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FAILURE OF A BURIED CORRUGATED METAL PIPE DURING THE 1994 NORTHRIDGE EARTHQUAKE

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ABSTRACT

During the January 17, 1994, Northridge Earthquake, the 2.4 m diameter corrugated metal pipe of the Lower San Fernando Dam was crushed over a 90 m length. The site conditions were investigated to determine the cause of failure. Liquefaction could not be the main reason for collapse because most of the pipe was located within nonliquefiable materials. A pseudo-static analysis revealed that the vertical earthquake acceleration was also not the main source of collapse. The failure of this drain line provides a unique opportunity to study the seismic response of flexible buried drains and culverts.

KEYWORDS

Corrugated metal pipe; Northridge Earthquake; pipe buckling; failure; sinkhole; liquefaction; lateral spreading; Lower San Fernando Dam; flexible buried pipe.

INTRODUCTION

The January 17, 1994, Northridge Earthquake caused intense damage in the Van Norman Complex of the Los Angeles Department of Water and Power in the northern San Fernando Valley (Bardet and Davis, 1996a). The Lower San Fernando Dam displayed substantial cracking induced by lateral spreading due to liquefaction (Bardet and Davis, 1996b). On the west side of the spreading zone, a sinkhole emerged over the 2.4 m corrugated metal pipe of Drain Line No. 1. Field investigations uncovered over 90 m of deformed and laterally crushed pipe, one of the largest cases of pipe failure in the Northridge Earthquake. Emergency repairs took over six months and $1,000,000 to complete. The failure of this type of buried structure has never been documented after an earthquake, making this case an unprecedented event.

The objective of this paper is to report on the collapse of the corrugated metal pipe of the Lower San Fernando following the Northridge Earthquake. This report provides the results and measurements of field investigations and only includes a preliminary analysis. A more detailed analysis of the pipe failure is underway. This failure is a rare and valuable case history for underground pipes and tunnels. The lessons learned from this case study are relevant to the seismic design of other underground structures such as buried culverts.

LOWER SAN FERNANDO DRAIN LINE NO. 1

The Lower San Fernando Drain Line No. 1 serves as a storm outlet line for the Lower San Fernando Dam. The 2.4 m diameter, unencased, corrugated metal pipe is 116 m in length. Figure 1 shows a few typical deformed shapes of this pipe which was extensively crushed during the Northridge Earthquake. Figure 2 summarizes the various major zones of deformation and collapse. More details on the pipe deformations can be found in Bardet and Davis (1995).

The Lower San Fernando Dam was subjected to severe ground motions. The Rinaldi Receiving Station located 500 m south of the collapsed pipe recorded peak ground accelerations of 0.84g horizontally and 0.85g vertically. The peak horizontal acceleration was generated by a large energy pulse which also produced a velocity of 177 cm/sec (Bardet and Davis, 1996a); the largest peak ground velocity ever instrumentally recorded from any earthquake.

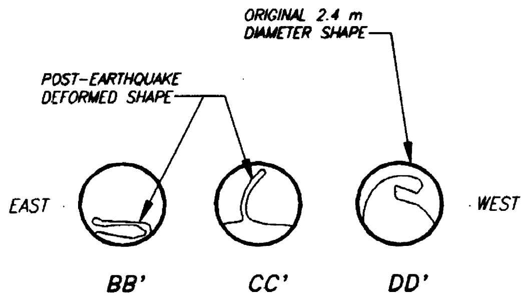

Fig. 1. Three typical buckling modes of Drain Line No.1 after the 1994 Northridge Earthquake.

Figure 2 shows a profile of Drain Line No. 1 as it was completed in 1973. Each pipe segment is distinguished by using a number in brackets. The segments are numbered with positive numbers moving south and negative numbers moving north from the sinkhole location. The drain line was constructed with 116 m of 2.4 m nominal inside diameter, 0.43 cm thick, galvanized, corrugated metal pipe placed in 7.3 m sections.

GROUND DEFORMATION

As shown in Figure 2, a sinkhole measuring 6 m in diameter and 3.7 m deep resulted near the south end of the pipe (over pipe segments [1] and [2]). Also shown in Figure 2, subsidence occurred over the collapsed pipe for a distance of 30 m south of the sinkhole. Section BB' of Figure 1 indicates the deformed shape of the pipe below the sinkhole. The northern end of the pipe (segments [1], [2], and [-1] through [-5]) was placed in a trench excavated through bedrock while the center (segments [3] through [7]) was excavated through alluvium. Groundwater was observed to be within 1 m of the bottom of the pipe in the bedrock and alluvium. Section CC' of Figure 1 shows the typical deformed pattern through the center portion of the pipe except for segment [7] which was undeformed.

Upstream of the reconstructed berm and east of Drain Line No. 1, the Lower San Fernando Dam spread laterally in the northern direction due to liquefaction, which caused sand boils and ground cracks to form. Liquefaction occurred within the saturated hydraulic fill slide debris which has remained in place since the 1971 San Fernando Earthquake (Bardet and Davis, 1996b). The southern end of the drain line trench (pipe segments [8] through [12] in Figure 2), was placed through the hydraulic fill slide debris during its original construction. This portion of the pipe was founded on alluvium and buried under 12 m of compacted fill encased within the hydraulic fill debris. The eastern side of the slide debris was saturated and ejected substantial volumes of water up to approximately 1 m above the top of pipe. Section DD' of Figure 1 shows the typical lateral pipe deformation located within the saturated hydraulic fill slide debris except for segments [11] and [12] where vertical deformation dominated.

Since only a small portion of the pipe was located within liquefiable material, it is clear that liquefaction was not the only cause of the pipe collapse. In addition, the deformed shapes shown in Figure 1 indicate that large deformations took place within the firm alluvium soils and bedrock.

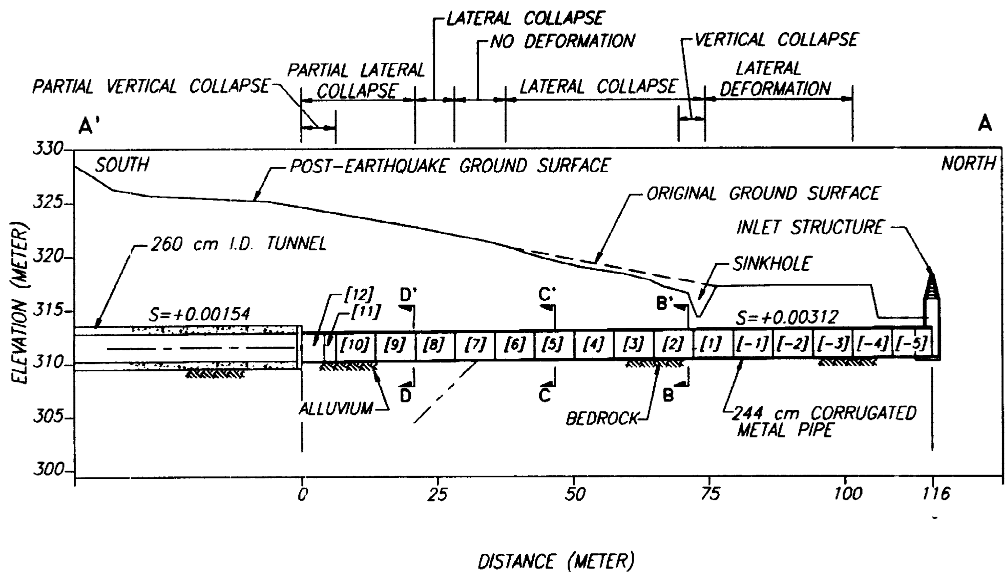

Fig. 2. Profile of Lower San Fernando Drain Line No. 1 corrugated metal pipe.

ANALYSIS

A simplified analysis, based on existing engineering methods, was performed to comprehend the pipe collapse after the earthquake. The pre-earthquake static loads were estimated using Marston's theory of loads on underground flexible conduits, as developed by Marston, and Spangler and Handy (1973).

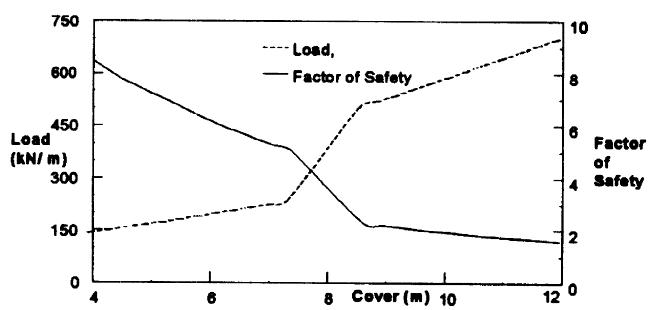

Fig. 3. Graph of static load and factor of safety against buckling for Drain Line No. 1.

Figure 3 shows the static load distribution along the corrugated pipe as a function of the thickness of fill cover. There are two distinct zones in Figure 3 which represent two cases of soil and trench conditions. The first case (4 - 7 m) represents the loads on the pipe segments north of [7] which was installed in a trench excavated through alluvium and bedrock. The second load case (8 - 12 m) denotes forces applied to the pipe in a trench excavated within the softer hydraulic fill slide debris south of pipe segment [7]. The latter condition puts more load on the pipe embedded in soft hydraulic fill. Figure 3 also shows static factors of safety, F_s, calculated according to the methods outlined by ASTM A796 (ASTM, 1990). F_s is defined as the ratio of buckling strength to applied loads.

The lowest value of F_S (i.e., 1.7) was on the south end where the pipe was placed within the weakest material and the thickest fill cover.

A simplified pseudo-static analysis was performed to evaluate the effect of vertical accelerations recorded near the pipe. As presented in Figure 3, the pseudo-static load was assumed to be proportional to the sum of static and maximum dynamic accelerations. The results indicated that 6.7g was required to cause a failure at the location of the sinkhole and 1.7g at pipe segment [8]. These values indicate that a pseudo-static analysis can not adequately predict the failure of pipe located within bedrock, alluvium, or hydraulic fill. However, an increase of vertical acceleration equal to 0.7g could fail pipe segments [11] and [12], located within the hydraulic fill and having the greatest soil cover. This value of vertical acceleration is consistent with the vertical buckling mode which occurred on these two segments and the peak vertical acceleration of 0.85g recorded at the Rinaldi Receiving Station just south of the pipe.

Besides vertical accelerations, other forces, such as lateral transient stresses, may have contributed to the failure of the majority of Drain Line No. 1. More advanced analyses (Moore, 1987) are therefore required to fully understand the collapse of Drain Line No. 1.

CONCLUSION

The 1994 Northridge Earthquake caused the lateral collapse of a 2.4 m corrugated metal pipe at the Lower San Fernando Dam. The pipe collapse and deformation extended over 90 m on the west side of the liquefied zone in the earthdam. However, liquefaction was not the main reason for the collapse because most of the pipe was located within nonliquefiable materials. A simplified pseudo-static analysis showed that the vertical earthquake acceleration did not solely contribute to the buckling of Drain Line No. 1. Advanced analyses including the effects of lateral transient stresses are now being performed to understand this pipe collapse.

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