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DYNAMIC FE ANALYSIS FOR STABILITY OF EMBANKMENT ON SILTY CLAY DURING EARTHQUAKES

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SUMMARY

Based on a series of dynamic centrifuge tests (1:50 scale) on embankments founded on clay the following was made clear : (i) a dynamic load with α = 250 gal, for example, induced large deformation and settlement in both embankment and clay under a gravity field of 50g; (ii) deformation and instability were minimized by installing the cement treated layer up to the bottom of ground. Despite these findings, however, it is still uncertain whether embankment should be safer than a clay foundation or which embankments or soil layers would give rise to instability during strong motion earthquakes. This paper presents the results of dynamic FE method applied to above problem. Increasing strength of embankment material and cement treated clay leads to increased overall stability of the embankment and foundation together. A design chart has been produced in order to decide which combination between embankment and cement treated clay foundation would tend to be more stable during earthquakes such that engineers can decide whether it is necessary to strengthen the embankment or foundation layer

INTRODUCTION

It has generally been said that fine-grained soils during earthquakes is more stable than sandy soils. However, some of the previously reported large earthquakes such as in Alaska (1964) or Mexico (1985) [Mendoza and Auvenet, 1988] as well as the recent earthquakes such as in Sagueney (1987) [Lefebrre et al, 1992] Loma Prieta (1989) [Boulanger et al, 1989] or Northridge (1994) [Holtzer et al, 1999] fine-grained soils including from highly plastic Mexico city clay to lean clay or low plasticity silt have suffered from damages in surface ground or structures on ground. The authors have concluded that fine-grained soils in these case records must play a role, to a greater or lesser degree, in causing damages during and after earthquakes [Yasuhara et al, 1998].

Recently in Japan, the high-graded embankments for the large rivers near the urban areas have sometimes been constructed or have been under construction on soft cohesive soils. For preventing serious damages from these river dykes on cohesive soils, a careful attention is required from seismic stability even if fine-grained soils were more stable than sandy soils because most of the large rivers pass through the urbanized area of the large cities. The present paper introduces the design chart for monitoring the situation of river embankments from stability to instability and performing the earthworks for banking of materials. The method proposed is constructed by plotting both the settlement ratios of ground and embankments based on the results from dynamic analysis using a modified FE code, SADAP which was developed by PWRI (Public Works research Institute), Ministry of Construction, Japan. From the design chart, in particular, an attempt has been made to estimate the effects of cement stabilization on increasing the stability of embankment and ground during earthquakes.

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2. DYNAMIC-CENTRIFUGE TESTS ON EMBAKMENT UNDERLAIN BY SILTY CLAY

2.1 OutlineofCentrifugeTests

Aseriesofcentrifugemodeltestsforinvestigatingthe behaviourofembankmentsonfine-grainedsoilsandthe effect of cement treated layeragainstits eformation and instability were carried out at Soil Dynamic Research Centre, Public Work Research Institute, Ministry of Construction. The details of the experiments were herefore described in the previous paper [Matsuo et al., 1997]. The modeled embankment on clay as illustrated in Fig. 1 was installed in the box-type soil tank with 89cm width, 30cm height and 20cm length. Three

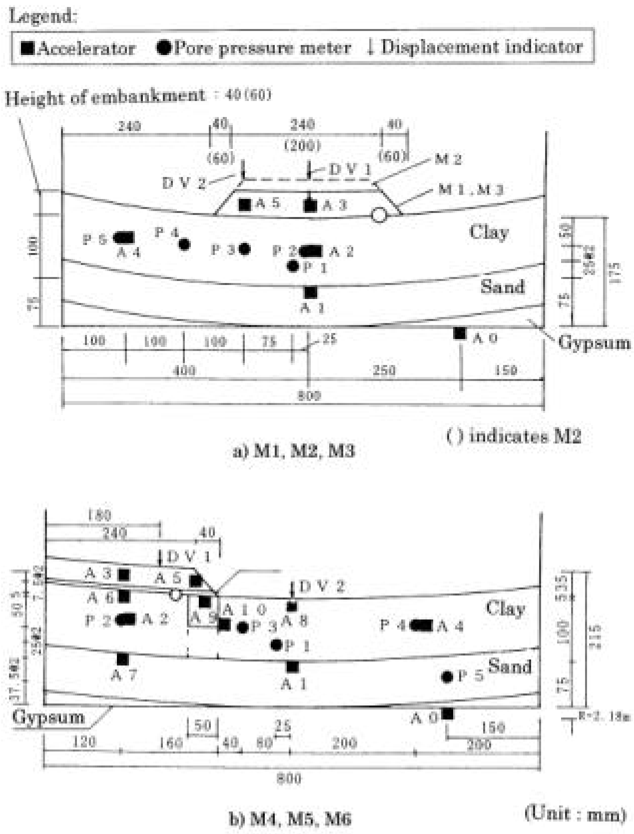


Figure 1: Cross Section of 2-D Dynamic Centrifuge Model Tests (Matsuo et al, 1997)

Kinds of the models were adopted : the model embankment with cement treated layer (CTL) up to full foundation depth ; (cases of M3 and M2) CTL up to certain depth and the model without CTL (case of M1). The representative index properties are ρ_s = 2.662, w_n = 51%, I_p = 17). The stabilising layer was formed by mixing cement with clay soil. To enhance the strength of cement-stabilized column, the model with the stabilised layer was left for 7days before starting the centrifuge test. The unconfined compression strength of silt for ground at this stage was 90 kPa on the average. After consolidating the modeled silt ground with and without the stabilising layer, dynamic loads were applied with and without sinusoidal wave and 60Hz to the modeled ground by stepping 4 stages from 100 gal to 350 gal. The number of load cycles was 20 for each step. The centrifuge acceleration rate was 50G during consolidation through dynamic loading.

2.2 Summary of the Results

Fig. 2 shows a set of typical illustration of deformation manner at the embankment and ground system observed at the final stage of dynamic loading with 350 gal. The following was pointed out fromFig. 2 :

(i) a dynamic load with α = 250 gal, for example, induced large deformation and settlement in clay under a gravity field of 50 gal. In addition, failure and large deformations were also observed in the embankments;

(ii) deformation and instability were minimized by installing the cement stabilising layer up to the bottom of the clay foundation ground ;

(iii) cement stabilized columns with partial depth did not have significant decrease in the deformation and instability of the clay foundation and embankment.

(iv) overall configuration of embankment and ground, particularly in the case without cement stabilising column seems to belong to lateral flow deformation rather than circular failure.

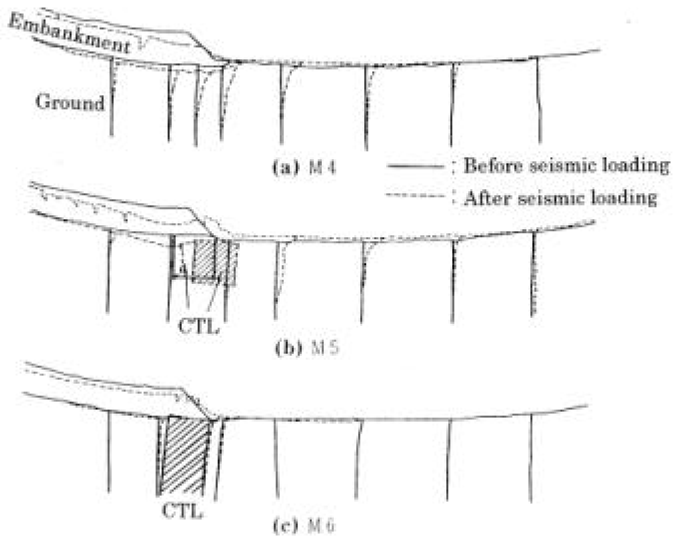


Figure 2: A Typical Example of Deformation Obtained in Dynamic Centrifuge Tests (Matsuo et al, 1997) (CTL: Cement Treated layer)

3. ANALYTICAL PROCEDURE

The computer code "SADAP" used in the present paper was developed by PWRI (Public Works research Institute), Ministry of Construction, Japan. This code incorporates the two models: (1) Hardin-Drnevich model [Hardin and Drnevich, 1972] for hyperbolic stress-strain relations during cyclic loading, (2) Ishihara-Towhata model [Ishihara and Towhata, 1980] for pore pressure generation and dissipation. It is characterized that it is capable of considering the degradation of stiffness step by step which is caused by generation of excess pore pressures during cyclic loading. The following is the procedure of computation using SADAP:

1) in the static analysis where displacement of ground due to self-weight of embankment is determined, construct the element stiffness matrix [k] for each element using the isotropic elastic stress-strain matrix [D].

2) determine the whole stiffness matrix [K] by superimposing [k], and calculate the displacement matrix {Δu} by solving:

$$\{\Delta f\} = [K]\{\Delta u\} \tag{1}$$

3) on the other hand, in the dynamic response analysis, displacement during earthquakes is evaluated by integrating directly the motion equation:

$$[M]\{\Delta \ddot{u}\} + [C]\{\Delta \dot{u}\} + [K]\{\Delta u\} = \{\Delta Q(t)\} \tag{2}$$

4) for every time step using the Newmark-β method. In the equation, [M] is mass matrix, [C] is damping matrix, [K] is stiffness matrix, and {ΔQ(t)} is external force matrix.

5) predict the excess pore pressure corresponding to the calculated shear stress determined through the displacement and stress calculated using Eq. (2). The magnitude of excess pore pressure is reflected to evaluation of degradation in stiffness of soils [Yasuhara and Hyde, 1997]. This has been given by :

$$\frac{G_{i,cy}}{G_{i,NC}} = \frac{1 - C\frac{1}{\Lambda}\ln(OCR_q)}{OCR_q} \tag{3}$$

where C and Λ are experimental constants [Yasuhara and Hyde, 1997] and OCR_q is given by:

$$OCR_q = \frac{1}{1 - \Delta u / p'_c} \tag{4}$$

This process is repeated until a prescribed time period is reached. In this way, deformation behavior during earthquakes can be predicted from time to time.

3.1 Parameter Determination

The parameters for index and mechanical properties of soils constituting embankment, ground and cement-stabilized body are summarized in Table 1. Strength parameters c' and ϕ' were determined from undrained triaxial compression tests on each soil specimen. The initial shear modulus G_i was determined by extrapolating G ~ γ curves obtained from dynamic deformation triaxial tests. To determine B'_p and B'_u related for generation of excess pore pressures during earthquakes, undrained cyclic triaxial tests were carried out.

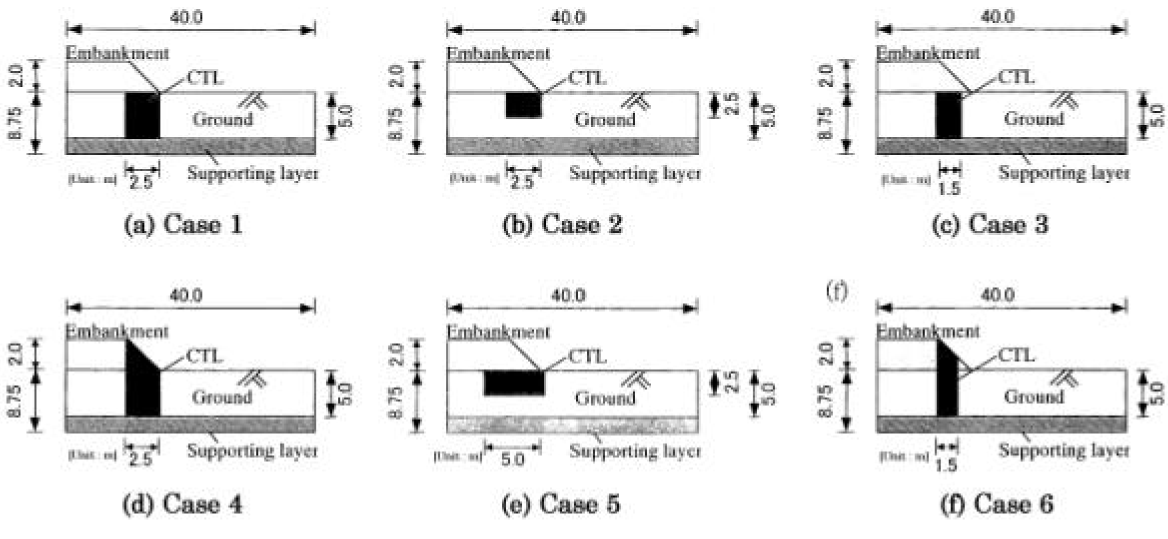


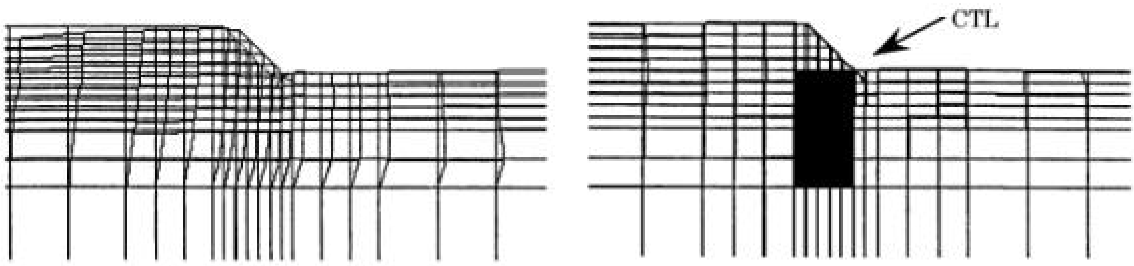
Figure 3: Various Models of Embankment on Cement Treated Soft Soil

Table 1 : Input Data for Finite Element Analysis

	Gi (tf/m^2)	ãt (tf/m^3)	c' (tf/m^2)	ö' (deg)	K0	ís	íD	á1	n1	á	Bp'	Bu'	ès'
Sand	10000	1.75	30.0	40.0	.357	.263	.263	1000	0.6	1	1.1	.2	40
Clay	406.4	1.75	0.56	32.79	.408	.290	.290	812.7	.497	1	.75	.05	45
Emb	400	1.70	1.5	10.5	.45	.3	.4	800	0.5	1	0	0	0
CTL	11180	1.57	18.17	19.39	.617	.381	.381	22360	0.5	1	0.1	.02	45

4. RESULTS FROM NUMERICAL ANALYSIS

The model grounds embankments used for numerical analysis are shown in Fig. 3. The present study particularly aims at explaining the effects of cement-treated layers. In addition, the effect of the sinusoidal (regular) and impact (irregular) waves were considered in the analysis. The acceleration rate for each case was 350gal and 400gal, respectively. Fig. 4 illustrates a set of the typical results of FE analysis to compare the seismic-induced deformation pattern of embankment founded on fine-grained soils with and without cement-treated layers. Fig. 4b shows the results corresponding to models in Fig. 3a. It demonstrates that installation of cement-treated layers prevents from large settlements and deformation of



(a) without cement-treated layer (b) with cement-treated layer

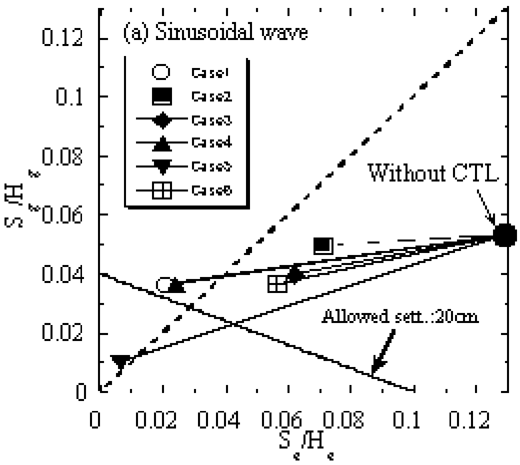
Figure 4: Deformation Pattern of Example Problem

both embankment and foundation together. In order to understand the mechanism and the effects of cement-treated layers on improvement for increasing stability of embankment on grounds during earthquakes, an attempt was made to construct a chart for execution management. For this purpose, the results from numerical analyses are shown in Fig. 5 in which the plots are given as both the settlement ratios S_g/H_g (S_g : settlement of ground and H_g : height of ground layer) and S_e/H_e (S_e : settlement of embankment and H_e : height of embankment) in longitudinal and horizontal axes. Figs. 5a and 5b correspond to the cases of sinusoidal and impact waves, respectively, as shown in Fig. 6a and Fig. 6b which are induced by earthquakes. The straight lines drawn in both figures indicate the critical value of settlement (20cm in this case) for high-graded river embankment based on the design manual tentatively regulated by the Ministry of Construction, Japan (1998). In other words, the embankment of soft soils would be safer if the plot were within the triangular space surrounded by the longitudinal axis, horizontal axis and this critical line. From Fig. 5, the following trends have been observed:

1) the wider the cement-treated layers are, the more marked the decrease in settlement of embankment is.

2) the deeper cement-treated layers are more effective for diminishing the settlement of grounds.

Therefore, configuration of cement-stabilisation of ground by the case <1> is the most effective among



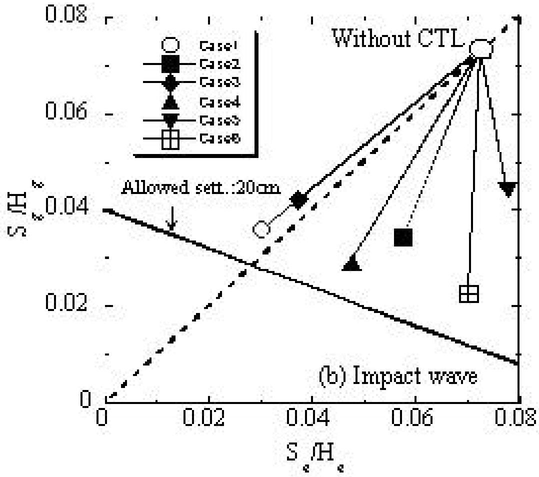


Figure 5: Plots of Settlement Ratio for Embankment and Ground Obtained from Dynamic FEM

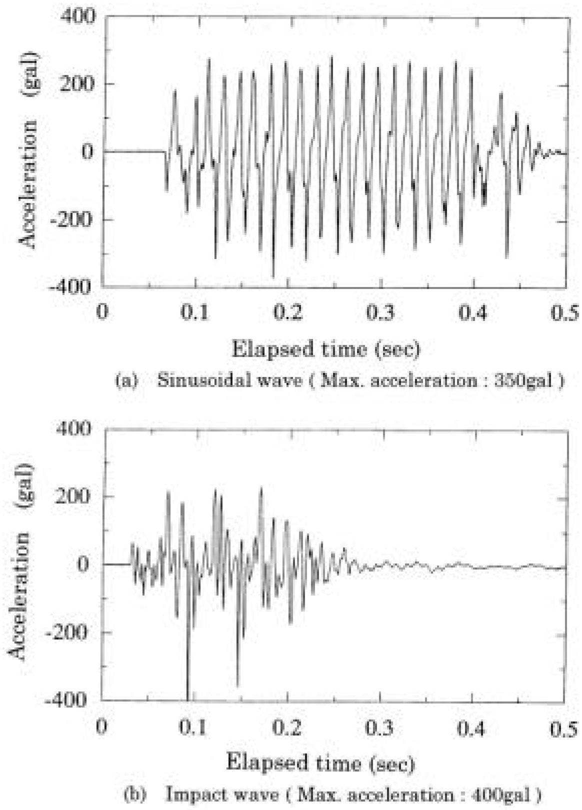


Figure 6: Sinusoidal and Impact Waves Used in FEM

the cases shown in Fig. 3 from decreasing the settlement and increasing the stability of river embankment on soft grounds. In other words, cement stabilized columns which were not long enough to reach the bottom of the clay foundation layer did not decrease the deformation and instability of the clay foundation and embankment. The above-stated behavior is in very good agreement with that observed in dynamic centrifuge model tests reported earlier.

5. CONCLUSIONS

1) Behaviour of embankment founded on fine-grained soils during simulated earthquake loading can be predicted by the dynamic analysis model which is capable of considering the cyclic-induced degradation in stiffness of soils.

2) The computer code modified from SADAP which was developed at PWRI is useful for explaining the effectiveness of installing cement-treated layers in embankment and foundation on increasing stability and decreasing settlements during earthquakes.

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