the dam crest in 1968 (Figure 3). Corrected accelerograms and integrated velocity and displacement curves from the San Fernando earthquake are shown in Figures 4, 5 and 6 (reference 15, Introduction).

References

Corps of Engineers, Los Angeles, California, 1954, Design Memorandum No. 2, San Antonio and Chino Creeks Improvement: p. 3-13 and figures.

_____, 1971, San Antonio Dam Outlet Works and Spillway Periodic Inspection and Continuing Evaluation: Rept. No. 1, p. 1-13 and figures.

Jenkins, O. P., and Rogers, T. H., 1967, Geologic Map of California: California Div. of Mines and Geology, San Bernardino Sheet and source data.

FIGURE 1. San Antonio Dam.

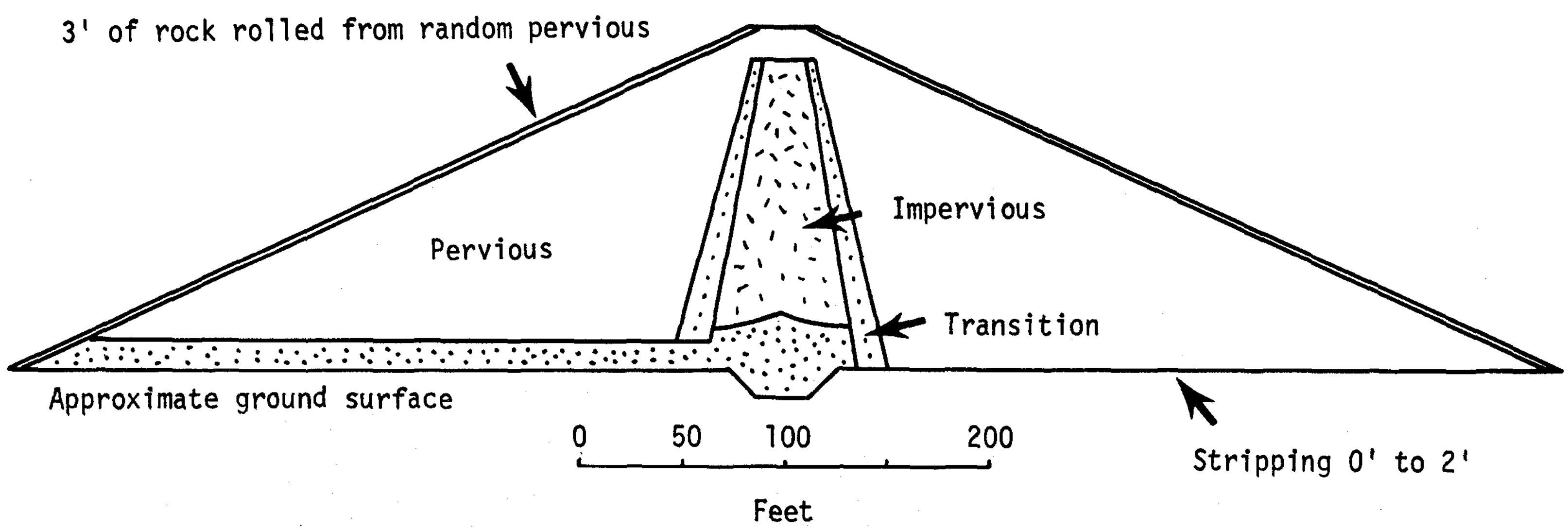


FIGURE 2. Typical section of San Antonio Dam.

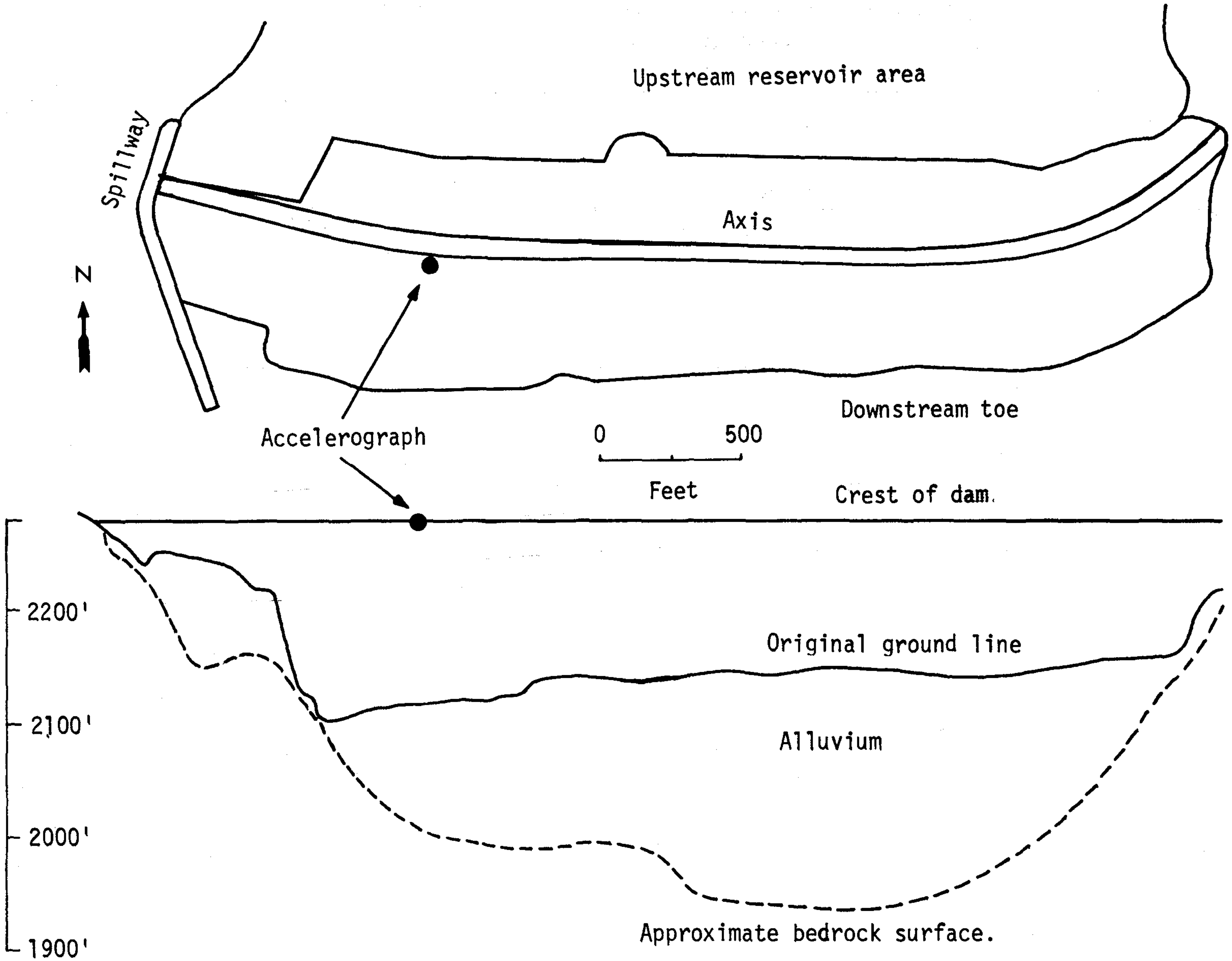


FIGURE 3. Location of accelerograph shown on the plan view and exploration profile of San Antonio Dam.

Figure 4.

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIN187 71.068.0 SAN ANTONIO DAM, UPLAND, CAL. COMP N75W

⊙ PEAK VALUES : ACCEL = -55.7 CM/SEC/SEC VELOCITY = -3.1 CM/SEC DISPL = -.7 CM

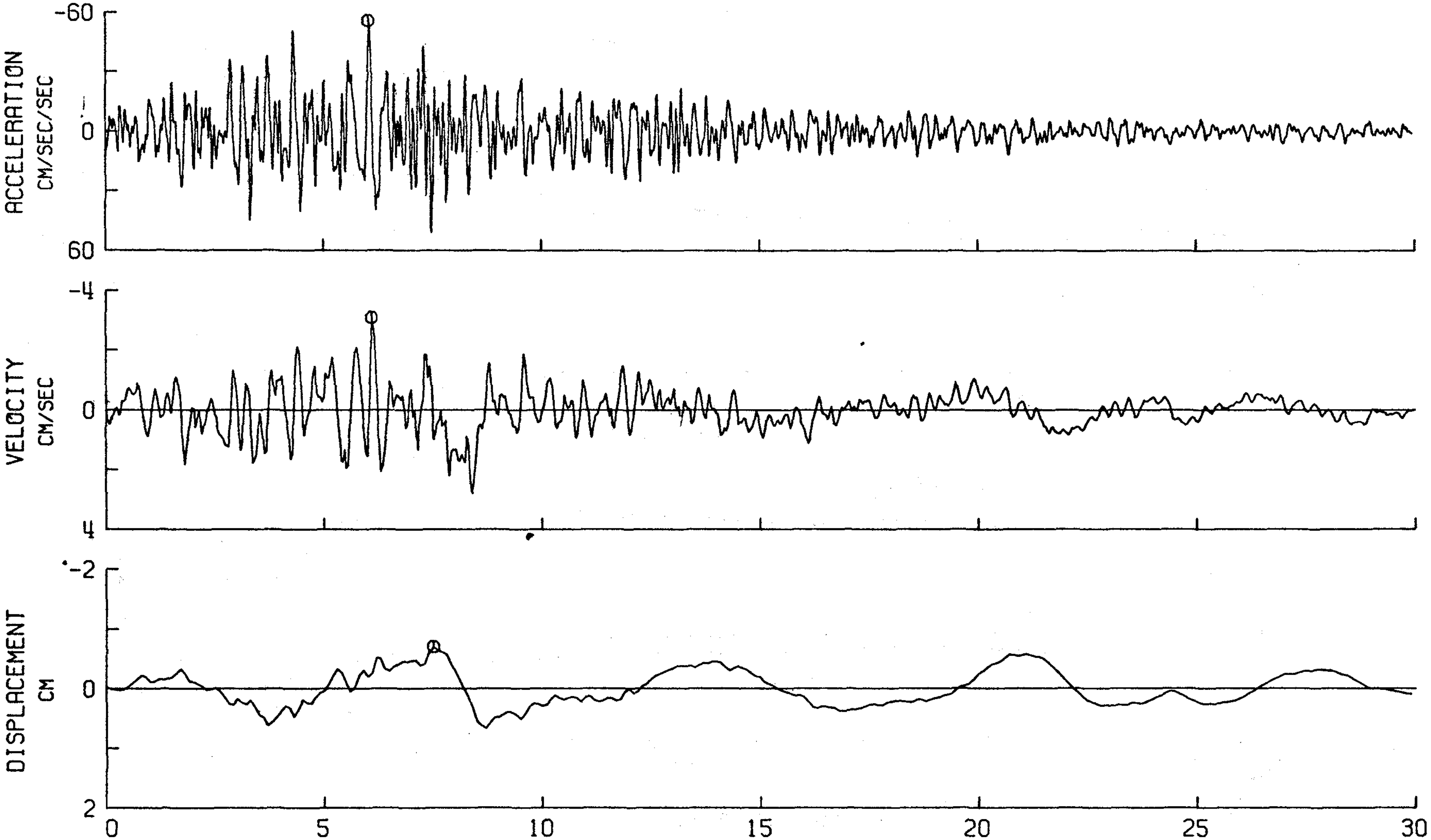


Figure 4. San Antonio Dam accelerogram, component N75W

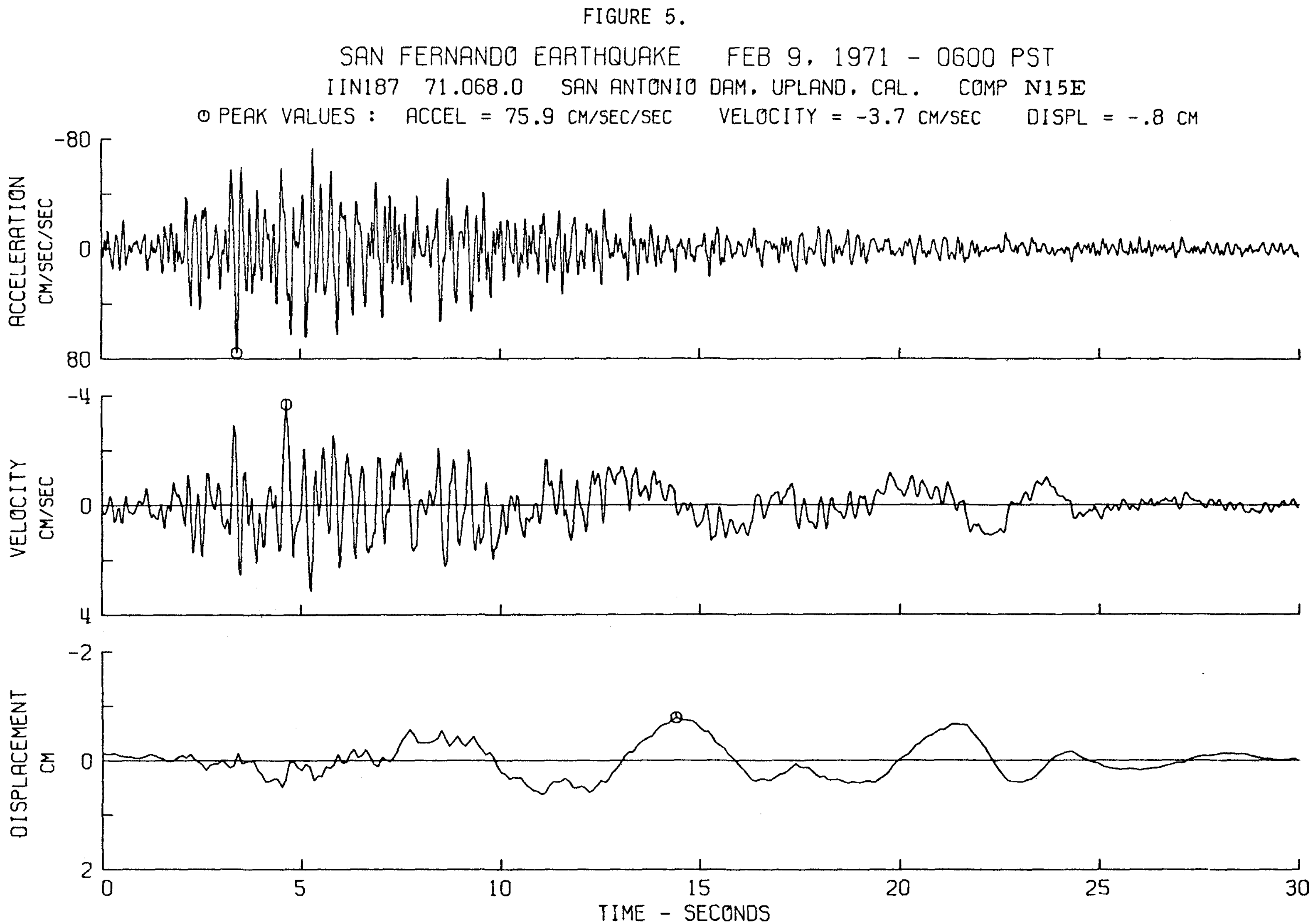


Figure 5. San Antonio Dam accelerogram, component N15E

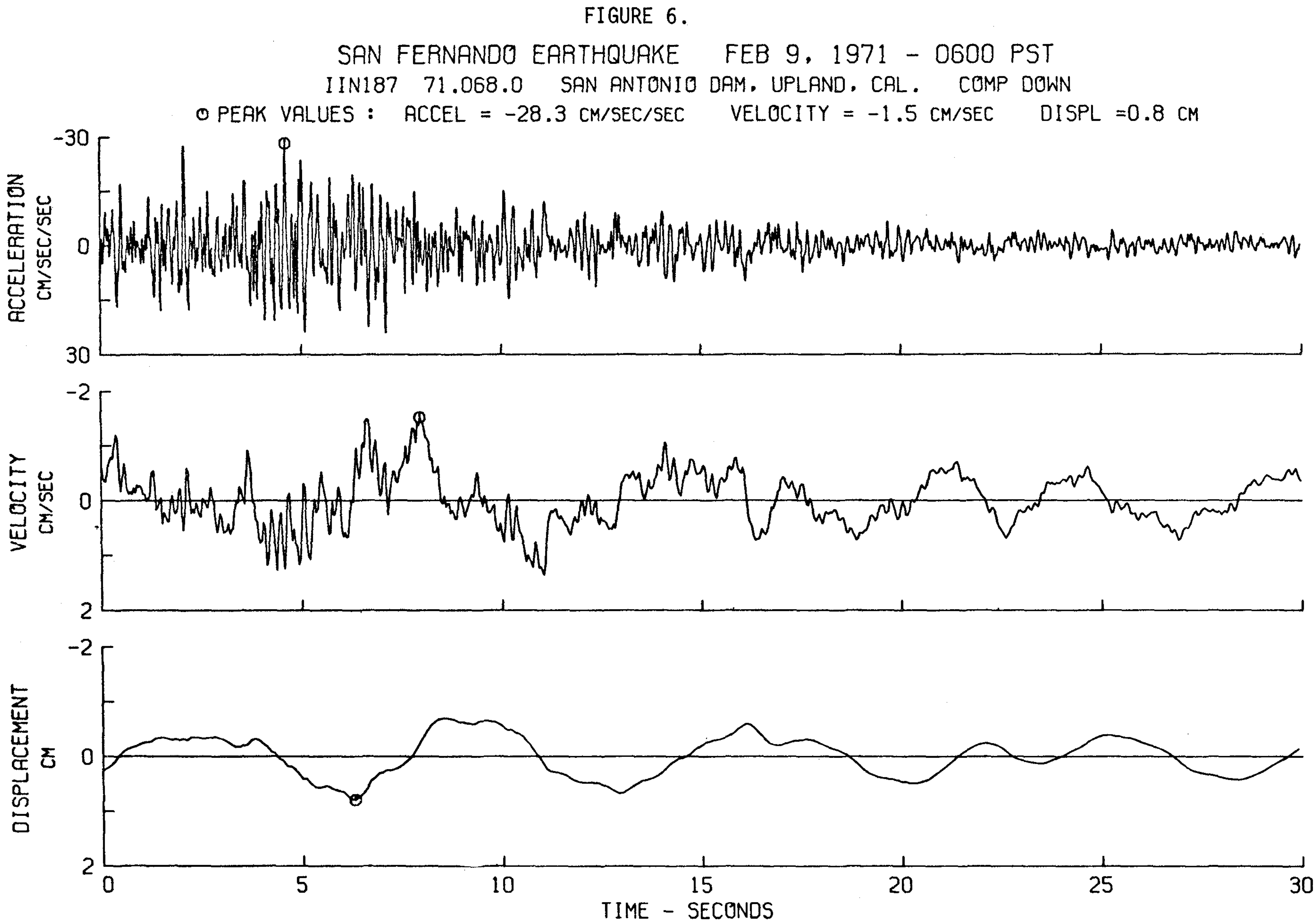


Figure 6. San Antonio Dam accelerogram, component vertical

14. FAIRMONT DAM

Introduction

Fairmont Reservoir is located in the southern portion of the Antelope Valley approximately 75 km north of Los Angeles (see Santa Felicia Dam, Figure 1). The reservoir was constructed by the Los Angeles Department of Water and Power in 1913 as a storage facility and to control the flow of water to two power plants located in San Francisquito Canyon. In addition, the dam serves as a regulatory facility and is part of a system which transports water from Owens Valley and Mono Basin south to the Los Angeles area.

Geology

The bedrock underlying the damsite consists primarily of quartz monzonite which is extensively exposed in the southwestern Antelope Valley region (Jenkins and others, 1964). The embankment rests directly on granitic bedrock that is massive but moderately weathered, except at the upper part of the left abutment where the foundation rock is pre-Pleistocene alluvium (Los Angeles Department of Water and Power, 1968 and 1973). This unit consists of firm, lenticular, fine to coarse grained sand and silt with some interbedded clay. Several east-west trending high angle reverse faults, located immediately east of the dam, have offset the bedrock-alluvium contact. Where Recent alluvium is present, the contact with the pre-Pleistocene alluvium does not appear to be disturbed by the faults.

The San Andreas fault zone is 4 km south of the reservoir and trends approximately N65°W in this region. The northeast trending Garlock fault is approximately 32 km north of the dam.

Description of the Dam

The dam is a hydraulic and earth-fill structure 1300 m long, 6 m wide, and 37 m high (Figures 1, 2 and 3). The upper 6 m of the embankment are rolled fill. A total of 5.86×10^5 m^3 of fill were used in the construction of the dam. The reservoir has a capacity of 9.24×10^6 m^3 (7500 acre-feet).

Strong-Motion Recordings

In 1965 a Standard Coast & Geodetic Survey accelerograph was installed in a one story garage on the right abutment (Figure 3). Corrected accelerograms and integrated velocity and displacement curves from the 1971 San Fernando earthquake are shown in Figures 4, 5 and 6 (reference 15, Introduction).

References

Jenkins, O. P., Jennings, C. W., and Strand, R. G., 1964, Geologic Map of California: California Div. of Mines and Geology, Los Angeles Sheet and source data.

Los Angeles Department of Water and Power, 1968, Fairmont Reservoir - Geologic Investigation for Borrow Material: Work Order J-314 and Addendum No. 1.

_____, 1973, Fairmont Reservoir Alternative Sites, Preliminary Geologic Report: Supplement No. 1.

FIGURE 1. Fairmont Dam. The accelerograph is located on the right abutment near the road.

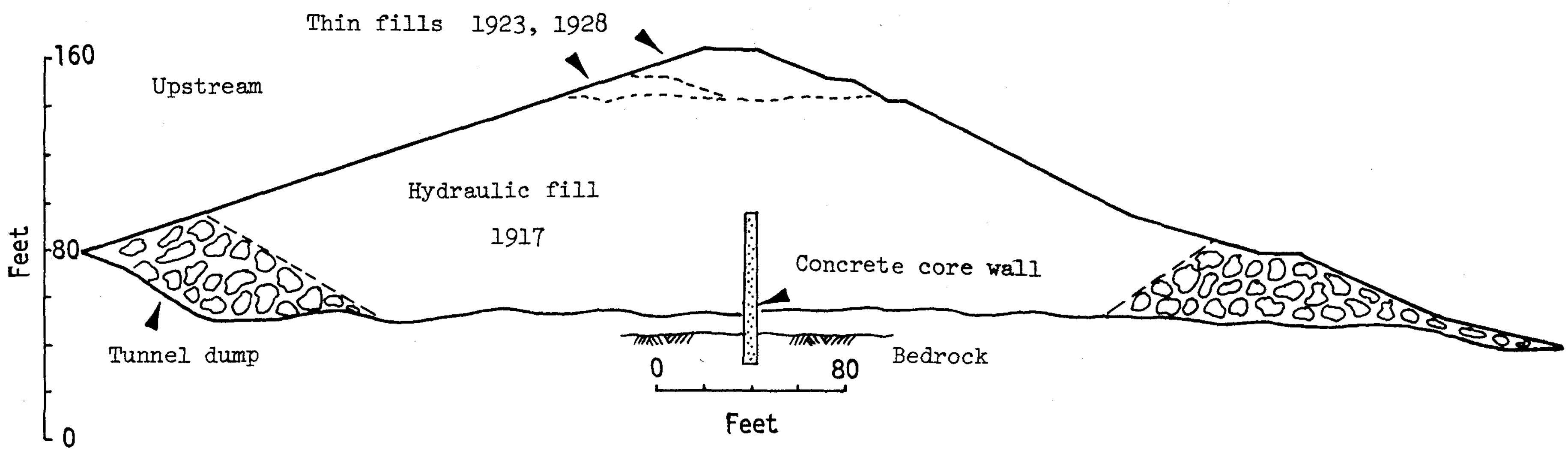


FIGURE 2. Typical Fairmont Dam Section.

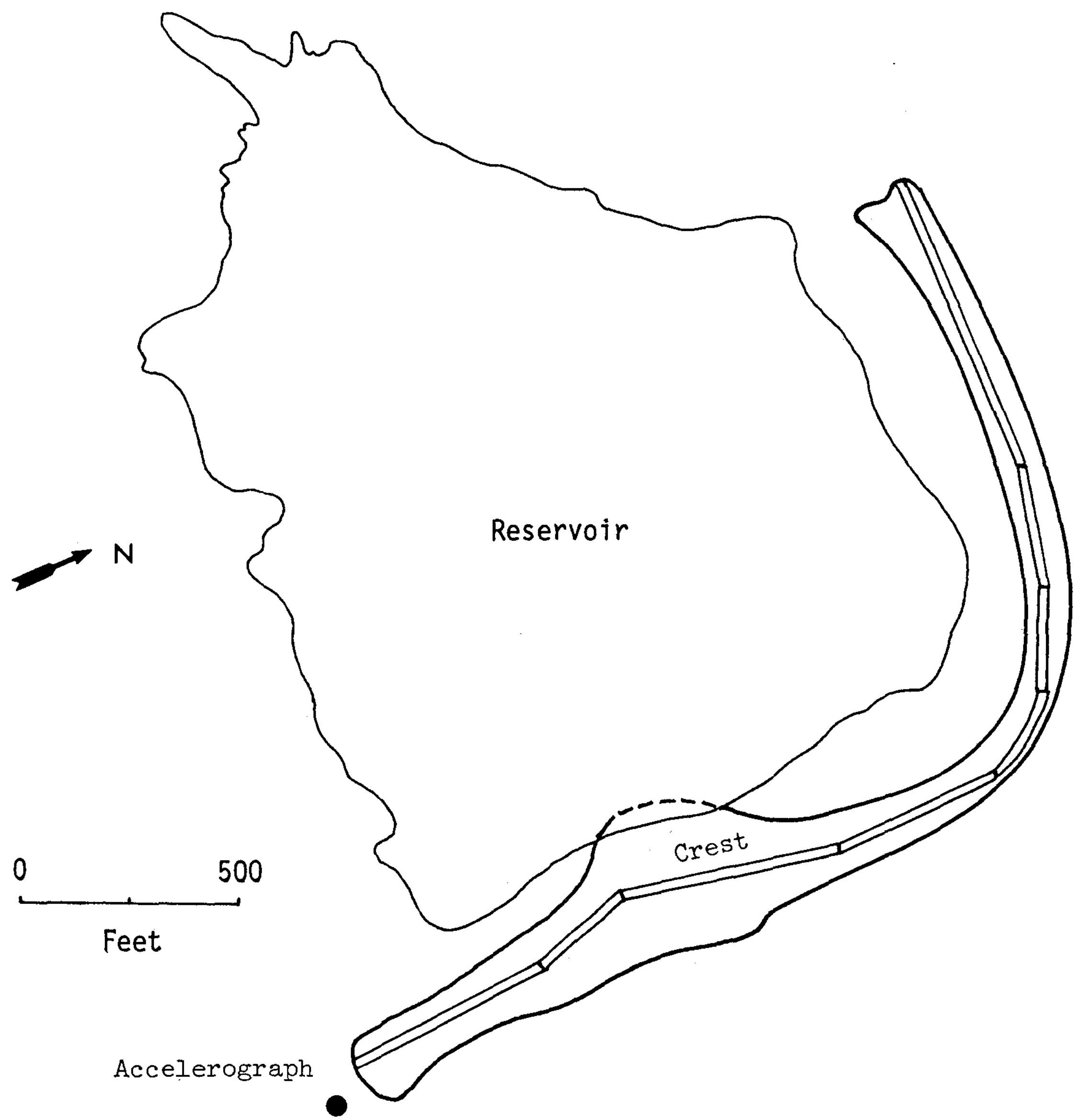


Figure 3. Plan view of Fairmont Dam showing the location of the accelerograph on the abutment.

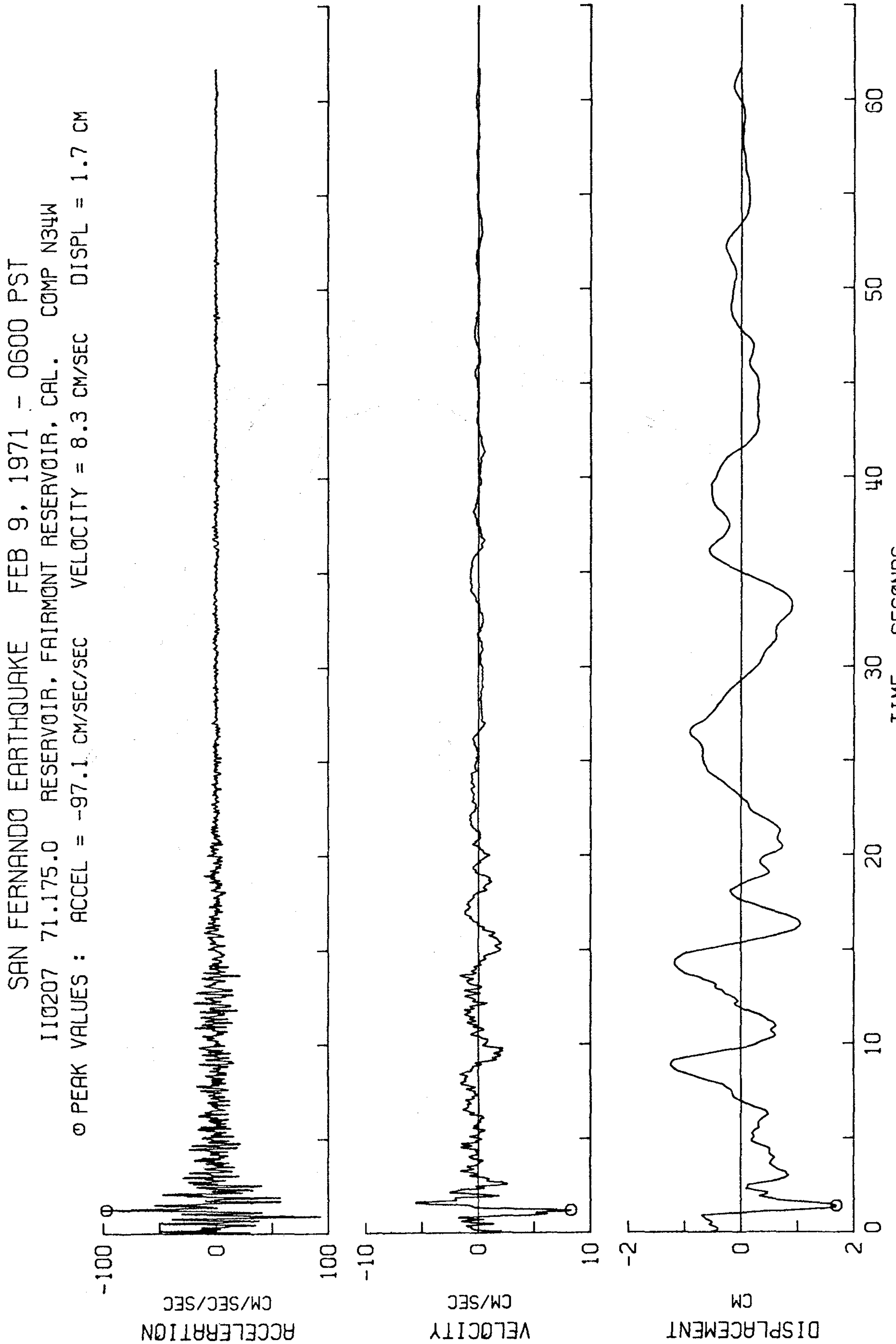


Figure 4. Fairmont Reservoir Accelerogram, Component N34W.

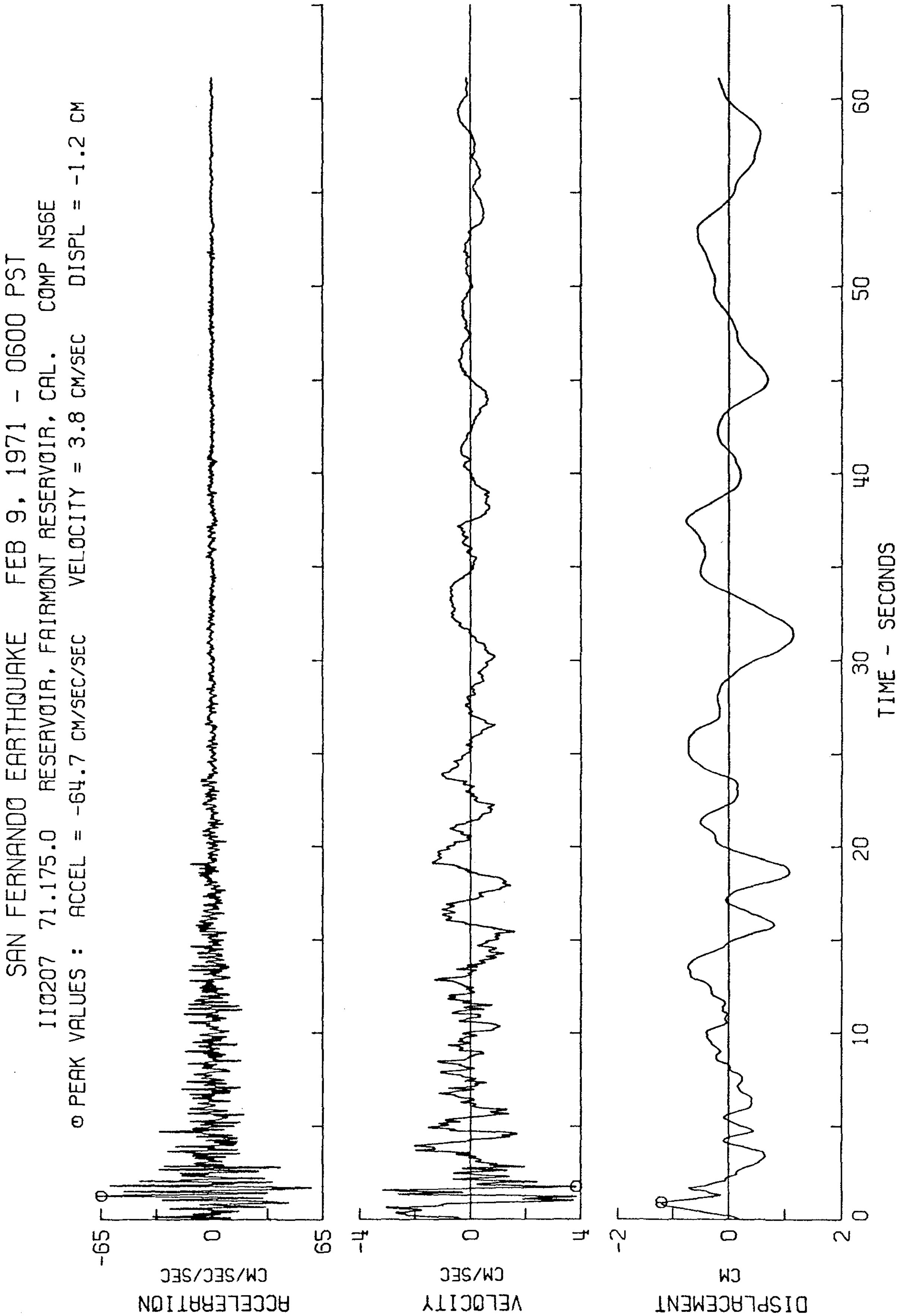


Figure 5. Fairmont Reservoir Accelerogram, Component N56E.

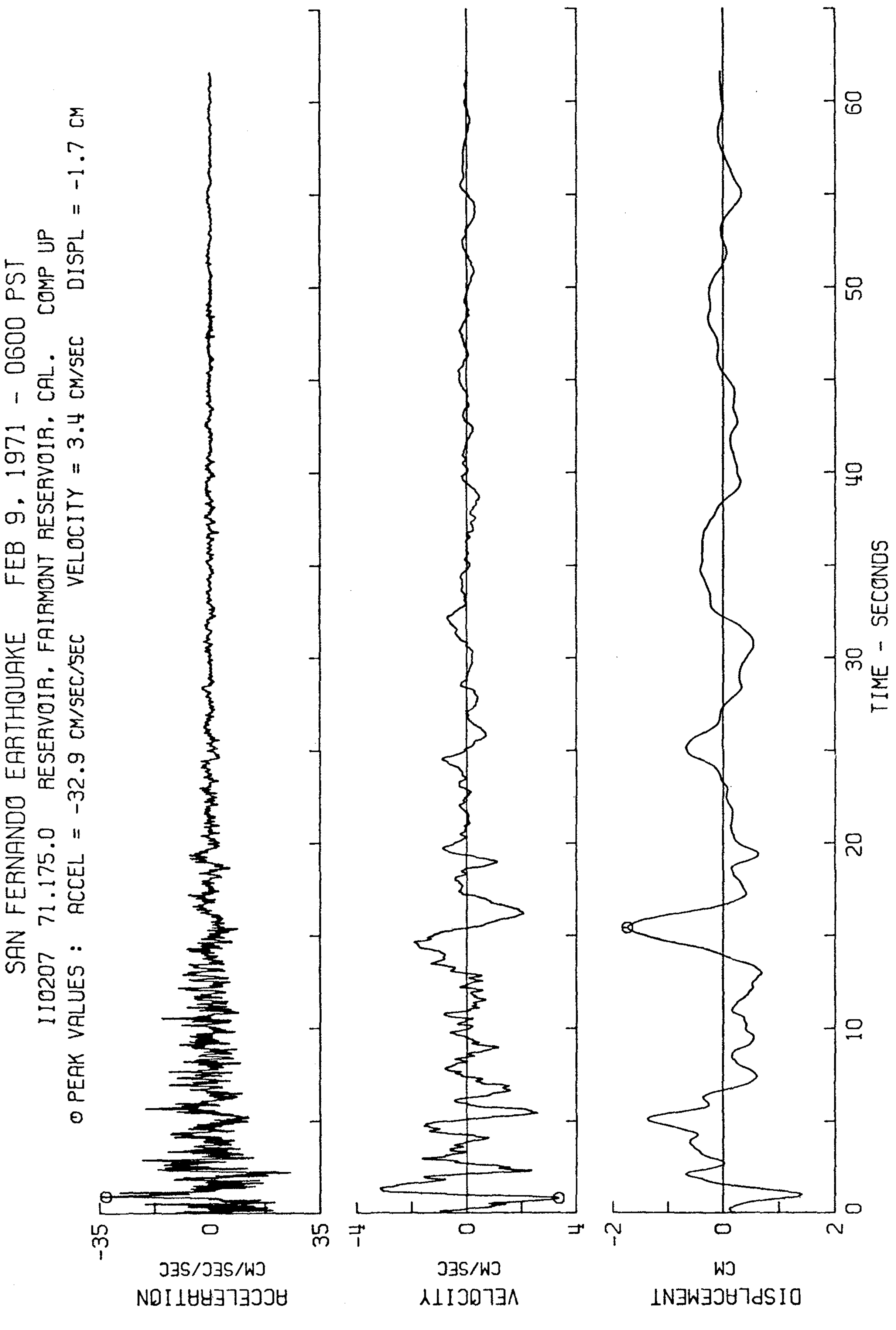


Figure 6. Fairmont Reservoir Accelerogram, Component Vertical.

15. SANTA ANITA DAM

Introduction

Santa Anita Dam, located 25 km northeast of downtown Los Angeles (see Santa Felicia Dam, Figure 1) was constructed by the Los Angeles County Flood Control District between 1924 and 1927. The crest of the dam extends east-west across Santa Anita Canyon, a north-south channel that drains 28 km^2 of the San Gabriel Mountains. The drainage area encompasses steep mountainous terrain rising 1600 m above the stream bed.

The following description of the dam and its geologic setting was taken from the Engineering Geology Report, Santa Anita Dam (1962) compiled by the Los Angeles County Flood Control District. Further reports on the project are available at the District's headquarters.

Geology

Santa Anita Dam lies near the southern extremities of the San Gabriel Mountains in the east-west trending Transverse Ranges of southern California. The structure rests on a well-jointed and fractured granite-diorite complex. The rock is cut by steeply dipping, weathered to moderately weathered andesitic dikes and by multi-oriented granite pegmatite dikes. There are prominant zones of shearing that trend basically NE-SW and NW-SE, parallel to the dominant jointing systems.

The dam is situated 35 km southeast of the San Andreas Fault and 0.9 km north of the potentially active Clamshell-Sawpit Fault zone, identified by the California Division of Mines and Geology (Morton, 1973) as part of the Sierra Madre Fault system.

Description of the Dam

Santa Anita Dam is a constant-arch concrete structure with a height of 76 m and a base width of 22 m (Figures 1, 2 and 3). The crest is 204 m long and 2.3 m wide. The reservoir has a maximum storage capacity of 7.22×10^5 m^3

(587 acre-feet).

Strong-Motion Recordings

Location of the strong-motion instrumentation, shown in Figure 3, includes a Teledyne AR-240 accelerograph installed in a steel instrument housing on the right abutment and a seismoscope located in a small building at the center of the crest.

Figures 4, 5, and 6 show the corrected accelerograms and the integrated velocity and displacement curves from the San Fernando earthquake of 1971 (reference 15, Introduction).

References

Morton, Douglas, 1973, Geology of Parts of the Azusa and Mount Wilson Quadrangles, San Gabriel Mountains, Los Angeles County, California: Calif. Div. Mines & Geology Special Report 105, 21 p.

Los Angeles County Flood Control District, 1962, Engineering Geology Report, Santa Anita Dam.

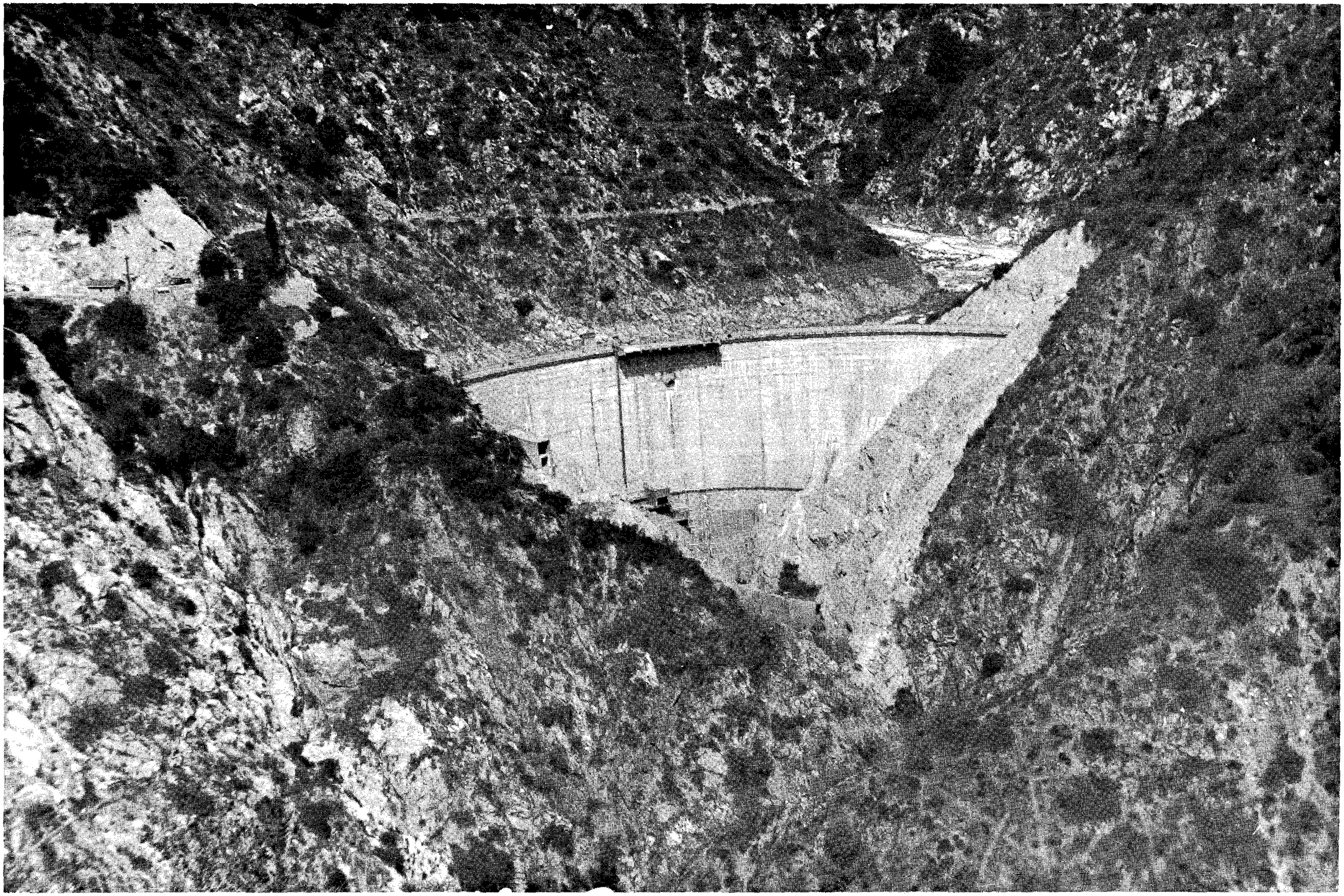


FIGURE 1. Santa Anita Dam. The accelerograph is located on the right abutment between the crest level and the upper road.

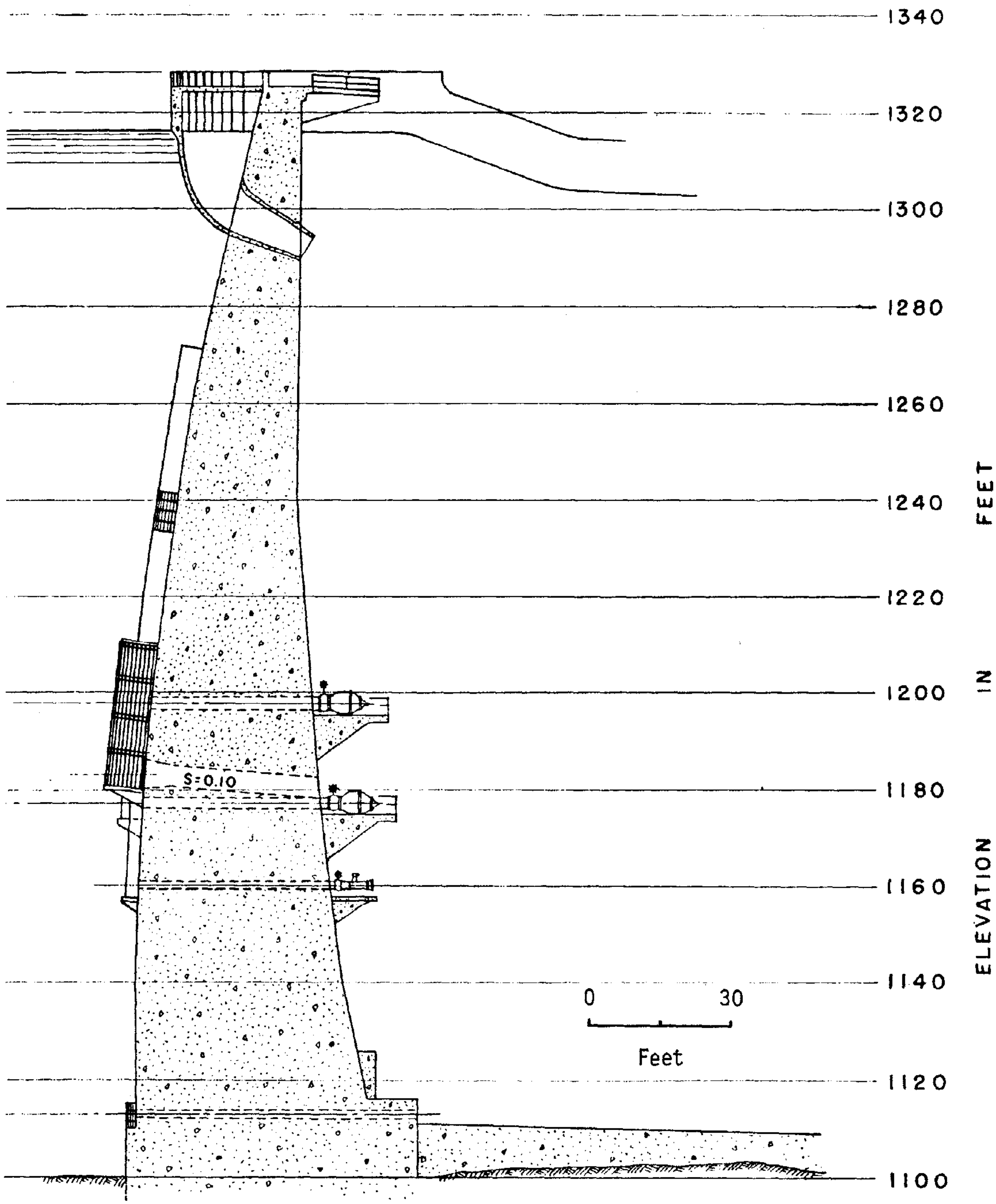


FIGURE 2. Cross-section of Santa Anita Dam.

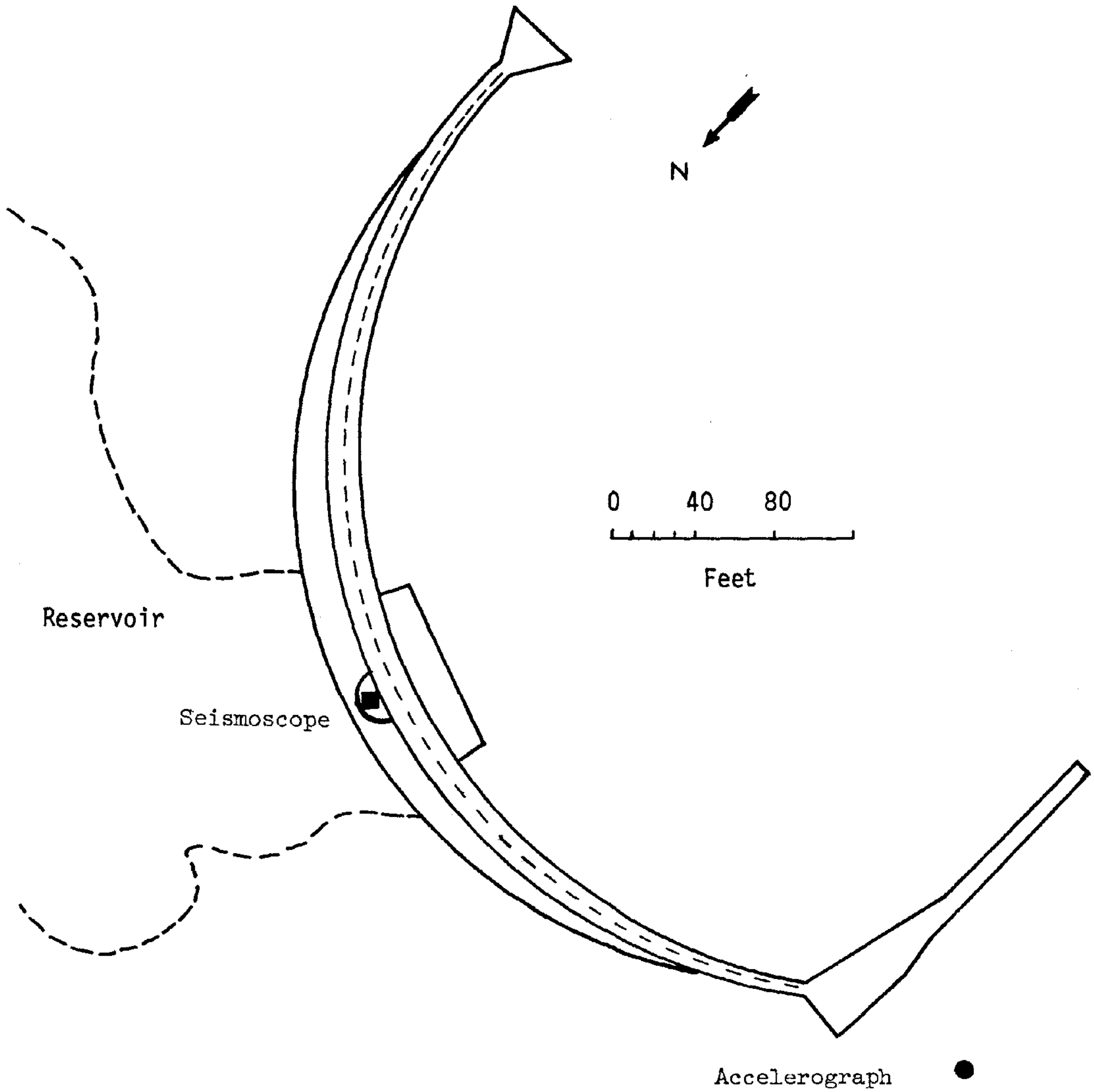


FIGURE 3. Plan view of Santa Anita Dam showing the locations of the accelerograph and seismoscope.

Figure 4

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIP221 71.150.0 SANTA ANITA RESERVOIR, ARCADIA, CAL. COMP N87W

⊕ PEAK VALUES : ACCEL = -165.8 CM/SEC/SEC VELOCITY = -6.6 CM/SEC DISPL = -5.9 CM

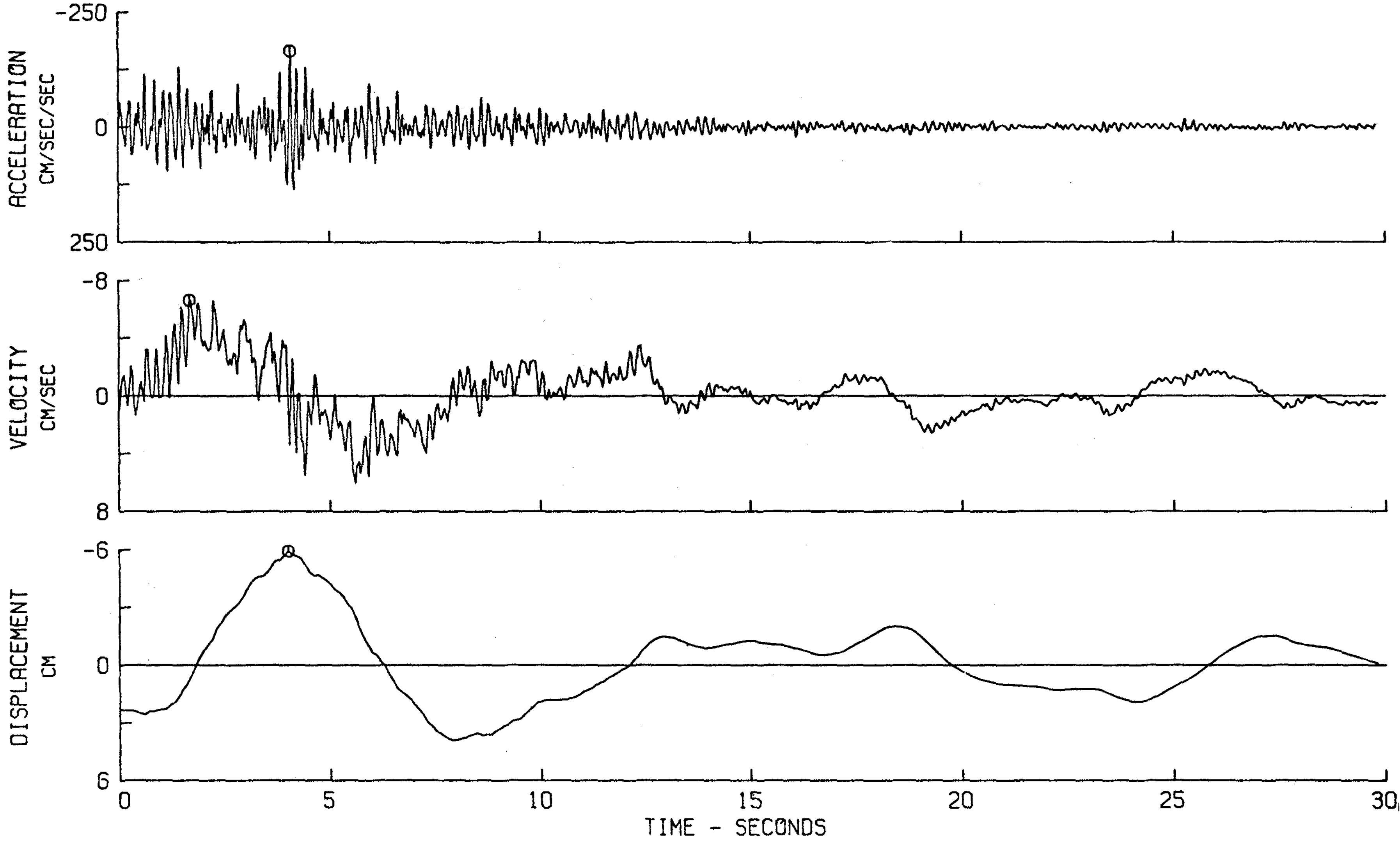


FIGURE 5.

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIP221 71.150.0 SANTA ANITA RESERVOIR, ARCADIA, CAL. COMP N03E

Θ PEAK VALUES : ACCEL = -137.7 CM/SEC/SEC VELOCITY = 5.0 CM/SEC DISPL = -3.1 CM

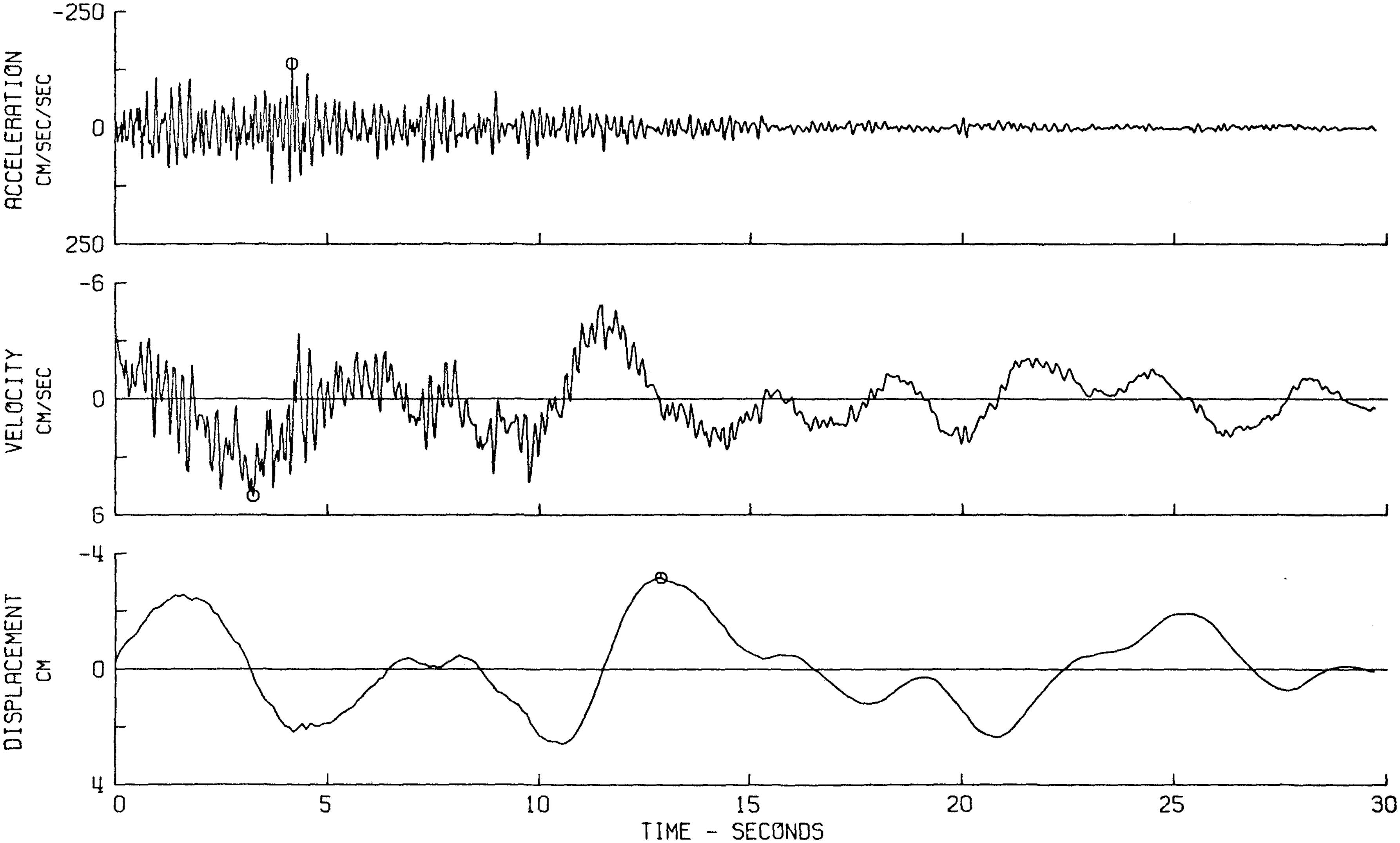
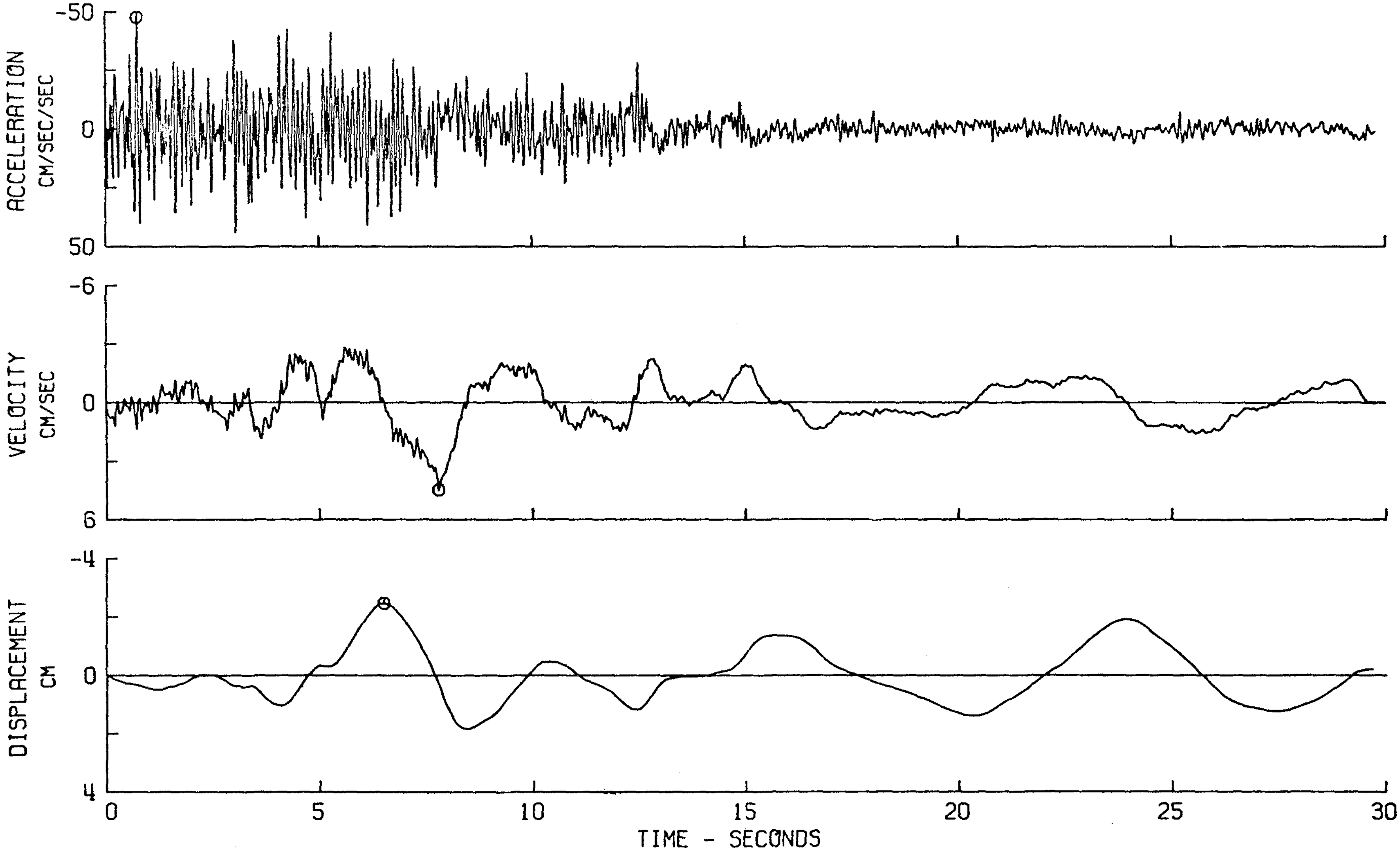


FIGURE 6.

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIP221 71.150.0 SANTA ANITA RESERVOIR, ARCADIA, CAL. COMP DOWN

⊙ PEAK VALUES : ACCEL = -47.6 CM/SEC/SEC VELOCITY = 4.5 CM/SEC DISPL = -2.5 CM



16. PUDDINGSTONE DAM

Introduction

Puddingstone Dam is located in the San Jose Hills approximately 40 km east of downtown Los Angeles (see Santa Felicia Dam, Figure 1), near the northern boundary of the Peninsular Ranges Province. This facility was constructed by the Los Angeles County Flood Control District in 1928.

Geology

Foundation rock at the dam site consists primarily of Miocene volcanic and sedimentary deposits. Two rock types in the vicinity of the abutments are of major engineering concern; a conglomerate of volcanic boulders and cobbles in a fine-grained matrix, and a siltstone and shale member of the Upper Miocene Puente formation (Jenkins and Rogers, 1967). The older volcanic sequence consists of cemented angular fragments of widely varying size which have been severely folded and fractured. The highly permeable and severely folded and fractured volcanic conglomerate in this area is responsible for the unusually high seepage from the abutments and resultant saturation of the embankment (Los Angeles County Flood Control District, 1970).

The Sierra Madre fault zone lies within 2.5 km of the main embankment (Yerkes and others, 1965). The Puddingstone Creek fault passes directly under the dam, and is related to the zone of weakness along which the river gorge was formed (Los Angeles County Flood Control District, 1967). The discovery of this fault resulted in the cancellation of construction of a concrete dam originally planned for the site. A number of minor faults have been mapped in the area of the west abutment, but it is not known if they extend beneath the dam.

Description of the Dam

The main embankment is a homogeneous earthfill structure 300 m long and 45 m high (Figures 1, 2 and 3). In addition, there are two smaller dams west of the main embankment. Each is approximately 240 m long and 15 m high (Figure 3). The crest of the overall structure is located at an elevation of 303 m. The reservoir has a capacity of 2.12×10^7 m^3 (17,190 acre-feet).

Strong-Motion Recordings

An AR-240 accelerograph was installed at the left abutment in 1965 with its horizontal component directions parallel and transverse to the axis of the main embankment. Two seismoscopes were also installed; one adjacent to the accelerograph and one on the crest (Figure 3). Corrected accelerograms and calculated velocity and displacement curves from the 1971 San Fernando earthquake are shown in Figures 4, 5, and 6 (reference 15, Introduction).

References

Los Angeles County Flood Control District, 1967, Engineering Geology of Puddingstone Dams: Vol. 1 and 2.

_____, 1970, Geotechnical Investigation and Stability Analysis - Puddingstone Dams: Vol. 1, Sec. II, IV and V.

Jenkins, O. P., and Rogers, T. H., 1967, Geologic Map of California: California Div. of Mines and Geology, San Bernardino Sheet and source data.

Yerkes, R. F., McColloh, T. H., Schoellhamer, J. E., and Vedder, J. G., 1965, Geology of the Los Angeles Basin - An Introduction: U.S. Geol. Survey Prof. Paper 420-A, 57 p.

FIGURE 1. Puddingstone main dam pictured in the foreground.

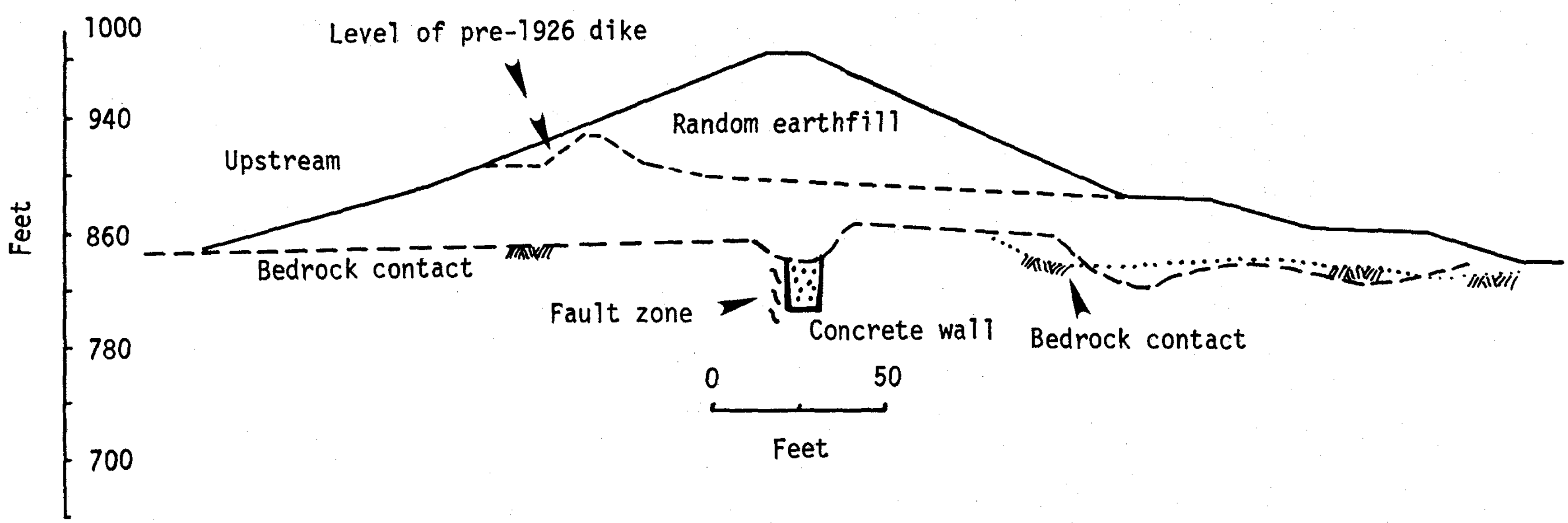


FIGURE 2. Maximum cross-section of Puddingstone Dam.

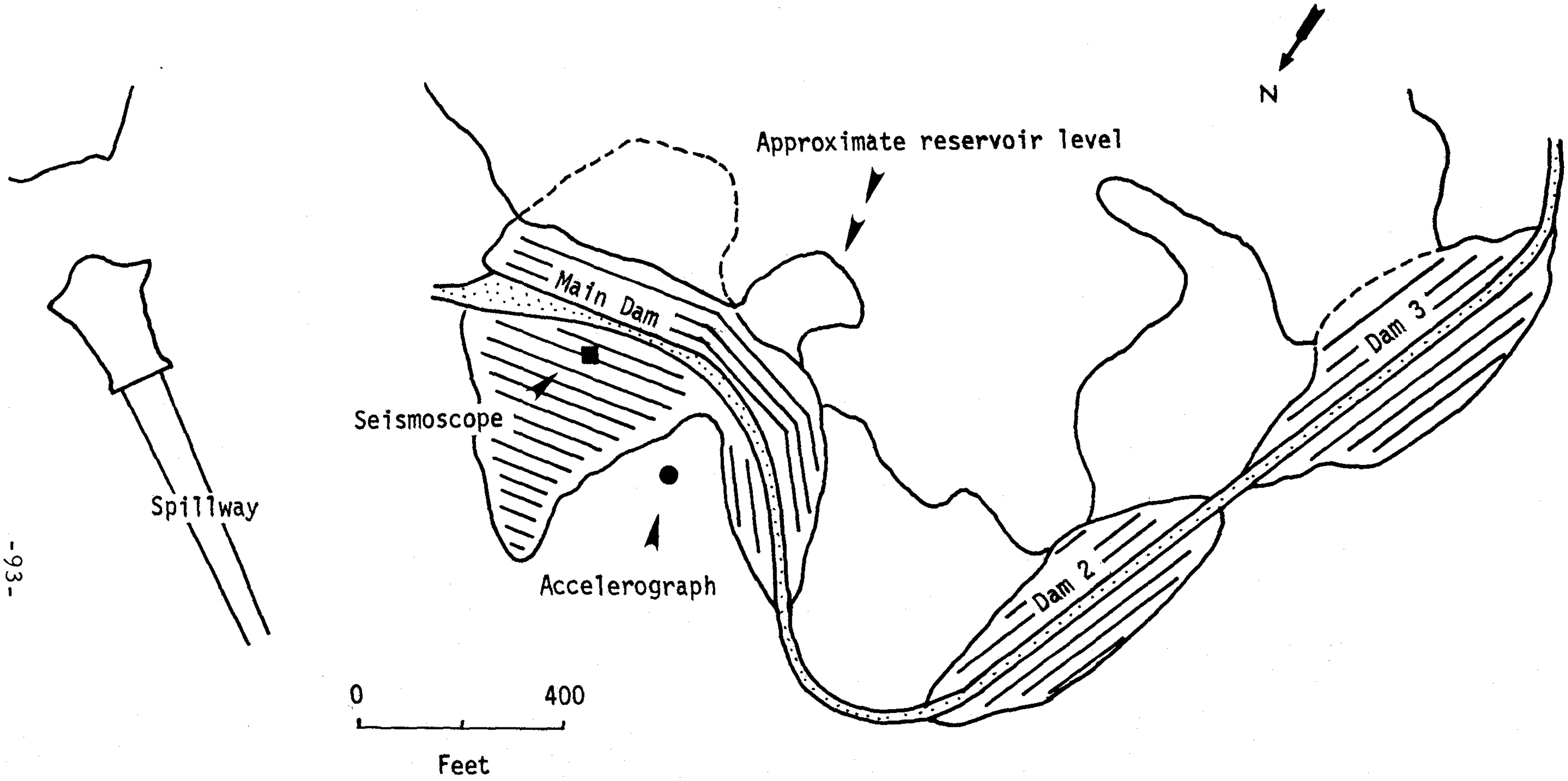


FIGURE 3. Plan view of Puddingstone Dam showing the accelerograph and seismoscope locations.

FIGURE 4.

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIP223 71.153.0 PUDDINGSTONE RESERVOIR, SAN DIMAS, CAL. COMP N35W

⊙ PEAK VALUES : ACCEL = 53.3 CM/SEC/SEC VELOCITY = -4.2 CM/SEC DISPL = 1.8 CM

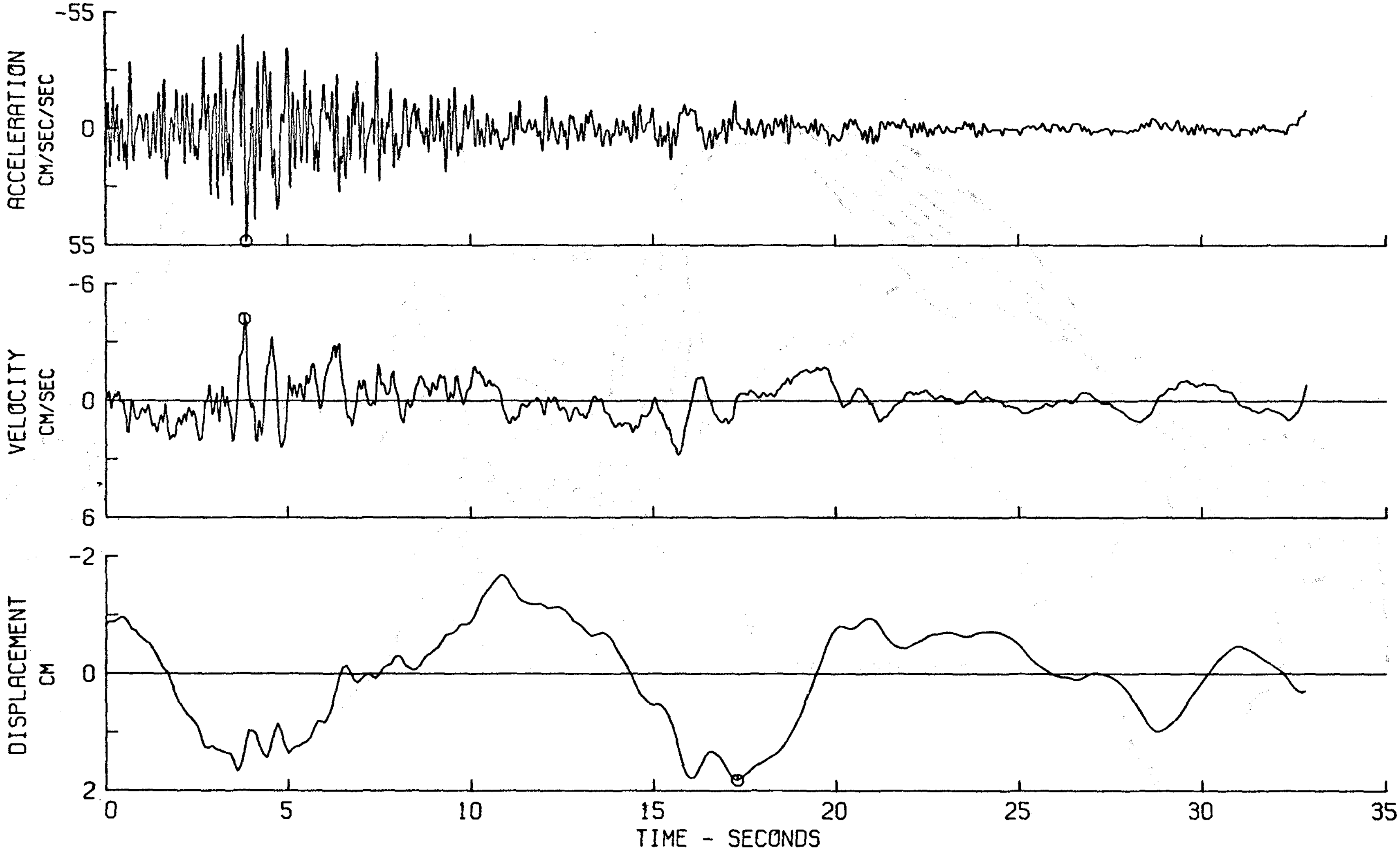


FIGURE 5.

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIP223 71.153.0 PUDDINGSTONE RESERVOIR, SAN DIMAS, CAL. COMP N55E

⊙ PEAK VALUES : ACCEL = -69.7 CM/SEC/SEC VELOCITY = 4.6 CM/SEC DISPL = -2.1 CM

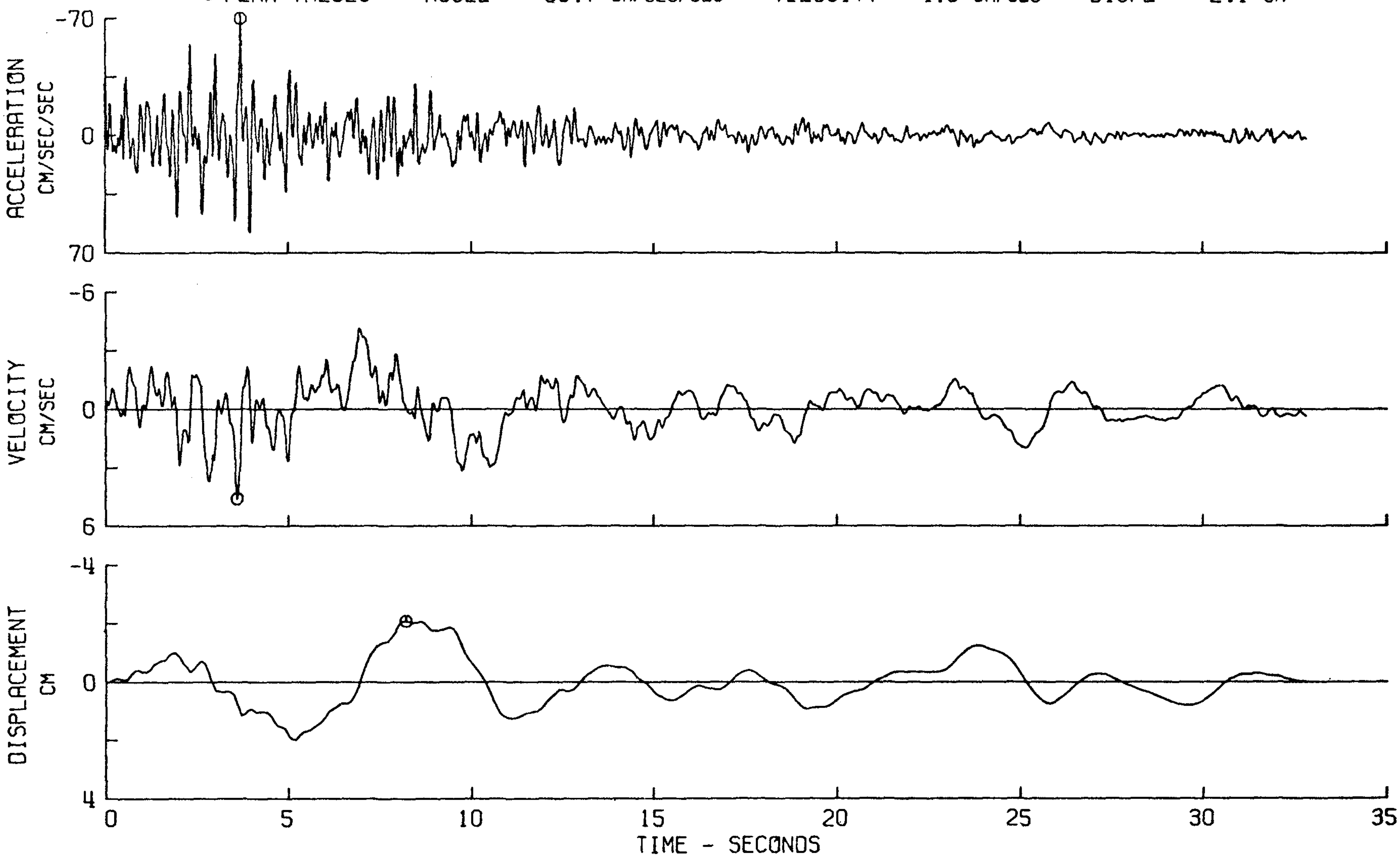
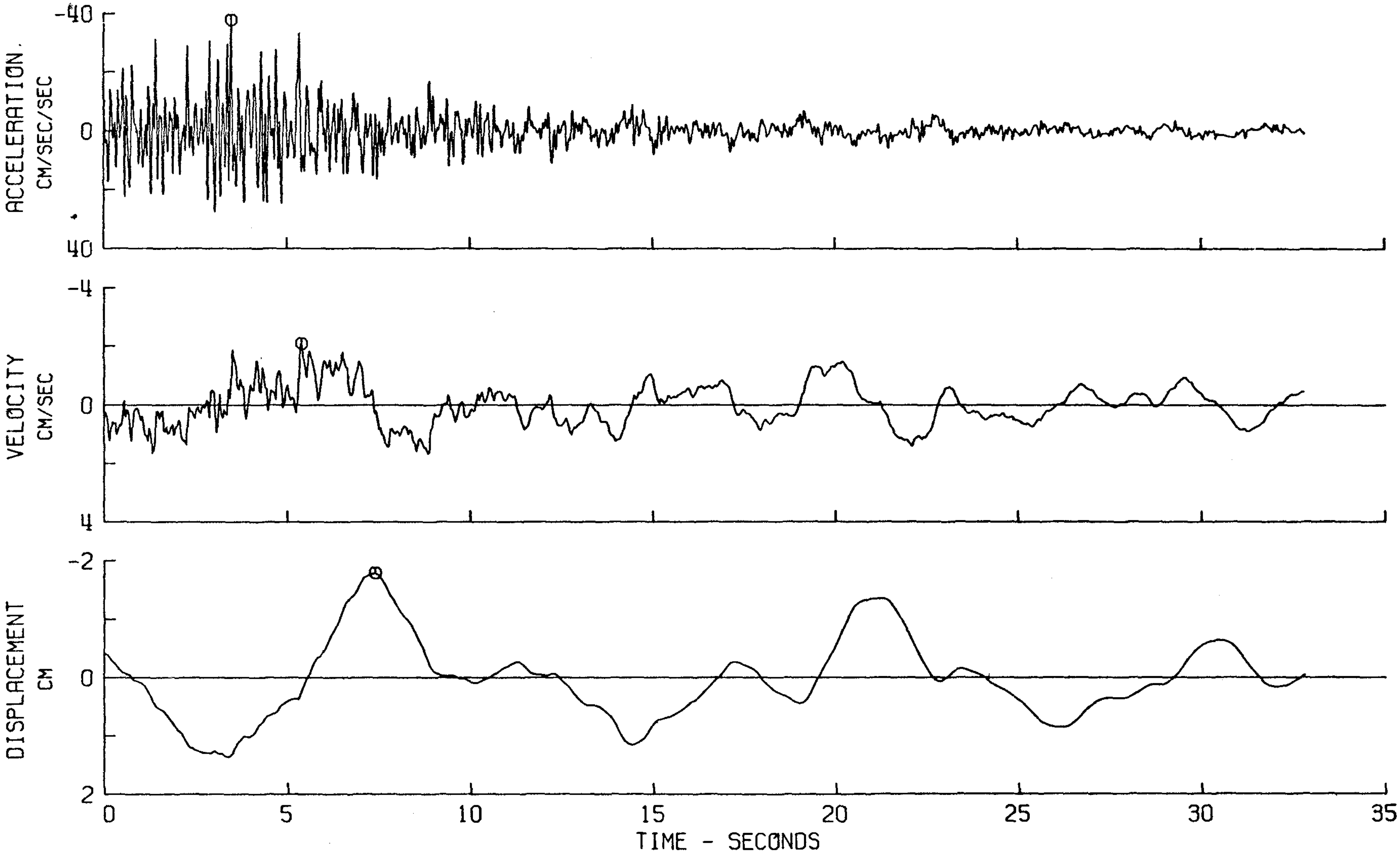


FIGURE 6.

SAN FERNANDO EARTHQUAKE   FEB 9, 1971 - 0600 PST

IIP223 71.153.0   PUDDINGSTONE RESERVOIR, SAN DIMAS, CAL.   COMP DOWN

ʘ PEAK VALUES : ACCEL = -37.8 CM/SEC/SEC   VELOCITY = -2.1 CM/SEC   DISPL = -1.8 CM



17. HSINFENGKIANG DAM

Introduction

Hsinfengkiang Dam is situated about 160 km northwest of Canton at approximately 23.71°N, 114.63°E in Kwangtung Province, China. Construction began in July 1958; reservoir impounding in October 1959; and power plant operation in August 1960. The reservoir serves an important role in industrial and agricultural development and in flood control.

Seismic activity became evident within 10 km of the dam soon after reservoir impoundment was initiated. These and subsequent earthquakes were apparently reservoir induced. On March 19, 1962, a nearby earthquake (M_S 6.1) caused horizontal cracks through the dam. Following this, strong-motion instruments were installed.

Geology

Hsinfengkiang Dam is located on Jurassic-Cretaceous granite. The dam and reservoir are situated on a huge unstable Late Mesozoic, granitic mass. Traces of previous structural movements (since Mesozoic) consist primarily of faults and secondary folds.

Orientation of the faults and folds indicates distinct E-W and NE-SW structural zones. The E-W fault/fold zone contains massive granitic intrusions that are widely distributed in the reservoir area. The NE-SW zone features reverse faulting that intersects the E-W structural zone in the vicinity of the dam site.

Description of the Dam

The diamond-head buttress dam consists of 19 blocks, each 18 m wide, flanked by gravity sections on both sides (Figure 1). The maximum dam height is 105 m, with a crest length of 440 m. The capacity of the reservoir is 1.15×10^{10} m^3 (9,350,000 acre-feet).

The dam was designed assuming an expected Modified Mercalli (MMI)

VI intensity. Because of frequent nearby earthquakes, the dam was strengthened in 1961 for an expected MMI VIII (Figure 1). As a result of the magnitude 6.1 earthquake, an 82-m-long crack appeared on the top part of the dam at an elevation of about 108 m near the right abutment. A second-stage of strengthening was later carried out to ensure the safety of the project (Figure 1).

Strong-Motion Recordings

A strong-motion accelerograph system was installed on the dam at different elevations as illustrated in Figure 2. The numbers 4, 5, 6, 8, 11 and 14 above the dam crest in Figure 1 indicate the piers where the accelerometers were installed. Most of them are located on the two highest piers (nos. 5 and 8), shown in Figure 2. Station C is situated on exposed bedrock about 100 m downstream on the left bank. A total of 12 accelerometers are located on the dam and 1 is on bedrock.

Table 1 lists those earthquakes for which satisfactory accelerograms have been obtained. Figure 3 shows the reproduced accelerograms of the largest event, Earthquake 22, that occurred on December 18, 1972 and had a magnitude (M_s) of 4.5. The maximum acceleration recorded on the 12 dam sensors is shown in Table 2 as a function of the sensor elevation and orientation.

The finite-element analysis method was applied to the record from Pier 5. Assuming the pier to be in a state of plane-stress and neglecting the dynamic water pressure, the dam response to the simultaneous input of the horizontal and vertical ground motion (at the foundation of the dam) of Earthquake 22 was computed. Good agreement was obtained between computed and observed results (Figure 4).

The distribution of principal stresses along the height of the dam was determined for Earthquake 22 showing maximum stress concentrations at

Elevations 100 and 108. The maximum stress computed for the magnitude 6.1 main shock was determined to be sufficient to cause cracking of concrete at the 100 and 108 m elevations, (the 82-m horizontal crack at Elevation 108 has already been mentioned). A subsequent drop in the water level revealed another fine crack at Elevation 97. The coincidence of cracking and stress concentration at these two places is significant verification of the method of calculation.

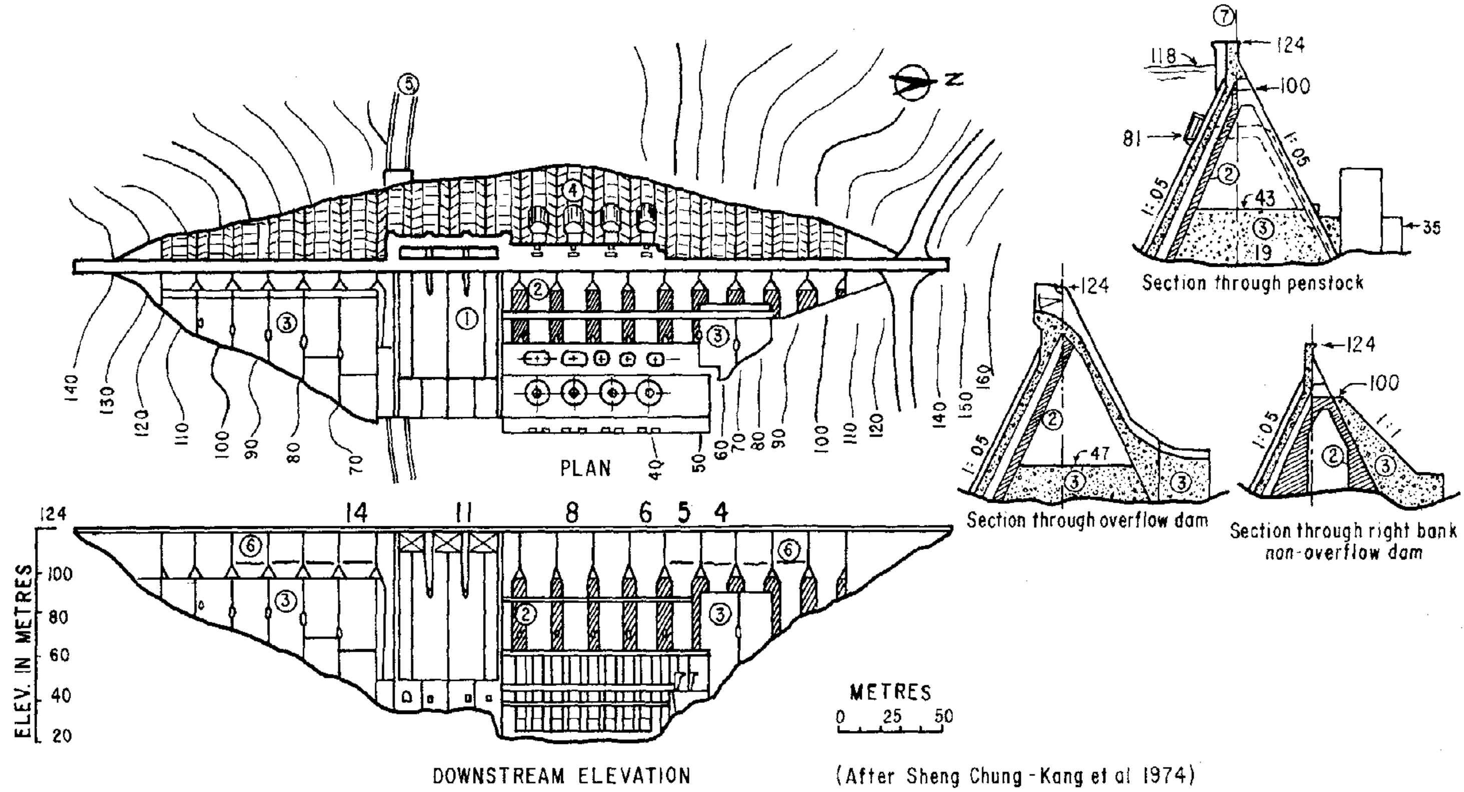
References

Bolt, B. A., and W. K. Cloud, 1974, Recorded Strong-Motion on the Hsinfengkiang Dam, China, Bull. Seism. Soc. Am., 64, p. 1337-1342.

Hsu, Tsung-Ho, and others, 1975, Strong-Motion Observation of Water-Induced Earthquakes at Hsinfengkiang Reservoir in China: Institute of Engineering Mechanics, Academia Sinica, May 1975.

Sheng Chung-Kang, and others, 1973, Earthquakes Induced by Reservoir Impounding and Their Effect on Hsinfengkiang Dam: Proc. 11th International Congress on Large Dams, Madrid, 1973.

FIGURE 1
HSINFENGKIANG DAM



Legend

① SPILLWAY

② FIRST-STAGE STRENGTHENING

③ SECOND-STAGE STRENGTHENING

④ INTAKE

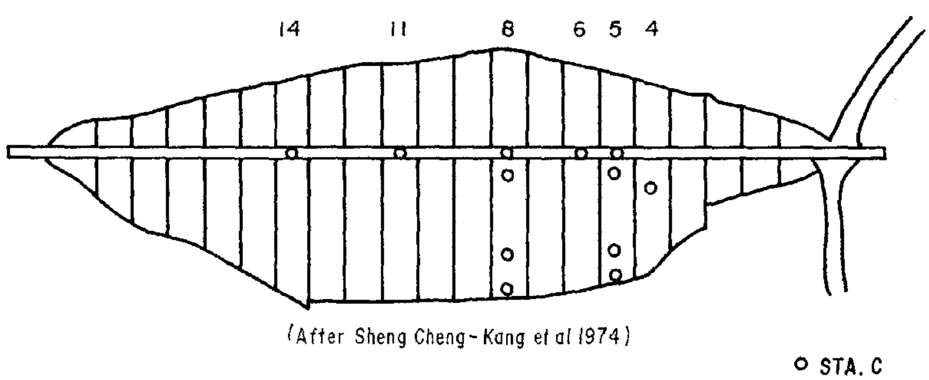
⑤ DIVERSION CHANNEL

⑥ CRACKS

⑦ DAM AXIS

THE NUMBERS ALONG THE CREST OF THE DAM REFER TO THE SITES OF THE ACCELEROGRAPH PICK-UPS

FIGURE 2
LOCATION OF STRONG-MOTION SEISMOGRAPH STATIONS



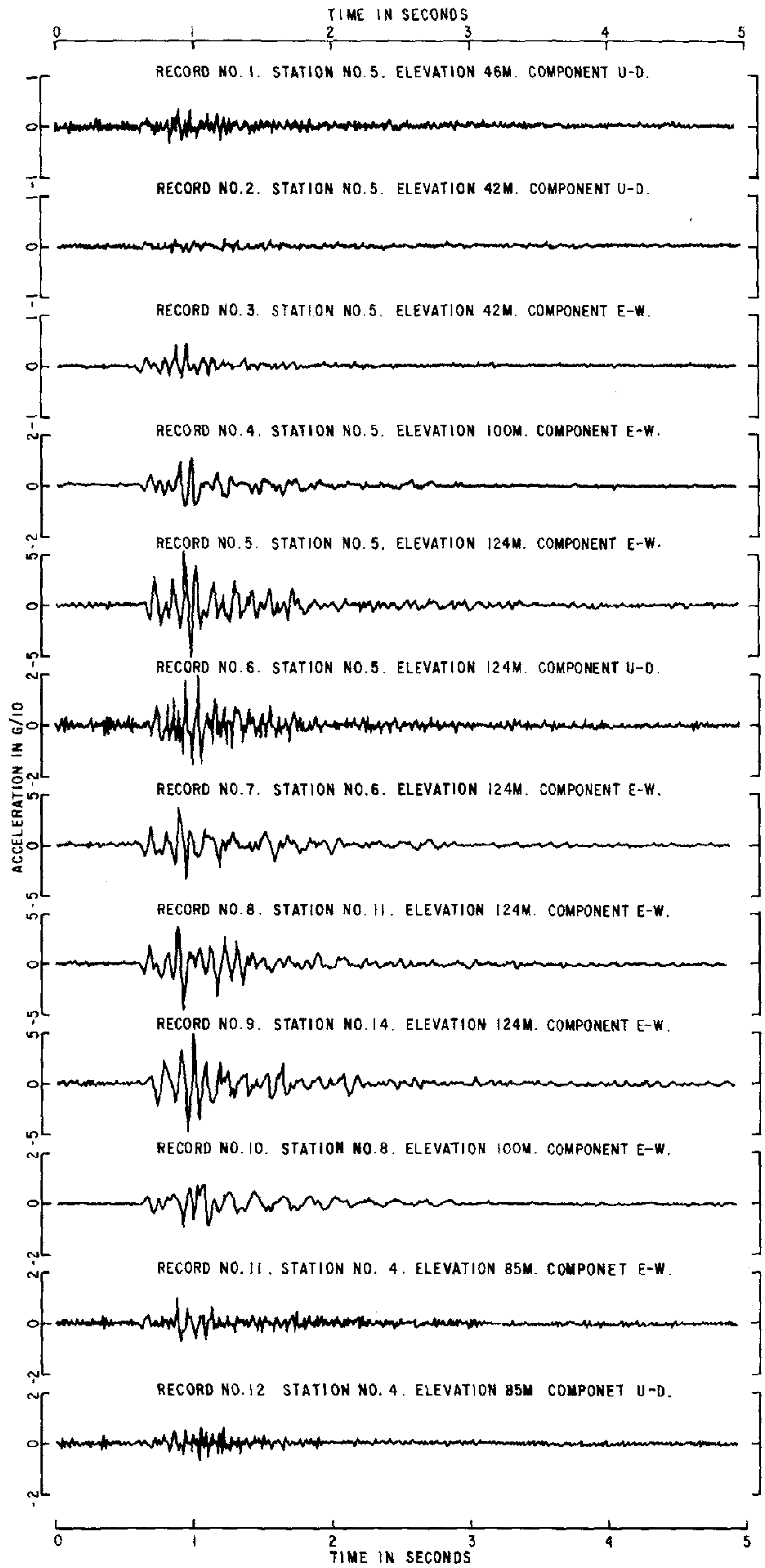


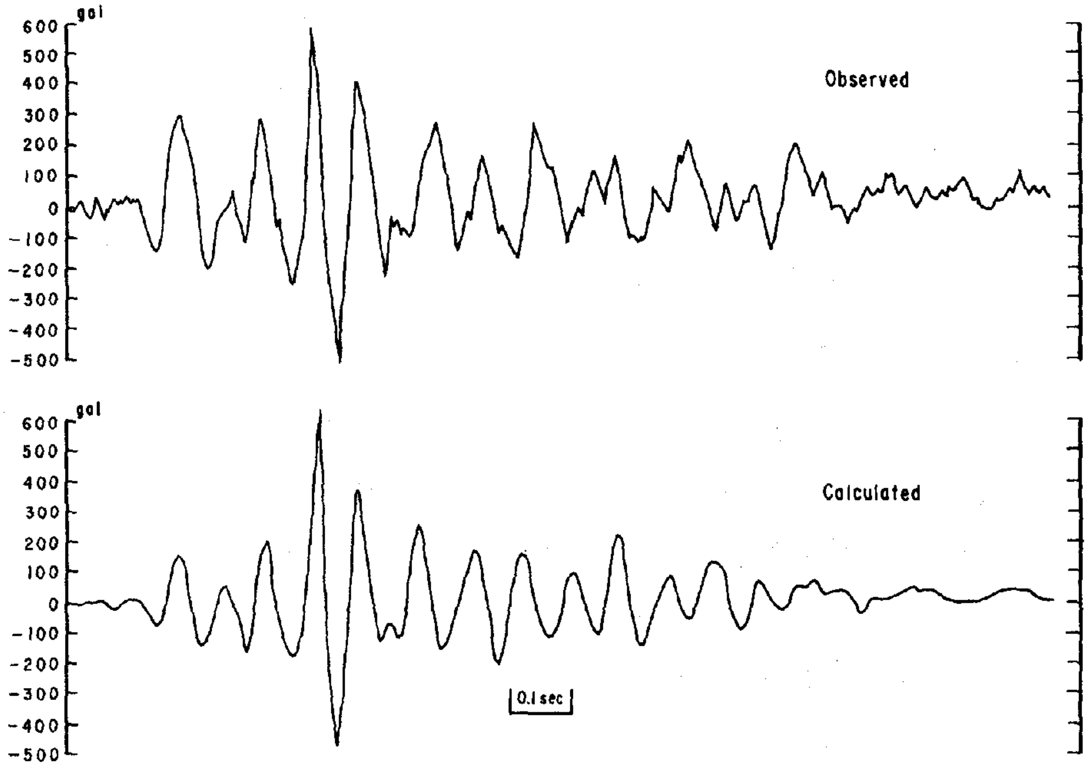
FIGURE 3. REPLOT OF THE STRONG-MOTION TRACES AFTER DIGITIZATION

THE LEFT-HAND SCALE GIVES THE ACCELERATION AS A FRACTION OF GRAVITY. THE RECORDING SITE CORRESPONDING TO EACH TRACE CAN BE DETERMINED FROM THE STATION NUMBER AND FIGURE 1 AND TABLE 1. THE TIME SCALE IS AS SHOWN

(After Bolt and Cloud, 1974)

FIGURE 4

OBSERVED AND CALCULATED ACCELEROGRAM AT ELEV. 124 m. OF PIER NO. 5 (E-W)



(After Sheng Cheng-Kang et al 1974)

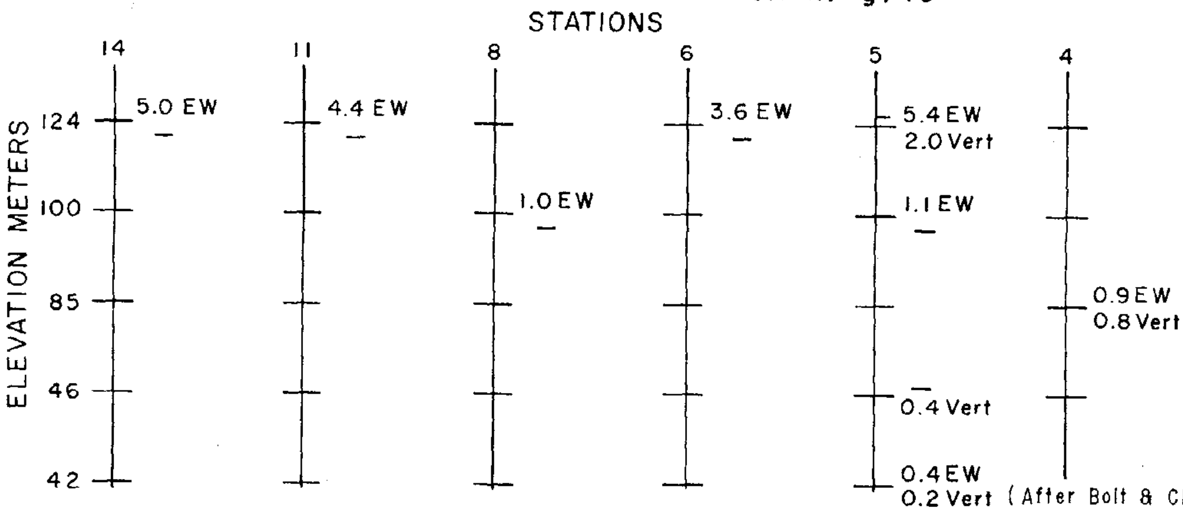
TABLE 1

Earth-quake no.	Date*	Time* hr.min.sec.	Magnitude M_s	Focal depth (km)	Epicentral distance (km)	Amax (gal) Nearby ground surface	Amax (gal) Foundation of the dam	Amax (gal) Top of the dam
1	1966.5.19	10–44–24.5	2.4	4.5	1.8	–	8.0	62.1
2	1966.5.28	10–08–18	3.2	7.2	2.8	36.7	9.8	81.8
3	1966.9.19	00–52–29.1	3.3	4.5	2.6	41.0	10.4	105.7
4	1967.7.29	19–07–31.2	3.6	5.3	3.3	64.2	22.0	248.0
5	1968.3.7	16–54–15.6	3.5	4.2	2.9	32.5	22.0	184.0
6	1968.3.19	02–28–29.9	3.5	6.5	1.6	7.7	4.7	54.9
7	1968.8.2	21–27–30.9	2.8	3.2	1.2	29.3	27.6	199.9
8	1968.8.4	04–56–40	2.6	3.4	0.8	31.4	24.0	124.0
9	1968.8.23	12–45–13.9	3.7	6.4	2.0	70.2	41.5	329.3
10	1970.2.19	04–47–7.3	1.7	9.0	4.8	–	20.2	116.8
11	1970.4.19	21–23–56.5	3.5	4.0	1.0	56.8	55.7	606.5
12	1970.4.19	21–23–59.8	1.1	4.0	1.0	23.7	23.4	66.4
13	1970.4.19	21–24–05	2.1	4.0	1.0	47.1	30.3	177.9
14	1970.5.9	00–01–32	2.8	3.7	2.5	47.5	40.5	516.0
15	1970.10.3	23–38–10.5	3.5	2.9	2.0	92.4	58.1	493.5
16	1970.10.3	23–38–23.6	1.3	2.9	2.0	34.7	10.2	215.0
17	1971.1.2	07–41–54.5	3.0	3.4	1.8	62.8	39.4	255.0
18	1971.1.2	08–23–59.6	3.1	3.3	2.1	58.1	33.6	159.5
19	1971.2.25	13–09–50	3.5	3.0	1.9	–	68.6	480.0
20	1971.10.22	17–57–08	3.2	6.5	1.2	69.9	36.9	491.0
21	1971.11.15	07–45–45.8	2.3	5.0	0.8	29.0	16.5	116.5
22	1972.12.18	17–05–20	4.5	9.9	4.9	74.0	56.0	597.0
23	1973.3.11	20–47–31	3.0	7.2	1.8	20.1	11.9	152.0
24	1973.6.2	20–42–1.1	2.6	6.2	1.0	10.3	7.9	56.3
25	1974.1.24	05–43–16	3.0	4.8	4.0	30.9	19.7	229.0
26	1974.3.1	06–14–46	3.1	6.9	2.5	15.4	6.6	32.0
27	1974.6.22	18–23–37.7	2.2	5.3	2.0	12.9	4.3	56.4
28	1974.8.16	07–33–58	3.0	6.8	2.5	–	4.3	56.9

* Peking local time.

(After Sheng Cheng-Kang et al 1974)

TABLE 2
MAXIMUM RECORDED ACCELERATION IN g/10



(After Bolt & Cloud, 1974)

18. EL INFIERNILLO DAM

Introduction

The following brief description of the dam and its geologic setting is taken for the most part from the paper by Raul J. Marshal and Luis R. de Arellano, published in 1967.

Geology

The foundation material at both abutments is silicified conglomerate. The main fracture system is oriented north-south and dips 70°W. The rock, although competent, is brittle and sensitive to blasting.

Description of the Dam

The structure is a rockfill dam (Figure 1) with a relatively narrow central clay core; it intercepts the waters of the Balsas River 70 km upstream from its mouth on the Pacific Ocean. The embankment is 148 m high and has a volume of $5.5\text{x}10^6$ m^3, of which $5\text{x}10^6$ consist of rockfills, transitions, and filters. The storage capacity of the dam is $1.2\text{x}10^{10}$ m^3 (10,000,000 acre-ft). The geometric features of the structure are presented in Figure 2, both in plan view and cross section. Because this dam is located in a highly seismic zone, a freeboard of 6.5 m was adopted (the difference between crest elevation and pool level when a flood of 28,000 m^3 per second is discharging into the reservoir). The dam was built at an approximately constant rate during a period of 15 months (August 1962 through December 1963).

The impervious core was built with clayey materials having an average water content of 4% above optimum. Well-graded, washed and screened sand was used in the 2.5-m-wide filters that were placed on both sides of the core. The transitions, outside of the filters, were the product of underground excavation and crushed quarry material. The largest volume of material occurs in the rockfill shoulders, which are split into two sections (Figure 1). The inner section contains material under 60 cm in size and the outer section includes larger sized materials.

Strong-Motion Recordings

The strong-motion instrumentation installed on this dam consisted of five 70 mm film recording accelerographs (Teledyne, RFT-250): one effectively at the centerline of the core's crest; two on the downstream face; one 400 m downstream of the toe on the right bank; and one 240 m from the left abutment inside the underground powerhouse.

The earthquake of July 3, 1973 provided one record from the crest accelerograph. Figures 3,4 and 5 show the recorded crest acceleration and the computed velocity and displacement. The original recorded data were digitized and processed according to the standard California Institute of Technology program. Figures 6,7 and 8 show the corresponding response spectra. It is seen that the longitudinal component of motion shows a strong periodicity at 0.65 seconds period, and the motion is more intense than in the transverse direction. (We are indebted to the Instituto de Ingeneria of the National University of Mexico for the digitized data.)

References

Marsal, Raul and Luis de Arellano, 1967, Performance of El Infiernillo Dam, 1963-1966, Journal of Soil Mechanics and Foundation Division, ASCE, SM4, p. 265.

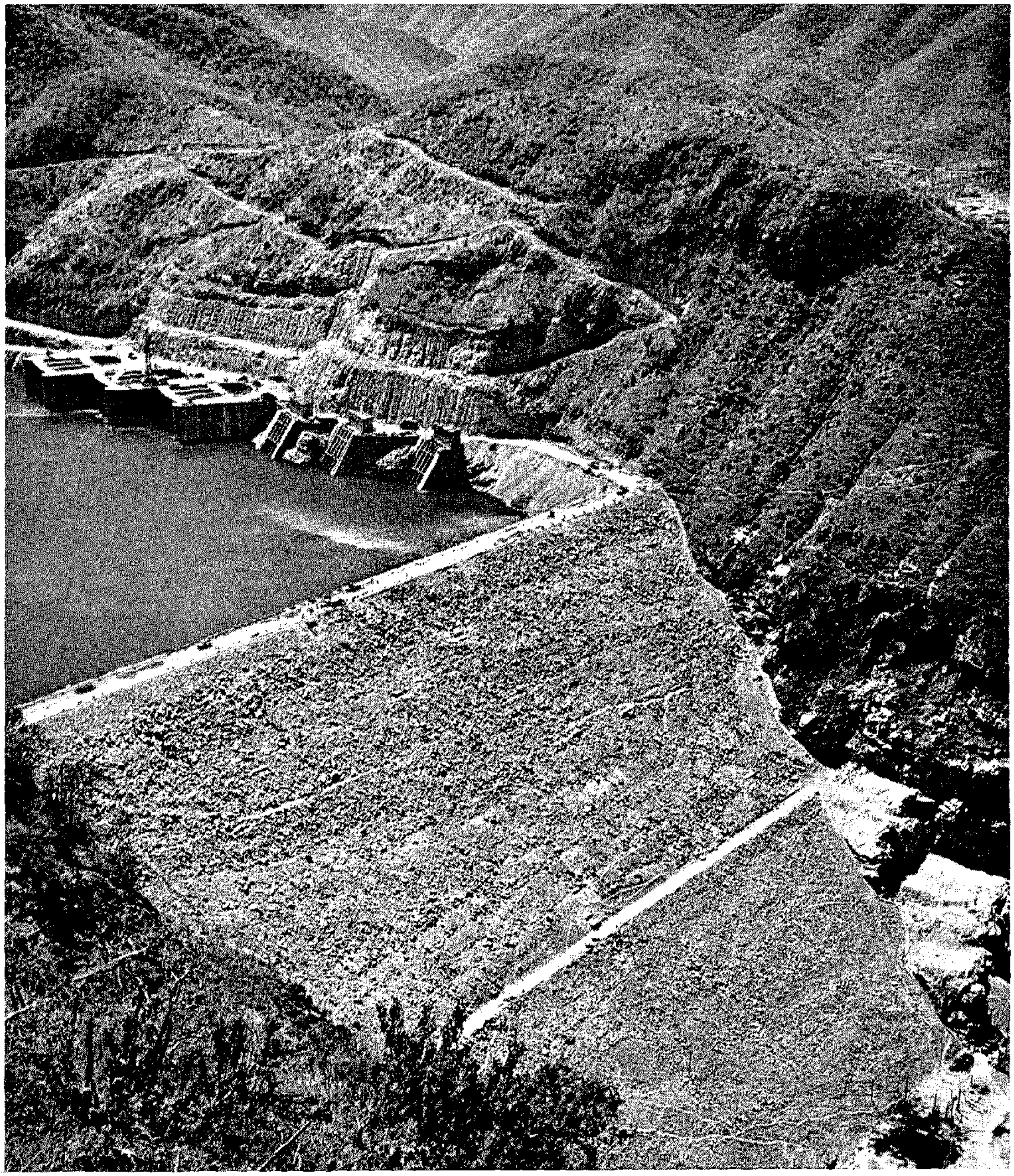


FIGURE 1. El Infiernillo Dam, Mexico.

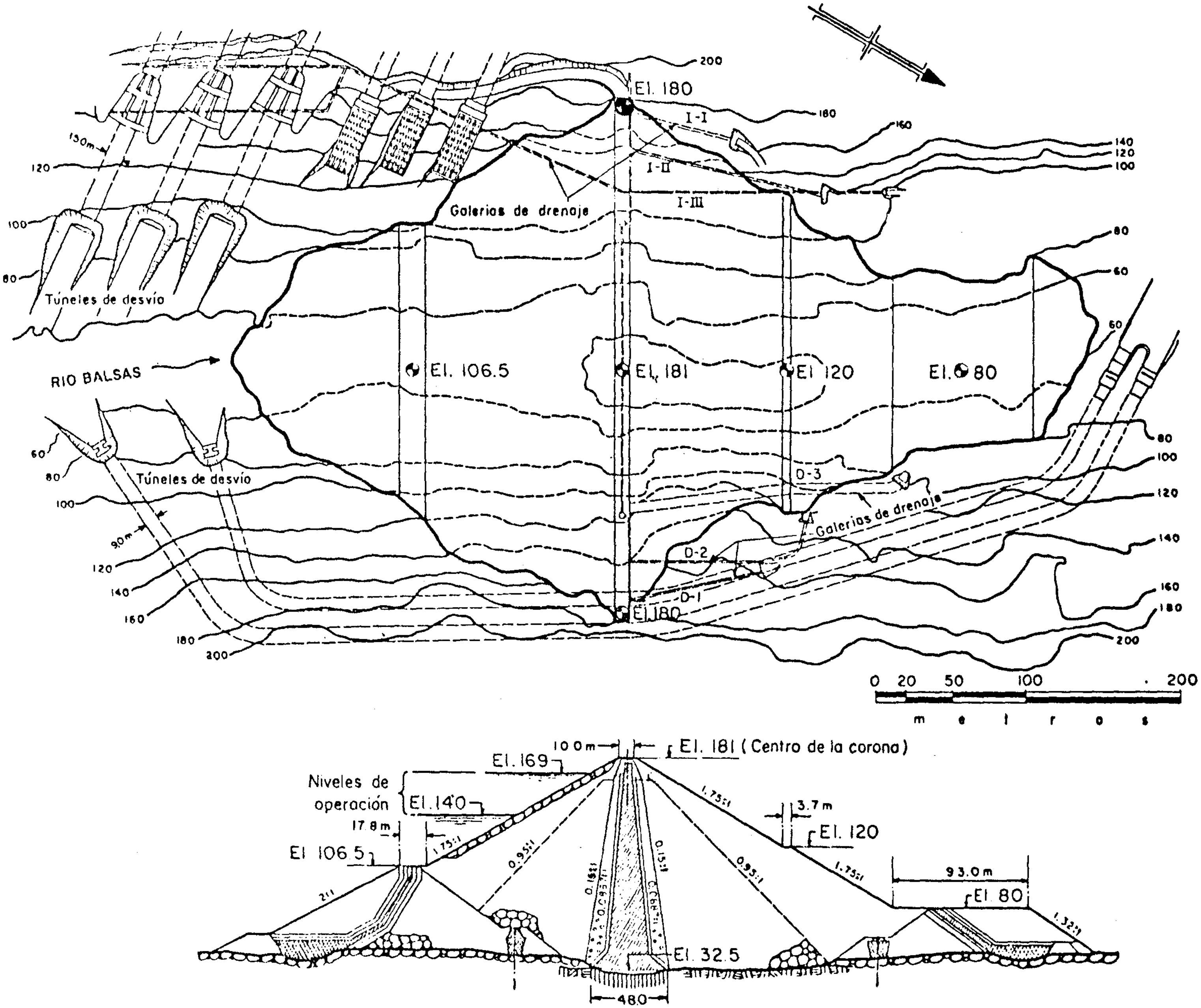


FIGURE 2. El Infiernillo Dam plan and cross section.

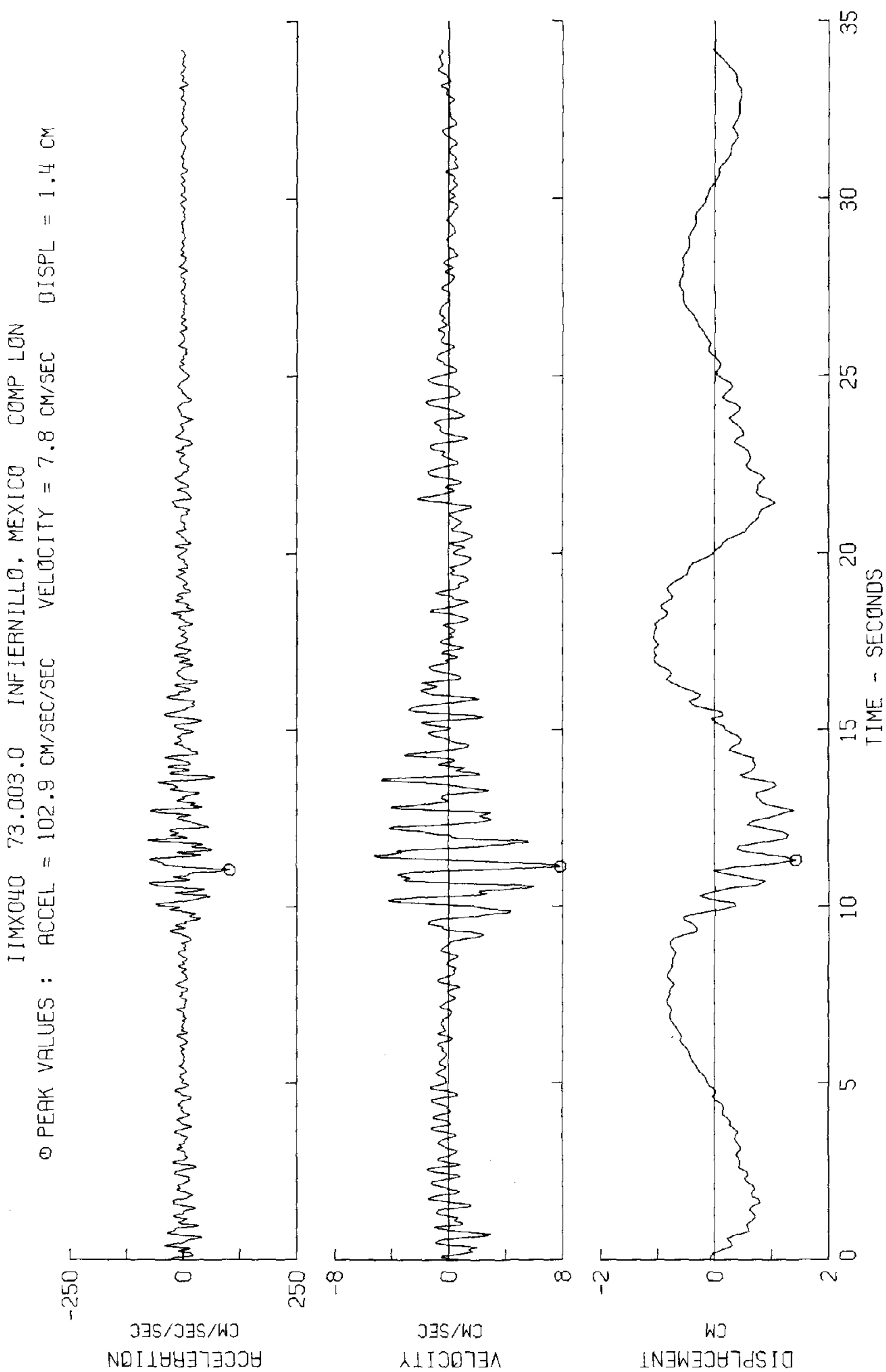


Figure 3. Motion on crest of Infiernillo Dam, longitudinal component. A period of .66 sec is visible on the record. The earthquake had a magnitude of approximately 6.0 with hypocenter approximately 60 km from the dam.

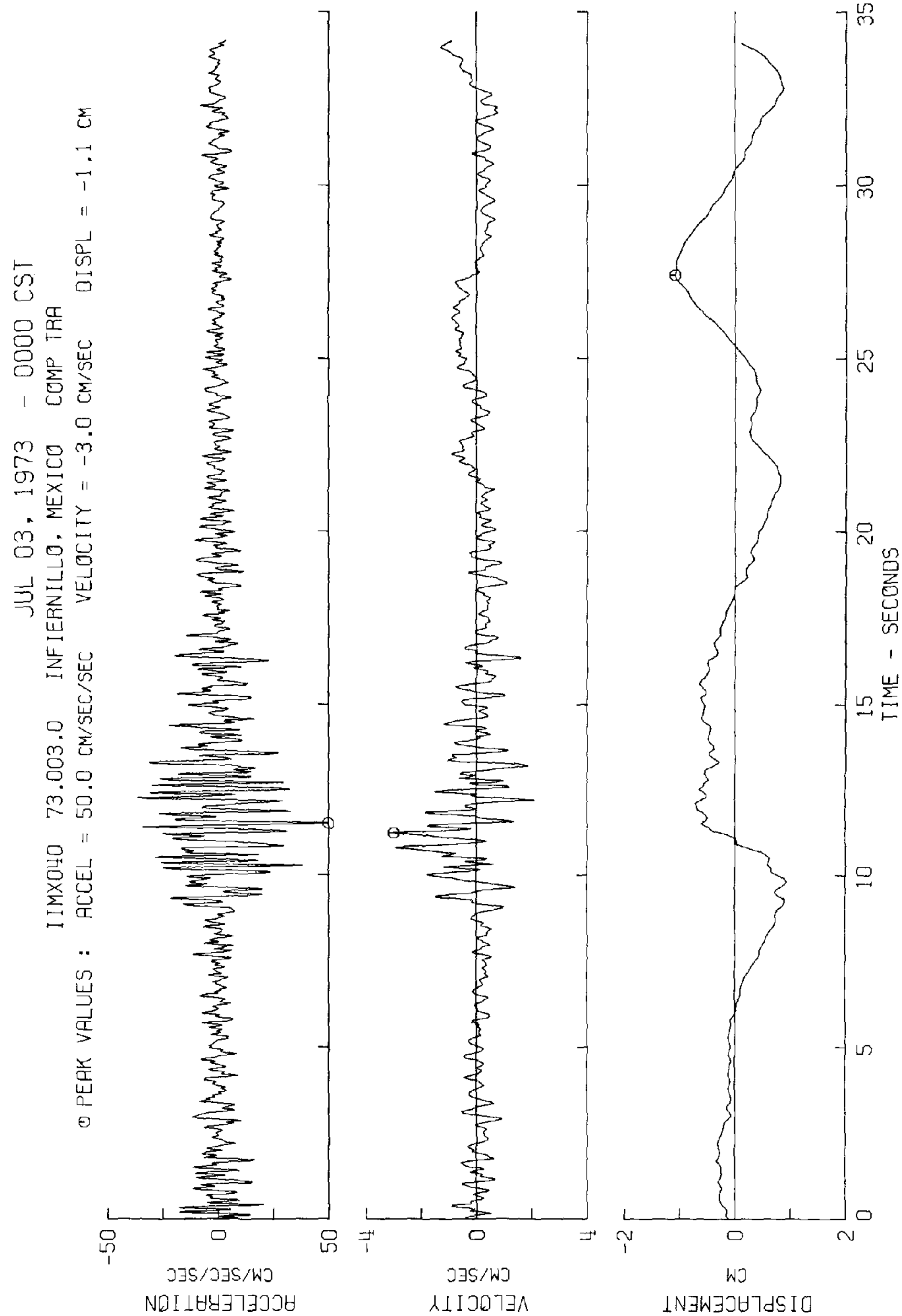


Figure 4. Transverse component of motion on the crest of Infiernillo Dam.

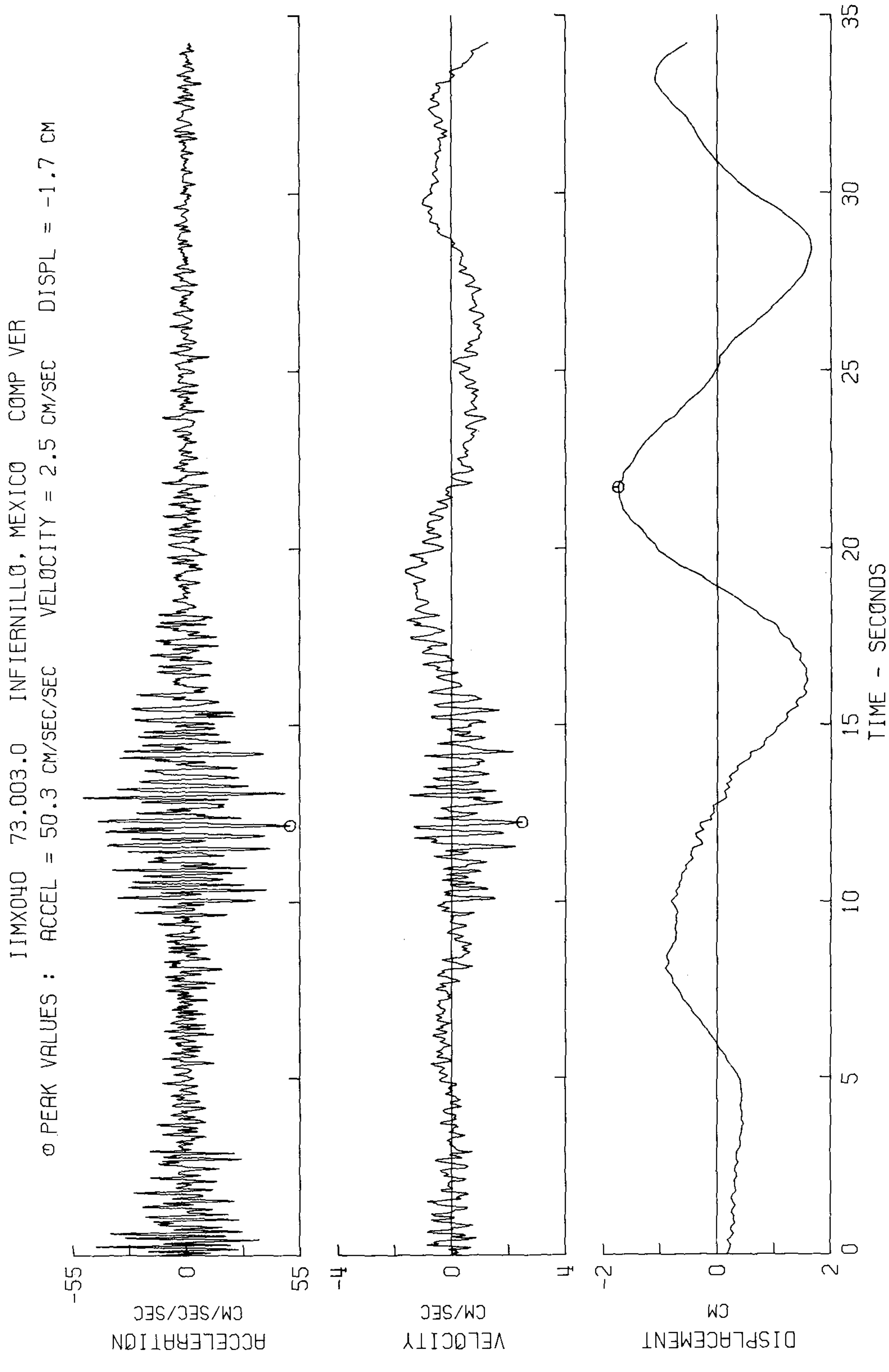


Figure 5. Vertical component of motion on Infiernillo Dam.

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DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL

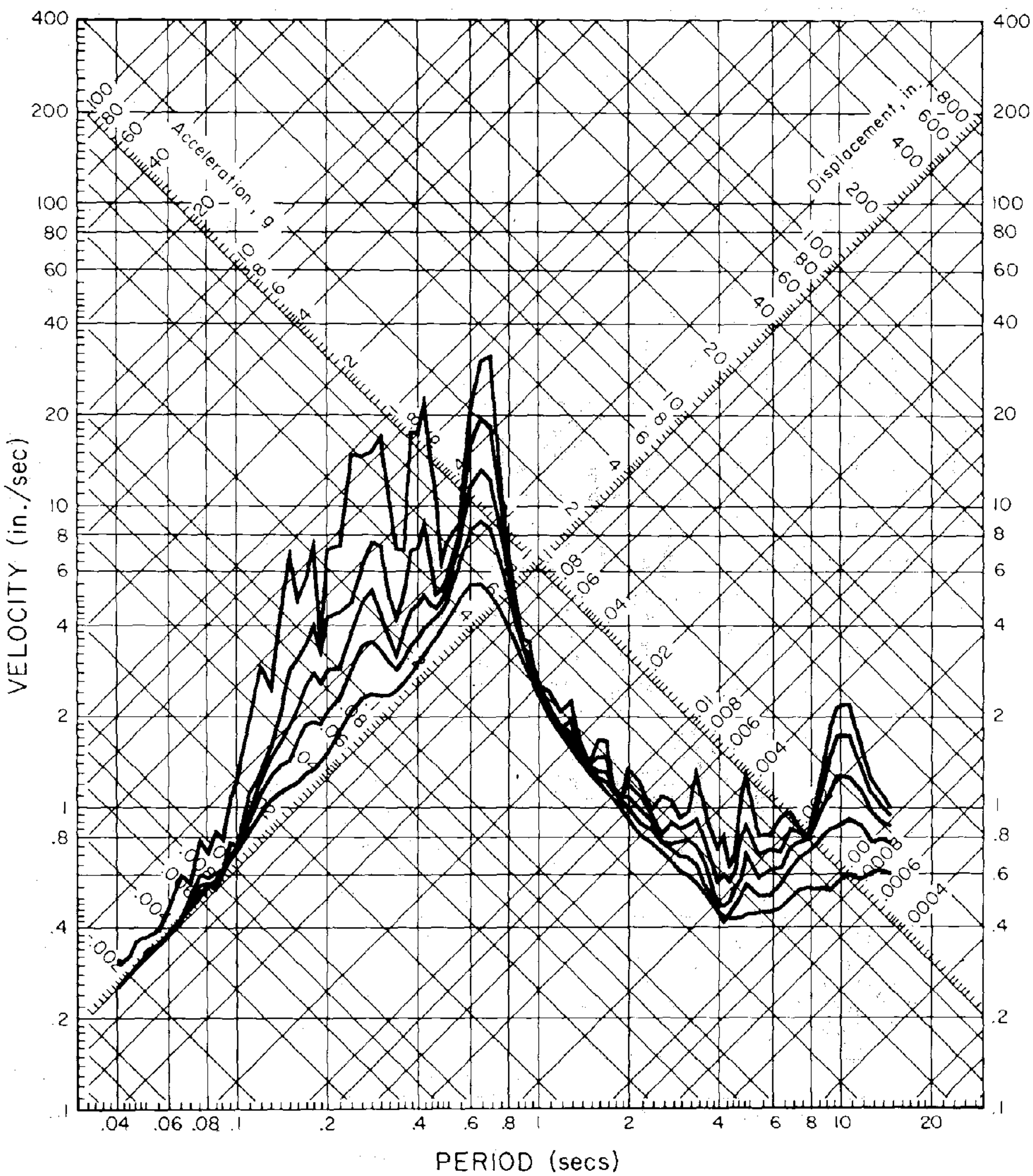

Figure 6. Response spectrum for longitudinal component of motion on Infiernillo Dam.

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DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL

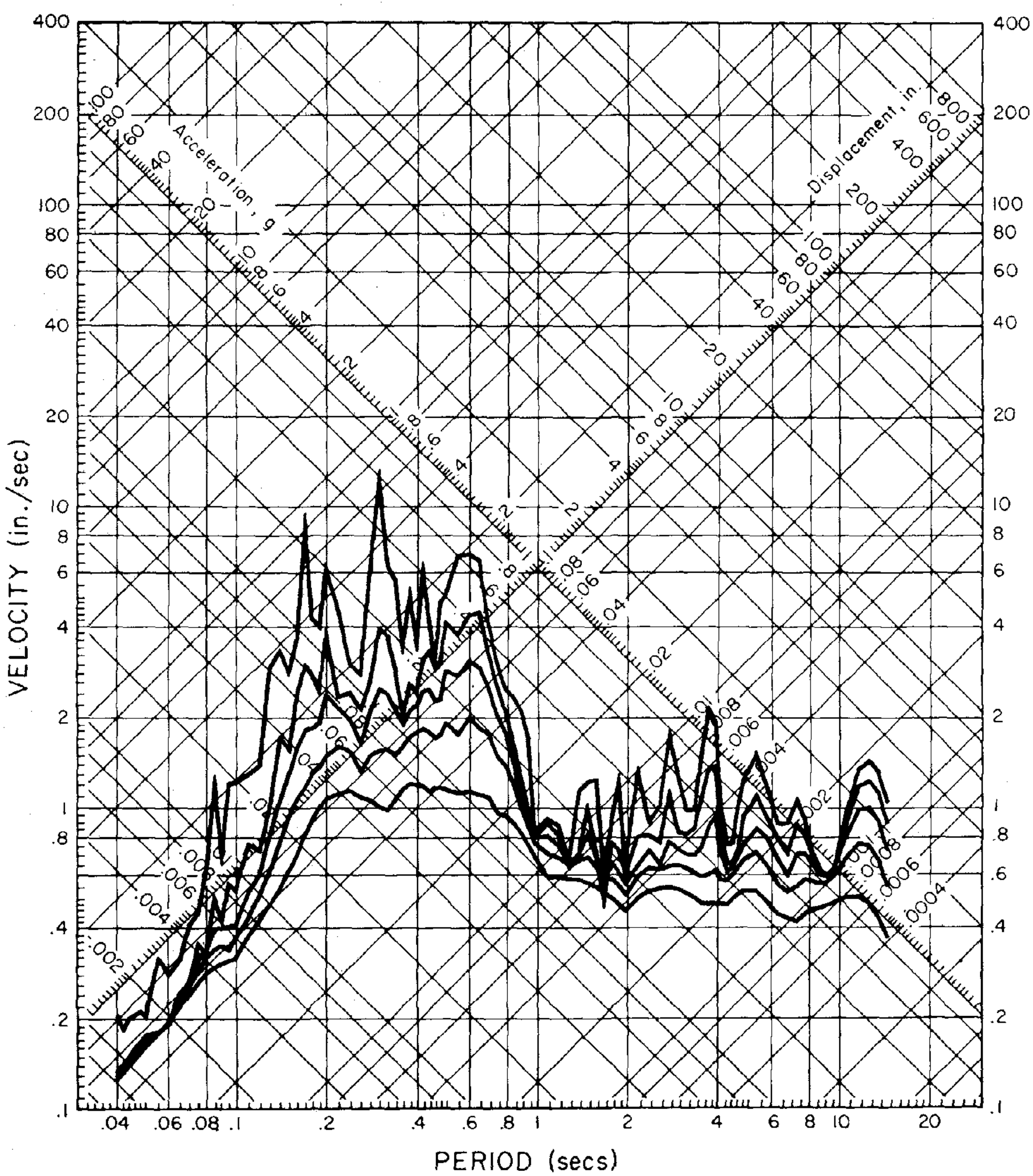


Figure 7. Response spectrum for transverse component of motion on crest of Infiernillo Dam.

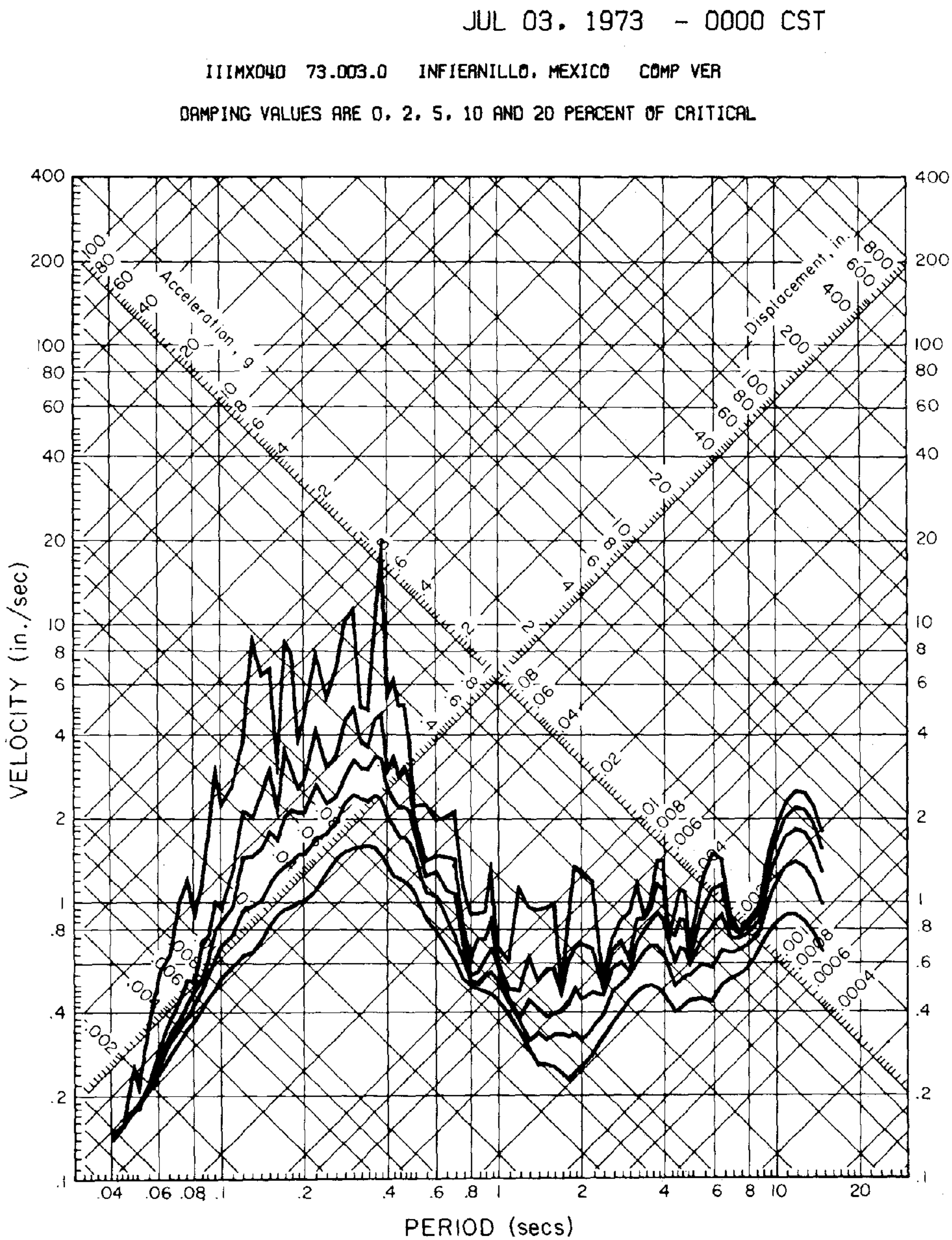


Figure 8. Response spectrum for vertical component of motion on crest of Infiernillo Dam.

19. OROVILLE DAM

Introduction

Oroville Dam, 39.53°N, 121.48°W, (Figure 1) is the keystone of the California State Water Project. The reservoir (Lake Oroville) is the source of water transported down the 644 km long California Aqueduct to Southern California. Dam construction was completed in mid-1968. On August 1, 1975 an earthquake (M_L=5.7) occurred within 12 km of the dam, resulting in no significant damage to the dam.

Geology

Oroville Dam and reservoir are located near the western extremity of the Sierra Nevada, where the western slope of the mountains dip under Tertiary and Quaternary sediments of the Great Valley. The dam is situated within a large belt of Paleozoic and Mesozoic metamorphic rocks which compose the western flank of the Sierra Nevada in this region. The reservoir is underlain by metavolcanic and metasedimentary rocks in the north and west and by granite in the east and south region. The Oroville Reservoir area lies within the Foothills Fault system (Figure 2). Younger rocks in the Sacramento Valley are believed to conceal those rocks cut by major faults of the Foothills system, for a distance of about 110 km between the Western Sierra Nevada and the Klamath Mountains. The Klamath Mountain region has a history similar to the Western Sierra Nevada with respect to deposition, vulcanism, deformation and plutonic intrusion. The Foothills system has been inactive since Cretaceous time (more than 70,000,000 years). Direction, sense, and amount of movement of the system have not been satisfactorily resolved. The foregoing may be subject to change pending the results of intensive geologic investigations related to Auburn Dam. Auburn Dam will be constructed in the Sierra Nevada foothills about 80 km south-southeast of Oroville Dam if favorable results are obtained from geologic investigations.

Seismicity

The historical record indicates that the Oroville region is one of low seismicity. Apparently the largest Modified Mercalli intensity (MMI) affecting the City of Oroville between 1851 and the August 1, 1975 (M_L=5.7) earthquake was V. The largest earthquake in the Oroville region occurred on January 24, 1875 near Oroville, and was reported felt as far away as Carson City, Nevada. On February 8, 1940 an earthquake of magnitude 5.7 occurred about 50 km north of Oroville. Foreshocks of the August 1, 1975 sequence (maximum MMI VIII) began on June 28, 1975, about 12 km south-southwest of the dam; the largest of these was M_L=3.5. The sequence appeared to have died out when on August 1, eleven foreshocks with magnitude up to 4.7 occurred within five hours of the main shock.

Description of the Dam

Oroville Dam is a zoned earth and rockfill structure with a maximum height of 235 m, a crest length of 1653 m, and a base width at maximum section of 1280 m. The dam crest is 15 m wide with an elevation of 281 m. The dam contains over 6.1×10^7 m^3 of embankment material, and about one-quarter million cubic meters of concrete. The reservoir has a maximum storage capacity of about 4.3×10^9 m^3 (3,500,000 acre-feet) at the normal pool elevation of 274.3 meters. The maximum dam section is shown in Figure 3.

Instrumentation

Figure 3 shows the dynamic instrumentation in the dam at the time of the August 1, 1975 earthquake (see below). Teledyne AR-240 accelerographs were installed on the crest and in the core block. Three-component force-balanced accelerometer units are imbedded in the dam as shown. Pore pressure cells are embedded in the dam downstream from the impervious zone and stress cells upstream from the impervious zone.

The dynamic instrumentation excluding the AR-240's is recorded on strip-chart recorders in an instrument house near the toe of the dam.

Instrumental Recordings

The August 1 earthquake triggered the crest AR-240 and a Standard Coast & Geodetic Survey accelerograph located at the Oroville seismograph station about a kilometer north of the dam. The core block AR-240 was inoperative. Initial accelerograms from the force-balanced instrumentation were marred by a power-supply failure which left 0.6 sec gaps in the recordings. However, the problem was remedied and later aftershocks were well recorded. The crest AR-240 was replaced about a week after the August 1 main shock with a Kinemetrics SMA-1 accelerograph.

Figure 4 shows the acceleration, velocity and displacement traces from the seismographic station and crest accelerograms. The crest N46°E component is oriented transverse to the dam's maximum section. Maximum accelerations, velocities and displacements are shown in Figure 4.

For information on Oroville Dam digitized force-balanced strong-motion data write:

Director, Department of Water Resources
P.O. Box 388
Sacramento, CA 95802

For information on the digitized AR-240 and SMA-1 data write:

U.S. Geological Survey
Seismic Engineering Branch
345 Middlefield Road
Menlo Park, CA 94025

At this writing, dynamic analysis of the dam response to the August 1, 1975 M_L = 5.7 earthquake is in progress.

Bibliography

Clark, L. K.,1960, Foothills Fault System, Western Sierra Nevada: Bull. Geol Soc. Am., 71.

Division of Water Resources, 1953, Geological Report on Preliminary

Exploration of the Oroville Dam Site, Butte County, California: State of California, Department of Public Works.

Morrison, P. W., and others, 1975, The Oroville Earthquake Sequence of August 1975: Bull. Seis. Soc. Am., 66, p. 1065-1084.

Project Geology Report C-34, Part 1; Final Report on Foundation Conditions and Grouting, Oroville Dam: State Water Facilities, Oroville Division.

U.S. Geological Survey, 1975, Seismic Engineering Program Report, July-September 1975: U. S. Geol. Survey Circular 717-C, 17 p.

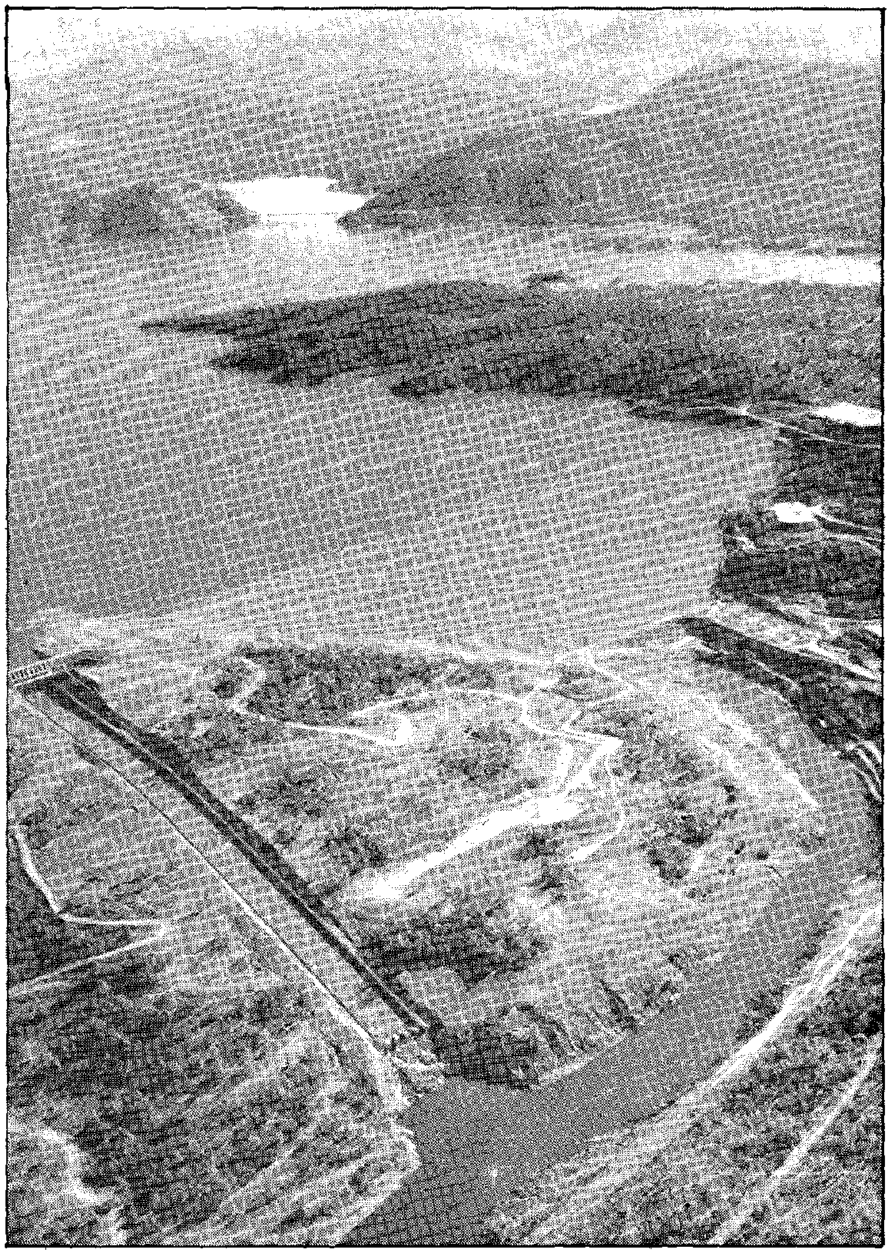


Figure 1. Oroville Dam and Spillway.

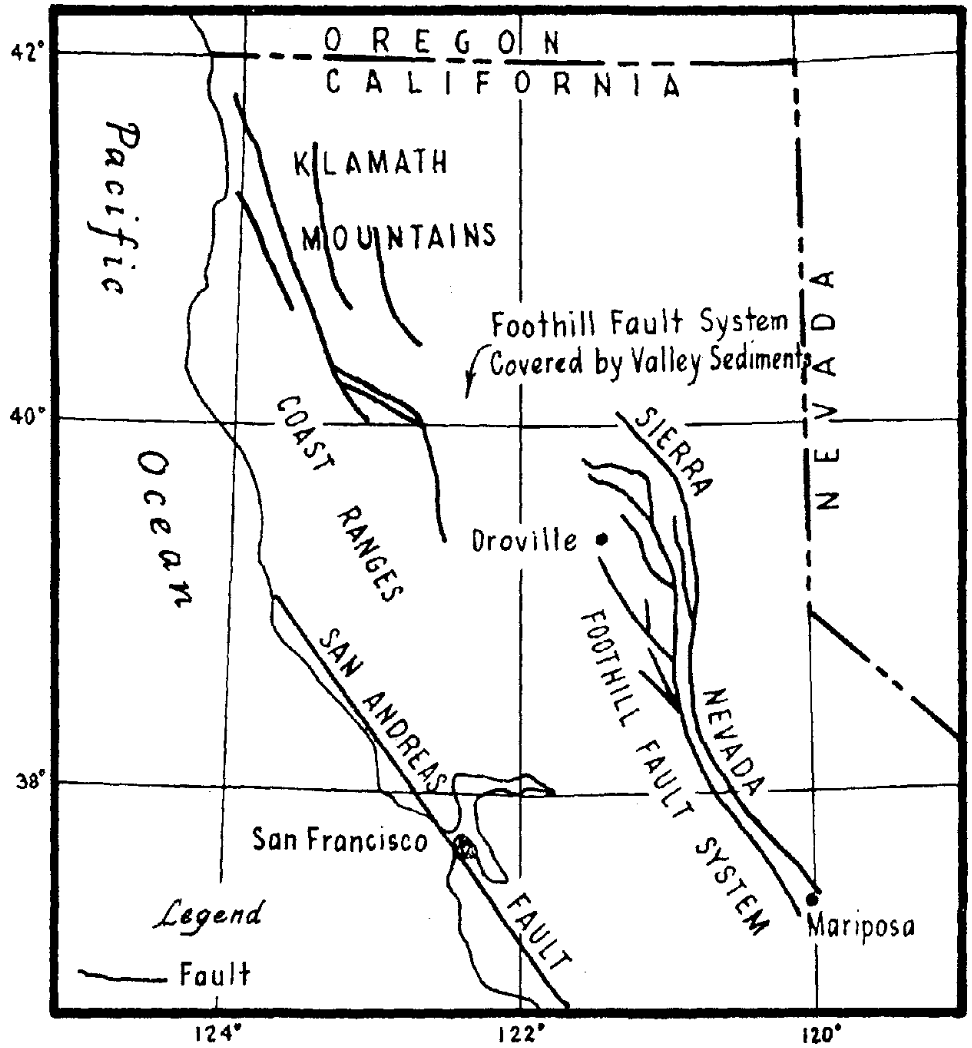
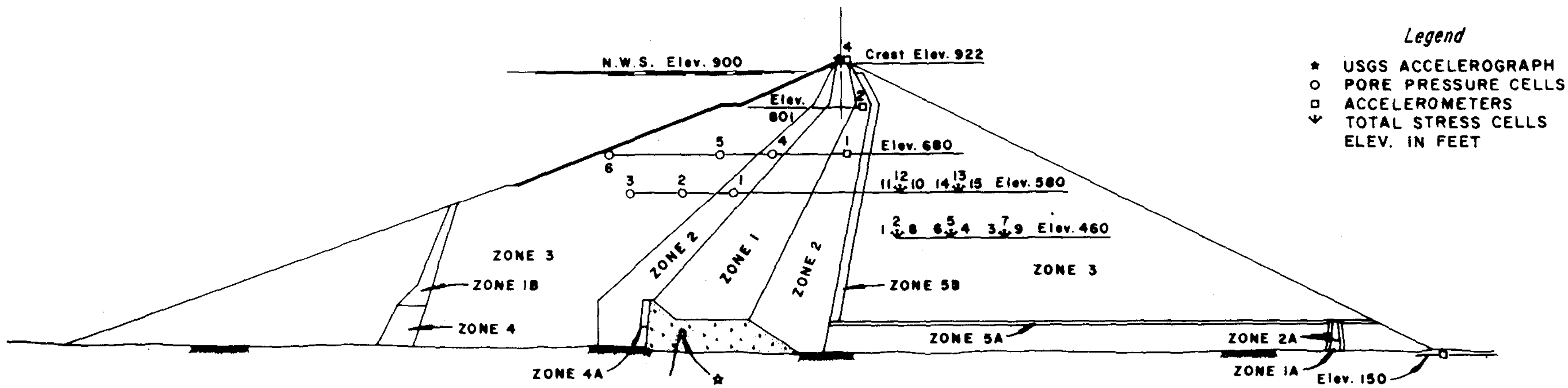


Figure 2. Foothill Fault System (After L.D. Clark)



MAXIMUM SECTION OF DAM

ZONE	MATERIAL
1	IMPERVIOUS CORE
1A	IMPERVIOUS SEEPAGE MEASUREMENT BARRIER
1B	IMPERVIOUS UPSTREAM CORE ABOVE ELEVATION 290
2	TRANSITION
2A	TRANSITION SEEPAGE MEASUREMENT BARRIER
3	PERVIOUS SHELL
4	IMPERVIOUS UPSTREAM CORE ABOVE ELEVATION 290
4A	IMPERVIOUS AT UPSTREAM FACE OF CORE BLOCK PARAPET
5A	DRAIN
5B	DRAIN

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
DIVISION OF DESIGN AND CONSTRUCTION

OROVILLE DAM
DYNAMIC INSTRUMENTATION

FIGURE 3

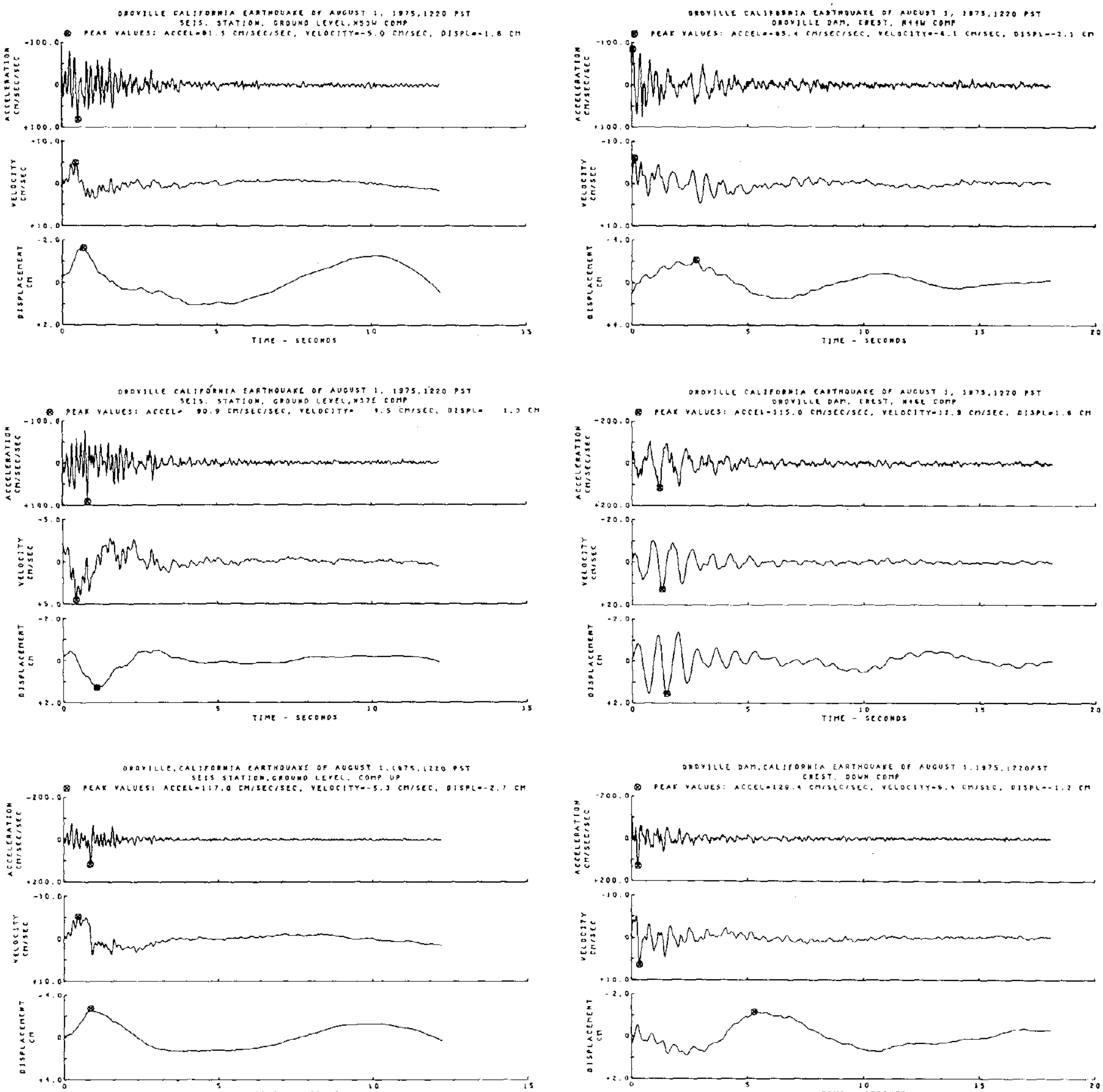


FIGURE 4. ACCELERATION AND COMPUTED VELOCITY AND DISPLACEMENT TRACES FOR THE OROVILLE SEISMOGRAPHIC STATION AND DAM CREST ACCELEROGRAPHS.