International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

1995 - Third International Conference on Recent Advances in Geotechnical Earthquake Engineering & Soil Dynamics

Apr 2nd - Apr 7th

Preliminary Investigation of a Buried Pipe Excited by an Earthquake

Hubert K. Law
University of Colorado, Boulder, CO

Hon-Yim Ko
University of Colorado, Boulder, CO

Jun Tohda
Osaka City University, Osaka, Japan

Liming Li
Osaka City University, Osaka, Japan

Takeshi Hamada
Osaka City University, Osaka, Japan

Recommended Citation

Law, Hubert K.; Ko, Hon-Yim; Tohda, Jun; Li, Liming; and Hamada, Takeshi, "Preliminary Investigation of a Buried Pipe Excited by an Earthquake" (1995). *International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*. 5.
http://scholarsmine.mst.edu/icrageesd/03icrageesd/session02/5

Proceedings: Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics,
April 2–7, 1995, Volume I, St. Louis, Missouri

Preliminary Investigation of a Buried Pipe Excited by an Earthquake

Paper No. 2.09

Hubert K. Law and Hon-Yim Ko
Department of Civil Engineering, University of Colorado,
Boulder, CO, USA

Jun Tohda, Liming Li and Takeshi Hamada
Department of Civil Engineering, Osaka City University,
Osaka, Japan

ABSTRACT: The consequence of a devastating earthquake is usually a result of fires, which are caused by breakage of gas pipelines and lack of water supply from damaged water pipelines. The seismic response of a buried pipe was studied using the geotechnical centrifuge facility at the University of Colorado, Boulder. Ottawa sand labeled F-75 was used to model the ground, which was contained in a rigid container with inside dimensions of 48 in. long, 12 in. wide and 9 in. deep. A 4-foot long micro PVC pipe having a 1/4-inch-inside diameter and a 5/16-inch-outside diameter was used to model a prototype pipe. When it is tested in a centrifuge at a 50 g acceleration, the model pipe represents a 1-foot-inside-diameter prototype PVC pipe with a 1.5 in. wall thickness (200 ft. long). The model pipe was instrumented with 12 pairs of strain gages to measure axial strains at 12 locations along the pipe, and was buried in the soil, which was underlain by a bedrock. The bedrock formations were different from one test to another. Each model was excited with the N-S component of the 1940 Imperial Valley earthquake recorded at the El Centro site, and the shaking direction was parallel to the long axis of the pipe. Axial strains of the pipe, accelerations of the ground, and settlements of the surface were measured during the earthquake. It appeared that the geologic feature of the bedrock played an important role on the pipe behavior.

1 INTRODUCTION

Earthquake damages to underground pipelines consist of pullout, rupturing, and cracking. During the great San Francisco Earthquake of April 18, 1906, that had a magnitude 8.3 extending the region of destructive intensity to some 400 miles, many pipelines were broken. This had an important effect in San Francisco, as lack of water supply let the fire get out of control. The great shock and resulting fires caused at least 700 deaths. Similar pipeline failures were also reported in the recent earthquakes such as the 1989 Loma Prieta and 1994 Northridge earthquakes. Preventing this type of failure requires a knowledge of a complex pipe-soil interaction mechanism during earthquake. The problem is more complicated when a liquefaction process is involved. Furthermore, the physical nature of the structure is a three dimensional system, even for a straight continuous pipe line without any connection joint. Thus any analytical procedure using a two-dimensional constraint is questionable, unless an appropriate action has been taken into consideration and it has to be verified for effectiveness. At the same time, a constitutive driver that is used in the computation should closely model the soil behavior under dynamic loading. Under a large deformation situation such as in the case of liquefaction, soil is unlikely to behave elastically. In fact, the recent conference on the verification of numerical procedures for the analysis of soil liquefaction has indicated the need for employing the Biot type coupled analysis and elasto-plastic constitutive model.

There have been some field measurements in the actual earthquakes. During the Loma Prieta Earthquake of Oct. 17 , 1989, some twelve displacement transducers installed in jointed ductile iron pipes constructed at Owen's Pasture near Parkfield, CA were triggered. But triggering did not start until 35 seconds after the start of the ground motion during which time the peak ground motion had already occurred (Isenberg and others, 1991). At the field observation facility at Sodegaura city, about 50 km east of Tokyo, a continuous steel pipe was instrumented for measuring strains and relative displacements during earthquakes. Since the installation of the pipe in 1989, several records have been acquired (Kawshima and others, 1991).

Earthquake damages to buried pipelines are intimately related to the local geologic conditions that create uneven ground motions along the direction where the pipelines are buried. Preliminary studies were made with the use of the centrifuge modeling technique to study the mechanism of a pipeline's failure and the effects of geological conditions during an earthquake. This paper describes the model pipe, test conditions, and test procedure of this test program. The preliminary test results from some models are presented.

2 CENTRIFUGE MODEL TEST

The response of a geotechnical structure can be studied with a reduced scale model. If this small scale test is to be conducted under normal gravity (1 g) conditions, the stresses in the model will be much smaller than those in the full scale prototype and, thus, the resulting strains will fail to correspond to those in the prototype. Results from such testing will lead to erroneous conclusions because of a similitude problem. It is, therefore, necessary to carry out the small scale model test in an appropriate gravity field; i.e., an N-th scale model is to be subjected to a gravity field equal to N times earth's gravity. In this manner, a stress distribution in the model similar to that in the prototype structure is obtained, and if the same material is used to construct the model as found in the prototype, the same state of deformation will also be obtained. As a result, similar failure mechanisms will prevail. Centrifuge testing technique has been widely used in studying many geotechnical issues including quasi-static and dynamic problems. There are well established scaling factors that were mostly derived either through dimensional analysis or from the differential equations that govern the physical phenomenon. Table 1 presents the scaling factors of some parameters that are used in typical centrifuge modeling of earthquake problems.

Table 1. Scaling relations

Quantity	Full Scale (Prototype)	Centrifuge Model
Gravity	1	N
Length	1	1/N
Velocity	1	1
Acceleration	1	N
Time (dynamic)	1	1/N
Stress	1	1
Displacement	1	1/N
Strain	1	1
Frequency (dynamic)	1	N
Mass density	1	1

3 TEST PROGRAM

This experiment program studied the performance of a buried straight PVC pipe without any joint due to seismic excitation. A micro PVC pipe whose dimensions were 5/16 in. (outside diameter), 1/4 in. (inside diameter), and 4 ft. (length) was used as the model pipe in this study. This corresponded to a prototype PVC pipe having dimensions of 15.6 in. (outside diameter), 12.5 in. (inside diameter), and 200 ft. (length) when it was tested at 50 g. A small segment of this micro PVC pipe (approximately 7 inch in length) was tested to establish it's static stress-strain behavior by loading axially with a strain rate of 0.65 %/min. It's Young modulus was 340 x 10^3 psi, and yield strength was 5.5 x 10^3 psi. The model pipe was instrumented with twelve pairs of strain gauges; each pair formed a half bridge circuit that measured only an axial strain along the long axis of the pipe.

The model pipe was buried 1.5 in. below the ground surface. The soil layer was constructed with silica sand with a label of F-75 having a mean grain size of 0.2 mm, and a coefficient of gradation of 1. The maximum and minimum dry densities are 109.1 pcf. and 91.5 pcf., respectively. The sand was rained through two layers of sieves to form an uniform density soil layer. In this test series, the soil layer was underlain by several different types bedrock formations, where earthquakes were prescribed. However, the experiments that employed two types of formations are presented in this paper. One was a level bedrock, and the other was a non-level bedrock.

The complete model consisting the micro PVC pipe, soil layer, and bedrock was contained in an aluminum container that had internal dimensions of 12 in. (wide), 9 in. (deep), and 4 ft. (long). The container with full soil, designed to withstand a 150 g centrifugal acceleration with a minimal deflection, weighted approximately 400 lb. Tests were conducted with a dry or partly wet condition; and bedrock formations were different from on test to others. Thus for a given test, the model pipe experienced different ground motions and thus strains at different locations along the pipe axis since the soil thickness varied along the pipe. Several accelerometers were placed in the soil mass, and surface settlements were measured with two LVDTs. Each model was subjected to a 50 g centrifugal acceleration in the centrifuge, and then shaken with the El Centro site record of the 1940 Imperial Valley Earthquake that was scaled to a 50 g.

All tests were performed in the 400 g-ton centrifuge at the University of Colorado. The radius of the machine is 18 ft. from the center of rotation to the top surface of the platform. It is equipped with a 64-channel data acquisition, that is capable of digitizing up to 10kHz with a 5 millie-volt resolution, and is integrated with an amplifier. The earthquake simulation was done with an electro-hydraulic shaking system. It can be programmed to generate virtually any earthquake record.

4 MEASUREMENTS

The test results from the first four tests (Models 1, 2, 3, 4) from a series of experiments are presented here. Models 1 and 2 were uniformly thick soil layers overlying on the flat container base, and therefore the container base can be considered as its bedrock. Models 3 and 4 consisted a 6-inch-thick bedrock covering one half length of the container. Each model was freshly prepared, and thus they were in a virgin state before shaking. Their pre-test conditions and model descriptions are shown in Table 2 and Figure 1. The measurements from Model 1 are presented in Figure 2. The test data include pipe's axial strains, ground accelerations, and surface settlements; all presented in the model scale. The corresponding transducer locations are shown in Figure 3. Since the accelerometers acc21 and acc22 were attached to the container base, their measurements are considered as base horizontal and vertical motions of the model.

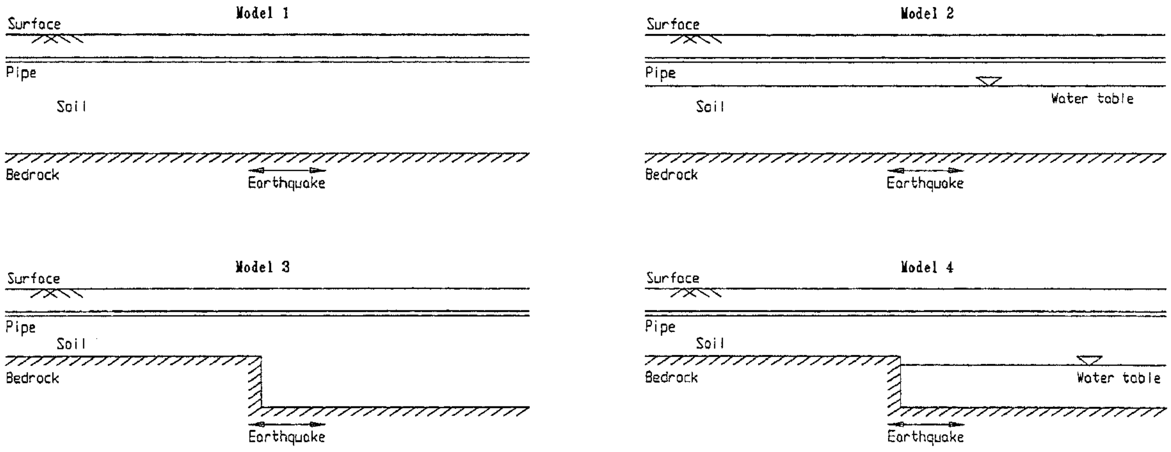

Figure 1. Test models

Table 2. Model conditions

Test #	Ground	Wet/dry	Unit weight	Earthquake
Test 1	Uniform	Dry	98 pcf	El Centro
Test 2	Uniform	Wet (partly)	96 pcf	El Centro
Test 3	Bedrock	Dry	98 pcf	El Centro
Test 4	Bedrock	Wet (partly)	97 pcf	El Centro

The peak axial strains and permanent strains of the pipe were plotted along the pipe axis despite the fact that the peak strains might have occurred at different times within the pipe. Figure 4 show these strain profiles for Tests 1, 2, 3, and 4.

5 CONCLUSIONS

Centrifuge model experiments have been conducted to study the dynamic behavior of a buried pipe. The first four tests from this series of experiments are described, and the results are presented. They provide an alternative way of obtaining seismic data since the field data

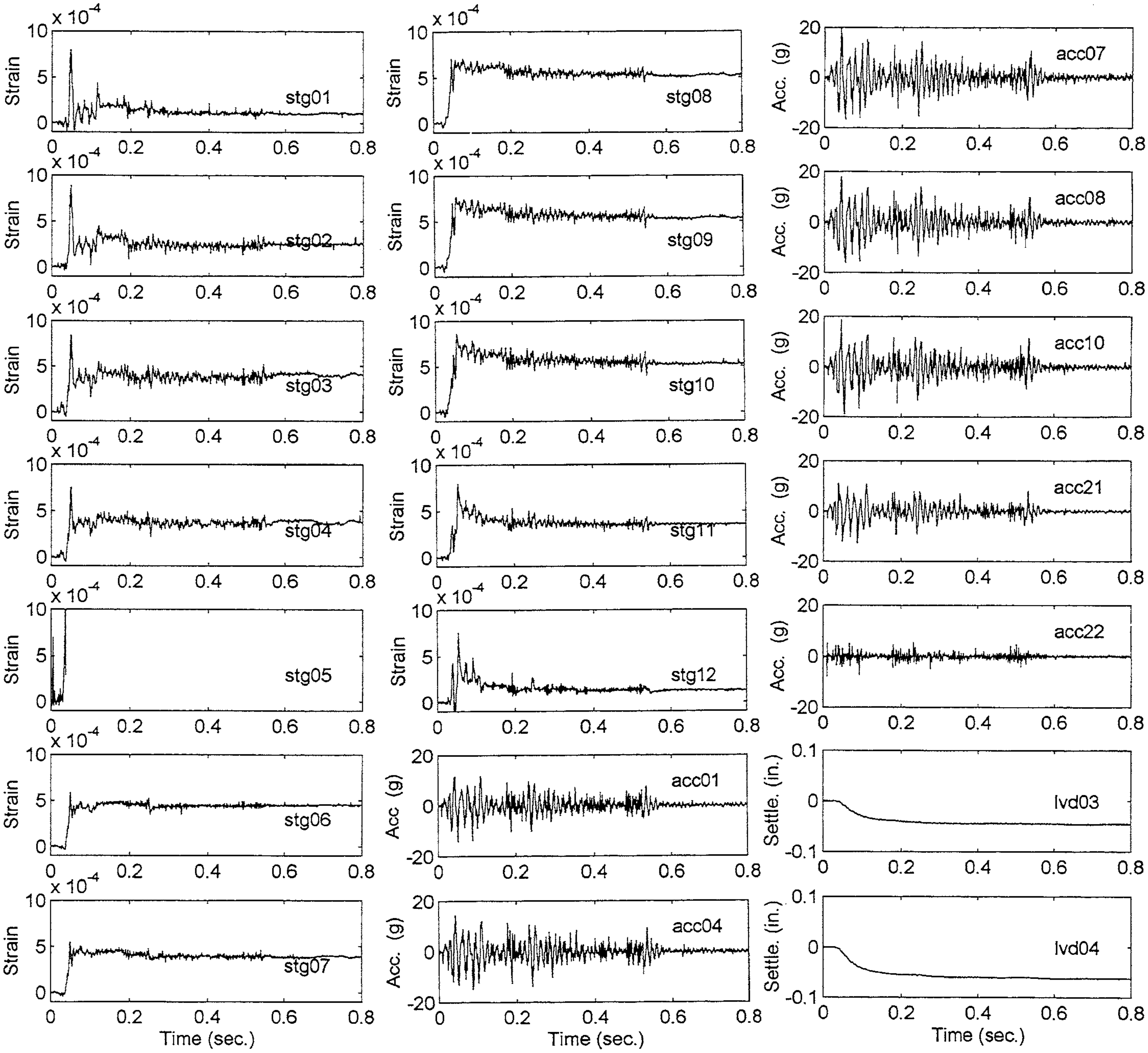

Figure 2. Measurements of Test 1

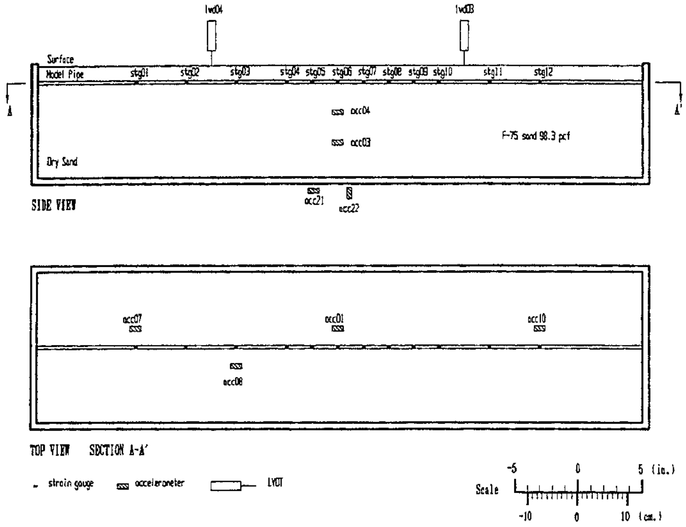

Figure 3. Transducer locations of Model 1

for the buried pipe problem are extremely difficult to measure. These centrifuge test results from the well controlled environment provide a basis for validating numerical analyses.

REFERENCES

J. Isenberg, and C. E. Taylor, "Performance of Water and Sewer Lifelines in the May 2, 1983 Coalinga, California Earthquake," Proceedings of a Symposium on Lifeline Earthquake Engineering: Performance, Design and Construction, Edited by J. Cooper, October, 1984, pp 176-189

J. Isenberg, E. Richardson, T. D. O'Rourke, and H. Kameda,"Response of Ductile Iron Pipelines at Parkfield, CA to Loma Prieta Earthquake, Proceedings of the Third U.S. Conference on Lifeline Earthquake Engineering, Edited by M. Cassaro, August, 1991, pp 186-195

L. R. L. Wang, H. Zhang, and I. Ishibashi,"Seismic Response of Buried Pipeline System in a Soil Liquefaction Environment," Proceedings of the Third U.S. Conference on Lifeline Earthquake Engineering, Edited by M. Cassaro, August, 1991, pp 460-469

M. Miyajima, and M. Kitaura, "Performance of Pipelines During Soil Liquefaction," Proceedings of the Third U.S. Conference on Lifeline Earthquake Engineering, Edited by M. Cassaro, August, 1991, pp 470-479

K. Kawashima, K Hasegawa, and H. Nagashima,"Seismic Behavior of Buried Pipelines through Field Observation," Proceedings of the Third U.S. Conference on Lifeline Earthquake Engineering, Edited by M. Cassaro, August, 1991, pp 234-243

Verification of Numerical Procedures for the Analysis of Soil Liquefaction Problems, Edited by Arulanandan and Scott, October, 1993.

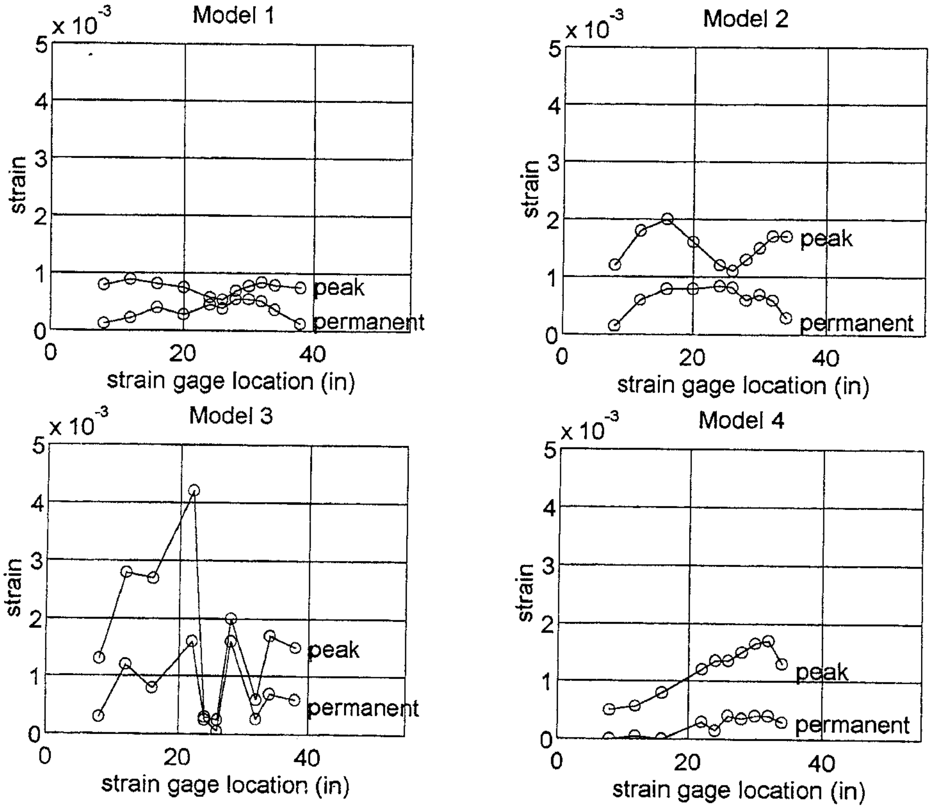

Figure 4. Strain profiles of Tests 1, 2, 3, and 4.