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SEISMIC PERFORMANCE OF UNDERGROUND WATER PIPELINES IN THE SOUTHEAST SAN FERNANDO VALLEY IN THE 1971 SAN FERNANDO EARTHQUAKE

By

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16. Abstract (Limit: 200 words)

This study examines the seismic performance of underground water pipelines in the southeast San Fernando Valley in the 1971 San Fernando earthquake. Studies were reported on the effects of corrosion on leaks in pipelines, made of steel and cast iron, that were damaged in regions where ground shaking was dominated by wave propagation. The present investigation extends previous work by considering a larger region of the southeastern San Fernando Valley where wave effects dominate ground shaking. It is part of the East Valley District of the Los Angeles Department of Water and Power and covers about 30 square miles which includes 71 main leak locations. The findings show that corrosion is a major factor in determining where leaks occur in areas undergoing ground shaking as well as under normal conditions. There are strong indications that the effects of ground shaking on pipelines continued in San Fernando Valley for several years after the earthquake. Included is a section on local geography.

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Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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SECTION 1

INTRODUCTION

The seismic performance of underground water transmission and distribution lines in earthquakes is a major area of concern for water utilities in seismically active areas. Damage to such pipelines in three U. S. earthquakes has been documented (References 1-4). In the 1971 San Fernando earthquake, surface ruptures in developed areas such as Sylmar caused extensive pipe damage. In other areas of the San Fernando Valley during the 1971 earthquake and in the 1965 Puget Sound and 1969 Santa Rosa earthquakes, pipelines were also damaged in regions where ground shaking was dominated by wave propagation. Reference 4 considers the effects of corrosion on leaks of the latter type in all steel and cast iron pipes in the Puget Sound and Santa Rosa earthquakes, and for a portion of such leaks in the San Fernando earthquake. The present study extends the previous work by considering a larger region of the southeastern San Fernando Valley where wave effects dominate ground shaking. The region considered here is part of the East Valley District of the Los Angeles Department of Water and Power. It covers about 30 square miles and includes 71 main leak locations (including the 27 leaks previously considered).

Corrosion adversely affects the seismic performance of steel and galvanized steel pipelines, Reference 4, and is suspected to affect cast iron pipe similarly. By reducing wall thickness locally, corrosion reduces the capacity of pipes to withstand earthquake-induced surge pressures and stresses transmitted by the soil, as well as their capacity to withstand ordinary working loads caused by traffic, temperature changes, internal pressure and water hammer. A significant percentage (45% to 70%) of all earthquake-related leakage described in Reference 4 occurred at points weakened by corrosion.

SECTION 2

LOCAL GEOLOGY,

GROUND SHAKING AND PIPELINE SYSTEM

2.1 Geologic Setting

The geologic setting of the San Fernando Valley area and the subsurface geological conditions at selected locations of instruments which recorded the main shock and certain aftershocks of the San Fernando earthquake are described briefly here. More complete information is presented in Reference 6. Figure 2-1 is a generalized geologic map which shows locations of the geologic cross section A-A´ traversing the area considered in the present study, which is known as LADWP Map 8 South. Reference 7 discusses engineering aspects of the deep subsurface formations identified in Figure 2-2, including shear and dilatational wave speeds. The following geologic description of the San Fernando Valley is from Reference 6:

> "Structurally, the valley is a faulted series of folds (Reference 8, cross section A-A´) that broadens and deepens to the east where it is truncated by the upfaulted southwest front of the Verdugo Mountains. To the north is a smaller fold known as the Little Tujunga syncline (Reference 9), that extends along the southern margin of the San Gabriel Mountains. The northern limb of this fold is truncated by the San Gabriel Mountains. The southern border of the valley is underlain by the north-dipping sedimentary formations that cap the Santa Monica Mountains (cross section A-A´).
>
> "The sediments underlying the valley at their deepest point include some 15,000 feet (Reference 10) of broadly folded and faulted Cenozoic and Mesozoic (?) rocks that unconformably rest on basement complex. . .Quaternary materials in the form of stream-deposited, coalescing alluvial fans and terrace deposits blanket most of the floor of the valley.
>
> "The southern margin of the valley is bounded by the east-west trending Santa Monica Mountains. Structurally, the mountainous area east of Topanga Canyon is a large, complexly faulted anticline which plunges to the west with basement rocks exposed to the east (cross section A-A´). Rocks of the area include a wide variety of coarsely crystalline plutonic rocks, other intrusives and pyroclastic rocks, metamorphic schists and slates, and a sequence of sedimentary rocks (Reference 11)."

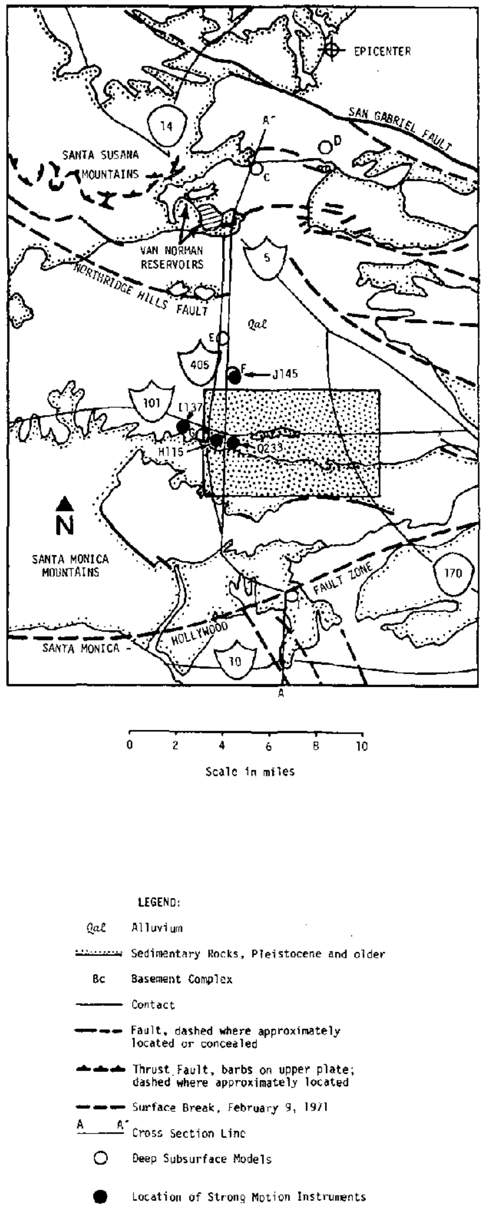


Figure 2-1. Geologic Map of San Fernando Valley from Johnson and Duke, Reference 6. Shaded area corresponds to Map 8 South of Los Angeles Dept. of Water and Power.

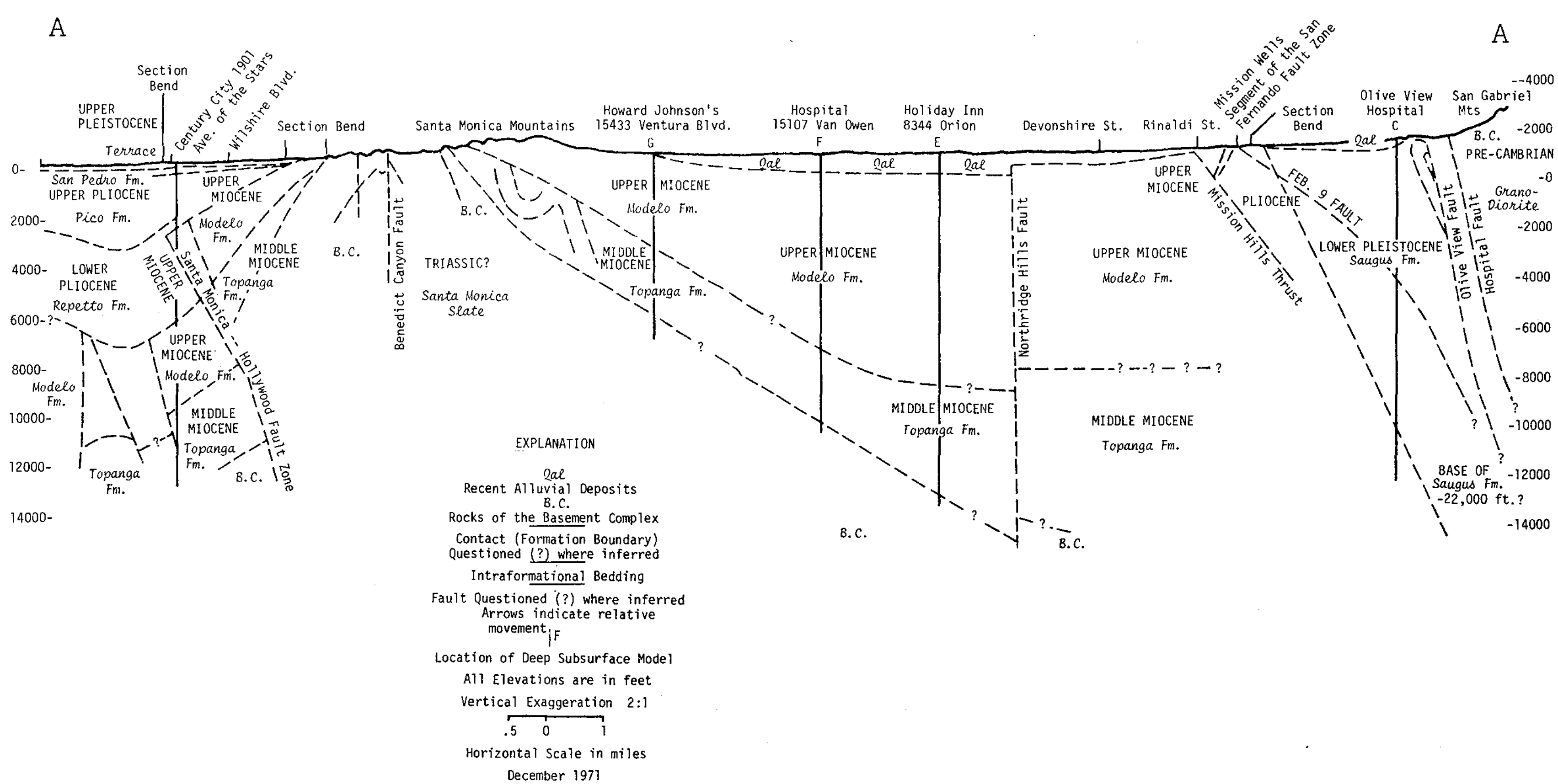


Figure 2-2. Geologic Cross Section A-A´ (see Figure 2-1), San Gabriel Mountains — north Los Angeles Basin from Johnson and Duke, Reference 6.

2.2 Ground Shaking

The region covered by Map 8 South includes two locations where strong ground shaking was recorded (H115 and Q233) and two other locations within 2000 feet of its boundaries (I137 and J145). These locations are indicated in Figure 2-1. The horizontal acceleration-time histories and pseudo velocity response spectra at each location, as described in Reference 12, are shown in Figure 2-3. The peak acceleration is approximately .25g. Peak spectral response occurs in the frequency range of about 1.5 to 4 Hz. Reference 4 describes a method of estimating average ground strain in an E-W direction along a 1.5 mile segment of Ventura Boulevard by subtracting the components of absolute displacements at locations H115, Q233 and I137 to obtain the relative displacement-time history and then dividing by the distance between stations. If the Caltech-corrected, displacement-time records are assumed to be accurate and to be unbiased by having been measured inside buildings, peak values of average ground strain (over distances of 730 km and 1700 km) are 0.6×10^{-4} to 2×10^{-4}. These values are consistent with estimates reported by Toki, Reference 13. Since these strains are much less than would be required to cause steel pipe to yield (required strain 1 to 2×10^{-3}), factors in addition to average ground strain must be postulated to explain damage to pipe in this area. Possibilities include local strain concentration, pipe-soil interaction resulting in resonance phenomena, increased internal pressure due to surge effects and local weaknesses in pipes such as those due to corrosion.

2.3 Pipeline System in Southeast San Fernando Valley

The area covered by Map 8 South is typical of the LADWP system. Figure 2-4 shows the area to contain several large transmission mains consisting of reinforced concrete and welded steel pipes greater than 30 inches in diameter; the 64-inch reinforced concrete main underlying Coldwater Canyon Ave.

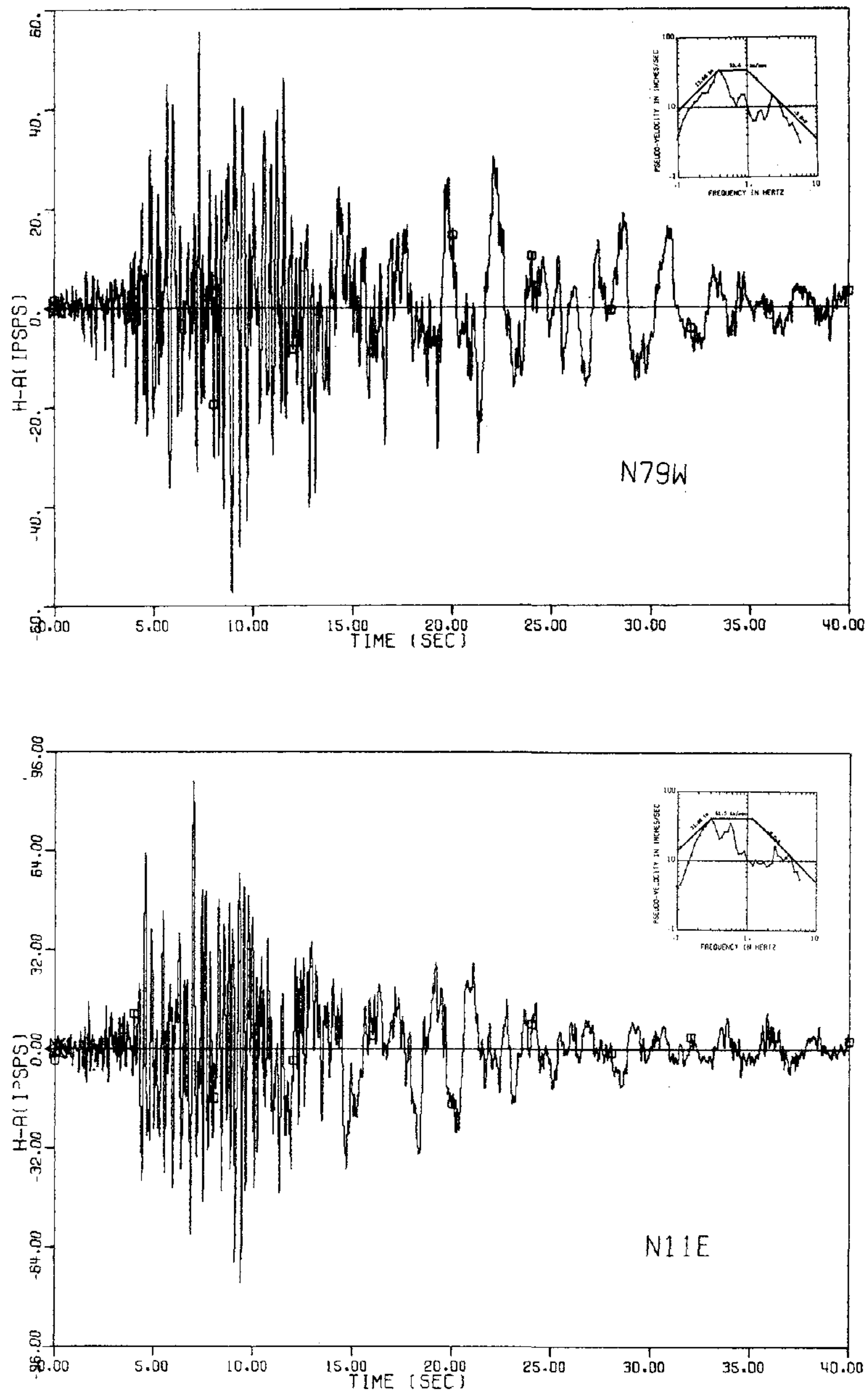
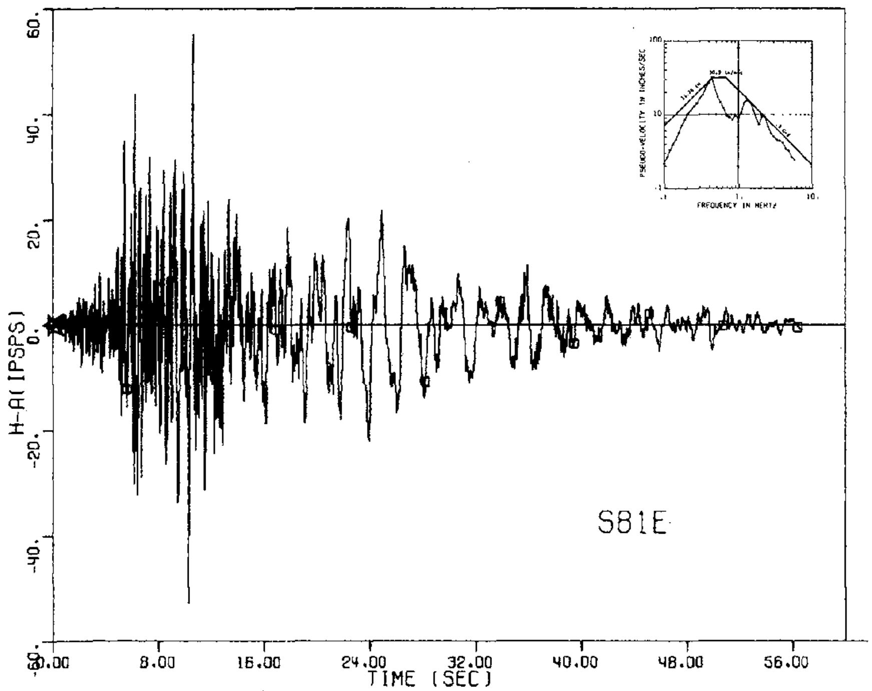


Figure 2-3a. Horizontal acceleration-time histories and pseudo-velocity spectra (5% damping) for location H115 (see Figure 2-1).



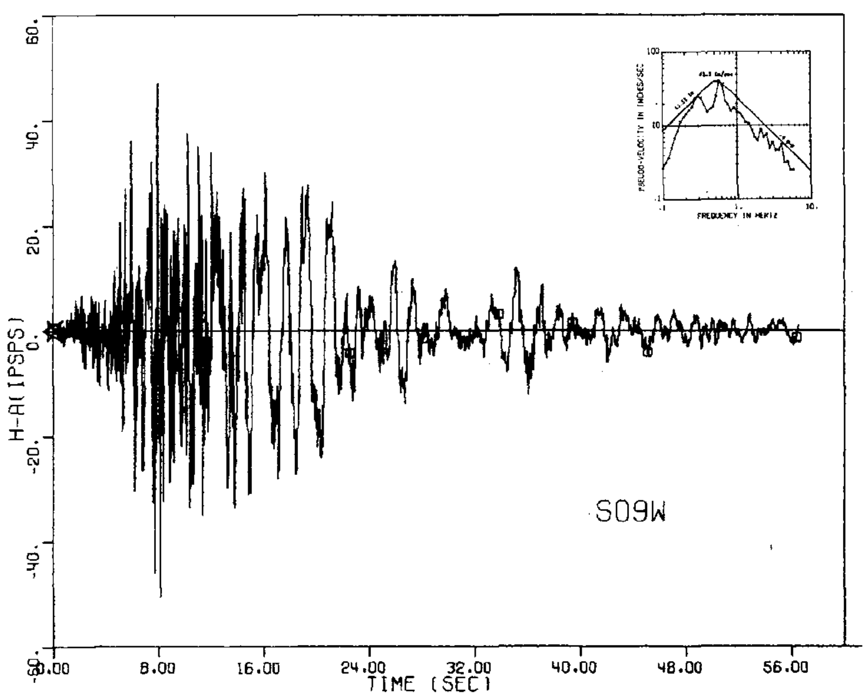
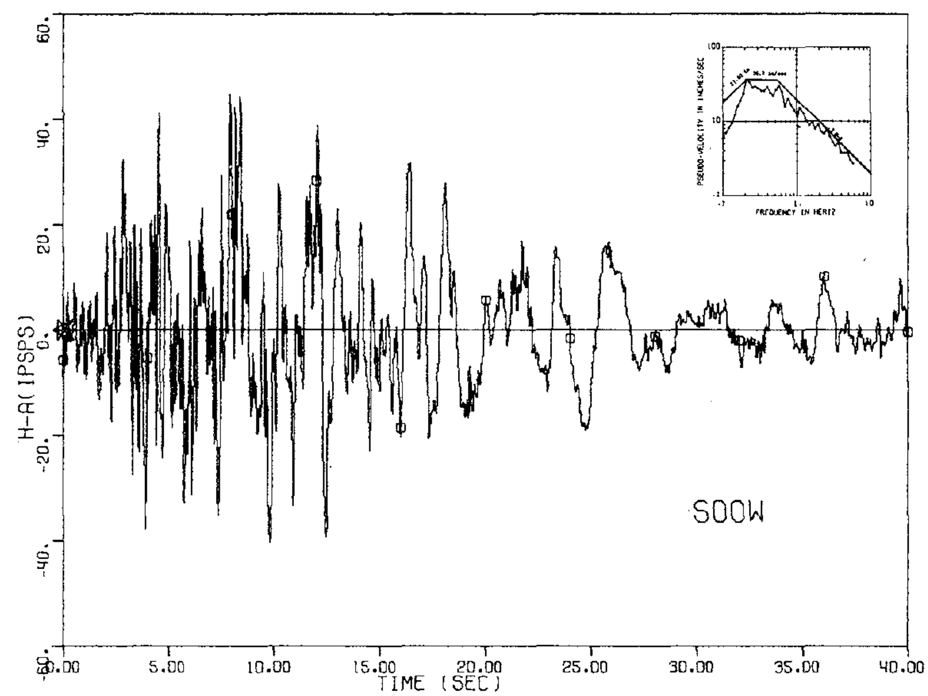


Figure 2-3b. Horizontal acceleration-time histories and pseudo-velocity spectra (5% damping) for location I137 (see Figure 2-1).



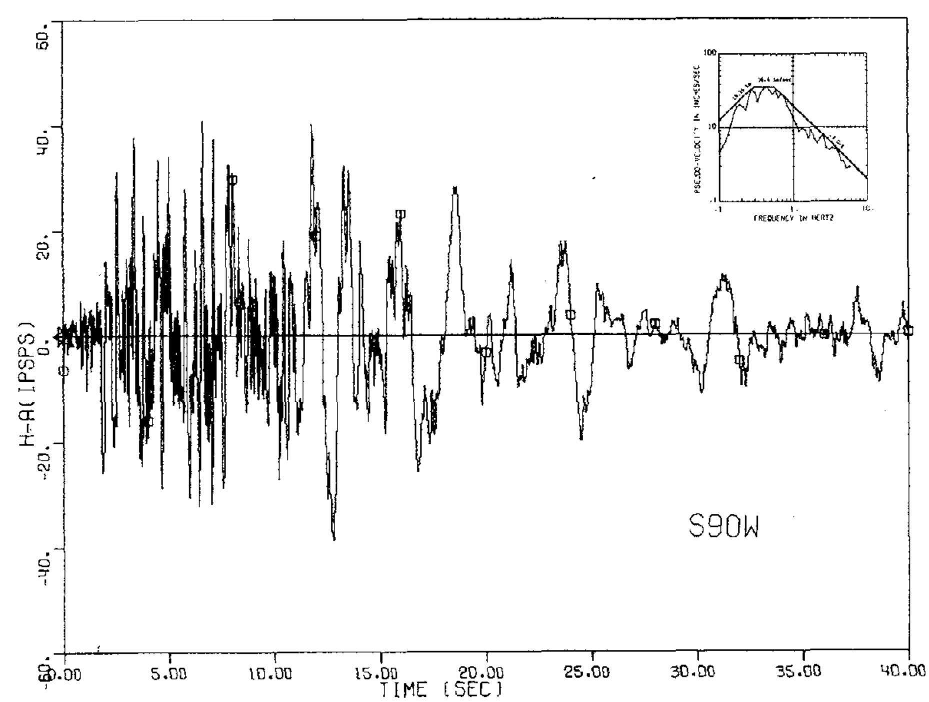


Figure 2-3c. Horizontal acceleration-time histories and pseudo-velocity spectra (5% damping) for location J145 (see Figure 2-1).

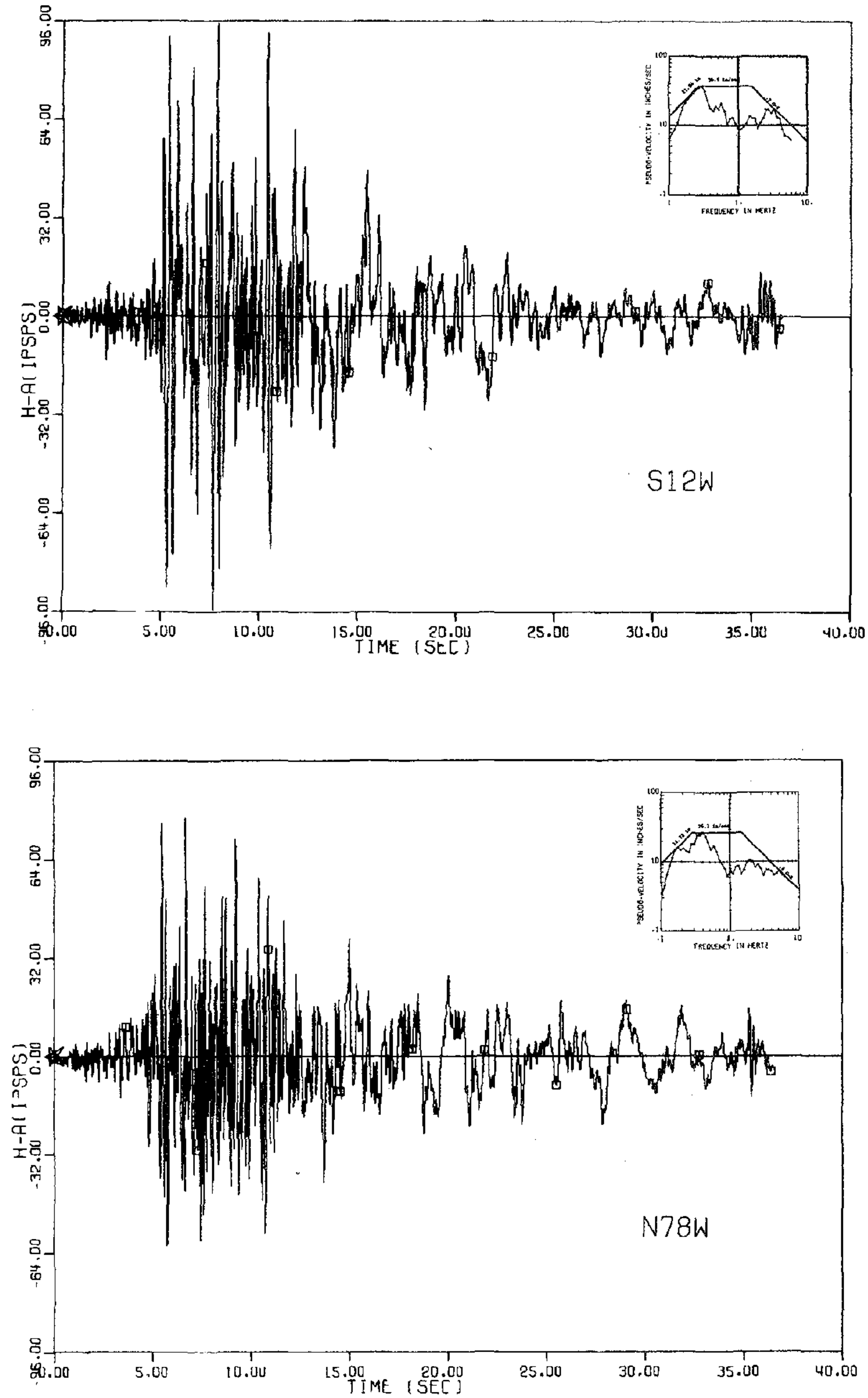


Figure 2-3d. Horizontal acceleration-time histories and pseudo-velocity spectra (5% damping) for location Q233 (see Figure 2-1).

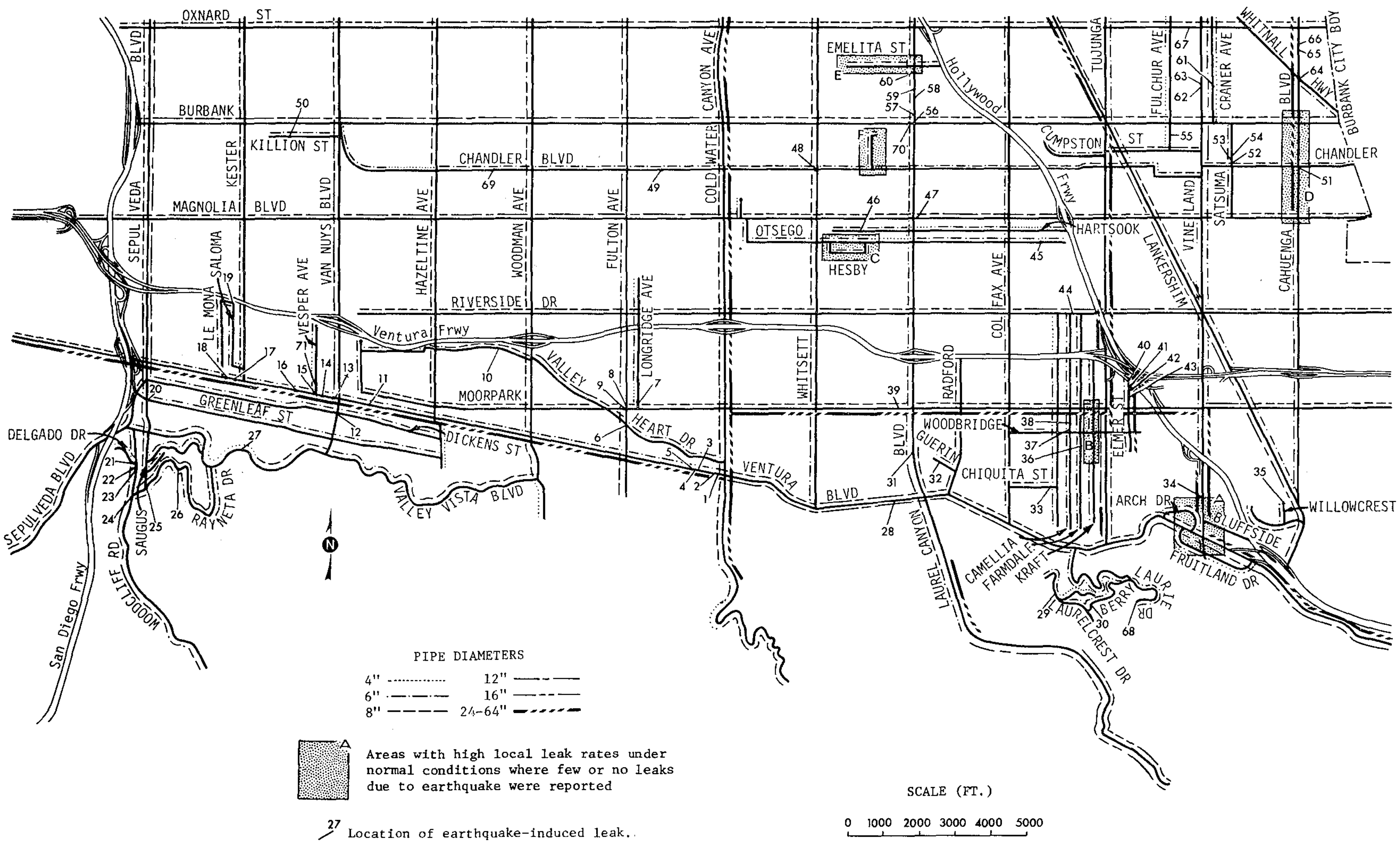


Figure 2-4. Selected pipelines within Los Angeles Department of Water and Power Map 8 South showing location of leaks after 1971 San Fernando Earthquake (see Figure 2-1).

is an example. Typical distribution mains are 6-inch or 8-inch steel lines with cement-caulked joints; cast iron is also used. Nearly every major street has such a main; some short residential streets have 4-inch mains. The 6-inch Mannesman milled-steel pipe along Ventura Blvd. is an example. Many of the distribution mains in this area were installed in the 1920's and 1930's and have no protection against external corrosion. Many of the pipes have cement linings which were put in after 1940 as part of a corrosion protection program.

As a preliminary step in the present study, the average annual leak rate under normal conditions for the area covered by Map 8 South was estimated so that it can be contrasted to earthquake-induced leakage. The average annual leak rate was defined to be equal to the average rates for pipes underlying 12 streets during the years from 1959 to 1975; 1971, the year of the San Fernando earthquake, was included, but leakage directly attributable to the earthquake was excluded from the statistics. The reaches of pipe considered are summarized in Table 2-1. They cover about 51.4 miles of 6-inch to 16-inch diameter distribution mains underlying major north-south and east-west streets. Most are steel and there is some reinforced concrete. The average annual leak rate for these pipes is compared in Figure 2-5 with that for all cast iron and steel pipes in the LADWP system. The comparison shows that the 12 San Fernando Valley Pipes have a higher leak rate than has the entire system. Not reflected in the Figure is the fact that the leaks are especially concentrated in short reaches of steel pipe, making the average leak rate for the steel pipes in this region of San Fernando Valley dependent on the length of pipe considered; in some cases, local leak rates over, say, 1000 feet are significantly higher than those shown in the Figure.

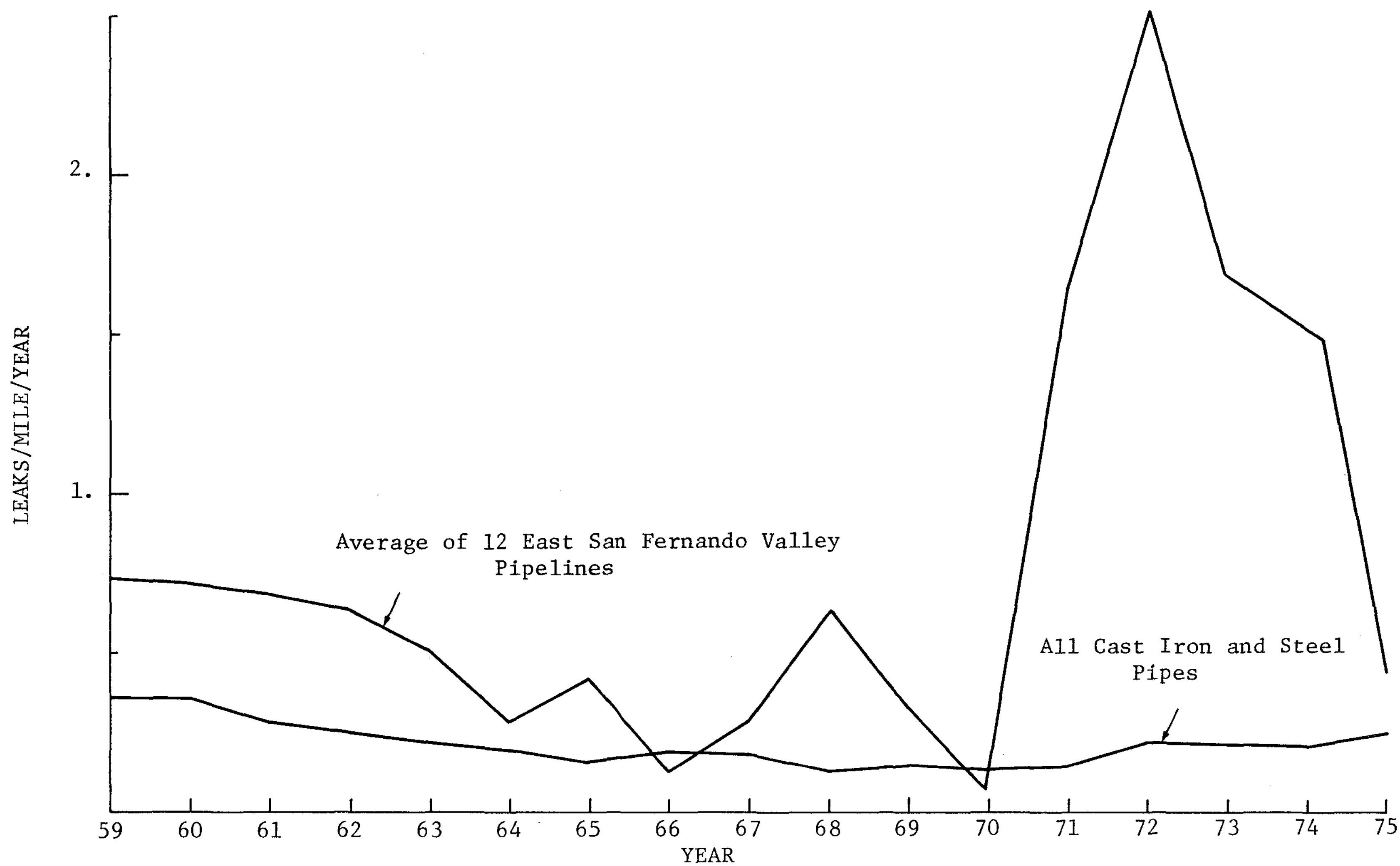


Figure 2-5. Average Annual Leak Rates for all Cast Iron and Steel Pipes in LADWP System and for 12 East San Fernando Valley Pipelines (total 51.4 miles) between 1959 and 1975.

The finding is that the leak frequency of both the 12 East Valley pipes and the entire LADWP system increased significantly over the previous leak rate during 1971 through 1974, whereas up to 1971 the rates had tended to decline. This suggests that the 1971 earthquake may have had a delayed effect on the pipe system, which only became apparent in subsequent years. This could happen if shaking accelerated the weakening of pipes and joints. A contributing factor was a change in the procedure for reporting leaks in cast iron mains in fiscal year 1974-75.

Under normal conditions, leakage is accelerated by corrosion. Low resistivity of the adobe soil is a major contributing factor; for example, the soil underlying Ventura Blvd. between Sepulveda Blvd. and Coldwater Canyon Ave. is on average about 1000 Ω/cm^3, which is borderline between severe and extremely severe conditions for corrosion of steel pipe. It is therefore to be expected that an unprotected steel pipe would experience corrosion-related damage, as does the 6-inch Ventura Blvd. main before, during and after the earthquake. An indirect measure of the importance of corrosion is the generally declining leak rate for all ferrous pipe between 1959 and 1970, during which time there was an active corrosion control program. This program is continuing and presumably will again be effective in reducing leak rates.

SECTION 3

SEISMIC PERFORMANCE OF WATER PIPELINES IN SOUTHEAST SAN FERNANDO VALLEY

3.1 Location of Leaks

Figure 2-4 shows 71 locations where leaks occurred in mains belonging to the LADWP due to the San Fernando earthquake. Repair reports are the principal source of information on the type of damage sustained. These reports, which were prepared by repair crews, indicate the location, size and type of pipe which was repaired, the type of damage (cracked joint or pipe, rust hole, etc.), the presence of internal or external corrosion and the type of soil. The type of repair is often informative regarding the cause of failure (for example, screw pins are commonly used to repair rust holes).

One place leaks are concentrated (1-5, 11, 13-18) is the 6-inch cement-caulked Mannesman steel line under Ventura Blvd. between Sepulveda Blvd. and Coldwater Canyon Blvd., most of which was installed about 1929. A second area of concentration (21-26) is on Woodcliff and Rayneta Drives where there is a similar type of pipe and joint. A third concentration (56-60) is on Laurel Canyon Blvd. between Burbank and Oxnard in a 6-inch Matheson steel line. Transmission lines which suffered a significant number of leaks (40-43) include the 51" welded steel line underlying Elmer Ave. between Moorpark Ave. and the Hollywood Freeway, and the 20-inch reinforced concrete line (51, 64-66) underlying Cahuenga Blvd. north of Chandler Blvd. These five regions contain 31 of the 71 leak locations covered by Map 8 South. The 6-inch Ventura Blvd. line alone contains 12 leaks. There is an apparent preference for leaks to occur in the southern part of the map; 45 of the 71 leak locations are south of the Ventura Freeway. This is an area where the depth to bedrock changes rapidly and, hence, where changes in ground motion that affect pipes might

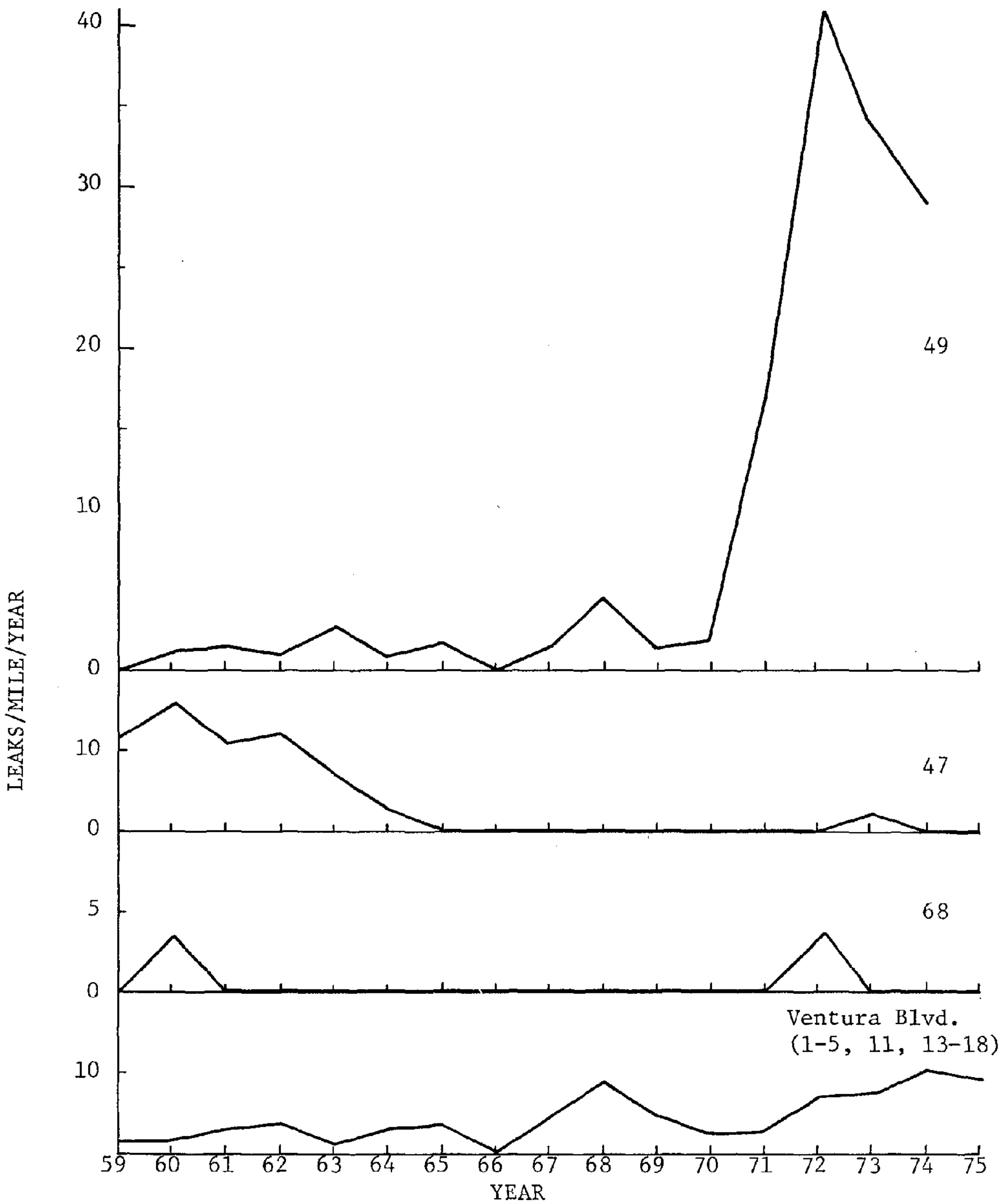


Figure 3-1. Average Annual Leak Rates in Four Southeast San Fernando Valley Pipelines Which Experienced Earthquake Damage From 1959 to 1975. Numbers refer to locations on Figure 2-4.

To illustrate this, locations 47, 49 and 68 (see Figure 2-4) are presented in Figure 3-1. The leak rate in the 6-inch Matheson steel pipe for 3/4 mile on either side of the break at location 49 exceeds the average rates prior to the earthquake. Accordingly, we might expect earthquake damage to occur here, and it did because the pipe was weakened by corrosion. Furthermore, the apparent leak rate increased dramatically in the years following the earthquake. This observation is similar to the one which was made for the 6-inch Mannesman steel pipeline underlying Ventura Blvd. In contrast, leakage was profuse at location 47 in the early 1960's; however, no leaks occurred between 1965 and 1972, except for the earthquake-related leak. The prior leak history at location 47 does not foreshadow the corrosion-related earthquake damage which occurred. The picture at location 68 is similar to that at location 47; the prior history of leakage gives no hint of the seismic vulnerability of this segment of pipe due to corrosion. These mixed results are found throughout the Map 8 South region, and they indicate that local leak rate alone cannot be relied upon to predict the location of corrosion-related leaks in earthquakes.

Another aspect of prediction is whether high local leak rates indicated that certain sections of pipe might be vulnerable to an earthquake but where little earthquake damage or none actually occurred. Figure 3-2 shows the historical leak rates at several locations (see Figure 2-4) where high leakage developed sporadically before the earthquake, but where few leaks or none developed immediately afterward. This finding also illustrates that local leak rate under normal conditions is an inaccurate or incomplete guide to specific locations of earthquake-induced leakage. As is the case in other reaches of pipe, however, the apparent leak rate in these areas significantly increased after the earthquake.

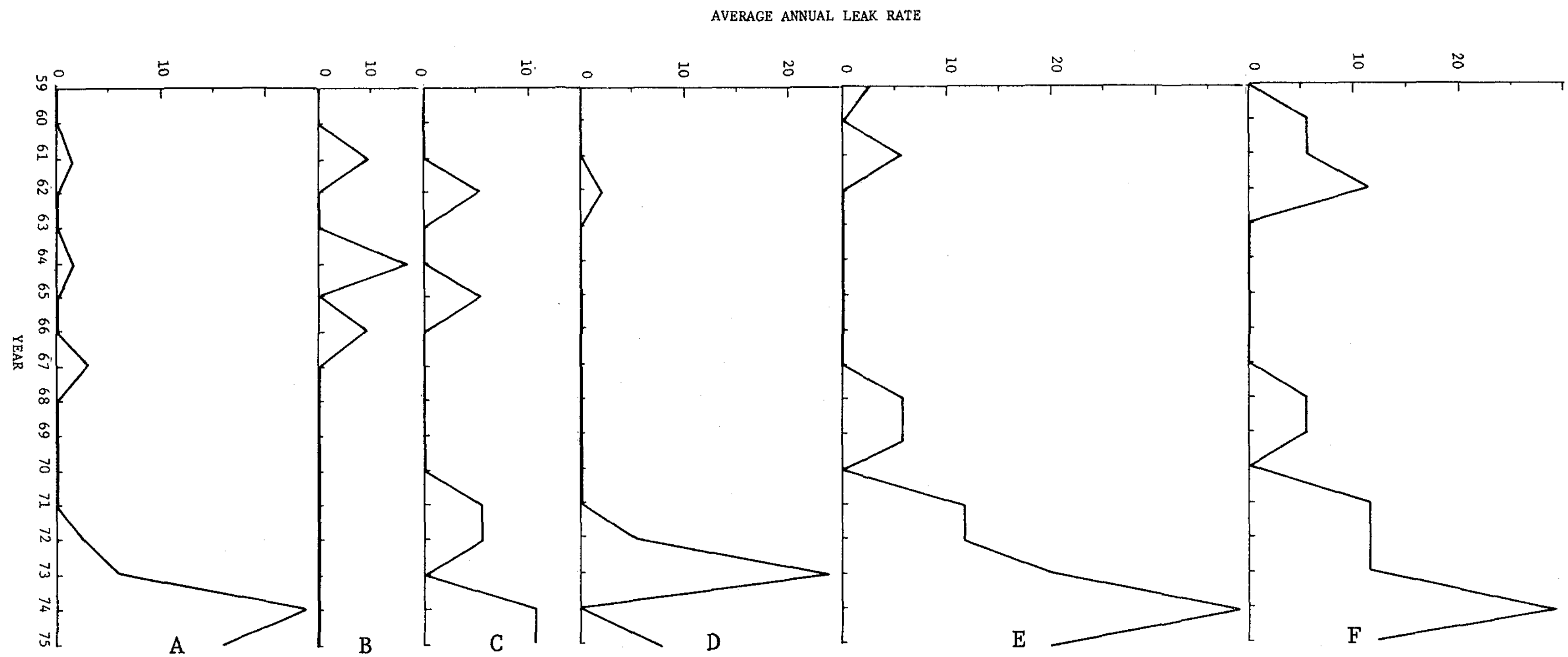


Figure 3-2. Average Annual Leak Rates in Six Areas of Southeast San Fernando Valley. These pipelines exhibited relatively high leak rates prior to the earthquake but suffered little or no damage immediately following the earthquake. Letters refer to locations on Figure 2-4.

3.4. Summary of Findings

In the region considered, over half the leaks are related to corrosion. Broken welds and round cracks in cast iron pipe were other categories of damage. Although the number of leaks appeared to be concentrated near the foothills, the type of damage was uncorrelated with location. In contrast to previous findings, the leak rate under ordinary conditions was not a reliable guide to predicting earthquake damage. In the Southeast San Fernando Valley and in ferrous pipes throughout the LADWP system, the leak rate increased significantly for several years following the earthquake (1971-1974). Part of the apparent increase is due to changes in reporting procedures for leaks in cast iron mains in fiscal year 1974-75. However, the evidence supports this finding with respect to steel mains which are the predominant type in the area of Map 8 South.

TABLE 3-2

MAIN BREAKS—1971 SAN FERNANDO EARTHQUAKE

Abbreviations

C - Corrosion
RC - Round Cracks

CJ - Cast Iron Joint Leak
BW - Broken Weld

GV - Gate Valve Failure
FH - Fire Hydrant

U - Unknown
Serv. - Service (?)

No.	Pipe Size	Type of Pipe	Type of Joint	Location of Break	Date Pipe Installed	Cause of Failure
1	6"	Steel	Cement Caulked	Ventura Blvd. W of Coldwater Cyn. Ave.	1929	C
2	6"	Steel	Cement Caulked	Ventura Blvd. W of Coldwater Cyn. Ave. (2)	1929	C
3	6"	Steel	Cement Caulked	Ventura Blvd. W of Van Noord Ave.	1929	C
4	6"	Steel	Cement Caulked	Ventura Blvd. W of Van Noord Ave.	1929	C
5	6"	Steel	Cement Caulked	Ventura Blvd. W of Van Noord Ave.	1929	C
6	6"	Steel	Cement Caulked	Fulton Ave. N of Valleyheart Dr.	1932	C
7	4"	Cast Iron	Cement Caulked	Longridge Ave. N of Moorpark St.	1927	RC
8	6"	Cast Iron	Cement Caulked	Fulton Ave. N of Moorpark St.	1925	C
9	8"	Steel	Cement Caulked	Moorpark St. W of Fulton Ave. (2)	1937	C
10	8"	Cement Lined Welded Steel	Welded	Valleyheart Dr.	1965	U
11	6"	Steel	Cement Caulked	Ventura Blvd. W of Tyrone Ave.	1929	C
12	6"	Cast Iron	Cement Caulked	Dickens St. E of Van Nuys Blvd.	1924	CJ
13	6"	Steel	Cement Caulked	Ventura Blvd.	1929	U

TABLE 3-2 (Continued)

No.	Pipe Size	Type of Pipe	Type of Joint	Location of Break	Date Pipe Installed	Cause of Failure
31	6"	Mannesman		Laurel Canyon at Woodbridge (2)		U
32	6"	Mannesman		Guerin St. at River Channel		U
33	6"	Matheson		Chiquita St. at Beck		U
34	51"		Welded	Vineland at LA River (3)		GV BW
35	6"			Willowcrest at Brookview		U
36	6"	Matheson		Farmdale Ave. at Woodbridge		U
37	6"	Mannesman		Camellia at Woodbridge (3)		C
38	6"	Mannesman		Camellia at Woodbridge		U
39	24"		Welded	Moorpark Blvd. at Radford (2)		U
40	51"		Welded	Elmer St. at Moorpark		BW
41	51"		Welded	Elmer St. at Rye St.		BW
42	51"		Welded	Elmer St. at Landale		BW
43	51"		Welded	Elmer St. at Landale (2)		BW
44	?			Riverside Dr. at Camellia		U
45	4"			Otsego St. at Irvine		U
46	6"	Mannesman		Hartsook St. at Laurel Grove		C

TABLE 3-2 (Continued)

No.	Pipe Size	Type of Pipe	Type of Joint	Location of Break	Date Pipe Installed	Cause of Failure
61	4"			Craner Ave. bet. Collins St. & Hatteras St.		RC
62	6"			Vineland Ave. bet. Collins St. & Hatteras St.		GV
63	6"			Vineland Ave. bet. Collins St. & Hatteras St.		U
64	20"	R		Cahuenga Blvd. at Whitnall Fwy. (2)		C
65	20"	R		Cahuenga Blvd. at Califa		C
66	20"	R		Cahuenga Blvd. at Califa		U
67	12"	R		Oxnard Blvd. at Ensign Ave. (5)		C,GV
68	8"	Matheson		Laurie Dr. at Lola Dr.		C
69	6"	Steel	Cement Caulked	Chandler at Matilja		C
70		Fire Hydrant		Burbank at Laurel Canyon		FH
71	6"	Steel		Vesper Ave. N of Ventura Blvd. (6)		C

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

This study and the one of Reference 4 show that corrosion is a major factor in determining where leaks occur in areas undergoing ground shaking as well as under normal conditions. Hence, steps to reduce corrosion rates will benefit utilities in both situations. Before this information can be put to practical use, however, weak reaches of pipe must be recognized. No methods of locating weak pipes underground are now readily available to utilities, and even if there were it appears impractical to try to identify specific weak points throughout a complex system such as the one operated by LADWP. A more manageable approach would be to subdivide a pipe network into regions, say, ¼ km or ½ km on a side, and to characterize the zone by such factors as the types and sizes of pipe within the zone and modified by an average stage of corrosion which characterizes that zone. Such characterization could become a basic element of repair criteria and probabilistic risk studies.

It remains to define a procedure for estimating the stage of corrosion and the rate of its progress. Since the use of the corrosion data will be in probabilistic analyses, it seems appropriate to obtain the data by random sampling. Devices such as that described in Reference 5 could be used to sample each zone as part of the inspection and maintenance routine. Leak rate, already used in a semi-automated manner by some utilities to guide replacement practices, Reference 14, should also be considered.

Although the findings are based on too narrow a study to merit being called conclusions, there are strong indications that the effects of ground shaking on pipelines continued in San Fernando Valley for several years after

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