Damage to Water Pipes During the 1994 Northridge Earthquake

Masanori Hamada
Professor of Civil Engineering, Waseda University

Takashi Tazoh
Senior Research Engineer, Shimizu Corporation

Toshiyuki Iwamoto
Senior Research Engineer, Kubota Corporation

Nobuhisa Suzuki
Senior Research Engineer, NKK Corporation

Jyohji Ejiri
Senior Research Engineer, Ohbayashi-Gumi Corporation

and

Keizo Ohtomo
Senior Research Engineer, Central Research Institute of Electric Power Industry

ABSTRACT

This paper presents damage to pipes of a water supply network system under the control of the Department of Water and Power of City of Los Angels (LADWP). Site investigation was conducted at San Fernando Valley where the damage to trunk lines, distribution pipes and service pipes were concentrated.

Sixteen breaks of large diameter trunk lines and approximately 1,670 breaks of small diameter distribution pipes and service pipes were damaged during the earthquake. The damage to the trunk lines contains breaks of joints and pipes of an old riveted trunk line buried along Roscoe Street, which breaks were occurred just over or very close to the epicenter. Other typical damage to the trunk lines were telescopic crashes and failures in tension of welded bell joints due to slight permanent ground movement at Balboa Boulevard.

Most of the breaks of small diameter distribution pipes were caused to old and weak gray cast iron pipes connected with sockets and spigot joints, whose flexibility or strength against dynamic and permanent ground movement could not be expected. And the breaks include those of the service pipes were concentrated in Northridge district including Granada hills, San Fernando district and Sherman Oaks district.

INTRODUCTION

Water supply system of City of Los Angels were affected by the 1994 Northridge earthquake, which magnitude was Ms=6.8. The epicenter was located at Northridge district of San Fernando valley and the depth was 18 km. Peak accelerations more than 1.0 g were measured at several observation points near the epicenter [1].

The epicenter area is adjacent to that of the 1971 San Fernando earthquake. As the earthquake occurred beneath an urbanized and populated area, there were also a lot of localized damage to other lifeline structures such as a gas supply system, a power supply system, a telecommunication system and a traffic system.

One of the most serious result occurred by the earthquake was a fire and flooded water on Balboa Blvd. It has been pointed out that an interaction between lifelines during an earthquake would become the most important subject. The chaos happened at Balboa Blvd. might be different from the interaction pointed out, however, it implied that we have to consider possible occurrences of similar confusion and scenarios how to cope with the unexpected confusion.

Sixteen breaks of large diameter trunk lines and approximately 1,670 breaks of small diameter distribution pipes and service pipes were occurred. The damage to the trunk lines contains breaks of joints and pipes of an old riveted trunk line buried along Roscoe Street which passes over the epicenter. Other typical damage to the trunk lines were telescopic crashes and failures in tension of welded bell joints due to slight permanent ground movement at Balboa Boulevard.

Most of the breaks of small diameter pipes, distribution pipes, were caused to old and weak gray cast iron pipes connected with sockets and spigot joints, whose flexibility and strength against seismic excitation could not be expected. And the breaks were concentrated in Northridge district including Granada hills, San Fernando district and Sherman Oaks district.

This investigation had been carried out for ten days from March 16 as a part of a study of the research group on 'Seismic Design and Mitigation of Structures at Water Front Area' organized in ADEP. As the investigation team was sent to the interested areas about two months after the earthquake, most of restoration works for the damaged water pipes had been completed. So most of the information described in this paper were offered by engineers of the headquarter and the West and East Valley District Office of LADWP.

WATER SUPPLY SYSTEM OF CITY OF LOS ANGELES

Distribution System

LADWP distributes 2,600,000 m^3 per day to 660,000 meters which are approximately equivalent to 3,600,000 customers [2]. The amount of water has been supplied from three sources which are the Los Angeles Aqueduct derived from Sierra Nevada mountains, ground water of San Fernando

Valley and purchase from the MWD (Metropolitan Water District). Percentage of the sources are 75 %, 15 % and 10 %, respectively.

The location of the aqueducts and reservoirs of LADWP are shown in Fig.1. Total length of distribution pipes is as long as 7,000 miles and their diameters range from 4 to 12 inches. The water gathered from the sources is saved in 107 reservoirs and is distributed by gravity flow or via 85 pump stations to 102 subdivided distribution blocks. The maximum reservoir is the San Fernando Lake, which locates in the north of San Fernando Valley.

The distribution area is subdivided into five districts as shown in Fig.2, which districts are the West Valley, the East Valley, the Western, the Central and the Harbor districts.

Damage to Pipes

Approximately 65 % of 1,670 breaks of the pipes were occurred in the West Valley district and 35 % of that in the East Valley district [3][4]. And most of the damage were concentrated in three areas as shown in Fig.3. About 800 breaks were reported within area A, and 60 in area B, and 360 in area C. The number of the damage to the trunk lines were accumulated to 16 including damage to Granada trunk line at Balboa Blvd.

WEST VALLEY DISTRICT

Distribution System

Figure 4 shows the network of trunk lines of the West Valley district of LADWP. Some of the trunk lines are riveted steel pipe constructed in the 1910's. Some of them are steel pipes with one end of the pipe is flared (bell joint) and the joints are connected with fillet-weld.

The bell joints with fillet weld have been used to reduce construction works and minimize the set-up time of the pipes in the U.S., on the contrary, butt-welded joints have been used for the construction to utilize the strength of steel pipes and survive against various seismic effects in Japan. The distribution pipes are gray cast iron pipes, ductile iron pipes, steel pipes and asbestos cement pipes and percentage of total length are 70-80 %, 15-20 %, 2-3 % and 2-3 %, respectively.

Damage to Pipes

The number of damage to the trunk lines was 16, the distribution pipes 800, and the service pipes 230. Ninety percent of the damage to the distribution pipes were occurred to the gray cast iron pipes having lead or cement caulked joints. There was no damage to the gray cast iron pipes having the joint sealed with a rubber ring because it generates enough bending flexibility of the joint against the ground motion.

The damage to the gray cast iron pipes were reported as breaks of the pipes and slip-out of the joints. The breaks of the pipes were mainly cracks in the circumferential direction and occurred at tapping sleeves for fire hydrants. The damage to the asbestos cement pipes were breaks of pipes

and joints because of their fragility and low strength. The damage to the steel pipes were cracks of welded joints of 45 degree bends. The ductile iron pipes could survive during the earthquake.

Six breaks were occurred to Roscoe trunk line as shown in Fig.4, which was constructed in 1918 and the diameter ranges from 35 to 42 in. The pipes of Roscoe trunk line were connected with rivets both in the circumferential and the longitudinal seams. Some of the damage can be considered as effects of ground deformation as Fig.5 shows cracks near the points on Roscoe St. where the damage were occurred.

Granada and Rinaldi trunk lines were broken in compression and tension at Balboa Blvd. The different kinds of failures of the two trunk lines were occurred at points whose distance was from 80 to 100 ft as shown in Fig.5. Photo 1 shows a compressed welded bell joint taken from Granada trunk line and the length of compression is estimated approximately 1 ft. The distance of the pipes failured in tension was about from 12 to 15 ft apart from each other. Another compressive collapse was reported at a point close to the intersection of Balboa Blvd. and Rinaldi St.

Table 1 shows observed changes of surface along Roscoe St. and related changes of sidewalks near damaged points. The numbers in the table correspond the damage to the pipe from the east to the west. And the street inclines toward the east as shown in the table. We can find obvious relationship between damage to pipes and cracks on the street at four of seven points of the table. We can also observe the cracks at 1/3 of flat point and 3/4 of inclined point. And widths of the opening cracks are from 0.2 to 0.4 in.

Ring supports of another 60 in. diameter trunk line was collapsed to the south of Lower Van Norman lake, which trunk line was constructed in the 1920's. This failure was affected by the link of concrete supports, however, the pipe and the joint themselves were undamaged as shown in Photo 2. It seems to be the most preferable failure mode under the effects of earthquakes.

EAST VALLEY DISTRICT

Distribution System

Steel pipes having diameters ranging from 16 to 60 in. are mainly used for the trunk lines of the East Valley District. The gray cast iron pipes are used for a very small percentage of the trunk lines. Also gray cast iron pipes are used for more than 90 percent of the distribution pipes and their diameters are smaller than 12 in.

The joints of the distribution pipes are lead or cement caulked or sealed with rubber rings. Ductile iron pipes have been used since 1980 instead of the gray cast iron pipes. Copper pipes are used for service pipes.

Damage to Pipes

Damage to the trunk lines were concentrated to the joints of the gray cast iron pipes whose diameter is 24 in. The number of reported damage was five, however, riveted steel pipes buried at the

same area survived and undamaged. Approximately 420 failures of the joints of the gray cast iron pipes were restored. There were no damage to the ductile iron pipes having been laid alongside the damaged gray cast iron pipes. More than 200 failures of the service pipes were reported.

CONCLUDING REMARKS

The damages to the distribution pipes, which diameters are comparatively small, were concentrated to the weak and old gray cast iron pipes having joints with less flexibility and strength. The damage were also concentrated at three areas in San Fernando Valley, where the foundation is soft or the boundary region of hard and soft foundations.

And the damage to Roscoe trunk line were comparatively small although the trunk line is buried just over the epicenter and the strength of the pipes could not have been expected against seismic excitation. On the other hand, the pipes of Granada trunk line and Rinaldi trunk line are connected with welded bell joints, however, there were some failures in compression and tension related to permanent ground deformations. Analytical and experimental studies should be required to estimate the strength of the joint and find out some countermeasures.

The maximum acceleration of ranging from 0.5 to 1.8 g were recorded, however, the damage to pipes or failure rate (number of failures per unit length) were smaller than those reported during past earthquakes. The failure rate of the pipes are equivalent to that have occurred by an earthquake with the magnitude of 0.30 g. Similar tendency of the damage was observed due to the 1993 Kushiro-oki earthquake. These facts may yield a consensus comment on that the seismic design of underground lifeline structures based on ground acceleration should be implemented or revised.

REFERENCES

[1] UCB, "Preliminary Report on the Seismological and Engineering Aspects of the January 17, 1994, Northridge Earthquake," UCB/ERRC-94/01, Jan. 1994.
[2] LADWP, 'Department of Water and Power, City of Los Angeles.'
[3] Lund, L.V., "Northridge Earthquake, January 17, 1994, Lifeline Performance," ASCE Technical Council on Lifeline Earthquake Engineering, 1994.
[4] Edited by Goltz J.D., "The Northridge, California Earthquake of January 17, 1994," Technical Report NCEER-94-0005, Preliminary, March 1994.

ACKNOWLEDGMENT

Most of the data used in this paper have been offered by engineers of LADWP. The authors would like to express their appreciation to Mr. R.L.Simmons and Mr. C.T.Horner of the Head Office of LADWP, Mr. J.A.Castruita and Mr. S.Malinoski of the West Valley District Office, and Mr. M.Lopez and Mr. R.Togazzini of the East Valley District Office.

The authors also wish to express appreciation to Prof. T.D.O'Rourke and Dr. Y.Shiba of Cornell University, Dr. R.T.Eguchi and Dr. J.D.Goltz of EQE International and Mr. J.Ikeda of ADEP for their invaluable advice and comments.

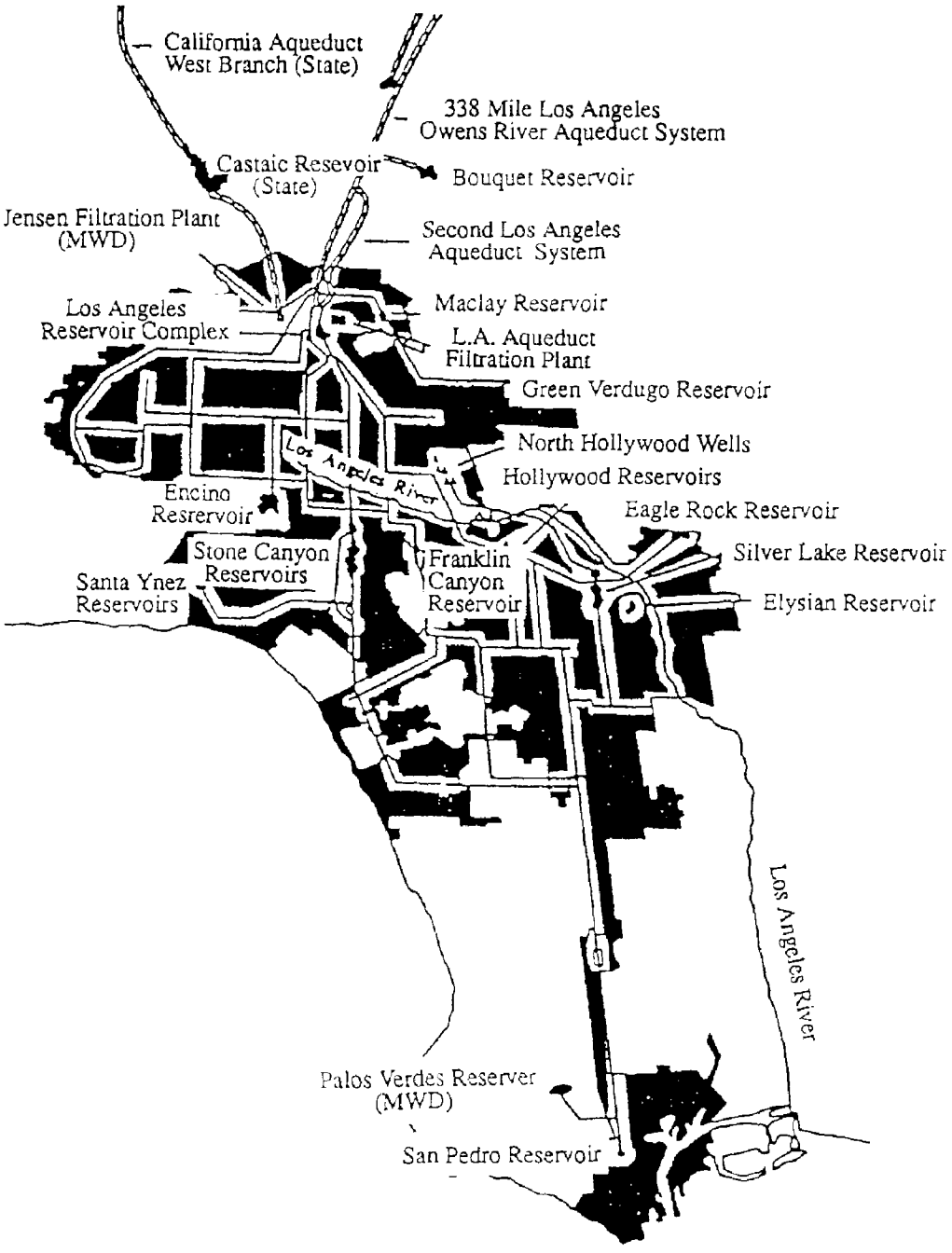


Figure 1 Aqueducts and Reservoirs of LADWP

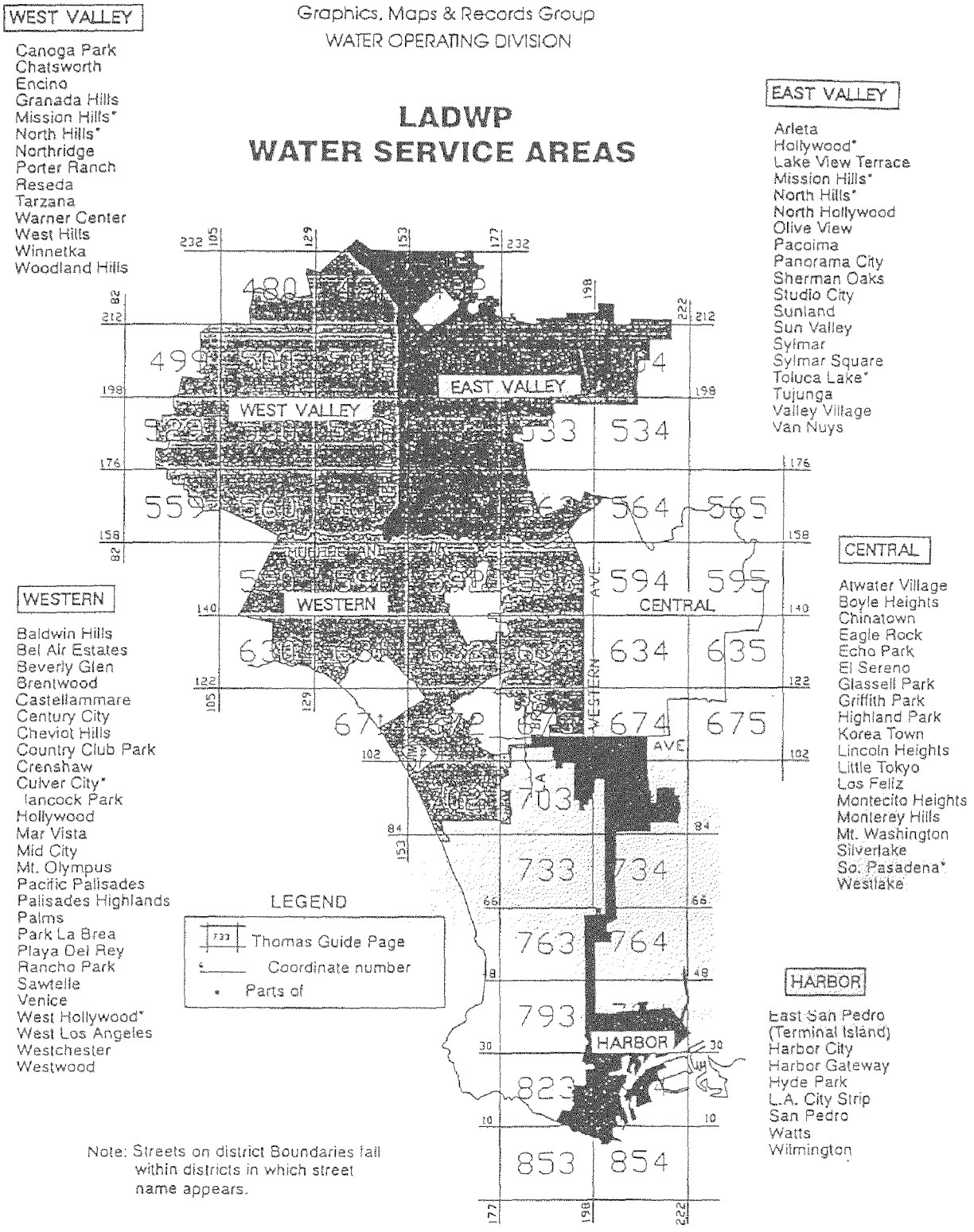


Figure 2 Water Distribution District of LADWP

Figure 3 Concentrated Areas of Damage to Distribution and Service Pipes

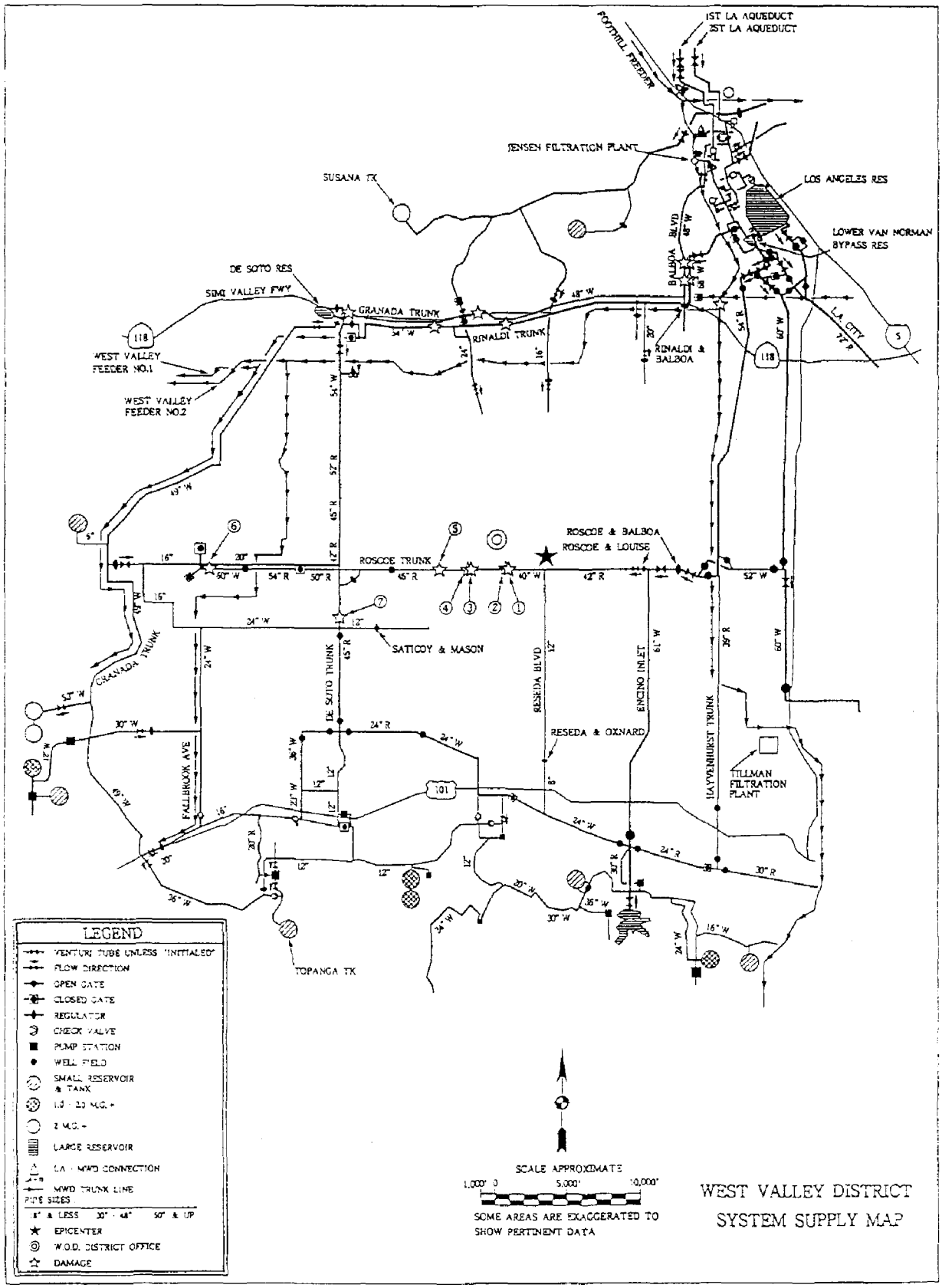


Figure 4 Damage to Trunk Lines at West Valley District

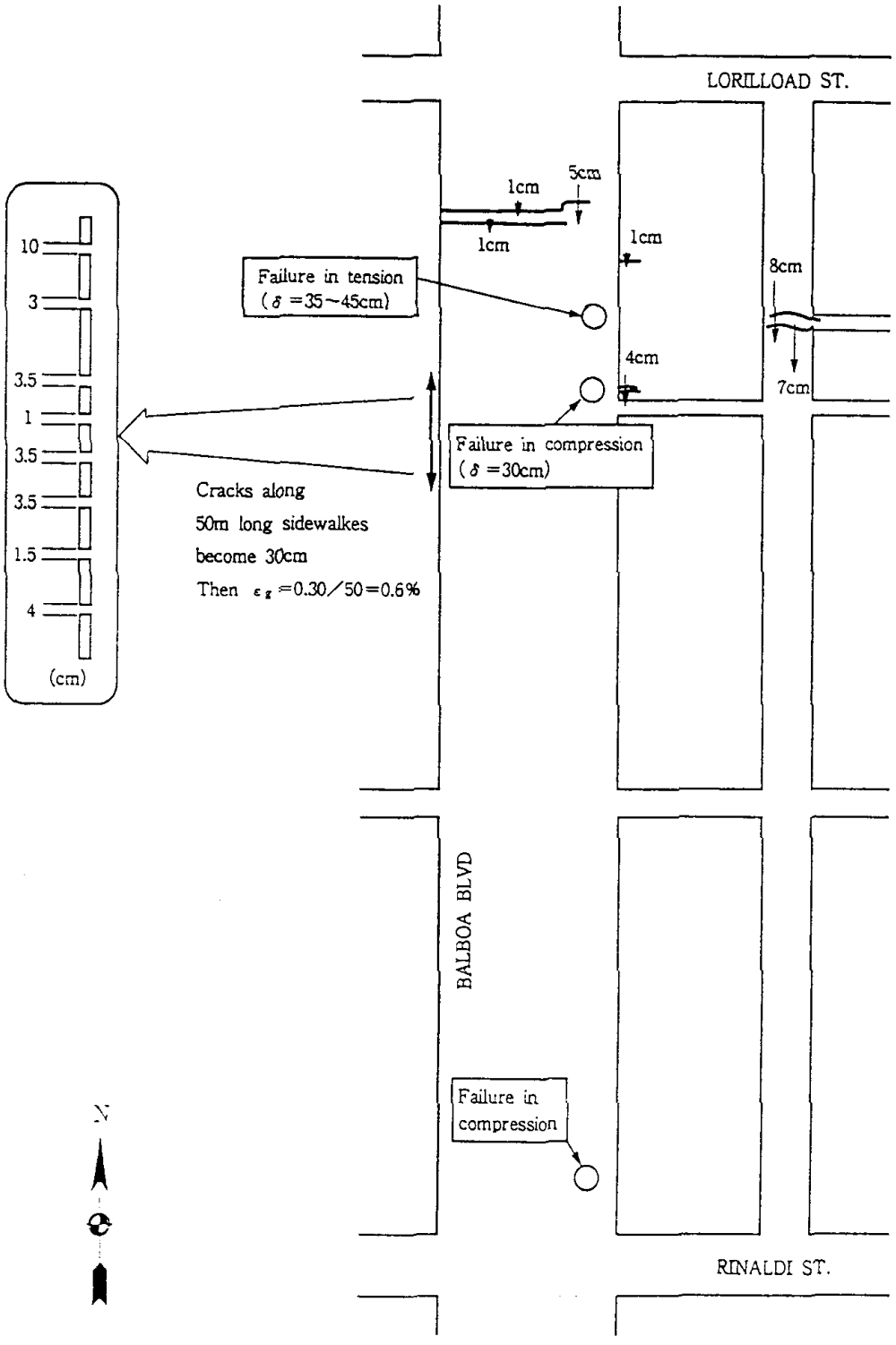


Figure 5 Damage to Trunk Lines at Balboa Blvd. and Permanent Ground displacements

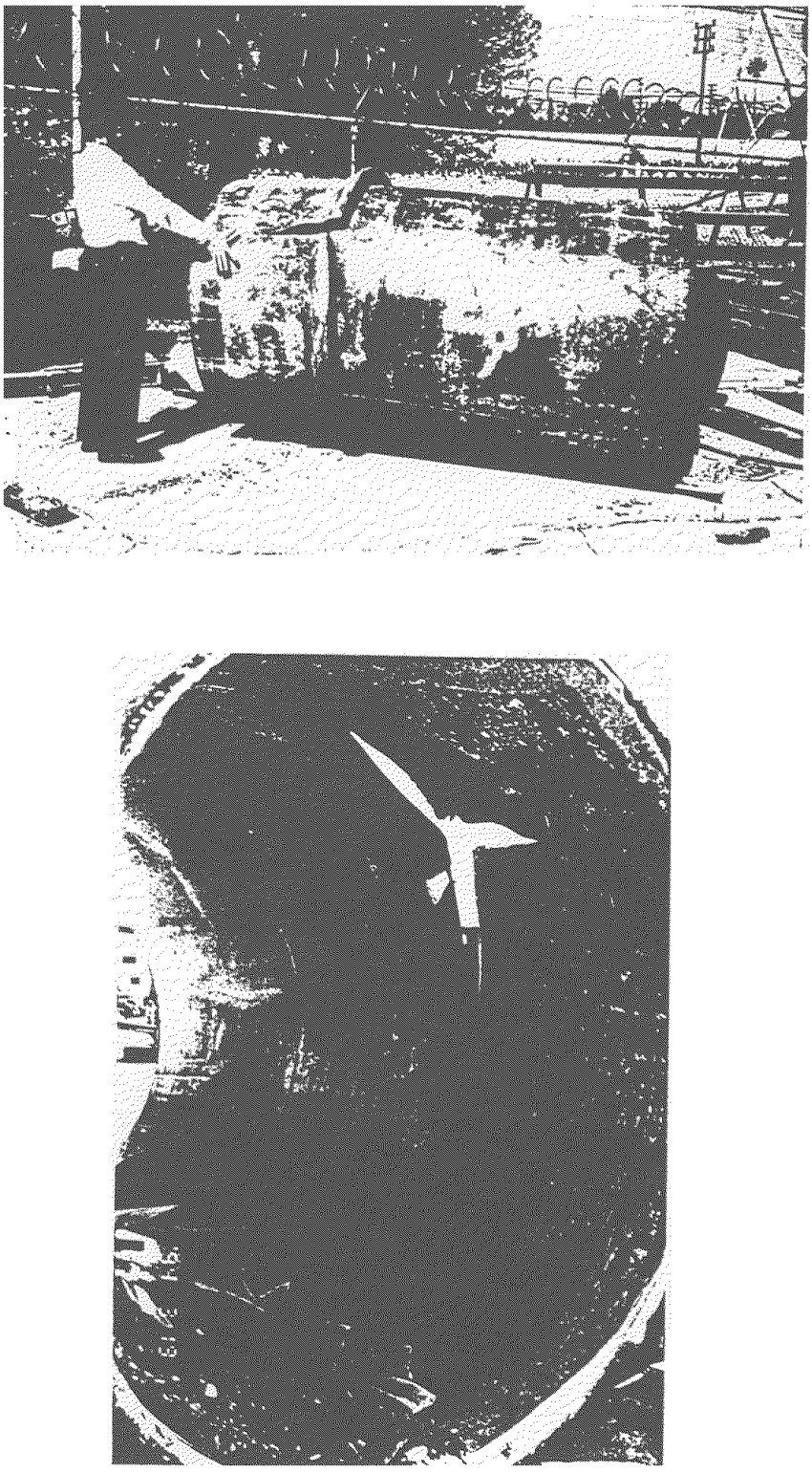
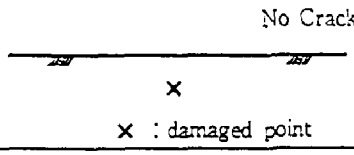
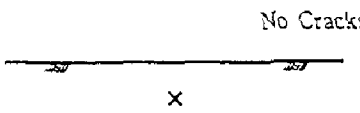
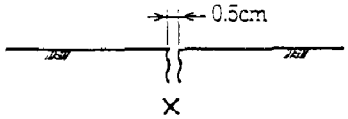
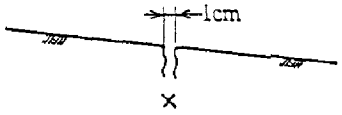
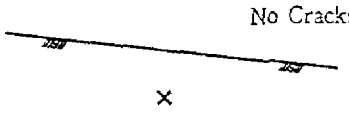
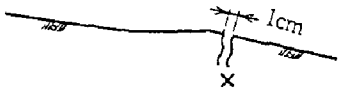
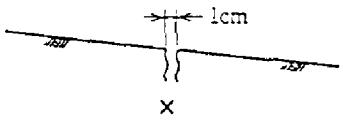


Photo 1 Damage to Granada Trunk Line

Table 1 Fissures Observed Near Damaged Points Along Roscoe Trunk Line

No.	Surface	Changes on Surface	Avenue
1	Flat		Fallbrook Ave.
2	Flat		Oakdale Ave.
3	Flat		Oakdale Ave.
4	Inclined		Shirely Ave.
5	Inclined		Shirely Ave.
6	Inclined		Wilbur Ave.
7	Inclined		Desoto & Ingomar