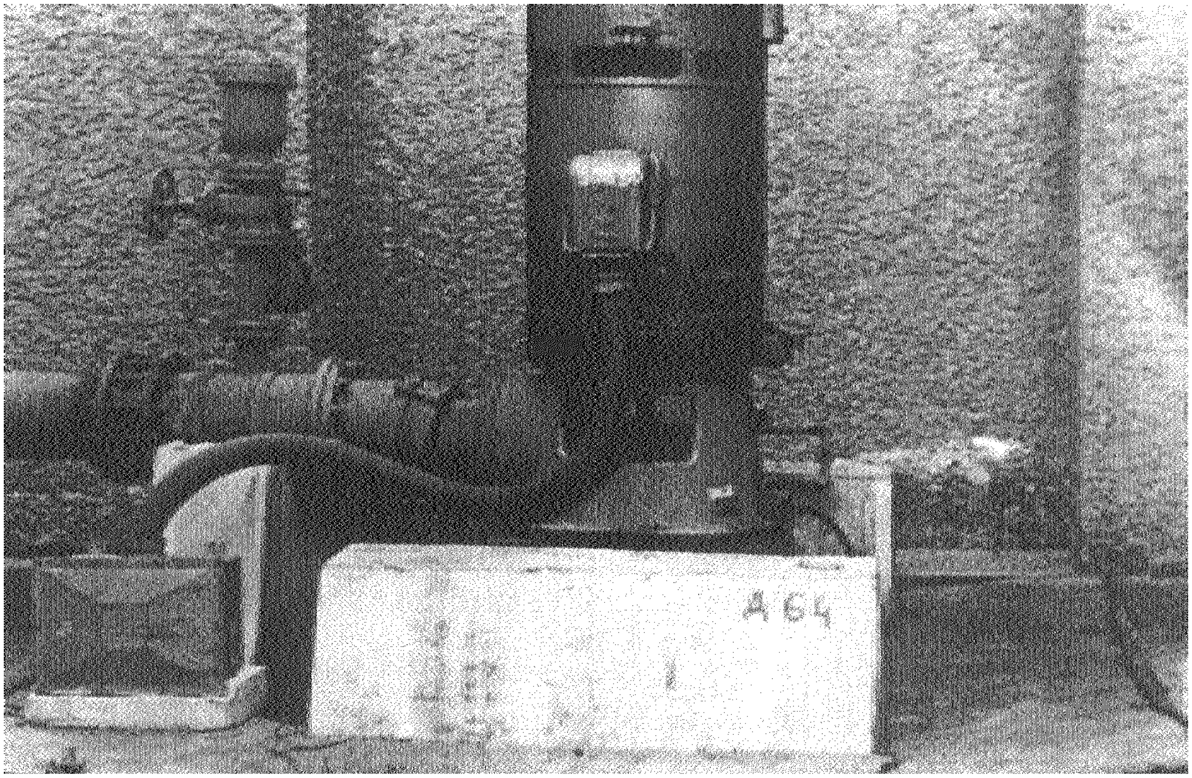

FIGURE 6-19 Well Damage At 'La Caldera' Tank, 1985 Michoacan Earthquake

TABLE 6-V Available Damage Statistics For The Municipio De Ecatepec

Diameter(in)	1/2	2 1/2	3	4	6	8	12	24	30	36	48
# of leaks.	185	15	68	26	14	9	7	1	2	1	1

and also produced a relatively rigid connection at the street main service connection interface. On the other hand, service connections in the State of Mexico were made of plastic materials such as PVC. A typical flexible service connection that behaved successfully during the Michoacan earthquake is shown in figure 6-20.

Apparently the flexible service connections used in the State of Mexico were able to accommodate, without failure, the seismically induced ground deformation. Many of the more rigid service connections used in the Federal District typically broke at the service connection street main interconnection point when subject to similar intensities of ground deformation.

6.4 Subsidence

As mentioned in section 6.1.3, long term subsidence is a possible contributing factor to seismic damage experienced by the Mexico City water systems. This subsidence is due to the removal by pumping of subsurface water and is most pronounced in the older parts of the city. Ground settlement versus time for two sites in the older part of the city is shown in figure 6.21. Note that during the thirty year period from 1940 to 1970, the ground settled about 5 meters at these two sites.

The settlement however was not uniform as shown by the equal subsidence contours in figure 6-22. In 1970 the settlement along Melchor Ocampo was between 3.0 and 3.5m. while the settlement along one section of Avenue Juarez was 8.5m. These two locations are seperated by about 2000m. Assuming the 2 km separation distance between the Melchor Ocampo and the Ave. Juarez sites remained constant since the turn of the century, (ie since substantial subsidence began) the subsidence induced ground strain between the two sites would have been about 3.1×10^{-6} in 1970. This subsidence induced ground strain is illustrated in figure 6-23.

As will be shown in Section 7, the earthquake induced ground strain in the Lake Zone soils are estimated to be at least two orders of magnitude larger than the subsidence induced ground strain calculated above. Hence although subsidence surely caused deformation at the joints of the segmented water

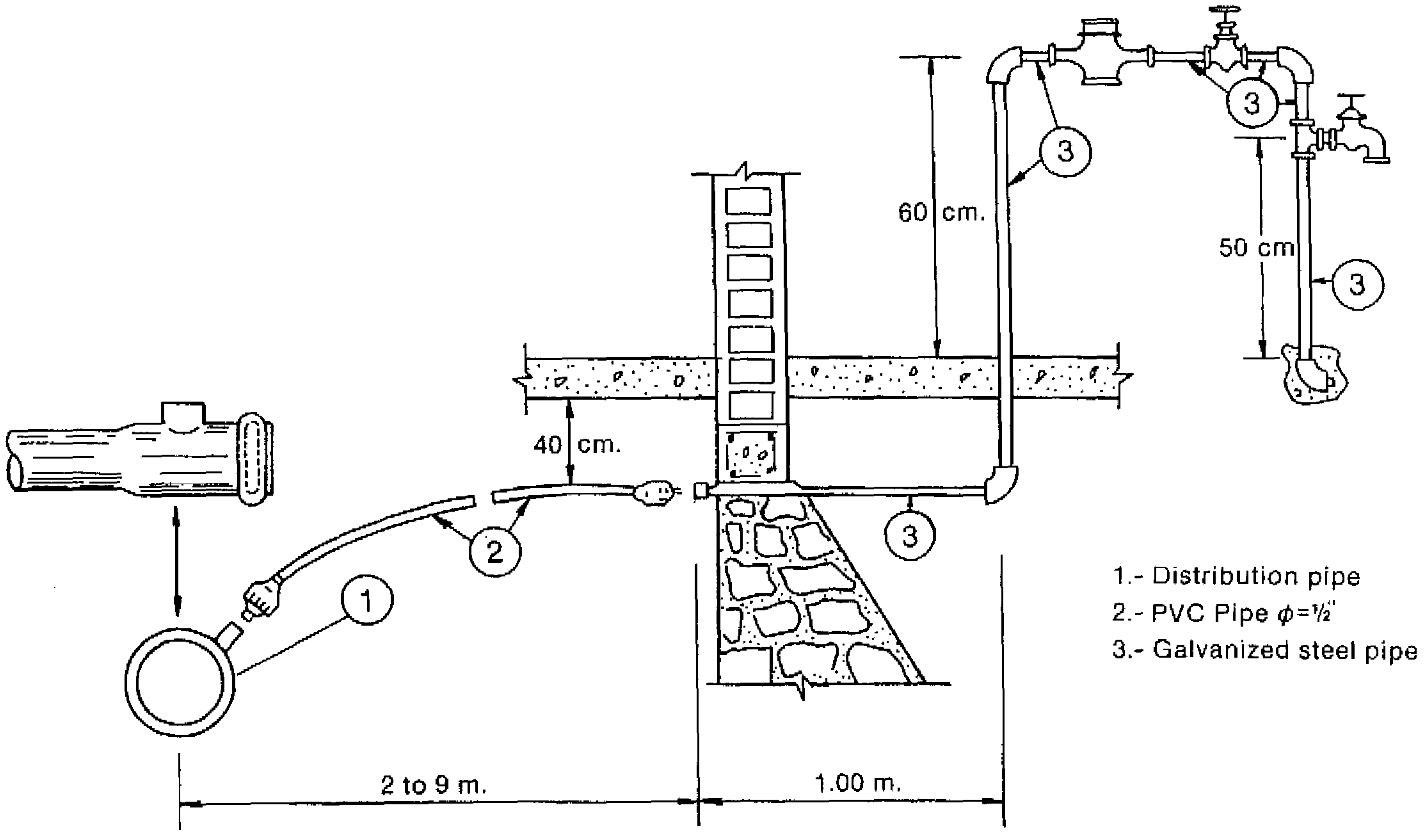

FIGURE 6-20 Typical Residential Service In The State Of Mexico (E.de.M.)

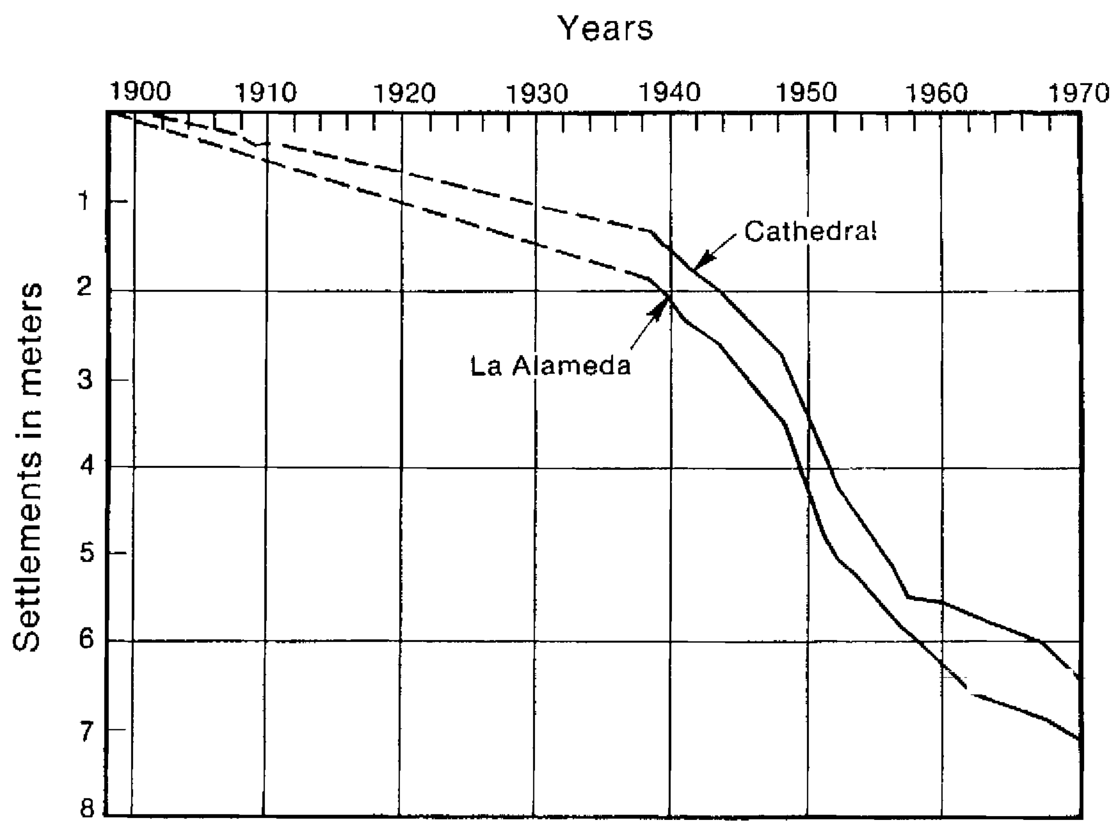

FIGURE 6-21 Settlement Vs. Time For Two Sites In Mexico City (After [5])

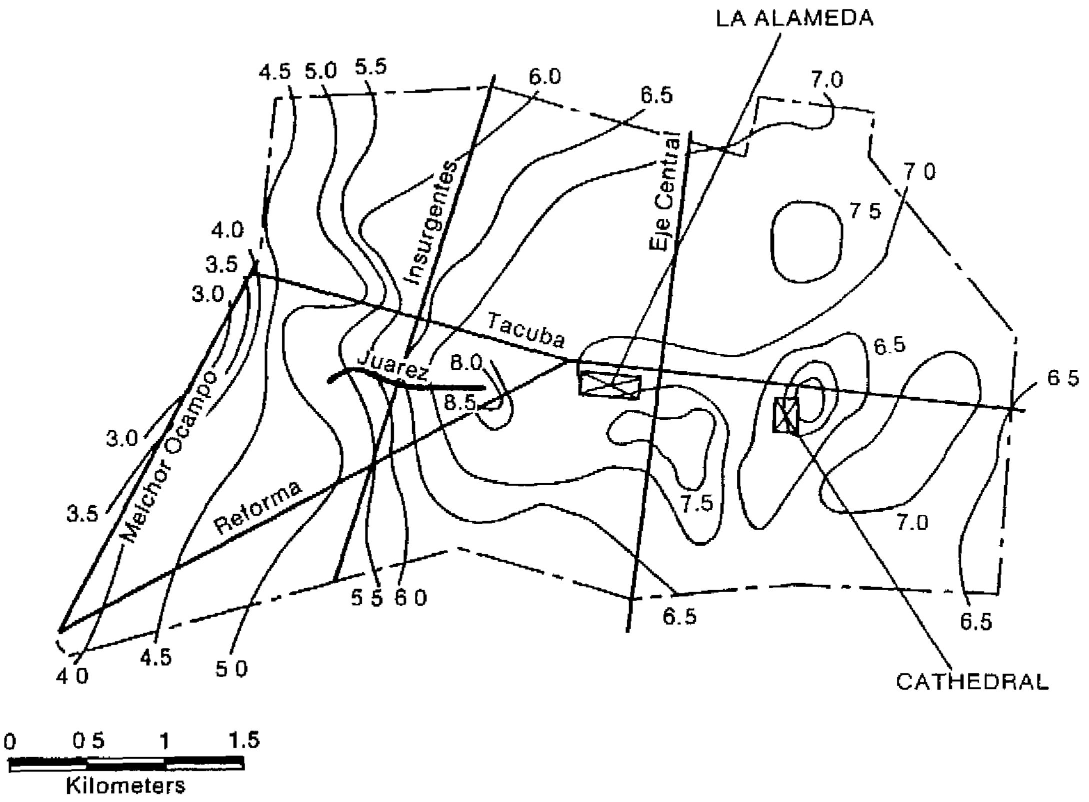

FIGURE 6-22 Contours Of Equal Subsidence In Old Mexico City As Of 1970 (After [5])

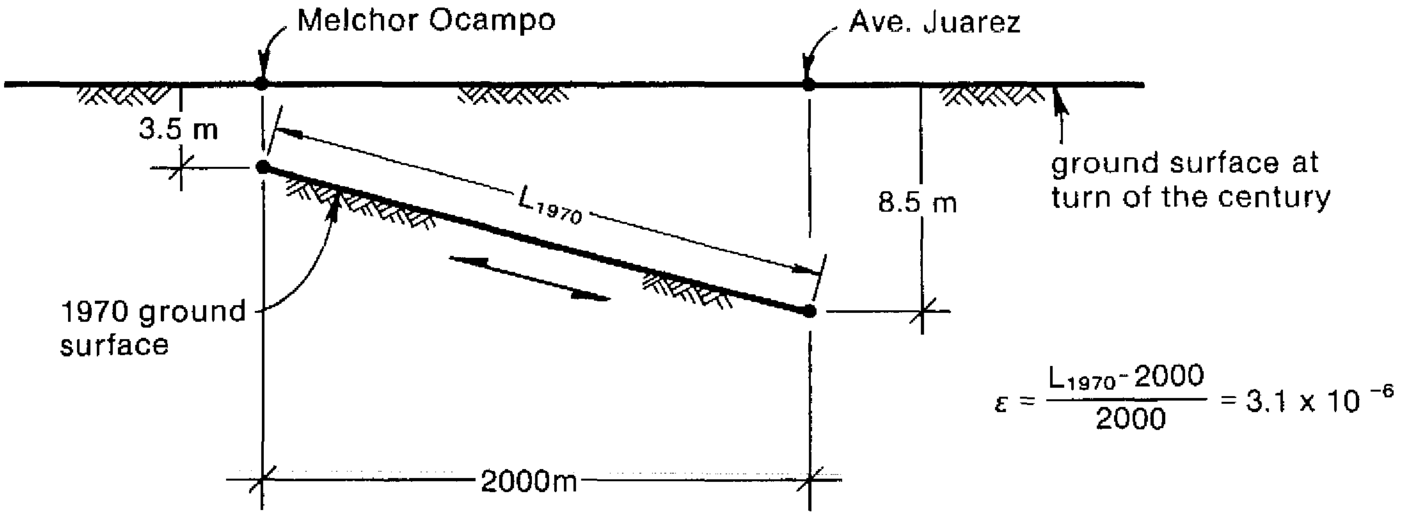

FIGURE 6-23 Ground Strain In Old Mexico City Due To Subsidence As Of 1970

system piping of Mexico City, it appears to be a second order effect vis-a-vis seismic wave propagation effects.

6.5 Comparisons with Other Earthquakes

Figure 6-24 shows data on pipe repairs versus peak ground acceleration, presented by Bresko [9], and based on damage data gathered by Katayama, [10]. Mexico City data for the Lake Zone is included in this figure. It can be seen that data from Mexico City falls within the band of damage data of other major earthquakes. Bresko suggests, based on these data, that failure rates can be expressed in terms of maximum ground acceleration as

$$\log N = A + 6.39 \log a_{max} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6.1)$$

where N is the number of repairs per kilometer, a_{max} is the maximum ground acceleration and, A is a function of factors such as soil conditions, pipe age, etc., and is defined as 4.75, 3.65 and 2.20 for poor, average and good conditions respectively.

Theoretical analysis suggests that seismic wave propagation induced ground strain is proportional to peak ground velocity. Figure 6-25 presents the average damage ratios in Mexico City, per soil zone versus peak ground velocity. As one might expect, the peak ground velocities and damage ratios are high in the Lake Zone. However the damage ratio in the Transition Zone is somehwat higher than that in the Hill Zone although the peak ground velocities are comparable. This difference between Transition and Hill Zone damage ratios could be attributed to additional incoherence in ground motion in areas with changing soil types (such as the Transition Zone).

A graph of damage ratio for primary distribution piping vs pipe diameter is shown in figure 6-26. It may be observed that, as previously mentioned by Katayama [10] and others, damage ratio tends to be smaller as pipe diameter increases. Also, as expected, pipeline damage was larger in soft soils than in hard soils as may be observed from the data in table 6-VI.

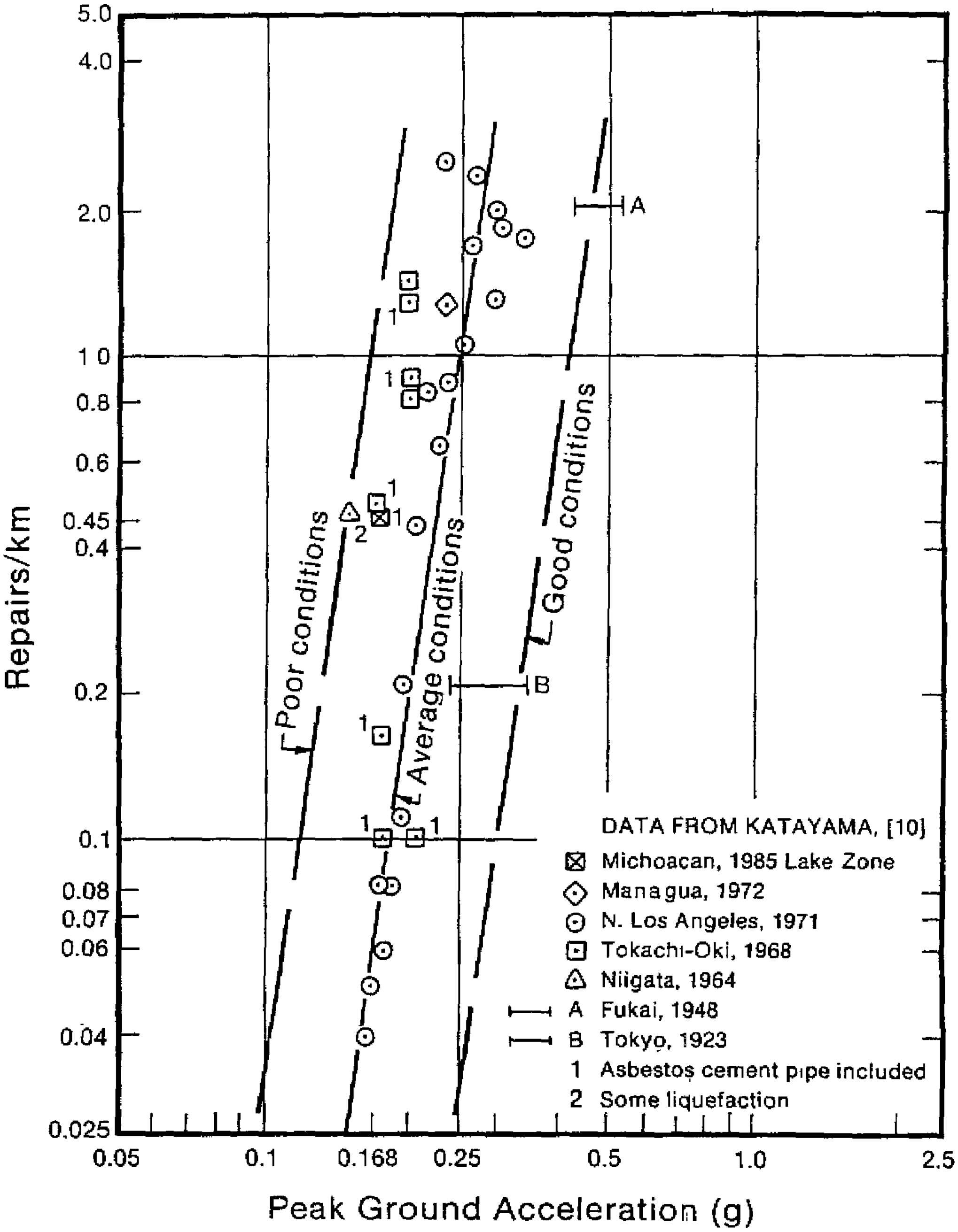

FIGURE 6-24 Pipe Repairs Per Km. Vs. Peak Ground Acceleration For Lake Zone In Mexico City 1985 And Other Historic Earthquakes

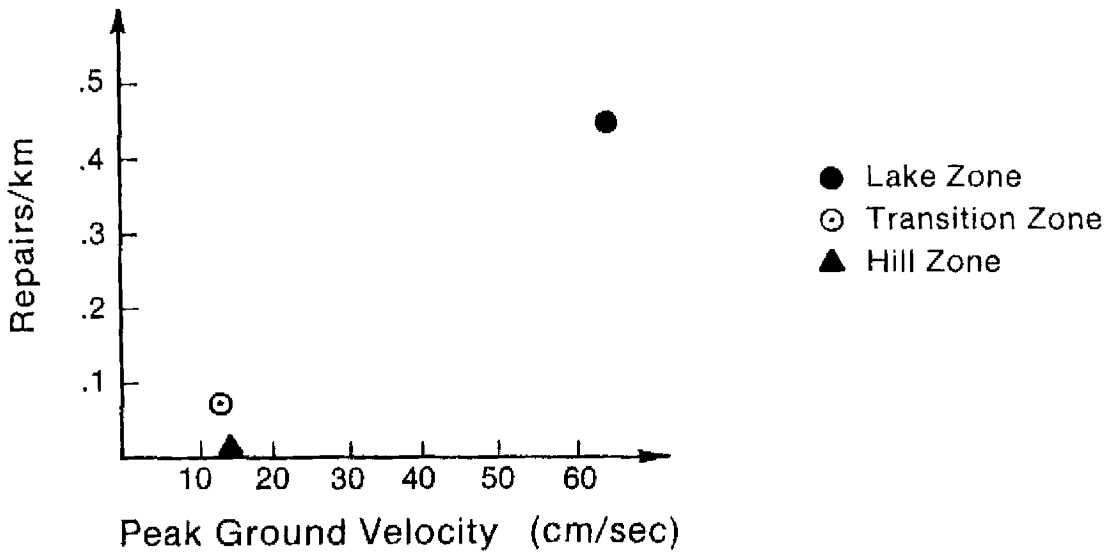

FIGURE 6-25 Damage Ratio Vs. Peak Ground Velocity, Mexico City 1985

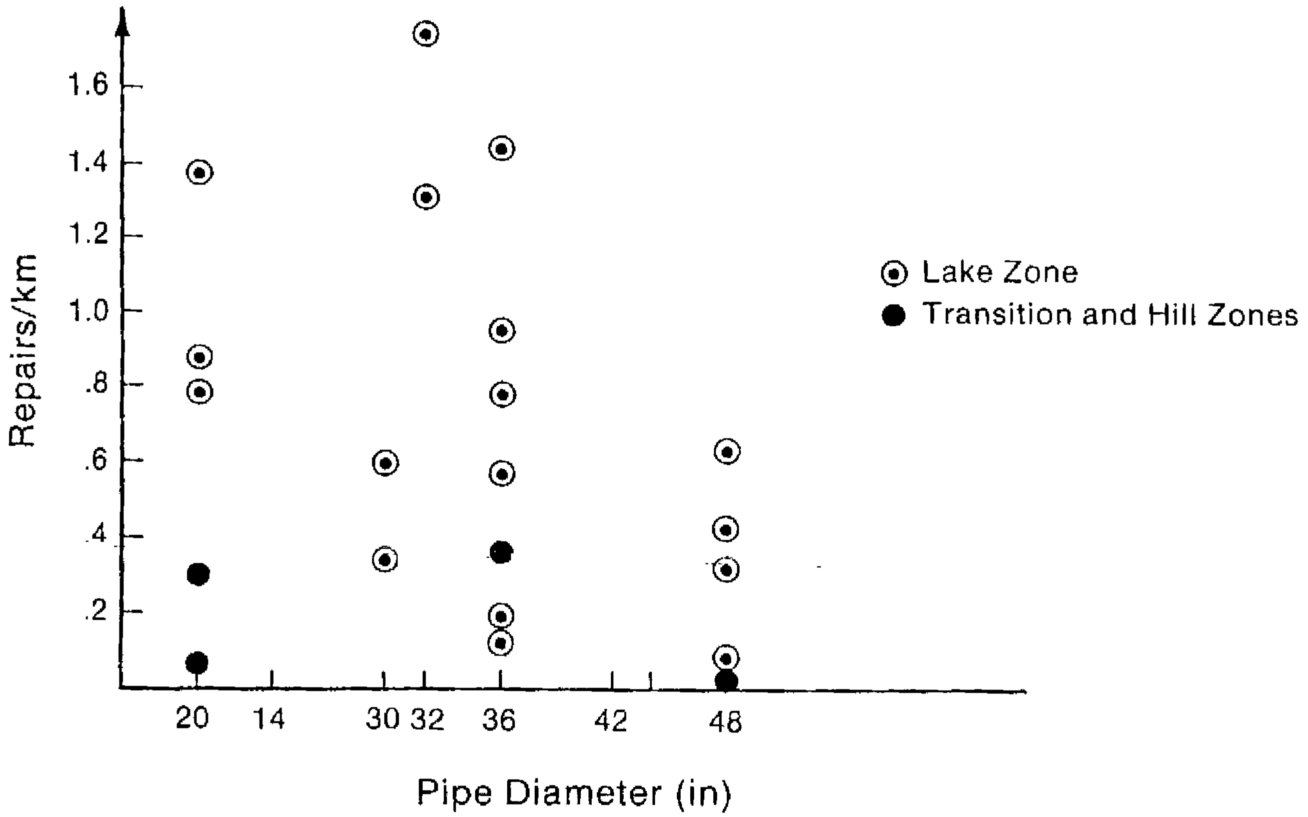

FIGURE 6-26 Damage Ratio Vs. Pipe Diameter, Mexico City 1985

TABLE 6-VI Damage Ratio And Maximum Ground Velocities For Different Soil Conditions

		Peak Ground Velocity V_{max} (cm/sec)		
Zone	$\frac{\text{\# Repairs}}{\text{km}}$	smallest value	average value	highest value
Lake	.45	36.1	48.0	64.1
Transition	.07	-	12.2	-
Hill	.01	-	11.45	14.3