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EARTHQUAKE DAMAGE EVALUATION AND DESIGN CONSIDERATIONS FOR UNDERGROUND STRUCTURES

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SANITARY SEWERS

City of Los Angeles, Department of Public Works

Sanitary sewers present a unique problem in determining damage since any damage is not readily apparent, as with aboveground facilities. In general they are too small to permit access for inspection.

Existing Sewer Facilities

The City of Los Angeles has over 6,000 miles of sanitary sewers. However, only those sewers in the northerly portion of the City were affected by the quake. Furthermore, in order to limit the area of investigation and to obtain useful information for the purpose of this report, an arbitrary boundary was established. This boundary is shown on Figure 1 , along with damaged sewers, fault zones, and uplift zones. The area encompasses approximately 15 square miles which includes the City of Los Angeles' communities of Knollwood and Sylmar, and a portion of the City of San Fernando. The sewer network of Los Angeles and San Fernando are interrelated in that some of Los Angeles' sewage flows through San Fernando and all San Fernando sewage ultimately enters the Los Angeles sewer network. The majority of the sewers in San Fernando were constructed in 1926 or before. The rest have been constructed since World War II. Ninety percent of the Los Angeles sewers have been constructed in the last 20 years.

The area is in the upper limits of the watershed for the sewer system and most of the sewers are local. There are only a few interceptors and they are small in size. The largest interceptor is 21" in diameter. Within this area there are approximately 110 miles of sanitary sewers. Ninety-five percent of these sewers are in the City of Los Angeles and the balance in the City of San Fernando. They are distributed according to size as follows:

8" diameter	455,500 lineal feet
10" diameter	29,400 lineal feet
12" diameter	38,000 lineal feet
15" diameter	21,000 lineal feet
18" diameter	33,100 lineal feet
21" diameter	3,000 lineal feet

Almost all sewers are vitrified clay pipe.

Damage Survey Procedures

Within a few hours after the earthquake occurred, employees of both Los Angeles and San Fernando were sent out to determine the location and extent of damage to sewerage facilities. In Los Angeles, initial investigation of the sanitary sewer system consisted of the lifting of manhole covers to determine damage to the manholes and to determine if sewage flow existed. If damage was observed, the manhole was entered and the sewer inspected with lights. This method provided only a rough indication of possible damage to the line, as only a small portion of the line could be observed. Three hundred and fifty miles of Los Angeles sewer lines in and adjacent to the earthquake area were given this type of visual inspection. By February 14, 1971, this visual inspection had been completed and the results plotted on maps. The perimeter of estimated major damage was established. This is essentially the area previously described as being covered in this report.

On February 15, 1971, Los Angeles began a program of rodding sewers in order to clear stopped lines and to make a better determination of the extent of damage. This program involved the use of hand and power rodding equipment. This proved to be a satisfactory and effective way to determine if the sewer line was completely collapsed or contained broken pieces. However, cracked sections, damaged joints or other damage which did not impede the passage of a rodding device could not be detected by this method.

The rodding program confirmed that severe damage did exist and that a more sophisticated means of inspection would have to be employed to determine the full extent of the problem.

Los Angeles had one television camera and supporting video tape equipment used for normal inspection procedures of the sewer system. However, one camera was totally inadequate for the massive task of inspecting all sewers in the earthquake area. As previously indicated, there are 110 miles of sewers in the most severely damaged area. It was obvious that outside help was needed. Therefore, the Corps of Engineers was requested to help as a part of their program of disaster assistance.

It was decided that the Corps would hire private companies with suitable television equipment to complete the survey of the earthquake area as fast as possible. This decision also included the City of San Fernando.

Fault Relationship

Initially, seventeen miles of sewers in the Sylmar area were selected for televising. These sewers were selected to determine whether their relationship to the major faults was significant. Television of this initial grid showed that heavy sewer damage did coincide with the surface faults. Following evaluation of the information derived from this initial grid, it was determined that it would be necessary to televise the balance of the sewers in the earthquake area.

By the end of summer, televising of all 110 miles of mainline sewers was completed. At one time eleven television crews were operating. The contract cost for obtaining video tapes by television inspection ranged between $0.35 and $1.20 per foot of sewer with the lower figure prevailing as experience was gained by the various firms doing the work.

Subsequent to completion of the televising of the sewers in the major damage area, other sewers beyond the limits of this area have been televised and additional damage has been found. However, information from this additional work has not yet been analyzed and is therefore not included in this report.

Extent of Damage

An assessment of the damage as shown by the video tapes indicated that 126,000 lineal feet of mainline sewer (approximately 22% of the total in this area) needed to be reconstructed. Various types of damage occurred and are discussed below:

1. Broken pipe: This damage includes crushed pipe and cracked pipe caused by shearing stresses or compression stresses.

2. Broken joints: Joints were broken either by excessive deflection or by compression. Where extreme compression occurred the bells were broken away from the pipes. The extreme compression that occurred is indicated by the fact that some blocks shortened by as much as five feet.
3. Pulled joints: This type of damage occurred where tension was the prime factor. Tension is indicated by the elongation of some blocks by as much as two and one-half feet. Even though actual pipe damage may not have occurred, the watertight integrity of the joint was destroyed. This made reconstruction necessary to prevent sewage leaking into and contaminating groundwater supplies.
4. Grade changes: These might also be considered as damage since the capacity of some sewers was significantly reduced. This type of damage will be discussed in greater detail later.
5. Manholes: More than 100 suffered damage significant enough to warrant repair. The principal form of damage was shifting of the rims and covers to an eccentric position with respect to the centerline of the manhole. Some cracking of the walls also occurred. A somewhat small number of manholes had minor cracks which were not repaired.
6. House laterals: Very little damage was found to house laterals. It is possible that 4-inch and 6-inch lines are more flexible. The few failures found were at the right angle connections to the mainline sewer.
7. River crossings and siphons: Two river crossings were found damaged. River crossings and long siphons (normally double

barrel, concrete encased lines) are very susceptible to earthquake damage. This is due primarily to the normal soil conditions found of sand with high groundwater tables, which are very fluid and offer little support during earthquakes.

8. Connection to structures: Some damage observed was the shearing of inlet and outlet pipe lines adjacent to structures (L.A. County Sanitation District 26, Treatment Plart).

Variable Factors Associated with Damage

There are numerous variables which could conceivably be related to the extent of pipe damage. These include the following:

1. Kind of pipe
2. Depth of pipe
3. Proximity of other substructures
4. Type of soil
5. Location with respect to fault zone and areas of vertical uplift
6. Size of pipe
7. Type of joint
8. Encasement of pipe

However, there is not sufficient information available concerning all of these variables to develop conclusions with respect to all eight items. For instance, the kind of sewer pipe could be very significant; but virtually all of the sewer pipe in the area was vitrified clay pipe, and therefore, no comparison with other types was possible.

Also, the relationship of soil type to damage could be very important. However, soil in the area is practically all a sandy loam and is, therefore, not a variable which can be evaluated in this case.

Depth of pipe ranged from 6 feet to 52 feet. There did not appear to be any correlation between depth and damage. Therefore, it is concluded that depth was not a significant variable.

No valid conclusion can be made with respect to proximity of other substructures on sewer damage. The sewers were almost always lower than other substructures and, therefore, apparently not influenced by them. In the few cases where they are adjacent, both the sewers and the other substructures are so badly damaged that it cannot be concluded with certainty that proximity to the substructures had any effect on the extent of damage to the sewers.

Greater information is available with respect to the remaining variables and this permits reasonably valid conclusions to be drawn.

The location, with respect to the fault zones and areas of vertical uplift, appeared to be a very important factor as is shown on Figure 1. No attempt has been made to develop any statistical correlation but it appears that the areas of greatest disturbance do coincide with the areas of greatest pipe damage.

Size of pipe and type of joint appear to be significant but encasement does not.[1] Data relating to these variables is shown on Table 1. Before this Table can be interpreted some further explanation about joint types and encasement is necessary. There are

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1. Los Angeles County Sanitation District and the Los Angeles County Engineer reported more damage to encased sanitary sewers than to those unencased in area northerly of area described herein.

TABLE 1

EXTENT OF SEWER PIPE DAMAGE

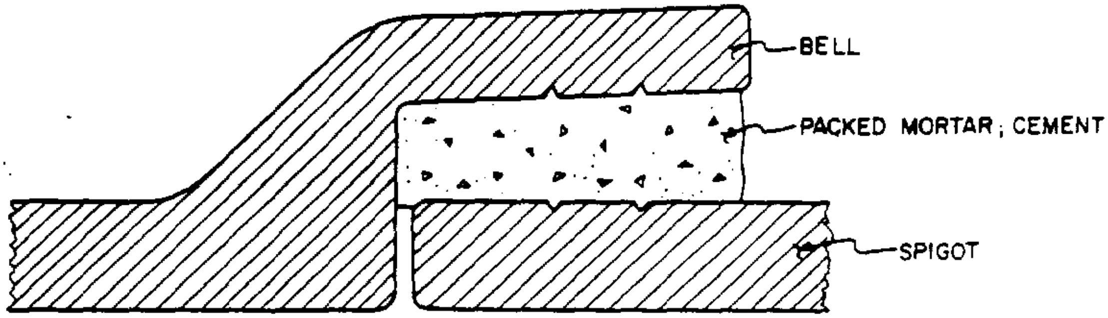
	Length Existing Pre-Earthquake In Lineal Feet	Length to be Reconstructed In Lineal Feet	Percent to be Reconstructed Flex.	Percent to be Reconstructed Rigid	Percent to be Reconstructed Encased
8" flex joints	363,600.	58,400	16.1		
8" rigid joints	90,600	30,900		34.1	
8" encased joints	1,200	260			21.6
10" flex joints	23,800	4,000	16.8		
10" rigid joints	5,300	1,000		18.9	
10" encased joints	270	40			14.8
12" flex joints	24,900	3,900	15.7		
12" rigid joints	9,700	2,800		28.8	
12" encased joints	3,400	1,800			53.0
15" flex joints	13,900	3,500	25.2		
15" rigid joints	3,500	1,800		51.5	
15" encased joints	3,600	1,000			27.8
18" flex joints	17,800	4,900	27.5		
18" rigid joints	8,000	6,100		76.3	
18" encased joints	7,300	5,600			76.8
TOTAL	576,870	126,000	22%		

basically two types of joints existing in the area. The first is a mortar joint which is considered to be rigid in the Table. This joint is shown on Figure 4. The second type of joint is the plastic compression joint which is also shown on Figure 4. This type of joint has come into almost universal usage in California in the last fifteen years. Polyvinyl chloride was initially used as the compression ring material. However, polyurethane is more commonly used now. This is considered to be a flexible joint, as eight-inch diameter pipe may be deflected up to two degrees and eighteen-inch diameter pipe may be deflected up to one and one-quarter degree.

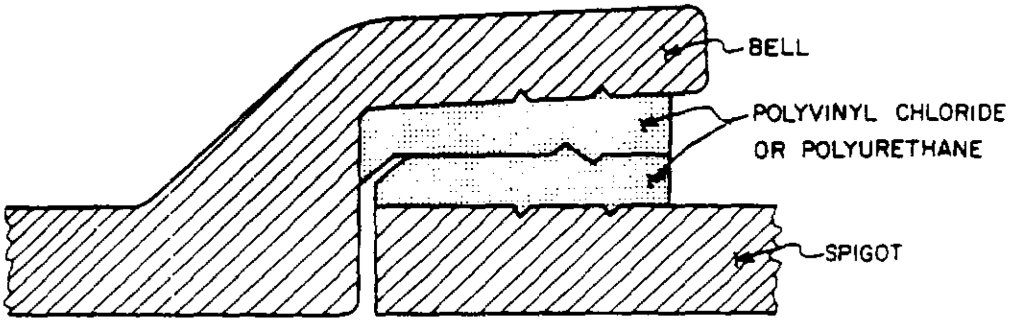
Encasement involved was both partial and complete concrete encasement. These two different types of encasement are shown on Figure 5. For purposes of this study, these two were lumped together. As noted earlier, there are only 3,000 feet of 21-inch sewer within the damaged area. This pipe is located at the lower boundary of the area. All 3,000 feet are rigid joint pipe, unencased, and none was damaged. Because of the limited quantity and the single type of pipe, no conclusions are made with respect to this size in this report.

Within the parameters stated above, the following observations may be made from Table 1:

1. For all sizes of clay pipe, the flexible joint pipe suffered significantly less percentage damage than the rigid joint pipe. Generally, the larger the size, the greater the advantage the flexible joints provided.
2. Pipe size appears to have a relation to damage. The greatest

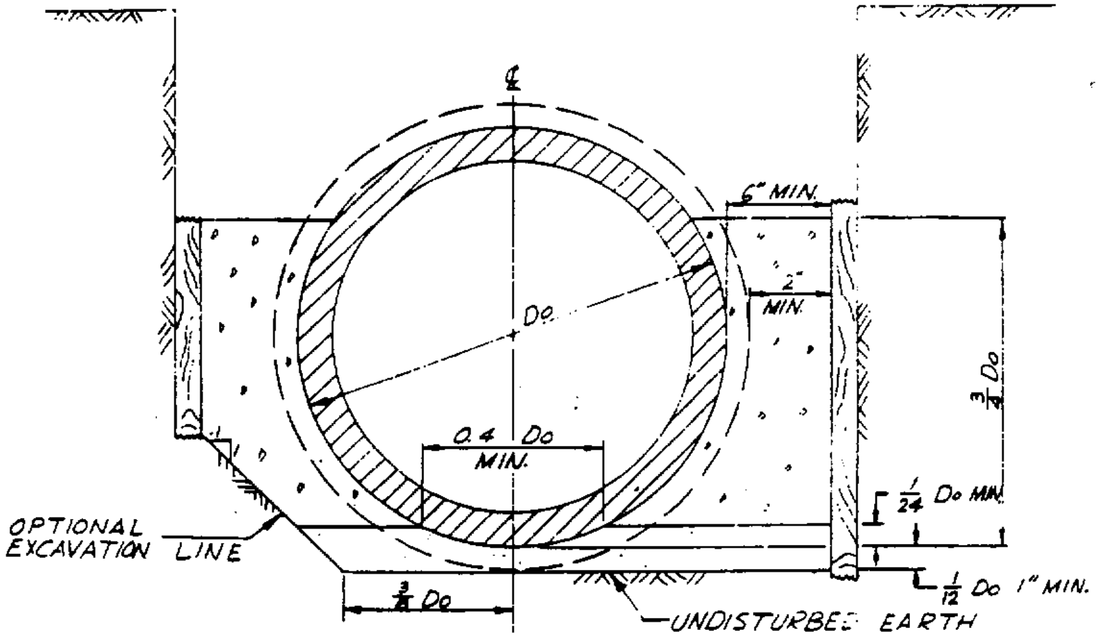


TYPICAL RIGID PIPE JOINT - MORTAR PACKED TYPE

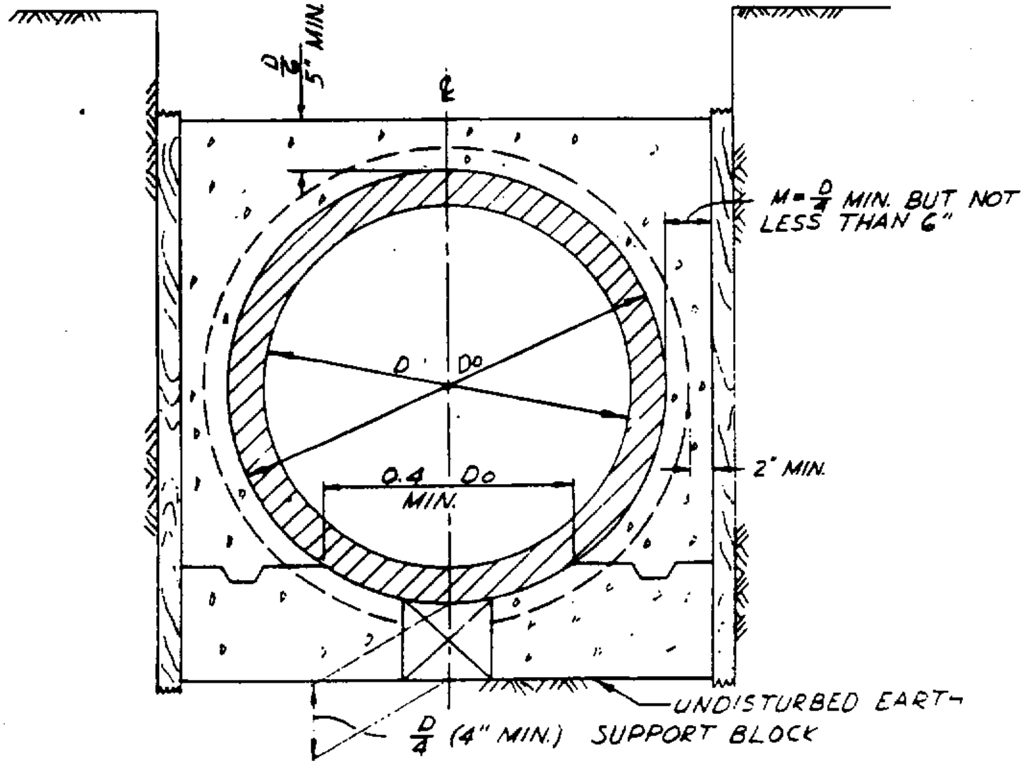


TYPICAL FLEXIBLE PIPE JOINT-PLASTIC COMPRESSION TYPE

Fig. 4



TYPICAL PARTIAL ENCASEMENT



TYPICAL FULL ENCASEMENT

Fig 5

percentage damage occurred in the 15- and 18-inch sizes and the least in the 8- and 10-inch sizes.[1]

3. The percentage damage which occurred to encased pipe is not consistently related to the damage in non-encased pipe.

Impact of Changes in Grade

The Sylmar area and the northwesterly portion of the City of San Fernando experienced the greatest changes in grade. These areas were vertically uplifted by the quake. The uplift was non-uniform and exceeded five feet in the easterly area of Sylmar. The uplift resulted in grade changes and therefore, changes in flow capacity to some extent, of virtually every sewer in Sylmar and portions of San Fernando. However, because of the generally good grades of the existing terrain and the gradual gradation of uplift, no reversal of flow occurred in any sewer.

Excess capacity existed in most of the sewers in the uplift area for several reasons. The design capacities were based on the sewers flowing only one-half full for 8-inch pipes and three-quarters full for larger sizes. The area is not fully developed, and 8-inch pipe is the minimum size used regardless of design flow. Therefore, the changes in flow capacity are not generally critical. It may mean that some relief sewers will have to be reconstructed in the future at a date earlier than anticipated.

The only flow capacity change causing concern is in an 18-inch interceptor sewer in Hubbard Street under the Foothill Freeway.

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[1] Note: No damage occurred in the 3,000 feet of 21-inch sewer within the damaged area.

Prior to the earthquake, the sewer had a design capacity of 5.5 cubic feet per second. As a result of uplift, this reach now has a design capacity of 3.6 cubic feet per second. The design capacity is determined assuming gravity flow with the water surface at 3/4 depth in the pipe.

Repair Procedures

Emergency repairs and cleaning were done by City crews in the first few weeks after February 9, 1971, in order to keep the system as functional as possible. The Corps of Engineers reconstructed approximately 3,700 feet of needed sewer within thirty days after the quake.

For the remaining portion of the sewer system, reconstruction plans were prepared on a priority basis as detailed damage information became available from the logs and video tapes produced by the television inspections. The reconstruction plans that were prepared are typical sewer construction plans calling for total or partial reconstruction of the various damaged sewers.

Conclusions

Based on observations and conclusions discussed in this report, it would first appear to be important to give major consideration to the effect of earthquakes in the design of sewer collection systems. However, further analysis indicates that such design factors are either automatically taken care of in normal design or overruled by competing considerations.

For instance, the use of flexible joints is virtually a standard construction practice at this time.

Alternate pipe material such as plastics could be considered and other materials may be developed which will provide strength and flexibility. At the present time, however, experience with such products is not considered sufficiently broad to justify their substitution for vitrified clay pipe as a protection against earthquake damage.

It does not appear that consideration could normally be given to restricting size as a protective measure against quakes. Pipe capacity to meet existing or future needs will almost always be an overriding design factor. It is possible, under certain conditions of land development and grades, that a collection system could be designed to use more footage of small pipes connecting to a large interceptor as opposed to a system using a gradually increasing size of collectors and interceptors. In addition, double lines of smaller pipe could be used in lieu of larger single lines. It is also possible that the design period for the system could be reduced, resulting in smaller sizes, but in an earlier date when capacity relief would be needed. None of these possibilities appear to deserve serious consideration.

In general, it will be very difficult to justify extra expense to reduce the risk of earthquake damage because of the uncertainties of earthquake frequencies. Any such decision will undoubtedly be made on a somewhat subjective basis.

Summary

1. In assessing the damage to the sewer collection system following a major catastrophe such as an earthquake, an appropriate sequence of investigation consists of the following:
    - a. Visual inspection at all manholes to establish the approximate perimeter of the damaged area.
    - b. Rodding of sewers to determine location and extent of collapsed pipe sections.
    - c. Televising of sewers to determine location and details of additional damage.
2. The types of sewer system damage which occurred included broken pipe, broken joints, pulled joints, changes in grade, and shifting and cracking of manhole structures.
3. For all sizes of clay pipe, flexible joint pipe suffered less damage than rigid joint pipe. (Generally, the larger the pipe, the greater was the advantage in favor of flexible joints.)
4. Damage is correlated with pipe size, with the 8- and 10-inch sizes having the least percentage damage and the 15- and 18-inch sizes having the greatest percentage damage.
5. There do not appear to be any major revisions in current design procedure which are indicated as a result of this investigation.
6. It is recommended that where encasement must be provided, that joints be placed at appropriate intervals (not exceeding 30 feet). Such joints should be located at the end of the bells of the vitrified clay pipe.
7. The typical plastic compression joint (Fig. 4) could be

modified to be more earthquake-resistant by placing a bead of the plastic material on the seat of the bell or on the spigot end to reduce damage due to hammering.

8. At changes in section or where pipes join a structure, provision for movement should be made by the use of appropriate joints.