WEIDLINGER ASSOCIATES, CONSULTING ENGINEERS

110 EAST 59TH STREET
NEW YORK, NEW YORK 10022

and

SUITE 245, BUILDING 4
3000 SAND HILL ROAD
MENLO PARK, CALIFORNIA 94025

THE ROLE OF CORROSION IN THE SEISMIC PERFORMANCE OF BURIED STEEL PIPELINES IN THREE UNITED STATES EARTHQUAKES

By

J. Isenberg

Grant Report No. 6

Prepared for
National Science Foundation (ASRA Directorate)
1800 G Street
Washington, D.C. 20550

Grant No. ENV P76-9838

Grant No. PFR 78-15049

JUNE 1978

ia

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. NSF/RA-780226	2.	3. Recipient's Accession No. PB285725

4. Title and Subtitle
Role of Corrosion in the Seismic Performance of Buried Steel Pipelines in Three United States Earthquakes, Grant Report No. 6

5. Report Date
June 1978

6.

7. Author(s)
J. Isenberg

8. Performing Organization Rept. No.
6

9. Performing Organization Name and Address
Weidlinger Associates, Consulting Engineers
110 East 59th Street
New York, New York 10022

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C) ENVP769838
(G) PFR7815049

12. Sponsoring Organization Name and Address
Applied Science and Research Applications (ASRA)
National Science Foundation
1800 G Street, N.W.
Washington, D.C. 20550

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)
This study considers the effects of corrosion on the seismic performance of underground water pipelines in three U.S. earthquakes: 1965 Puget Sound, Washington; 1969 Santa Rosa, California; and 1971 San Fernando, California. Seismic performance depends on soil conditions, intensity of ground shaking, surges in internal pressure, the diameter and wall thickness of the pipe, and the strengths of materials used in the pipe and its joints. The report concentrates on steel pipe damage in regions where the maximum ground displacements are of the order of 10 cm. Numerous leaks in the pipes were traced to local weaknesses caused by corrosion. Some evidence suggests that the likelihood of earthquake-induced leakage may be estimated from leak rate under normal conditions; however, inadequate data in the three earthquakes studied does not permit correlation. The corrosion control programs used by the utilities whose earthquake experience is reported in the study are briefly discussed. They consist of wrapping and cathodic protection, and replacement of corroded pipe with non-corroding asbestos-cement pipe.

17. Document Analysis a. Descriptors

Pipelines	California	Earthquake resistant structures
Earthquakes	Washington	
Underground corrosion	Leakage	

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
NTIS.		85
	20. Security Class (This Page)	22. Price A05-A01

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

CAPITAL SYSTEMS GROUP, INC.
6110 EXECUTIVE BOULEVARD
SUITE 250
ROCKVILLE, MARYLAND 208[illegible]2

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INTRODUCTION

The seismic performance of underground water pipelines depends on numerous factors such as the soil conditions, intensity of ground shaking, surges in internal pressure, the diameter and wall thickness of the pipe and the strengths of materials used in the pipe and in its joints. The condition of underground pipes is clearly important in predicting performance. The present study considers the effects of corrosion on the seismic performance of steel pipes in three U. S. earthquakes--1965 Puget Sound, Washington; 1969 Santa Rosa, California; and 1971 San Fernando, California. Statistics are given below which indicate that corrosion is a major contributor to pipe leaks in these earthquakes and under normal conditions.

The practical application of these data by water utilities lies primarily in the area of selecting materials for new and replacement pipe and in deciding when to replace pipe. All utilities have a formal or an informal policy governing selection of materials and replacement schedules under normal conditions, which includes corrosion, and a few consider earthquakes in establishing such policy (Reference 1). It would be beneficial if the degree of corrosion in a pipe system could be estimated so that it could be considered in predicting seismic performance. One possibility, which is suggested by data from the Santa Rosa and San Fernando earthquakes, is that leak frequency under normal conditions is a useful guide to the degree of corrosion as it affects seismic performance. In fact, in the cases reported below, pipes whose leaking in earthquakes is related to corrosion frequently have an unusually high rate of leakage under normal conditions. If performance under normal conditions is systematically recorded, it may eventually become possible to forecast performance under postulated seismic ground shaking, and this would form part of the basis for replacement policy.

This report concentrates on pipe damage in regions where the maximum ground displacements are of order 10 cm and, in the case of San Fernando, where relative ground displacements of order 10 cm occurred over station spacings of about 1 km. These movements are associated with wave propagation. Other earthquake phenomena, such as surface faulting, also damage both new and corroded pipes. The reason for studying cases involving wave effects is that damage seems to occur preferentially in pipes that have become weakened due to corrosion. This is considered only a first step toward evaluating the role of corrosion in cases where the ground strain is significantly greater.

Both cast iron and steel pipe receive attention under corrosion control programs at some utilities. However, the damage statistics reported below are exclusively for steel and galvanized steel pipe. No data were found which clearly linked earthquake-induced leakage in cast iron pipe to corrosion. However the present study is limited and is not yet complete, so that conclusions pertaining to seismic performance of corrosion-weakened cast iron cannot be drawn.

SECTION 2

ROLE OF CORROSION IN PIPELINE PERFORMANCE IN THREE UNITED STATES EARTHQUAKES

The present study is based on observations of pipeline performance during three U. S. earthquakes and under normal conditions. The principal sources of data are records maintained by the Los Angeles Department of Water and Power (LADWP), Santa Rosa Water Department (SRWD) and the Seattle Water Department (SWD). In response to a questionnaire circulated by Weidlinger Associates, Reference 1, each utility furnished a brief physical description of its pipeline system and these are included. The performance of the pipeline systems under normal conditions and in the earthquakes are described. Where possible, interpretation of the results is expanded to include the effects of local ground strain and surge pressures.

2.1. 1971 SAN FERNANDO, CALIFORNIA, EARTHQUAKE

> "The San Fernando, California, earthquake occurred at 6:01 a.m. (local time) on February 9, 1971, killed 58 persons, 47 in the collapse of the nonearthquake-resistive Veterans Hospital, and caused over 2,500 hospital-treated injuries in the San Fernando Valley, which had a population of over 1,200,000 at the time of the earthquake. The earthquake's epicenter was in the San Gabriel Mountains, its strong motion lasted about 12 seconds, and its magnitude has been assigned as 6.4 on the Richter scale.

"Direct damage to buildings and other structures exceeded half a billion dollars. This amount was divided about equally between public and private property. Most of the severe damage and major losses were along the southern foothills of the San Gabriel Mountains and along a narrow band of surface faulting that runs east-west on the valley floor." From Reference 2.

The February 9, 1971, San Fernando earthquake damaged the water distribution system of the LADWP. A physical description of the system, furnished in answer to a questionnaire circulated by Weidlinger Associates, is given in Table 1. Most of the damage occurred in the northern San Fernando Valley where the ground shaking was most intense. However, significant damage also occurred in other areas, including 76 leaks in distribution mains of the LADWP East Valley District which is in the southern San Fernando Valley and which is the subject of the present study. The area is bounded on the south by Mulholland Drive, on the north by Oxnard Boulevard, on the west by the San Diego freeway and on the east approximately by Lankershim Boulevard. The east-west length of the region is 7.6 miles and the north-south length is 6.6 miles.

A sample of 27 leaks was considered in a subregion lying within .6 miles on either side of Ventura Boulevard between the San Diego freeway and Coldwater Canyon. (A summary of these leaks which was compiled by the LADWP is given in Table 2.) Repair reports for these leaks indicate that 19 involve small holes at isolated points that have been weakened by corrosion; one is known to be due to other causes; and seven are due to unknown causes (five repair reports are unavailable).

Typical of the steel pipes in this segment of the distribution system is a 6-inch diameter, cement-caulked steel main which was laid in 1929 and which lies along Ventura Boulevard. Data on the grade of steel are unavailable. The cement caulking is considered to be among the toughest joint types used by the LADWP; it is estimated to have a strength well above that of ordinary concrete.

Ten leaks were reported in a 3.3 mile reach of this line as a result of the February 9, 1971, San Fernando earthquake (Reference 3). The repair reports indicated that the leaks were local and occurred at points where there was corrosion. Six of the reports mentioned external corrosion and four mentioned internal corrosion. Repairs were made with screw pins, which is the usual method of plugging small, localized leaks.

The performance of the line under normal conditions was poor. The number of leaks per mile per year (leak rate), shown in Figure 1, is of order ten times greater than that for all cast iron and steel pipes in the LADWP system (Reference 4). Poor performance of this segment of pipe is attributed to corrosion due to low soil resistivity. A profile along Ventura Boulevard, Figure 2, shows that electrical resistivity of the soil fluctuates around 1,000 Ω/cm^3, which, on the scale used by LADWP, is the border line between severe and extremely severe conditions for corrosion of steel.

In order to establish the level of ground shaking which damaged the 6-inch Ventura Boulevard main, reference is made to Volume II of the California Institute of Technology library of strong motion records. It is postulated that the principal damage mechanism is ground strain, which is estimated by subtracting the components of absolute displacement parallel to the pipe from two adjacent accelerograph stations. The time history of average ground strain is then computed by dividing the relative displacement-time history by the distance between the stations. It is assumed for the purposes of this discussion that the displacement records are accurate and that they are unbiased by having been measured inside buildings and that pipe-soil interaction effects may be neglected so that the ground strain and pipe strain are equal. The records chosen and approximate distances between the stations are as follows:

Record	Address	Distance (Meters)
I137	15910 Ventura Blvd.	
		1,700
H115	15250 Ventura Blvd.	
		730
Q233	14724 Ventura Blvd.	

(Street numbers increase toward the West.)

In order to compute relative displacements from absolute displacements, it is necessary to assign to these records a common starting time. Following the approach suggested by Hanks (Reference 5) it is assumed that the first S! signal arrives simultaneously at all three stations. This assumption is reasonable because the three stations, which lie along virtually an East-West line, are at almost the same azimuth and distance from the causative fault.

The three velocity-time histories for the records listed above are shown in Figures 2 through 5. Following the examples in Reference 5, it is easy to identify S! arrivals in records I137 and H115, as is shown. Identifying S! arrival in Q233 involves some guesswork; fortunately the peak relative displacements are rather insensitive to reasonable variations in the assumed S! arrival time.

Relative displacements between I137 and H115 and between H115 and Q233 can now be obtained by subtracting the absolute displacements at the same time. Time histories of relative displacement, shown in Figures 6 and 7, indicate that the maximum relative displacements are of order 10 to 15 cm. Assuming that the relative displacements are uniform over the distances between stations leads to a range of strains from 0.6×10^{-4} to 2×10^{-4}. Considering the uncertainties associated with these estimates, it appears reasonable to assume that a peak value of average ground strain of 10^{-4} exists for the duration of the strong shaking. This value may be influenced by the local geology which includes an alluvial wedge that becomes thinner toward the southern edge of the San Fernando Valley (Figure 8; Reference 6).

A peak average strain of 10^{-4} is consistent with some of the results obtained by Toki (Reference 7), who estimated extensional and shear strain components at four sites. He reports peak values as follows:

		Strain ($\times 10^{-4}$)		
		Extensional		Shear
Record	Address	(Transv.)	(Long.)	
D057	Hollywood Storage	1.2	1.0	3.9
E072	4680 Wilshire Boulevard	1.4	.9	
J145	15107 Van Owen Street	1.3	1.9	1.4
I137	15910 Ventura Boulevard	.7	1.4	2.4

The shear strains are for depths greater than ten meters and are not relevant to the present discussion. The values given above do not indicate that strains along the southern edge of San Fernando Valley are larger or smaller than those elsewhere. The number of cases is too small to permit drawing any conclusions, however.

On the basis of this analysis, the value of average ground strain along a 1.5 mile segment within the 3.3 mile reach of Ventura Boulevard is assumed to be of order 10^{-4}. Assuming a Young's modulus for this pipe of 30×10^6 psi and that the strains in the ground and along the pipe are equal, the maximum axial tensile and compressive stress in the pipe would be of order 3,000 psi. It would require strain of order 10^{-3}, or ten times greater than the estimated peak average ground strain, for a new pipe made of mild steel to approach its yield point. Whether 3,000 psi axial stress is enough to cause corroded pipes to leak is not known. It may be necessary to postulate, in addition to weakening due to corrosion, local ground strain higher than the average, surge pressures, dynamic resonance of the pipe or a combination of these and other mechanisms.

In summary, many leaks in steel pipes in the district considered in this study were directly traceable to local weakness caused by corrosion. A 3.3-mile reach of 6-inch steel pipe underlying Ventura Boulevard developed 10 leaks due to the earthquake at points which were weakened by corrosion. The performance of this line under normal conditions was unusually poor, having an annual leak rate ranging from 20 to 30 times higher than the average for the system. This suggests that the likelihood of earthquake-induced leakage may be estimated from leak rates under normal conditions. Average values of ground strain along the pipe are too small to account for leakage in new pipes. The strain required to cause corroded pipe to leak is unknown.

2.2. 1969 SANTA ROSA, CALIFORNIA, EARTHQUAKE

"Santa Rosa, Calif., was damaged at 9:57 p.m. (Pacific daylight time) on October 1, 1969, by a magnitude 5.6 earthquake located very close to the city. Later the same evening at 11:20 p.m., a second earthquake also centered near the city and having a 5.7 magnitude, created additional damage. Since repairs obviously could not be made between earthquakes, since the damage usually could not be assigned to either shock, and since damage was cumulative, the two events should be considered as a single series of earthquakes from a damage standpoint.

"The Santa Rosa earthquakes of October 1 are of substantial engineering interest because of disproportionate damage to earthquake-resistive buildings and because of the concentration of dwelling damage into a relatively small area, among other reasons." (From Reference 8).

The October 1, 1969, Santa Rosa earthquakes caused 22 water main breaks, 32 service lateral breaks and four fire protection lateral breaks according to an internal memorandum of the City of Santa Rosa Water Department, Reference 9. It was reported that the principal areas affected were the central, northeasterly and southeasterly portions of the city. Reference 9 continues: "throughout the emergency, water supply and routine working pressures were maintained to all service areas of the city." Repair of earthquake-related damage required about three weeks. No delayed leakage attributable to the earthquake was reported.

In response to a questionnaire circulated by Weidlinger Associates, the SRWD provided in April 1977 the summary given in Table 3 of physical characteristics of its water pipeline system. A more recent estimate indicates that there are 10 miles of steel pipe and 10 miles of galvanized steel pipe, most of which is in service laterals 2 inches in diameter and smaller. At the time of the earthquake, it is estimated that there were an additional 10 miles of steel and galvanized steel pipe which have since been replaced under a water main replacement program. According to an SRWD estimate there were about 16 miles of steel pipe and about 14 miles of galvanized steel pipe, especially in service laterals, in the system at the time of the earthquake. The present study considers the entire SRWD distribution system.

The causes of breaks in October 1, 1969, earthquake are summarized in Table 4 according to the type of pipe material. This list of breaks is based on the SRWD memorandum which summarized damage after the earthquake. Mr. S. Dolinsek, present Water Service Maintenance Supervisor, believes that there may have been damage to at least two steel pipes that are not on this list. These have been added to the Table and so noted. Where the description of earthquake damage provided by Mr. Dolinsek was more precise than that given in the SRWD memorandum, his description has been used.

Of the nine main leaks in steel pipes that are reported in Reference 9, eight are related to corrosion; only the Polk Street leak cannot definitely be placed in this category. Pipes whose leakage in the earthquake was related to corrosion also leaked under normal conditions due to corrosion. The Grahn Drive and Brigham Street pipes, not mentioned in Reference 9, also leaked frequently under normal conditions due to corrosion. In these cases, corrosion is believed to have started when the tar wrapping sagged at the invert of the pipe and ground moisture penetrated to the pipe surface. No measurements of the electrical resistivity of the soil are available, but many parts of Santa Rosa are underlain by adobe clay, which typically has low soil resistivity which enhances corrosion.

Of the five leaks in galvanized steel mains, two locations on Brookside Drive and one on Gilbert Drive, three are possibly associated with corrosion. These pipes leaked prior to the earthquake, especially Brookside Drive. The Buena Vista leak is probably unrelated to corrosion and the Doyle Peak Drive leak is definitely unrelated. Neither of the latter two pipes leaked under normal conditions.

The seven main breaks in cast iron were apparently unrelated to corrosion. It is postulated that the Sonoma Avenue failures were started by flexural tensile stresses. At Norte and Grahn Way a bolted connection failed. The Wheeler Street failure was due to loosening of a joint (joint type is unknown, but bolted is likely). No leaks in these lines were reported prior to the earthquake.

Corrosion was a significant factor in a large percentage of the damaged galvanized service laterals, many of which failed at threaded connections where the wall is thinnest and where the galvanized coating has been removed to make the threads.

Breaks in cast iron pipe (CIP) are apparently unrelated to corrosion. No significant leakage in CIP under normal conditions is reported by the SRWD, which is somewhat surprising in view of the age of the system, the adobe soil and the absence of a cathodic protection program.

Under normal conditions, leakage in steel and galvanized steel pipes was concentrated in the 10 miles of pipe which have been replaced since the earthquake. Although documentation of normal leakage in the form of leak maps and repair reports is unavailable, it is estimated that there were over 100 leaks per year in these reaches of pipe, due largely to corrosion, making the annual leak rate over 10 leaks per year per mile. The normal leak rate, calculated on the basis of the total length of steel and cast iron has been estimated as .5 to 1.0 leaks per mile per year. To put this in perspective, the normal leak rate for all cast iron and steel pipe in the LADWP system, which has an active corrosion control program, ranged between .3 and .7 leaks per mile per year between 1957 and 1975. The leak rate in a 6-inch steel main underlying Ventura Boulevard varied from about 1 leak per mile per year to about 8 leaks per mile per year, which is considered to be poor.

Thus in Santa Rosa as in San Fernando Valley there were, prior to the earthquake, short reaches of corroded pipe which were exceptionally leaky. Leaks in steel and galvanized steel pipes due to corrosion were a significant problem in Santa Rosa which began to diminish after 1970. At that time, a water main replacement program was initiated under which annually 1-3 miles of the worst steel, galvanized steel and cast iron pipe is replaced, primarily by asbestos-cement pipe. The high rate of corrosion-caused leakage under normal conditions prior to the earthquake and the observations that the earthquake-caused leaks occurred at points of corrosion agrees with observations on Ventura Boulevard in the 1971 San Fernando earthquake.

In summary, steel and galvanized steel mains which leaked during the earthquake did so primarily at points which were weakened due to corrosion. The pipes which leaked in the earthquake had a normal leak rate which was about 10 times higher than the system as a whole. In fact many reaches in these pipes leaked so frequently under normal conditions that they were replaced under the SRWD water main replacement program. Data are unavailable to establish how many areas with high normal leak rates did not leak as a result of the earthquake. Thus the Santa Rosa experience does not help to answer the question whether leaks in earthquakes can be predicted from the frequency and location of normally-occurring, corrosion-caused leaks. Since many of the leaky steel pipes have been replaced with new asbestos-cement pipe, the steel and galvanized steel mains remaining in the SRWD system are presumably less vulnerable to corrosion-related earthquake leakage than they were in October 1969. Also, since steel connections and galvanized service laterals are replaced with copper and other corrosion-resistant materials when the mains are replaced, their vulnerability in earthquakes is also reduced.

2.3. 1965 PUGET SOUND, WASHINGTON, EARTHQUAKE

> "The Puget Sound earthquake of April 29, 1965, had a felt area of 130,000 square miles (336,700 km^2) and a

Richter magnitude of 6.5. There were some limited areas in which the maximum intensity was VIII; however, the general intensity over most of the area of substantial damage was VII. The focal depth of the earthquake was about thirty-seven miles (59 km), comparable to that experienced in 1949, and in this event was well-documented from many stations.

"Damage surveys indicate that the 1949 earthquake was more destructive. The damage pattern was quite similar for the two occurrences, and because the 1965 epicenter was substantially closer to Seattle, the major urban center, there was less opportunity for attenuation of high frequency impulses generally affecting short-period structures.

. . .

" . . . A number of water main breaks occurred; the most serious was that of two forty-eight-inch mains carrying water across Ebey Slough to serve the city of Everett. No fire problems occurred in conjunction with this earthquake; however, the serious water main loss in Everett substantially reduced the margin of safety until corrective steps were taken." From Reference 10.

In response to a questionnaire circulated by Weidlinger Associates, the Seattle Water Department provided in April 1977 a summary, Table 5, of physical characteristics of its water pipeline system. Of particular interest to the present study are the steel transmission mains (including 43 miles of steel mains 60 inches in diameter or greater) and the service connections (including 159 miles of service connections two inches in diameter or less).

The SWD reported 66 leaks and breaks in the South District and North District Distribution systems which are attributed to the April 29, 1965, earthquake. The leaks occurred primarily in the South District. A memorandum summarizing the location and nature of damage is attached as Appendix I. An interpretation of the causes of damage, furnished by Mr. Dale Emerson, current Director of Support Services, SWD, led to an estimate of the number of main and service leaks where corrosion was an important factor. These are listed in Tables 6 and 7. They comprise 36 to 39 of the 65 leaks attributed to the earthquake. The majority of leaks are in 3/4-inch and 2-inch diameter galvanized steel service laterals, which usually failed at exposed, threaded portions of the pipe adjacent to a fitting. The galvanized protection does not exist there and the pipe wall thickness is reduced due to the threading. The mode of failure was splitting or tearing in the circumferential direction (parallel to the threads). In addition, there were nine leaks or breaks in steel mains which were attributed to corrosion. The most frequent mode of corrosion-related leaking in mains was 1/4 to 1/2-inch diameter holes at rust spots.

The impact of the earthquake damage is also indicated in Figure 9 where leaks and breaks following the earthquake are contrasted to those during the earthquake are mostly due to leaky lead joints, whereas the earthquake damage occurred in several modes, including leaks in rust spots. All service leaks in Figure 9 are corrosion-related. There are two fewer service leaks shown in Figure 9 than are indicated in Table 6. The reason for this is unknown, except that the information was prepared at two different times for two different purposes. There are many fewer main leaks in Table 7 than are shown in Figure 9 because the former lists only those which are considered to be related to corrosion whereas the latter lists leaks due to all causes.

The SWD maintains records on major breaks and leaks. However, records of the location, time and cause of smaller breaks and leaks are available only for a relatively recent period. Hence, it is not possible to correlate corrosion-related leakage with seismic performance in the 1965 earthquake. The data which are currently being collected, however, will be extremely valuable in interpreting future seismic performance. During the 20 days preceding the April 1965, earthquake, Figure 9, main leaks were caused primarily by failure of lead joints due to traffic vibration, settlement and similar causes. Service leaks were almost exclusively related to corrosion.

The specific reason why the earthquake ground shaking caused corrosion-weakened pipes to break is not known. In Section 2.1 an effort is made to relate ground strain induced in the 1971 San Fernando, California, earthquake in the civinity of a leaky pipe to the extent of damage. This is possible because three strong motion records are available along the damaged reach of pipe. Only 1 record is available for the city of Seattle in April 29, 1965 Puget Sound earthquake so that relative motions cannot be estimated.

However, a possible contributing factor, in addition to ground strain, is excess internal pressure due to surges induced in the mains by ground shaking. A number of records are available which shows that surge pressures in the South District Distribution System exceeded the normal pressures by 50 percent to 100 percent. A typical measurement showing the earthquake-induced surge is given in Figure 10. It is likely that the surge pressures were even greater than those shown in such records because of the coarse sampling rates (once every 15 seconds or once every minute, depending on the instrument). Surge pressures are considered capable of damaging mains, but would be greatly diminished in small pipes, such as service laterals. Significant surges were also observed in the February 9, 1971, San Fernando earthquake, Reference 11; however, no attempt has yet been made to correlate surge pressures with pipe leaks there.

In summary, approximately 60 percent of the total number of breaks and leaks in the SWD distribution system occurred in steel and galvanized steel mains and service laterals which had been weakened by corrosion. Corrosion-related damage in mains occurred at rust spots, reminiscent of damage to mains in the 1971 San Fernando and 1969 Santa Rosa earthquakes. Damage to service laterals appeared almost exclusively as circumferential splitting of corrosion-weakened, threaded connections. Data on leaks prior to the earthquake are inadequate to permit correlation with earthquake damage. Surges were recorded in mains which caused the maximum pressure to become twice the normal value. Even higher surge pressures may have occurred. These are considered by some in the SWD to be the principal mechanism by which corrosion-weakened zones in mains were ruptured. Other factors, such as ground strain, cannot be investigated for either mains or service laterals in this earthquake owing to lack of free-field data.

SECTION 3

CORROSION CONTROL PROGRAMS

Corrosion is the result of an electrochemical process through which metal, such as iron, is converted into a stable compound, such as iron oxide, using electricity as a source of energy. Electrical current migrates through the soil and enters the metal pipe at a cathode. Corrosion occurs where the electrical current leaves the pipe at an anode.

Several methods of protecting pipes against corrosion are used to varying degrees by the three utilities whose earthquake experience is reported above. All three coat and wrap new steel pipes with coal tar in an effort to insulate the pipe from the soil, which acts as an electrolyte. The practice of coating, formerly with asphalt, has been followed by LADWP for about 40 years. Older pipes, such as the 6-inch Ventura Boulevard main discussed above, have no such protection. In addition, LADWP has a program of lining ferrous pipes with cement mortar.

Both LADWP and SWD also have cathodic protection programs for inevitable breaks or holidays in the coating. This type of protection, which is applied chiefly to large pipes, make the pipe in its entirety the cathode of a purposely designed electrochemical cell. There are several methods of accomplishing this. One uses a sacrificial galvanic anode, usually made of magnesium, buried adjacent to the pipe. Current flows through the electrolyte soil from the magnesium to the pipe and is carried back to the magnesium by a copper wire. The corrosion occurs at the magnesium block. Installation of one such device costs about $100. Other methods, such as rectifier groundbeds, are also used but it is beyond the scope of the present report to describe them. Further information can be obtained from sources such as the Journal of the National Association of Corrosion Engineers; for example, see Reference 12.

In addition to wrapping and cathodic protection, the three utilities discussed in this report consider corrosion in selecting replacement materials. Under the SRWD water main replacement program, about 10 miles of leaky steel pipe have been replaced with non-corroding asbestos-cement pipe. The SWD has gradually been replacing its plastic tubing, and, in a few cases, copper for sizes two inches and under; sizes four inches and above are being replaced, when warranted, with ductile cast iron pipe. As the relationship between corrosion and seismic performance becomes better known, utilities may begin to consider earthquakes as a factor in their corrosion control programs.

SECTION 4

SUMMARY AND RECOMMENDATIONS

The role of corrosion in the seismic performance of water pipelines has been investigated in the 1965 Puget Sound, Washington; 1969 Santa Rosa, California; and in the 1971 San Fernando, California, earthquakes. The study concentrates on regions where the maximum ground displacement is thought to be of order 10 cm or less, and excludes regions, especially in San Fernando, where surface faulting was reported. This selection probably has the effect of increasing the percentage of corrosion-related leaks because the ground shaking may not be severe enough to cause widespread damage to new pipe.

The present study confirms the findings of post-earthquake damage inspections which indicate that corroded pipes and service laterals comprise a significant percentage of earthquake-induced leaks. However, predictions of earthquake damage cannot be made unless the locations of corroded pipes and the extent of the corrosion are known. The finding of the present study is that the leak rate under normal conditions for a reach of pipe may provide a valuable clue to its seismic performance. Once enough data have been gathered for a specific system, it may become possible to identify seismically vulnerable reaches of pipe as ones with leak rates that exceed those of other pipes or of the system as a whole. Other factors such as local geology and backfill may also play a role.

In order to take advantage of such correlation, it is essential for utilities to maintain leak maps from which leak rates (for example, leaks per year per mile) can be computed. Apparently this is currently done only by some of the largest utilities, even though it would benefit all.

REFERENCES

1. Isenberg, J., and Wright, J. P., "Survey of Existing Underground Water Pipelines with Emphasis on Their Seismic Resistance," Weidlinger Associates, Consulting Engineers. Interim Grant Report IR-1 to NSF/ RANN, July 1, 1977.

2. Murphy, L. M., Steinbrugge, K. V., and Duke, C. M., "The San Fernando Earthquake," San Fernando, California, Earthquake of February 9, 1971, Vol. I, Effects on Building Structures, Part A, Introduction, Buildings, U. S. Department of Commerce, NOAA, 1973.

3. Private communication, Paul H. Lane, Chief Engineer of Water Works, Los Angeles Department of Water and Power, 5 August 1976.

4. Private communication, R. F. Steffan, Corrosion Section, Los Angeles Department of Water and Power, 4 October 1977.

5. Hanks, T. C., "Strong Ground Motion of the San Fernando, California, Earthquake: Ground Displacements," Bulletin of the Seismological Society of America, Vol. 65, No. 1, February 1975.

6. Johnson, J. A., and Duke, C. M., "Subsurface Geology of Portions of the San Fernando Valley and Los Angeles Basin," San Fernando, California, Earthquake of February 9, 1971, Vol. III, Geological and Geophysical Studies, U. S. Department of Commerce, NOAA, 1973.

7. Toki, K., "Strain Amplitude by Body and Surface Waves in a Near Surface Ground," Proceedings, U. S.--Japan Seminar on Earthquake Engineering Research with Emphasis on Lifeline Systems, November 8-12, 1976, Tokyo.

8. Steinbrugge, K. V., Cloud, W. K., and Scott, N. H., "The Santa Rosa, California Earthquakes of October 1, 1969," U. S. Department of Commerce, National Earthquake Information Center, 1970.

9. City of Santa Rosa Water Department, "Effects of the October 1, 1969 Earthquake on Water Service," January 1970.

10. U. S. Department of the Interior, Geological Survey, "A Study of Earthquake Losses in the Puget Sound Area," Open File Report 75-375, 1975.

11. Murphy, L. M., "San Fernando, California Earthquake of February 9, 1971. Vol. II, Utilities, Transportation and Socialogical Aspects," p. 1973, 1973.

12. Tefankjian, D. A., "Application of Cathodic Protection, Journal of National Association of Corrosion Engineers, Material Protection and Performance, November 1972.

TABLE 1

PHYSICAL DESCRIPTION OF LOS ANGELES DEPARTMENT OF

WATER AND POWER SYSTEM *

Transmission
Diameter (inches)

Material	20-23	24-29	30-41	42-50	60 and above	Common Joint Type
Steel	23.0	54.0	148.0	55.9	50.2	Welded slip joint
Concrete	0.4	1.1	3.4	8.6	24.9	Rubber gasket
Cast Iron	46.6	58.0	10.8	-0-	-0-	Cement

Distribution
Diameter (inches)

Material	4-5	6-7	8-11	12-15	16-19	Common Joint Type
Steel	69.3	245.9	195.3	114.8	50.6	Welded slip joint
Concrete	-0-	-0-	-0-	0.4	0.5	Rubber gasket
Asbestos-Cement	34.9	317.7	165.7	29.9	-0-	Rubber gasket
Cast Iron	737.3	2401.3	1321.5	543.7	105.2	Rubber gasket (cement before 1960)

Service
Diameter (inches)

Material	Less than 1	1-2	Greater than 2	Common Joint Type
Steel	-0-	-0-	10	Welded
Cast Iron	-0-	22	41	Lead, cement
Copper	625	1,800	-0-	Soldered

*From Reference 1

This Table indicates approximate length in miles of pipes of different sizes and materials.

TABLE 2

MAIN BREAKS--1971 SAN FERNANDO EARTHQUAKE

(Select Area East Valley District)

Furnished by LADWP 10/21/76

No.	Pipe Size	Type of Pipe	Type of Joint	Location of Break	Date Pipe Installed	Date of Repair	Method	Foreman
1	6"	Steel	Cement Caulked	In Ventura Blvd.--42' N ₵ 32' W ₵ Coldwater Cyn. Ave.	1929	2/13/71	Screw Pin	Mitchell
2	6"	Steel	Cement Caulked	In Ventura Blvd.--42' N ₵ 196' W ₵ Coldwater Cyn. Ave.	1929	2/19/71	Screw Pin	Sullivan
3	6"	Steel	Cement Caulked	Ventura Blvd.--42' N ₵ 126' W ₵ Van Noord Ave.	1929	2/09/71	Screw Pin	Duchesnea
4	6"	Steel	Cement Caulked	Ventura Blvd.--42' N ₵ 275' W ₵ Van Noord Ave.	1929	2/11/71	Screw Pin	Duchesnea
5	6"	Steel	Cement Caulked	Ventura Blvd.--42' N ₵ 302' W ₵ Van Noord Ave.	1929	2/09/71	Screw Pin	Duchesnea
6	6"	Steel	Cement Caulked	In Fulton Ave.--5' W ₵ 12' N ₵ Valleyheart Dr.	1932	2/11/71	Screw Pin	Bryan
7	4"	C. I.	Cement Caulked	In Longridge Ave.--11' W ₵ 122' N ₵ Moorpark St.	1927	2/14/71	360° Repair Clamp	Quesada
8	6"	C. I.	Cement Caulked	In Fulton Ave.--12' W ₵ 30' N ₵ Moorpark St.	1925	NO REPAIR REPORT AVAILABLE		
9	8"	Steel	Cement Caulked	In Moorpark St.--22' S ₵ 11' W ₵ Fulton Ave.	1937	2/14/71	Wood Plug	Bryan

TABLE 2 (CONTINUED)

No.	Pipe Size	Type of Pipe	Type of Joint	Location of Break	Date Pipe Installed	Date of Repair	Method	Foreman
10	8"	Cement Lined Welded Steel	Welded	In Valleyheart Dr.--18' S ₵	1965	NO REPAIR REPORT AVAILABLE		
11	6"	Steel	Cement Caulked	In Ventura Blvd.--42' N ₵ 195' W ₵ Tyrone Ave.	1929	2/10/71	Screw Pin	Quesada
12	6"	C. I.	Cement Caulked	In Dickens St.--10' S ₵ 18' E ₵ Van Nuys Blvd.	1924	2/12/71	Recaulked Joint	Duchesnea
13	6"	Steel	Cement Caulked	In Ventura Blvd.--42' N ₵	1929	NO REPAIR REPORT AVAILABLE		
14	6"	Steel	Cement Caulked	In Ventura Blvd.--42' N ₵ 160' E ₵ Vesper Ave.	1929	2/15/71	Screw Pin	Quesada
15	6"	Steel	Cement Caulked	In Ventura Blvd.--42' N ₵	1929	NO REPAIR REPORT AVAILABLE		
16	6"	Steel	Cement Caulked	In Ventura Blvd.--42' N ₵ 51' E ₵ Cedros Ave.	1929	2/09/71	Screw Pin	Shoff
17	6"	Steel	Cement Caulked	In Ventura Blvd.--42' N ₵ 42' W ₵ Kester Ave.	1929	2/09/71	Screw Pin	Quesada
18	6"	Steel	Cement Caulked	In Ventura Blvd.--42' N ₵ 130' E ₵ Lemona Ave.	1929	2/20/71	Screw Pin	Sullivan
19	6"	C. I.	Cement Caulked	In Saloma Ave.--12' S ₵ 43' N ₵ Camarillo St.	1960	2/14/71	Screw Pin	Sullivan
20	6"	Steel	Cement Caulked	In Greenleaf Ave.--4' S ₵ 42' W ₵ Saugus Ave.	1928	2/15/71	Screw Pin	Sullivan
21	6"	Steel	Cement Caulked	In Woodcliff Rd.--14' W ₵ 13' S ₵ Del Gado Dr.	1929	2/15/71	Screw Pin	Bryan

TABLE 2 (CONTINUED)

No.	Pipe Size	Type of Pipe	Type of Joint	Location of Break	Date Pipe Installed	Date of Repair	Method	Program
22	6"	Steel	Cement Caulked	In Woodcliff Rd.--14' W ₵ 231' S ₵ Del Gado Dr.	1929	2/10/71	Screw Pin	Duchesnea
23	6"	Steel	Cement Caulked	In Woodcliff Rd.--14' W ₵	1929	NO REPAIR REPORT AVAILABLE		
24	6"	Steel	Cement Caulked	In Woodcliff Rd.--14' W ₵ 111' S ₵ Kingswood Rd.	1929	2/11/71	Screw Pin	Duchesnea
25	16"	C. I.	Cement Caulked	In Rayneta Dr.--7' S ₵ 284' E ₵ Woodcliff Rd.	1954	2/21/71	Bell Clamp on Joint	Mitchell
26	6"	Steel	Cement Caulked	In Rayneta Dr.--St. ₵ 25' N ₵ Cody Dr.	1932	2/19/71	Plug and Clamp	Sullivan
27	6"	Steel	Cement Caulked	In Valley Vista Bl--13' S ₵; E P/L Kester Ave.	1926	2/14/71	Screw Pin	Sullivan

TABLE 3

PHYSICAL DESCRIPTION OF WATER PIPELINES IN SANTA ROSA WATER DEPARTMENT SYSTEM*

Transmission

Material	Diameter 20-23	24-29	30-41	42-49	60 and above	Common Joint Type
Steel		1.5				Welded
Concrete	0.35	0.35				Rubber ring and grout

Distribution

Material	Diameter 4-5	6-7	8-11	12-15	16-19	Common Joint Type
Steel	2	8	3	2		Flex. couplings
Concrete (Cylinder)					3	Rubber ring and grout
Asbestos-Cement	25	75	30	21		O-ring
Cast Iron	22	68	27	19		Bell and spigot mech. joint

*From Reference 1

This Table indicates approximate length in miles of pipe of different sizes and materials.

TABLE 3 (CONTINUED)

Material	Service Diameter: Less than 1	Service Diameter: 1-2	Service Diameter: Greater than 2	Common Joint Type
Asbestos-Cement			20	Ringtite
Cast Iron			20	Mech. joint
Other: Copper or polybutylene plastic	23,000*	1,700*	60	Solder or compression

*Number of connections, not length in miles

TABLE 4

PERFORMANCE OF WATER MAINS IN 1969 SANTA ROSA EARTHQUAKE

Material	Installed	Dia. (in.)	Location	Earthquake Damage	Performance Under Normal Conditions
Steel**	1939	16	Sonoma Avenue (2 locations)	1/2-inch diameter holes at spots which were rusted through	5-7 leaks per year in 2-mile reach
Steel	1939	10	Talbot and Leonard (2 locations)	Small diameter holes at rust spots	3-4 leaks per year in short reach
Steel*	1947	6	Salem Avenue (2 locations)	Small diameter holes at rust spots	2-3 leaks per year in 1-block (200 feet)
Steel	1925	2	Polk Street	Small hole	No leaks
Steel*	1947	6	Bridal Trial	Small diameter holes at rust spots	20 leaks per year in 1,200-foot reach
Steel*	1900	3	North Street between College and Spencer	Small diameter holes at rust spots	30 leaks per year in 4-block reach
Steel**		4	Grahn Drive near El Camino Way	Not reported	3-4 leaks per year in 2-block reach
Steel**		8	Brigham Street	Not reported	6-7 leaks per year in 1,500-foot reach

*Replaced since 1970 under Water Main Replacement Program

**Possible leaks not reported in Santa Rosa Water Department memorandum

TABLE 4 (CONTINUED)

Material	Installed	Dia. (in.)	Location	Earthquake Damage	Performance Under Normal Conditions
Galvanized Steel	1946	2	Brookside Drive (2 locations)	Side walls of pipe split, possibly along seam weakened by rusting	25-30 leaks per year in a 500-foot reach
Galvanized Steel	1947	2	Doyle Park Drive	Pipe sheared next to existing repair clamp	No leaks
Galvanized Iron	1949	2	Gilbert Drive	Side wall of pipe split, possibly along seam weakened by rusting	3-4 leaks in 2-block reach in 10-15 years
Galvanized Iron	1930	2	Buena Vista Drive	Small hole	No leaks
Cast Iron	1906	12	Sonoma Avenue (5 locations Sotoyome Street to Farmers Lane)	5 sections of cast iron pipe snapped just behind the bells. 2 bolt connection systems used here is very rigid	No leaks
Cast Iron	1955	8	Norte and Grahn Way	4-3/4-inch holes sheared on mechanical joint (pipe displaced on alignment)	No leaks
Cast Iron	1945	4	Wheeler Street	Crack in joint (no pipe displacement)	No leaks
Asbestos-Cement	1964	6	LaCrosse Avenue	3/4-inch corporation stop threaded into pipe was blown out with minor damage to top of pipe. No pipe displacement	No leaks

TABLE 5

PHYSICAL DESCRIPTION OF SEATTLE WATER DEPARTMENT SYSTEMS*

TRANSMISSION

Diameter (inches)

Material	20-23	24-29	30-41	42-49	60 and above	Common Joint Type
Steel	5.875	7.69	14.5	19.9	43.23	Welded
Concrete						
Prestressed Cyl.		9.61	20.58	5.4	27.92	Rubber Gasket
Asbestos-Cement						
Cast Iron	52.2	16.11	17.342	1.8		Caulked Lead
Ductile Iron						Rubber Gasket
Wood Stave					9.577	Continuous

DISTRIBUTION

Diameter (inches)

Material	2-3	4-5	6-7	8-11	12-15	16-19	Common Joint Type
Steel		6.25	4.84	.374	162.08	1.456	Caulked Lead
Concrete							
Asbestos-Cement		1.63	.58	.80			
Cast Iron		64.27	147.83	913.95	161.917		Caulked Lead
Ductile Iron						47.785	Rubber Gasket
PVC	1.24						
Wood	.13	.1	.55	.061			
Other	62.38						

SERVICE

Diameter (inches)

Material	Less Than 1	1-2	Greater Than 2	Common Joint Type
Steel	102	57	10	Threaded
Concrete				
Asbestos-Cement				
Cast Iron			6	Caulked Lead
Ductile Iron			.2	Rubber Gasket
PE Plastic	222	29		Compression Couplings
Copper	443	57		Flared

*From Reference 1

This table indicates approximate length in miles of pipes of different sizes and materials

TABLE 6

SEATTLE WATER DEPARTMENT GALVANIZED SERVICES WHICH LEAKED IN 1965 PUGET SOUND EARTHQUAKE IN WHICH CORROSION WAS A CONTRIBUTING FACTOR

Diameter	Location	Cement
3/4 inch	5312 S. W. Lander	Service
3/4 inch	27th S. W. and S. W. Andower	Blind leak
2 inches	1801 16th Avenue	Service
2 inches	2046 Westlake	Service
2 inches	Airport Way S45 Holgate	Service
2 inches	Airport Way S & S Bayview	Service
3/4 inch	2616 16th Avenue S. W.	Service
3/4 inch	2517 57th Avenue S. W.	Service
3/4 inch	3729 40th Avenue S. W.	Service
3/4 inch	2645 W. Newton	Service
3/4 inch	Airport Way S & S Day	Service
3/4 inch	20th Avenue S. W.	Service
3/4 inch	3913 S. W. Holgate	Service
3/4 inch	2520 Westlake	Service
Unknown	3031 Harbor Avenue S. W.	Service
3/4 inch	218 S. Holden	Service
3/4 inch	58th S. W. & S. W. Stevens	Service
3/4 inch	2704 36th Avenue S. W.	Blind leak
2 inches	39th S & S Dawson	2 inches galvanized pipe leak
3/4 inch	3405 30th Avenue S. W.	Service
3/4 inch	31st S. W. and S. W. City View	Service
3/4 inch	3668 33rd Avenue S. W.	Service
3/4 inch	3905 S. W. 109th	Service
3/4 inch	55th S. Atlantic Street	Service
3/4 inch	6711 25th Avenue S. W.	Service
3/4 inch	5047 35th Avenue S.	Service

TABLE 6 (CONTINUED)

Diameter	Location	Cement
2 inches	3315 31st Avenue S. W.	2 inches galvanized pipe leak
2 inches	2100 N. 102nd	Cap blew off 2 inches galvanized

TABLE 7

LEAKAGE UNDER NORMAL CONDITIONS FOR SEATTLE WATER DEPARTMENT

STEEL MAINS WHICH ALSO LEAKED IN 1965 PUGET SOUND EARTHQUAKE

IN WHICH CORROSION WAS A CONTRIBUTING FACTOR

Diameter	Location	Earthquake Performance	History
4 inches	2235 S. W. Othello	Broken Main	3 leaks in adjacent pipes 1970-1977
66 inches	28th S. and S. Weller (2 locations)	Leak	15 leaks in adjacent pipes 1964-1977
6 inches	39th S. W. and S. W. 109th	Leak	2 leaks 1971; 2 leaks 1977; hundreds of leaks in surrounding steel mains taken over from old district
48 inches	Aqua Way near 110th (2 locations)	Leak	2 leaks 1972-1977; no records for adjacent mains
66 inches	18th Avenue S. and S. Jackson (2 locations)	Leak	Same as 28th and Weller
6 inches	Airport Way S. and S. Hill	Broken Service	No data

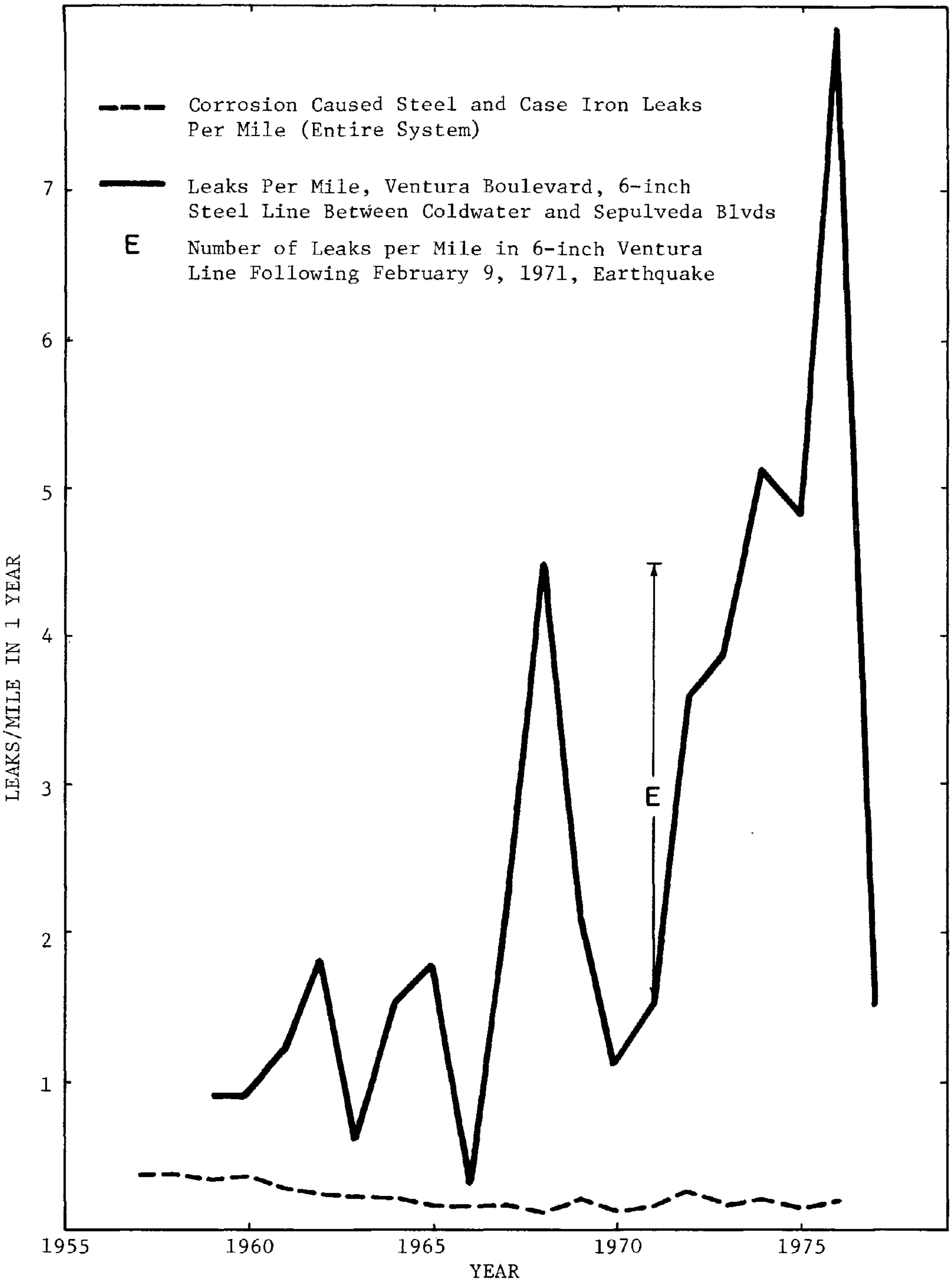

Figure 1. Leaks Per Mile Per Year in Ventura Boulevard Line and in All LADWP Cast Iron and Steel Lines

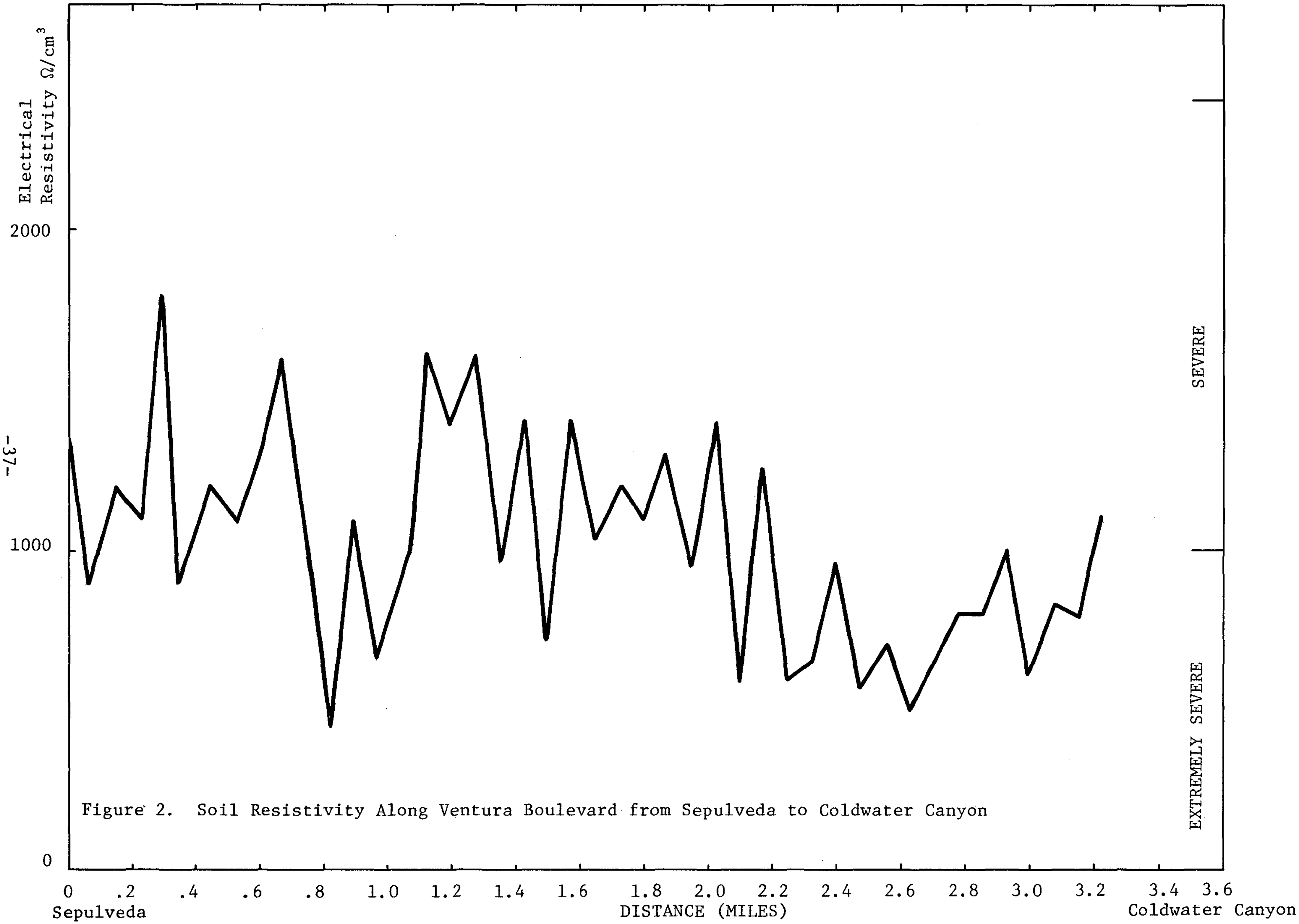

Figure 2. Soil Resistivity Along Ventura Boulevard from Sepulveda to Coldwater Canyon

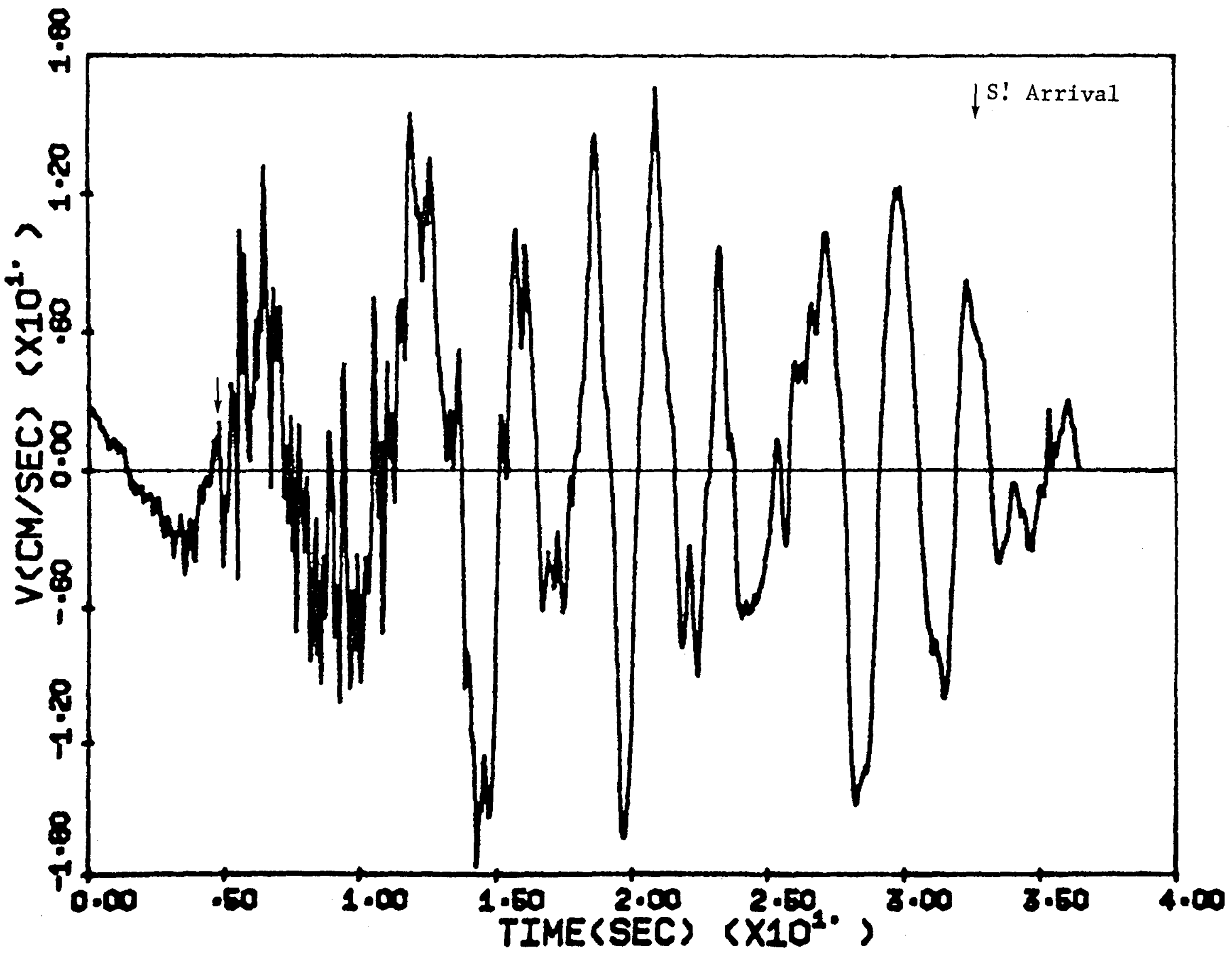

Figure 3. Absolute Velocity-Time History, EERL-CIT Record Q233, N78W Component at 14724 Ventura Boulevard 1971 San Fernando Earthquake

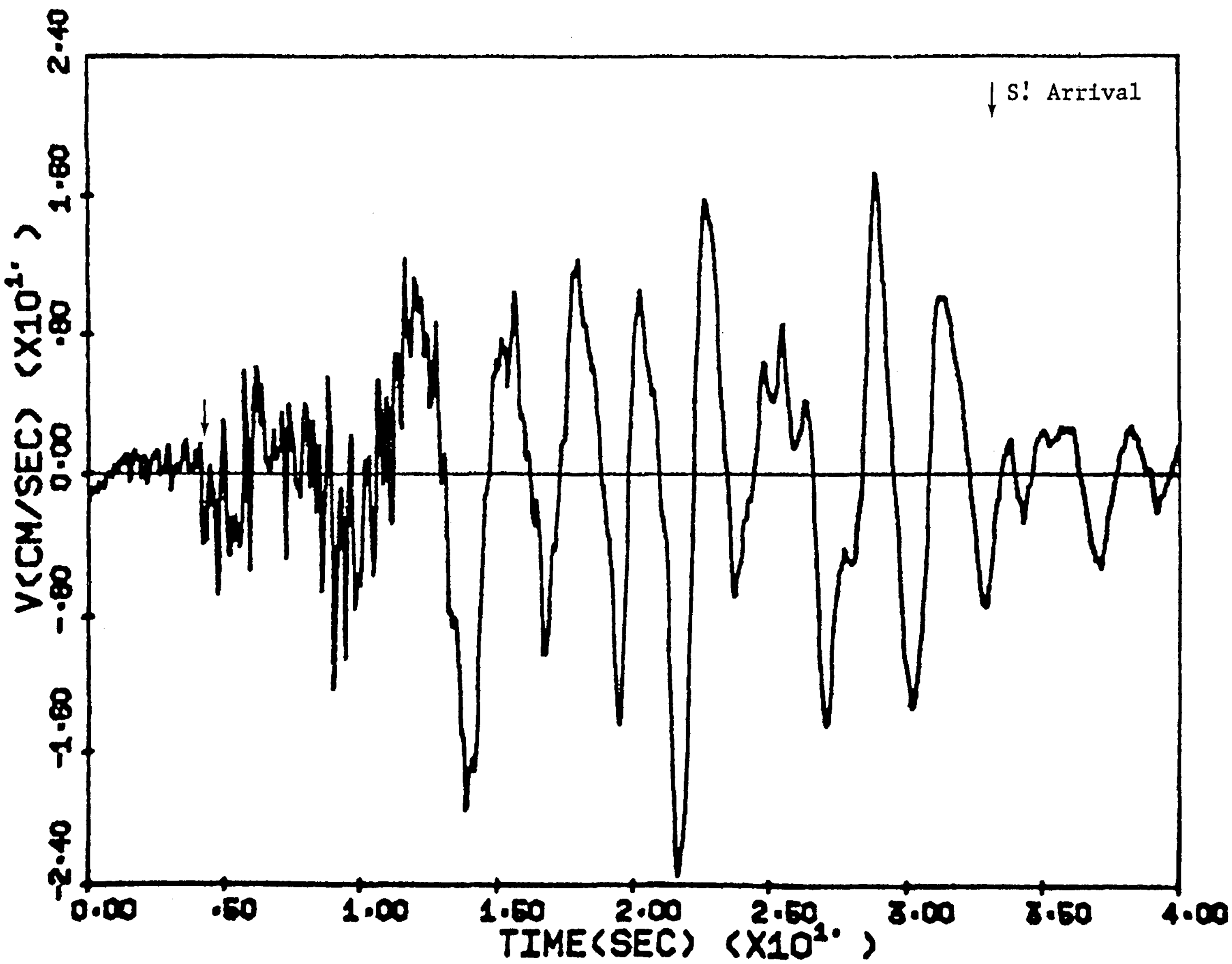

Figure 4. Absolute Velocity-Time History, EERL-CIT Record H115, N76W Component at 15250 Ventura Boulevard, 1971 San Fernando Earthquake

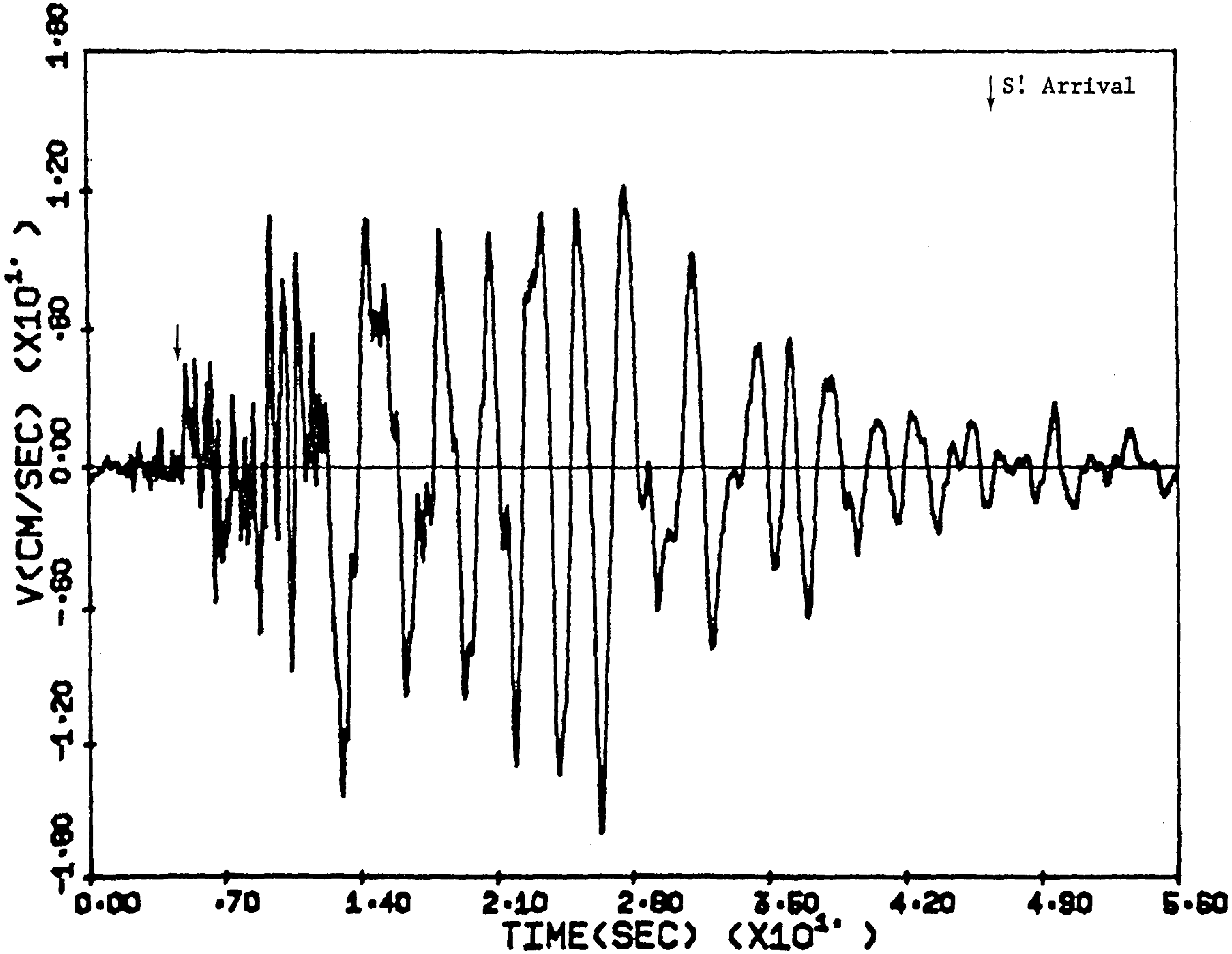

Figure 5. Absolute Velocity-Time History, EERL-CIT Record I137, S81E Component at 15910 Ventura Boulevard, 1971 San Fernando Earthquake

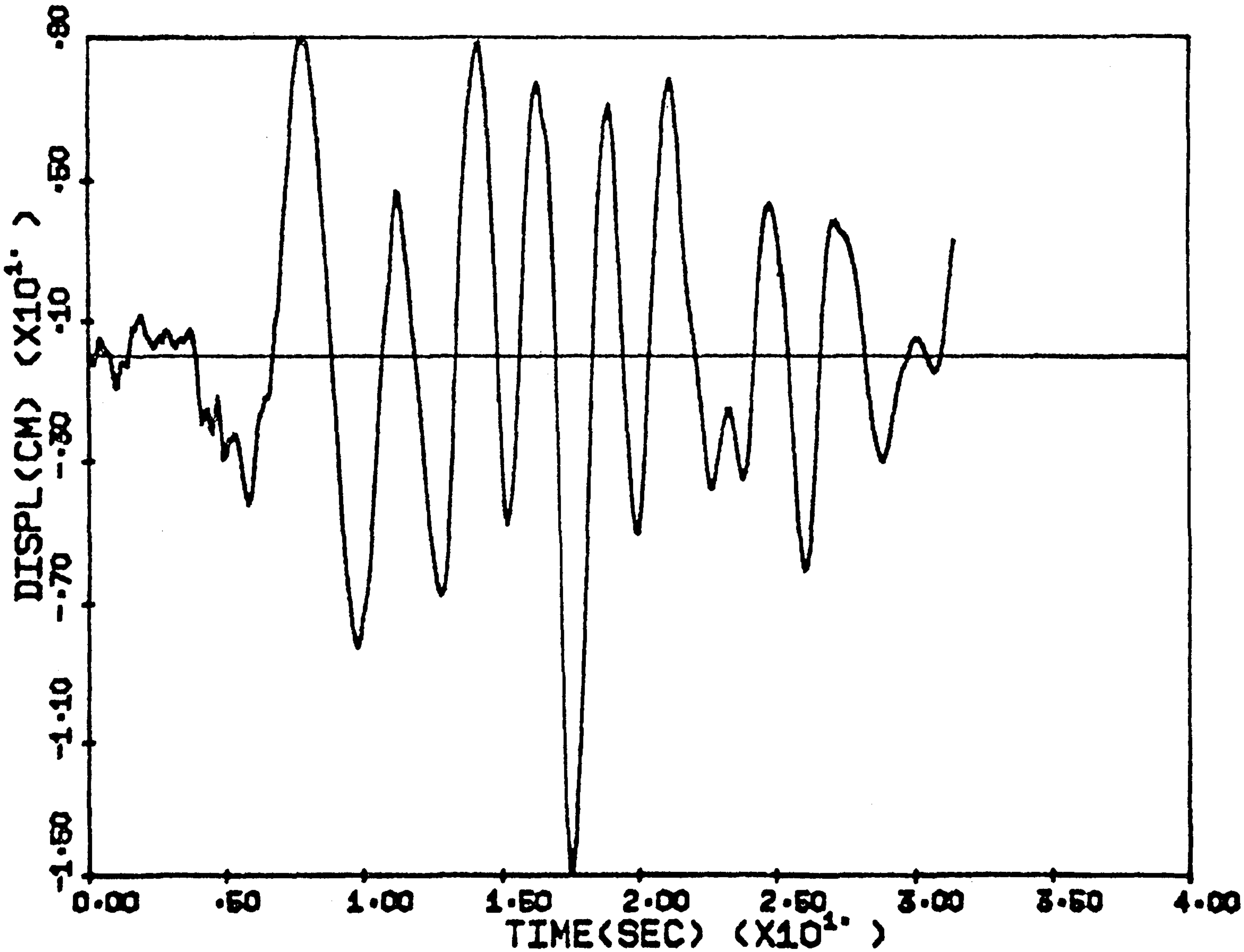

Figure 6. Relative Displacement-Time History, EERL-CIT Record H115 Minus I137, 1971 San Fernando Earthquake

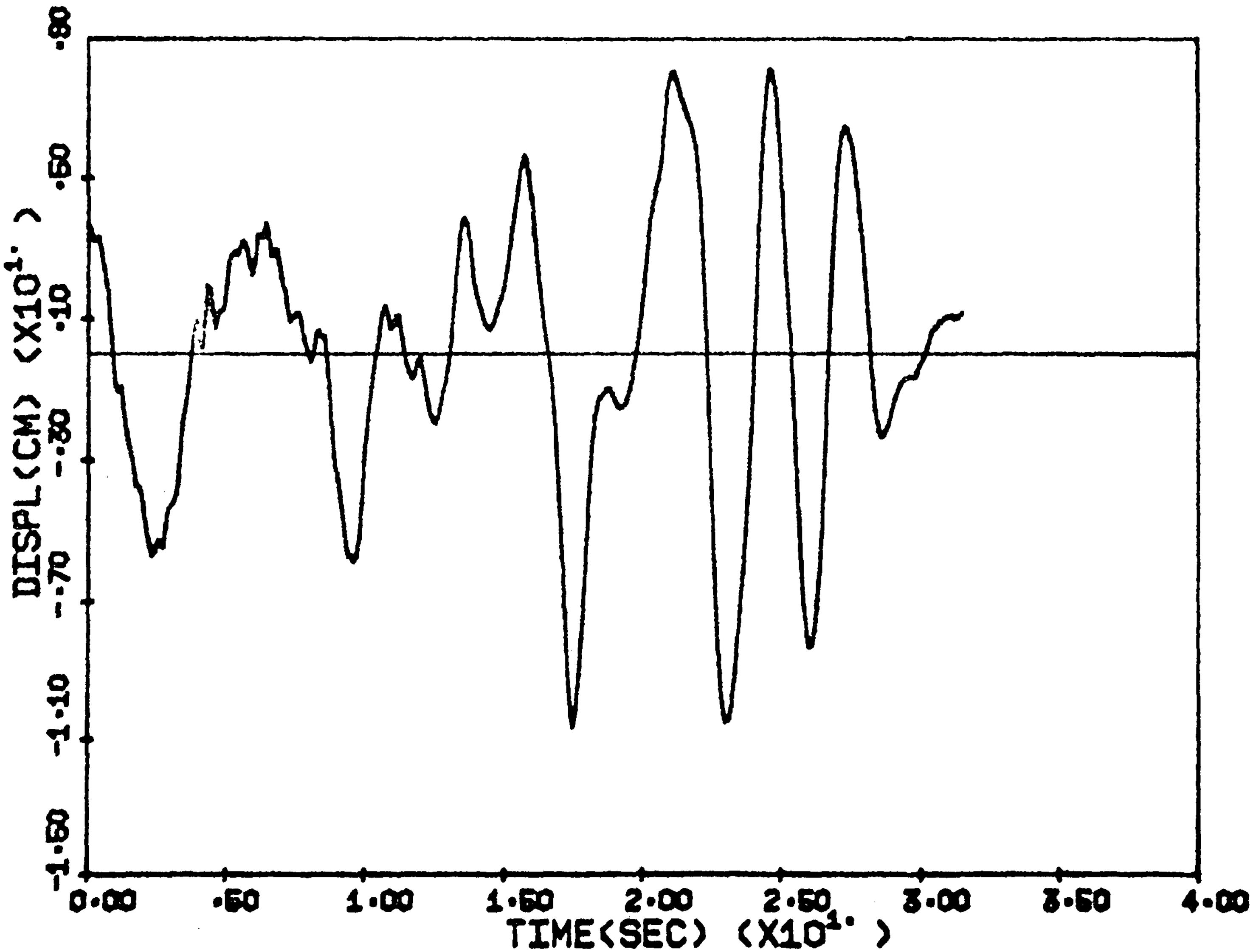

Figure 7. Relative Displacement-Time History, EERL-CIT Record H115 Minus Q233, 1971 San Fernando Earthquake

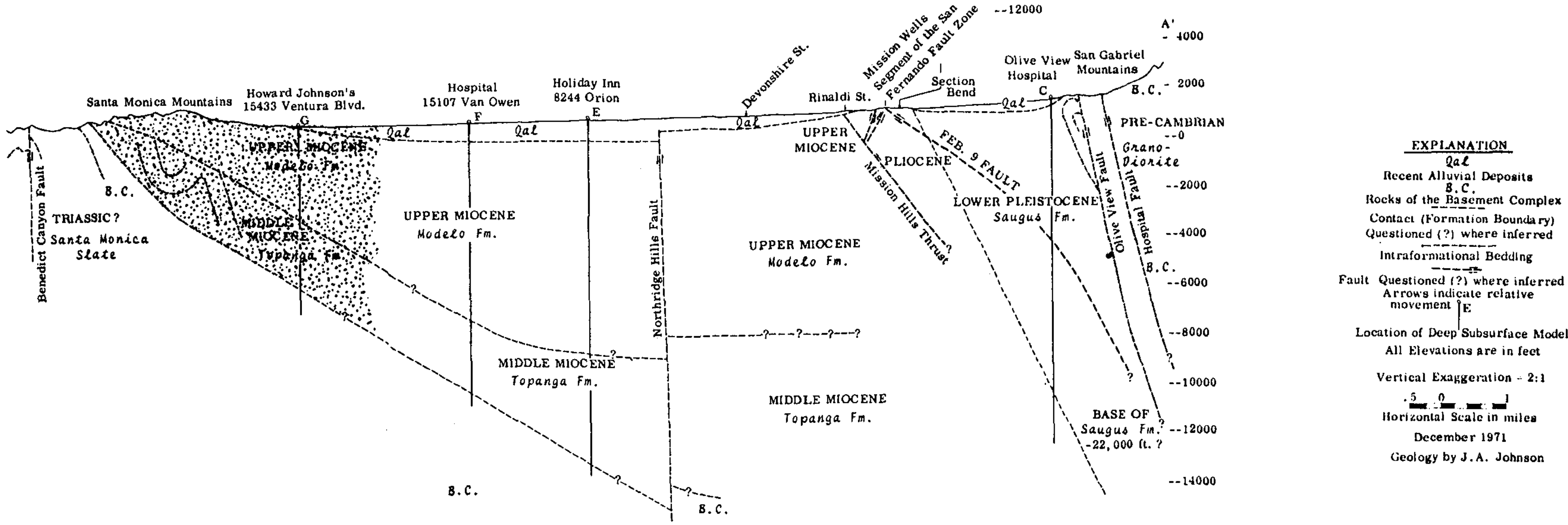

Figure 8. Geologic Cross Section--Southern San Fernando Valley. Shaded Region Indicates a Soft Dipping Layer Overlying the Stiff Basement Complex Where Focusing may Occur. From Reference 2

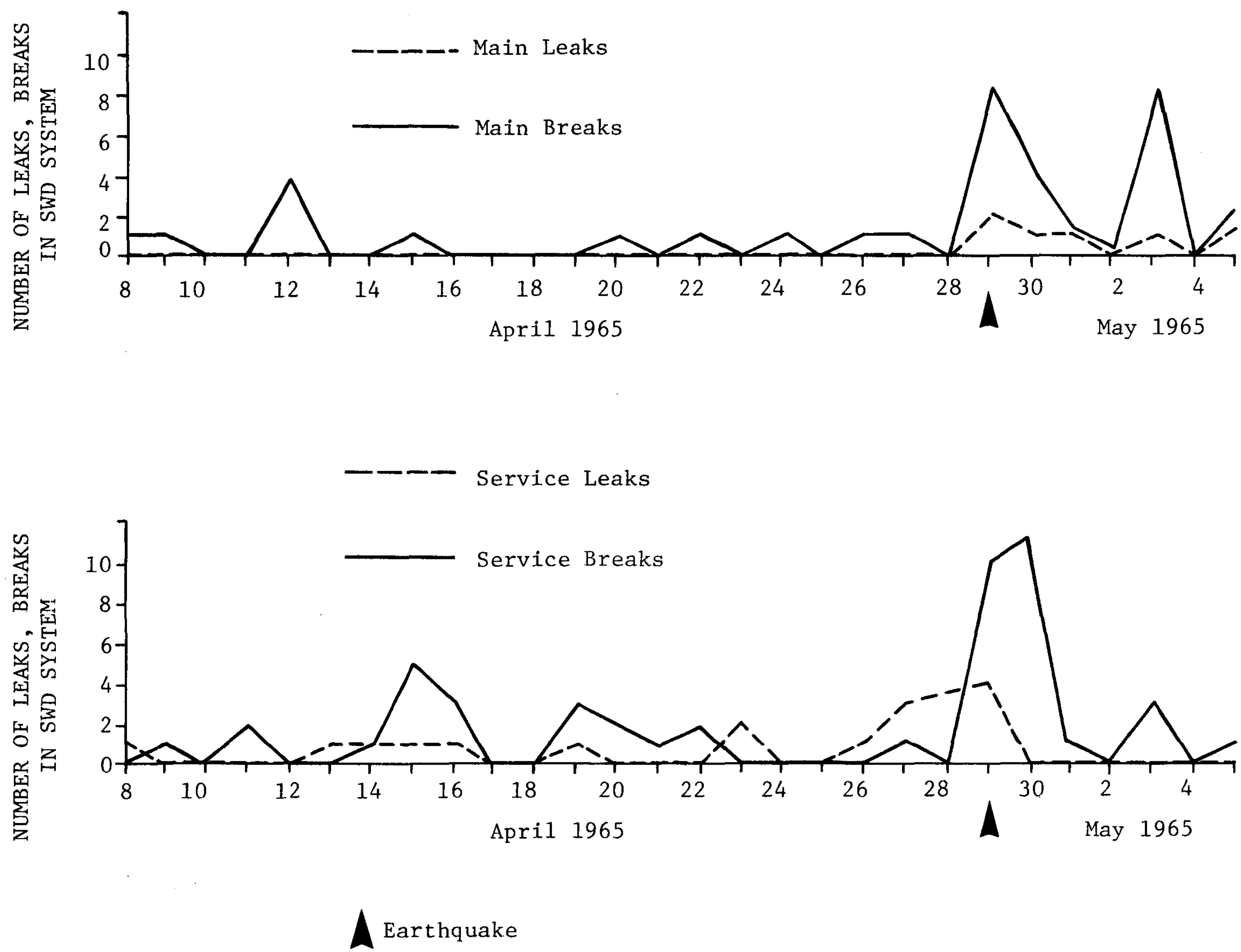

Figure 9. Leaks in Mains and Service Laterals for Seattle Water System Immediately Before and After 1965 Puget Sound Earthquake

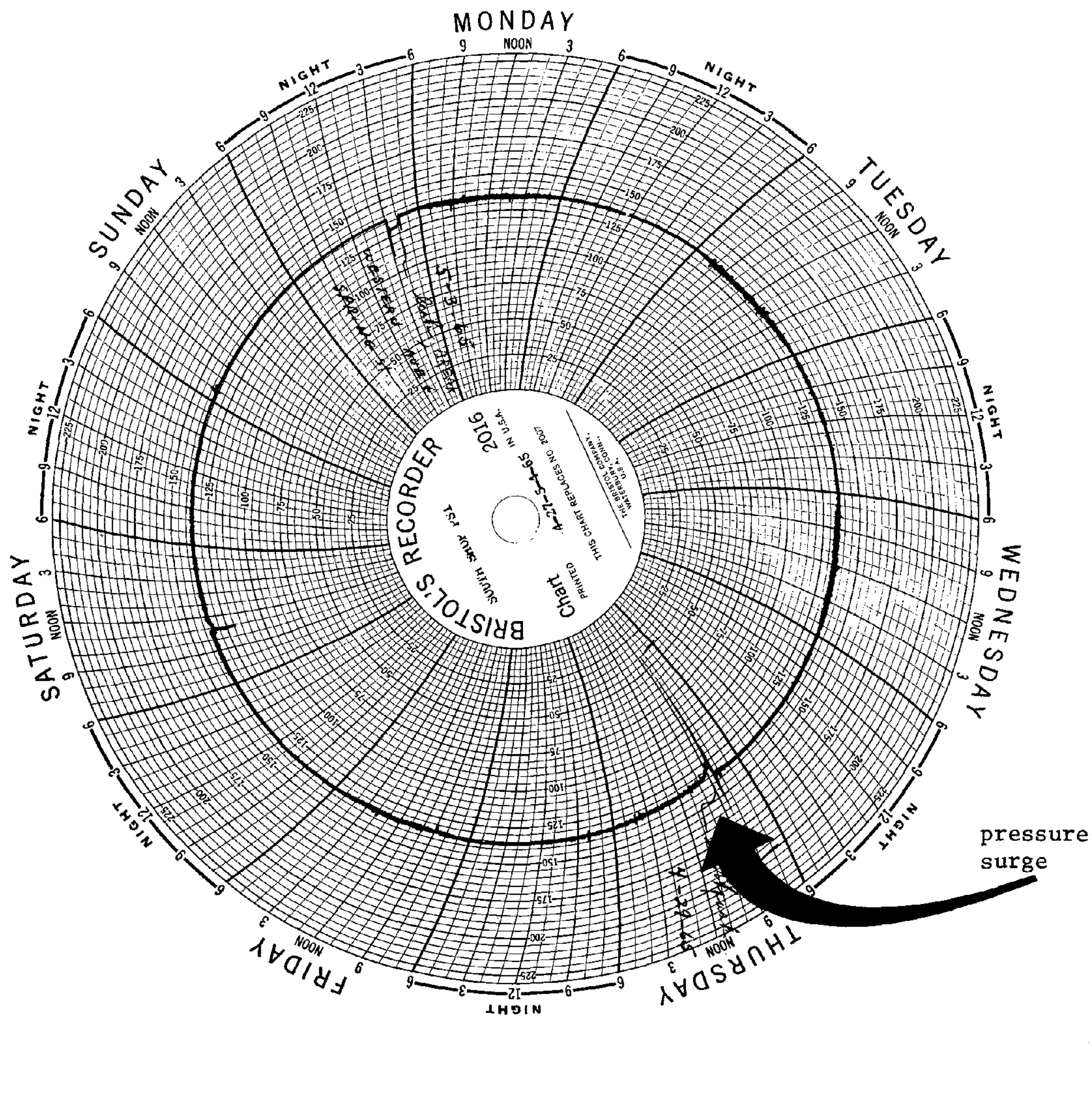

Figure 10. Example of a Surge in Pressure Caused in a Water Main of the Seattle Water Department due to April 29, 1965, Puget Sound Earthquake

ACKNOWLEDGMENT

The idea of using differential ground displacements as a measure of average strain at the south end of the San Fernando Valley from the 1971 San Fernando earthquake was suggested by T. C. Hanks of U. S. Geological Survey. Processing the Cal Tech Vol. II ground motion records to obtain relative displacements along Ventura Boulevard was done by I. Nelson of Weidlinger Associates, New York. Data on main breaks in the San Fernando earthquake, including repair reports, were assembled by R. S. Bryant of the Water Operating Division of the Los Angeles Department of Water and Power. Data on main breaks under normal conditions and on soil resistivity were supplied by R. F. Steffan also of the Water Operating Division, LADWP. Data on effects of the 1969 Santa Rosa earthquake were supplied by Mr. Frank Poulsen, Deputy Director--Utilities, and Mr. Steve Dolinsek, Water Service Maintenance Supervisor, both of the Santa Rosa Public Works Department. Data on effect of the 1965 Puget Sound earthquake were supplied by Mr. Dale Emerson, Director of Support Services, Seattle Water Department.

APPENDIX I

SUMMARY OF DAMAGE TO SEATTLE WATER DEPARTMENT SYSTEM IN 1965 PUGET SOUND EARTHQUAKE

A. Main Leaks

Date		Location	Type
4/29/65		11th SW and SW Hanford	Hydrant branch
4/29/65		29th SW and SW Spokane	20" CIP joint
4/29/65		Utah Avenue S and S Stacy Street	12" CIP joint
4/29/65		18th Avenue W and W Dravus	12" × 16" CIP joint
*4/29/65		Airport Way S and S Bayview	2" steel main
4/29/65		11th Avenue SW and SW Florida	Hydrant branch
4/29/65		1957 1st Avenue S	12" Smith branch
4/29/65		2803 Magnolia Boulevard W	6" CIP joint
4/29/65		336 NW 88th	6" CIP joint
*4/29/65		2100 NW 102nd	Cap blew off 2" steel
4/29/65		9038 3rd Avenue NW	8" CIP joint
4/29/65		8500 Greenwood Avenue N	12" CIP joint
4/30/65		2800 Harbor Avenue SW	20" CIP joint
4/30/65		34th SW and SW Spokane	Hydrant branch
4/30/65		11th SW and SW Spokane	Hydrant branch
5/01/65		Airport Way S and S Diagonal	Hydrant branch
5/03/65		Wilson Avenue S and S Dawson	8" CIP joint
*5/03/65	(2)	18th Avenue S and S Jackson	66" steel
5/03/65		10th Avenue E and E Pine	30" CIP joint
5/03/65		29th Avenue SW and SW Spokane	20" CIP joint
*5/03/65		39th Avenue SW and SW 109th	6" steel
5/03/65		11th Avenue SW and SW Hanford	12" CIP
*5/03/65	(2)	Aqua Way and S 110th	48" steel

Date		Location	Type
5/03/65		Aqua Way and S 110th	48" steel
5/05/65	(2)	28th Avenue S and S Weller	66" steel

B. Main Breaks

Date	Location	Type
4/29/65	37th Avenue SW and SW Grayson	8" CIP
4/29/65	27th Avenue SW and SW Florida	12" CIP
*4/30/65	2235 SW Othello	4" steel
5/01/65	55th Avenue S and S Hazel	8" CIP
5/03/65	Western Avenue and Spring	20" CIP

C. Service Leaks

Date	Location	Type
*4/29/65	5312 SW Lander	3/4" service
*4/29/65	27th Avenue SW and SW Lander	3/4" service
*4/29/65	1801 16th Avenue SW	2" service
*4/29/65	2046 Westlake Avenue N	2" service
*4/29/65	Airport Way S and S Holgate	2" service
*4/29/65	2616 16th Avenue SW	3/4" service
*4/29/65	2517 57th Avenue SW	3/4" service
*4/29/65	3729 40th Avenue SW	3/4" service
*4/29/65	2645 Newton	3/4" service
*4/29/65	Airport Way S and S Day	3/4" service
*4/30/65	4029 20th Avenue SW	3/4" service
*4/30/65	3013 SW Holgate	3/4" service
*4/30/65	2520 Westlake Avenue N	3/4" service
*4/30/65	2nd Avenue and Steward	3/4" service

Date	Location	Type
*4/30/65	3031 Harbor Avenue SW	3/4" service
*4/30/65	218 S Holden	3/4" service
*4/30/65	58th SW and SW Stevens	3/4" service
*4/30/65	2704 36th Avenue SW	3/4" service
*4/30/65	39th Avenue S and S Dawson	2" service
*4/30/65	3405 30th Avenue SW	3/4" service
*4/30/65	31st Avenue SW and SW City View Drive	3/4" service
*4/30/65	3668 33rd Avenue SW	3/4" service
*5/01/65	3905 SW 109th	3/4" service
5/03/65	2600 26th Avenue SW	2" service
*5/03/65	55th S and S Atlantic	3/4" service
*5/03/65	5711 25th Avenue SW	3/4" service
*5/05/65	5047 35th Avenue S	3/4" service
*5/05/65	3315 31st Avenue SW	2" service

D. Service Breaks

Date	Location	Type
4/29/65	602 W Blewett	3/4" service
4/29/65	1002 1/2 SW Idaho	1-1/2" service
*4/29/65	Airport Way S and S Hill	6" service
4/29/65	Airport Way S and S Bayview	2" service

*Leaks or breaks in which corrosion was a contributing factor

PERRY Y. AMIMOTO, ENGINEERING GEOLOGIST
CALIFORNIA DIVISION OF MINES AND GEOLOGY
1416 9TH STREET, ROOM 118
SACRAMENTO, CA 95814

SUBHASH C. ANAND
DEPARTMENT OF CIVIL ENGINEERING
CLEMSON UNIVERSITY
CLEMSON, SC 20631

H. WALTER ANDERSON, P. E.
ASSISTANT TO CHIEF, DIVISION OF DESIGN
U.S. DEPARTMENT OF THE INTERIOR
ENGINEERING & RESEARCH CENTER
RM 1440,BLDG 67 DENVER FEDERAL CENTER
DENVER, CO 80225

DR. ROBERT ANDERSON
G. A. I. INC.
570 BEATTY ROAD
PITTSBURGH, PA 15146

PROFESSOR ALFREDO ANG
UNIVERSITY OF ILLINOIS
DEPARTMENT OF CIVIL ENGINEERING
SCHOOL OF ENGINEERING
URBANA, IL 61801

MR. WALTER F. ANTON
DIRECTOR OF ENGINEERING
EAST BAY MUNICIPAL UTILITY DISTRICT
2130 ADELINE STREET
P. O. BOX 24055
OAKLAND, CA 94623

PROFESSOR T. ARIMAN
DEPARTMENT OF AEROSPACE AND
MECHANICAL ENGINEERING
UNIVERSITY OF NOTRE DAME
NOTRE DAME, IN 46556

DR. R. STEVEN ATKINS
G. A. I. INC.
570 BEATTY ROAD
PITTSBURGH, PA 15146

MARY AYRES
AYRES AND HAYAKAWA
1180 SOUTH BEVERLY DRIVE
LOS ANGELES, CA 90035

JULIAN BARDOFF
SAN FRANCISCO WATER DEPARTMENT
PUBLIC UTILITIES COMMISSION
425 MAIN STREET
SAN FRANCISCO, CA 94101

WEIDLINGER ASSOCIATES
110 EAST 59TH STREET
NEW YORK, NY 10022
ATTN. DR. MELVIN L. BARON
ATTN. MR. PAUL WEIDLINGER

KEITH G. BARRETT, CHIEF, DESIGN BRANCH
THE RESOURCES AGENCY, STATE OF CALIF.
DEPARTMENT OF WATER RESOURCES
POST OFFICE BOX 388 1416 NINTH STREET
SACRAMENTO, CA 95814

JAMES E. BEAVERS
UNION CARBIDE CORPORATION
NUCLEAR DIVISION BUILDING 9733-2
POST OFFICE BOX Y, MS1
OAK RIDGE, TN 37830

LYNN S. BEEDLE
DIRECTOR, FRITZ ENGINEERING LABORATORY
LEHIGH UNIVERSITY
BETHLEHEM, PA 18015

MR. R. BEHNKE
ST. LOUIS COUNTY WATER COMPANY
8390 DELMAN BOULEVARD
ST. LOUIS, MISSOURI 63123

JACK R. BENJAMIN
EDAC SUITE 301
480 CALIFORNIA AVENUE
PALO ALTO, CA 94306

JOSEPH W. BERG, JR.
DIVISION OF EARTH SCIENCES
NATIONAL ACADEMY OF SCIENCES
2101 CONSTITUTION AVENUE NW
WASHINGTON, DC 20418

R. V. BETTINGER
CHIEF, CIVIL ENGINEER
PACIFIC GAS AND ELECTRIC COMPANY
77 BEALE STREET
SAN FRANCISCO, CA 94106

PROFESSOR J. M. BIGGS
DEPARTMENT OF CIVIL ENGINEERING
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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