AN EXPERIMENTAL BEHAVIOR OF BURIED PIPES DURING LIQUEFACTION OF SATURATED SANDY SOIL

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ABSTRACT

This paper describes dynamic behavior of power cable ducts buried in saturated sandy soil. One and tenth-scale models of the duct are buried in saturated soil masses retained by a steel box on a shaking table. Before, during and after liquefaction of the sand dynamic responses of the duct were observed in twelve series of the testing. Peak acceleration responses of the duct were observed at a process immediately before liquefaction perfectly developed. Through entire processes of liquefaction of the mass there were observed two times of predominances in displacements of the duct relatively larger than oscillatory ones. First, the duct was lifted up during liquefaction being developed. Next, it was sunk down after fading liquefaction away.

NOMENCLATURE

Pore water pressure ratio is defined as a ratio between pore water pressure and initial effective stress.

INTRODUCTION

In this paper are presented dynamic behaviors of power cable ducts buried in saturated sandy soil using experimental methods. This is an aim of this experiment to induce a mechanism of deformations of the buried duct suffered from strong earthquake motions. As known well, every experience of earthquake disasters has brought a much damage in such structures as buried ducts or pipes laid in saturated sandy subgrounds[1] The damage was typically observed in lifting, sinking, bending out and breaking of them especially at locations near man-holes, pipe-joints and boundaries of subsurface soils.

In this experiment one and tenth scale-models of the duct are employed in twelve series depending on types of supports at both edges, stiffnesses of the duct and properties of its suraounding soil. Soil masses simulated for the subsurface ground retained by a steel box fixed on a shaking table. Measurements were done by contact gauges for strain of the duct, pore water pressure gauges for soil masses and accelerometer for both.

PROTOTYPES OF BURIED DUCTS

A type of buried ducts has been developed by Chubu Electric Power Company Incorporated in the last decade for the purpose of use to enclose power lines installed in urban areas especially, subsurfaces of sidewalks.[2] As shown in Fig. 1. four cable ducts are enclosed by placing concrete with a rectangular shape 50 cm wide and 53cm high, with a strip of gravel foundations 10 cm thick, and underneath 1.0 m from surfaces of grounds to the top of the duct.

MECHANICAL MODELS OF BURIED DUCTS

In order to eliminate edge effects of rectangular shapes of sections of the duct, round shapes of the mechanical model with mechanical properties shown in Table 1. were employed in the section which has an equivalent stiffnesses. As shown in Fig. 2. the model with boundary conditions of fixed or free at its both edges was laid underneath 10 cm from surfaces of subground models with 50 cm thick to tops of the duct model. Soil masses with 50 % of relative density for enclosing the duct model were composed of Kiso-gawa sand with physical properties shown in Table 2. and a gradation curve shown in Fig. 3. They were retained by a steel box 1.0 m wide and long on a shaking table as shown in Fig. 4. In order to keep a deformability of the sand mass in shearing deformations relatively soft material, a kind of shock absorbers was lined off both sides in the box for the direction of shaking. Physical similarities between the model and prototype are shown in Table 3.

EXPERIMENTS

Sinusoidal oscillations with frequencies from zero to 3.1 Hz and accelerations upto 300 gals holizontally were employed for loading to the model in which the duct model was orthogonally laid for it as shown in Fig. 4. Accelerations were measured on the duct model and the steel box.

Longitudinal strains of the duct model were measured by four sets of contact gauges, wire-strain gauge with water proof capabilities, on tops, bottoms and both sides at its mid spans.

Changes of pore water pressures of the subground model were measured by pore water pressure gauges which were installed aparted 20 cm from the duct model and underneath 10 cm from the surface of the soil mass.

Twelve combinations of experiment series were conducted as shown in Table 4.

RESULTS OF EXPERIMENTS

Typical examples of the experiment, envelops of time dependent response accelerations and stains of the duct model, and pore water pressures of the subground model are shown in Fig. 5. A time dependent change of the neutral axis of the duct model is shown in Fig. 5-(d). Those are examples when bringing perfect liquefaction of the soil mass during oscillation.

When bringing the imperfect liquefaction an example is shown in Fig. 6. and an extreme example near liquefaction in Fig. 7.

Peak values in every series of the experiments are shown in Table 4.

There are shown relationships between the input acceleration and the response acceleration of the duct, the strain and the peak pore water pressure ratio, respectively in Fig. 8., 9. and 10.

DISCUSSIONS AND CONCLUSIONS

The peak response acceleration and strain of the duct model can be observed immediately before perfect liquefaction occurred or during imperfect liquefaction of the soil mass. It suggests that maximum shearing strains of the soil mass could be occurred before perfect liquefaction.

Lifting of the neutral axis of the duct model are clearly observed before perfect liquefaction. On the contrary sinking of the axis are clearly done. It suggests that dilatation of the soil mass could be occurred during liquefaction and the contraction after liquefaction.

In this experiment it can be obviously said that four times or less of the response of the duct model fixed at the both ends are observed when bringing perfect liquefaction. It suggests that free or flexible supports would be better to avoid the damage of the duct caused by liquefaction.

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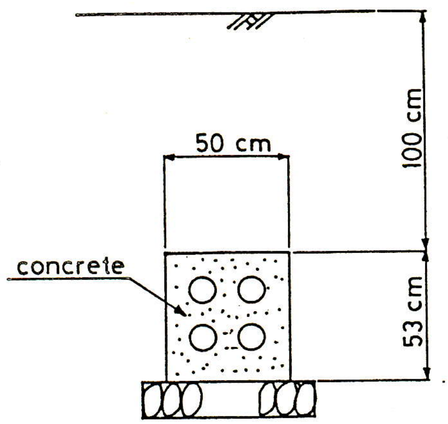

Fig. 1 Prototypes of Buried Ducts

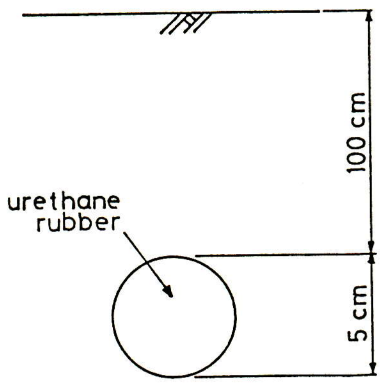

Fig. 2 Mechanical Model of Buried Ducts

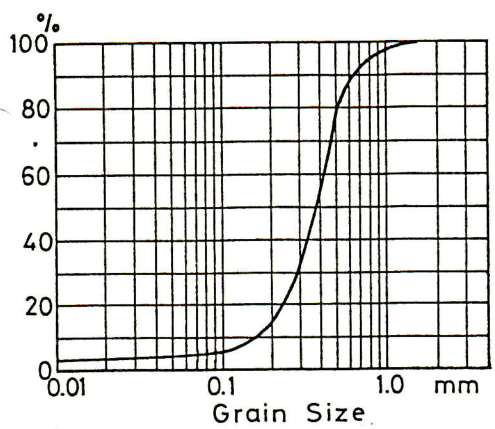

Fig. 3 A Gradation Curve of Sand for Models of Subground

Table 1 Mechanical Properties of Duct Models

Material	Urethane Rubber
Dimensions	5 cm x 95 cm
Young's Modulus	900 kgf/cm^2
Unit Weight	1.13 gf/cm^3

Table 2 Physical Properties of Sand for Subground Model

Density (kg/cm^3)	2.65
Gravel Fraction (%)	0.56
Sand Fraction (%)	94.47
Silt Fraction (%)	2.41
Clay Fraction (%)	2.56
Maximum Grain Size (mm)	4.76
60 % Grain Size (mm)	0.43
30 % Grain Size (mm)	0.27
10 % Grain Size (mm)	0.17
Uniformity Coefficient	2.53
Void Ratio in Loosest State	0.86
Void Ratio in Densest State	0.61

Table 3 Physical Similarities of Models

Geometry		1/10
Mass Density	Sand	1/1
	Duct	1/2
Young's Modulus		1/150
Strain		1/15
Frequency of Sand		1/ 10

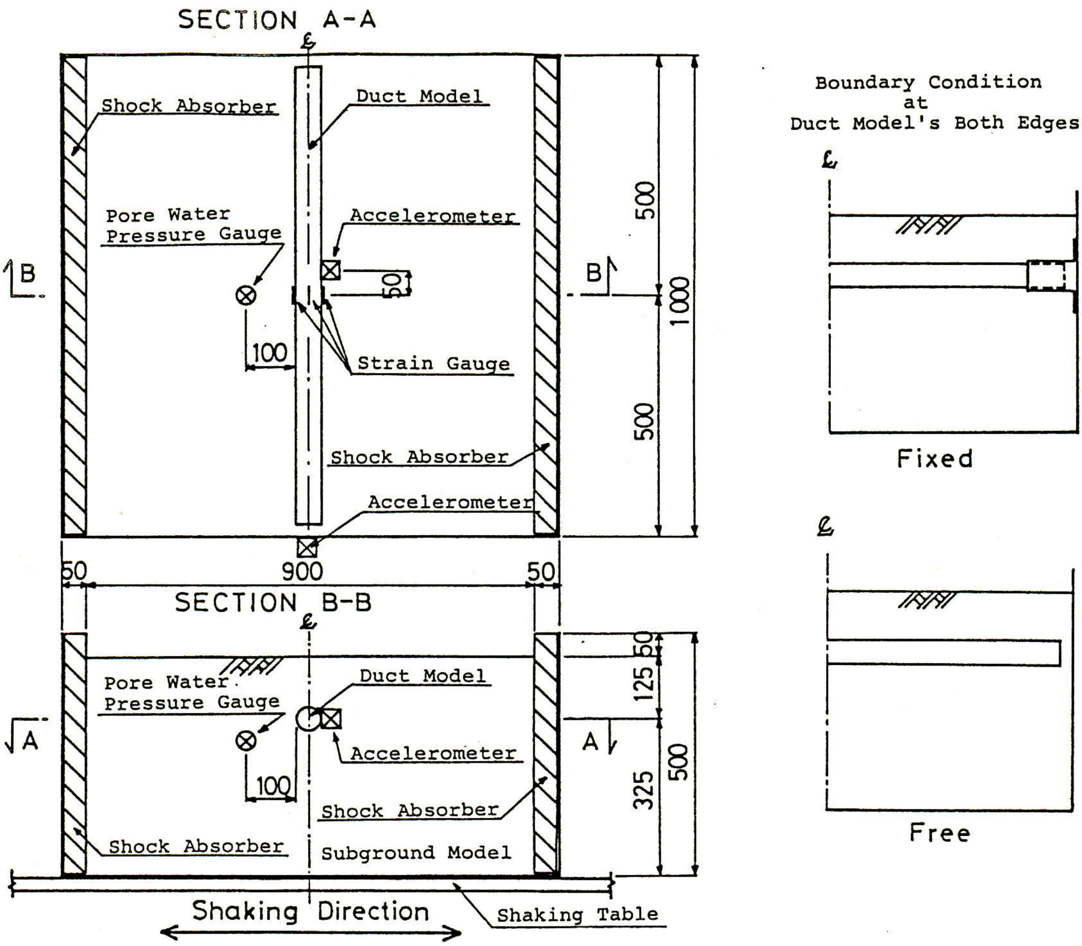

Fig. 4 Models fixed on A Shaking Table

Table 4 Results in Series of Experiments

Test No.	Boundary Condition	Input Acc.	Res. Acc. of Duct	Mag. of Res.	Initial Eff. Stress	Excess Pore Water Pressure	Pore Water Pressure Ratio	Peak Strain of Duct
		(gal)	(gal)		(gf/cm^2)	(gf/cm^2)		(μ)
1	Fixed	400	670	1.68	15.6	16.0	1.03	1860
2	〃	350	570	1.63	14.7	14.8	1.01	1650
3	〃	330	680	2.06	19.6	14.9	0.76	1890
4	〃	260	460	1.77	14.7	12.8	0.87	1980
5	〃	230	350	1.52	19.2	10.7	0.56	670
6	〃	220	260	1.18	18.1	7.8	0.43	80
7	〃	170	220	1.29	18.1	6.1	0.34	130
8	Free	360	700	1.94	18.1	19.6	1.08	540
9	〃	340	740	2.18	25.3	17.0	0.67	450
10	〃	310	630	2.03	22.3	16.8	0.75	0
11	〃	260	510	1.96	19.4	15.8	0.81	110
12	〃	240	300	1.25	17.1	10.8	0.63	0

Acc. = Acceleration : Res. = Response : Mag. = Magnitude : Eff. = Effective

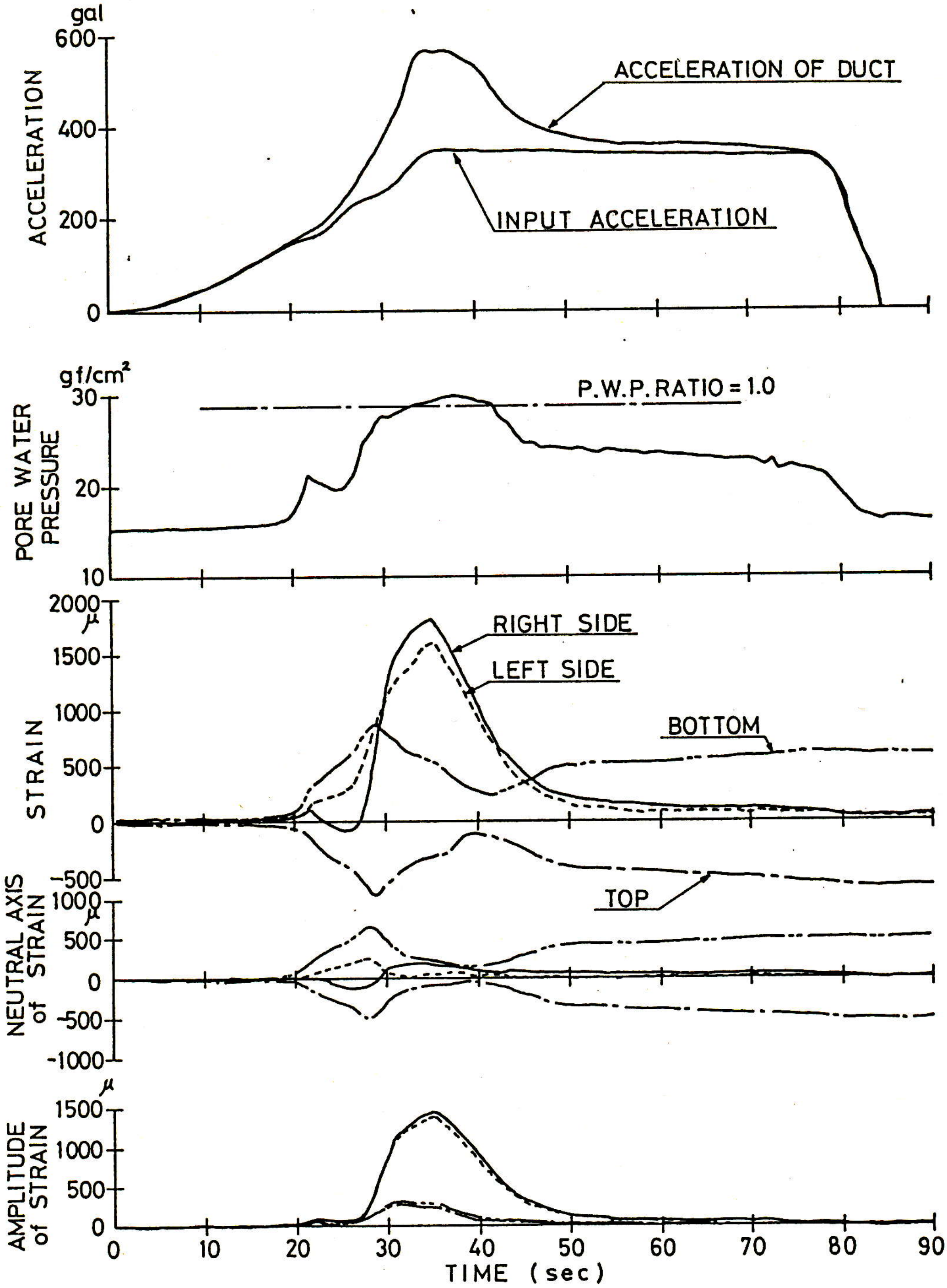

Fig. 5 A Typical Example of Time Dependent Responses (Test No. 2)

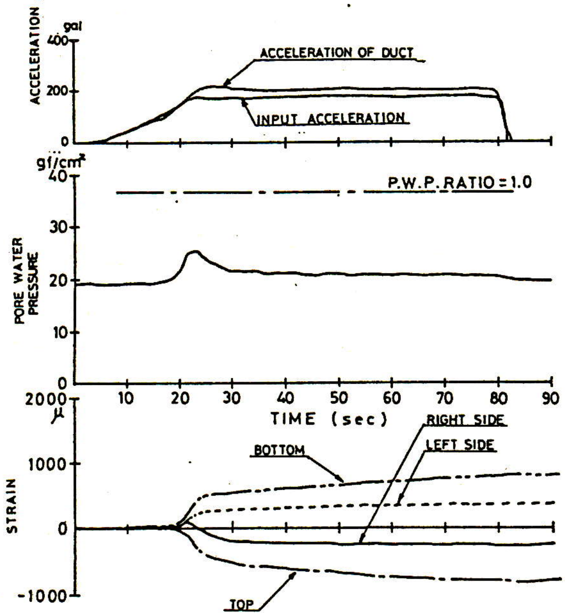

Fig. 6 Time Dependent Responses in Test No. 7

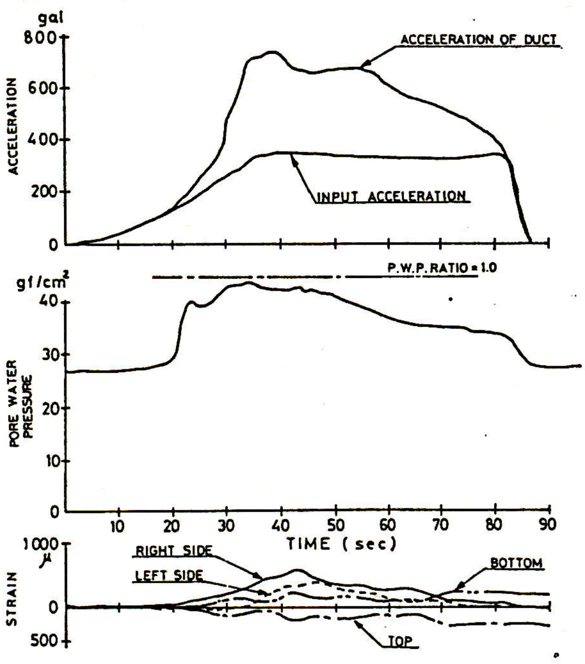

Fig. 7 Time Dependent Responses in Test No. 9

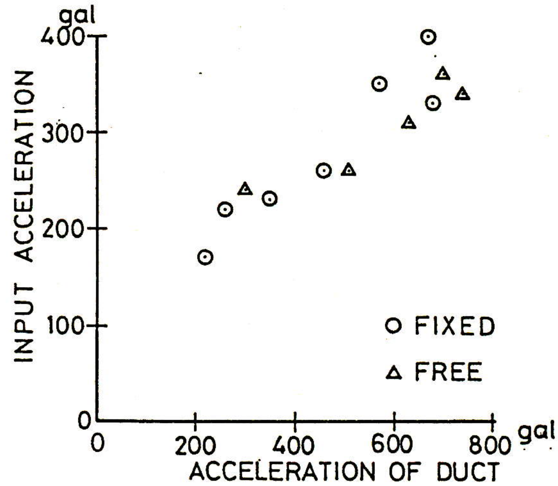

Fig. 8 Peak Acceleration of Duct

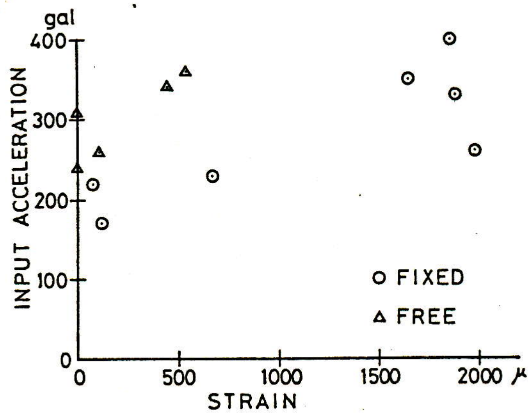

Fig. 9 Peak Strain of Duct

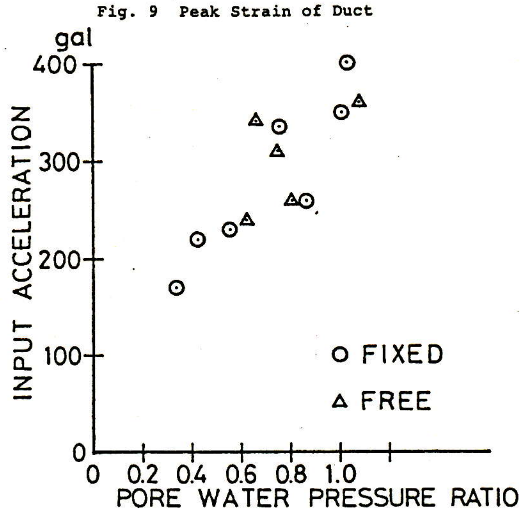

Fig. 10 Peak Pore Water Pressure Ratio