The 14th World Conference on Earthquake Engineering
October 12-17, 2008, Beijing, China

THE INFLUENCE OF CLAY CORE COMPOSITION ON THE PERMANENT DISPLACEMENT OF EMBANKMENT DAMS

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ABSTRACT :

Composite clay is a mixture of clay, as the main body and aggregates which are floating within the clayey matrix. Undrained behavior of composite clays in its natural or compacted state e.g., core material of embankment dams has a great importance for the geotechnical engineers. On the other hand, experience has shown that significant pore pressure could build-up during cyclic loading in composite clays. In this paper, the results of dynamic analyses performed on Karkheh embankment dam in Iran, incorporating different core materials, are presented. Appropriate models for the core materials are utilized, based on the laboratory test results. The Newmark method is used to evaluate the permanent displacement. It is shown that seismic pore pressure build-up in composite clays can significantly increase the Newmark permanent displacement.

KEYWORDS: Composite Clay, Aggregates, Pore pressure build-up, Karkheh dam, Newmark method

1. INTRODUCTION

Compacted aggregate-clay mixtures are currently successfully used as the cores of embankment dams. These materials, referred to as composite clays by Jafari and Shafiee [2004], are usually broadly graded and comprise clay as the main body mixed with sand, gravel, cobble or and even boulders, which float in the clay matrix.

It is a current practice to employ a mixture of highly plastic clay with aggregates as the core of embankment dams. A review of published literature on the monotonic behavior of composite clays reveals that, in general, shear strength (usually stated in terms of drained angle of friction) increases when aggregate content is raised [Schultze, 1957; Holtz, 1961; Patwardhan et al.; 1970; Irfan and Teng, 1993]. Comprehensive studies by Jafari and Shafiee [2004] on gravel-clay and sand-clay mixtures confirmed previous results on monotonic loadings, meanwhile they indicated that the appreciable increase in aggregate content drastically increases excess pore pressure in cyclic loading, leading to a reduction in cyclic shear strength.

Pore pressure build-up in composite clays deserves more scrutiny, especially for the seismic stability of embankment dams. Seco and Pinto [1993] indicated that a primary cause of damage or failure is the build-up of pore pressures in the embankment and the possible resulting loss of strength. Sarma [1975] proposed using the Newmark [1965] model to analyze the effects of inertia forces and pore pressures on the factor of safety (*FS*), critical acceleration and subsequent displacement during an earthquake. The Sarma [1975] method does not incorporate the variation of pore pressures during movement of the sliding surface.

Makdisi and Seed [1977] presented a simplified procedure that incorporated pore pressure build-up for the seismic design of embankments. The most sophisticated method for seismic slope stability calculations is dynamic analysis [Cotecchia, 1987] or stress-deformation analysis [Kramer, 1996], which typically incorporates a finite-element or finite-difference mathematical model. Dynamic analyses provide the facilities to compute variation of acceleration with embankment height and pore-water pressure build-up.

This paper evaluates the effect of pore pressure build-up in composite clays on the seismic stability of Karkheh embankment dam in Iran utilizing a finite element scheme introduced in the computer program PLAXIS, and then incorporates the influence of clay core composition on the permanent displacement of embankment dams.

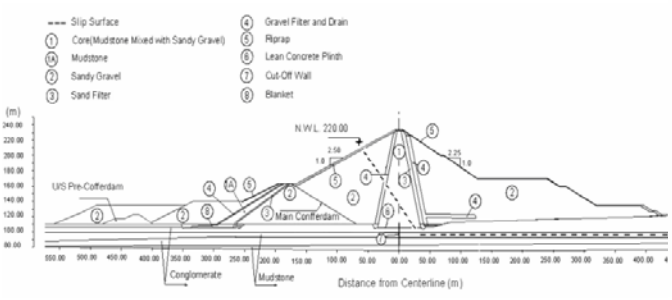

Figure 1 Typical cross section of Karkheh dam

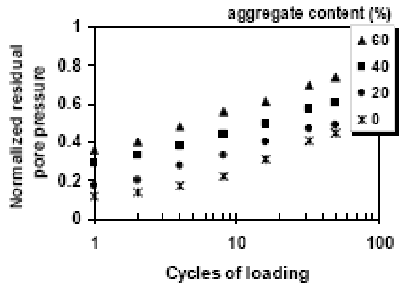

Figure 2 Pore pressure build-up in composite clays in strain-controlled cyclic triaxial

2. General Specifications of Karkheh Dam

Karkheh is a large multi-purpose embankment dam, with 32 million cubic meters of fill, which has recently been constructed in southwest Iran in Khuzestan province. It was designed to store 7800 million cubic meters of water at maximum capacity. The dam has a crest length of 3030 m, a height of 127 m and a width of 12 m at the crest and 1100 m at the foundation level. The slopes of the upstream and downstream shells are 1V:2.25H and 1V:2.50H, respectively. The foundation consists of interbedded layers of conglomerate and mudstone. A schematic cross-section of the dam is shown in Figure 1.

The dam site is situated in the Zagros zone, which is one of the most seismotectonic active zones in Iran. Tectonic studies show that the Lehbary fault is the nearest active fault to the dam site [MGCE, 1998]. The fault has a length of about 150 km and is 20 km away from the dam site. Seismosity studies show that peak ground acceleration (PGA) of 0.40g at bedrock level should be anticipated at the level of maximum credible earthquake

[MGCE, 1998]. Selecting the proper core material for Karkheh dam was a great challenge. The available material was mudstone with a maximum plasticity index of 45%. Since plastic clays may cause appreciable post construction settlement and a pronounced arching effect across the core due to major differences between the stiffness of the core and the shell, it was decided to mix the plastic clay with sandy gravel to overcome these potential problems. This proposal also solved the difficulties in compaction of the plastic clay.

On the basis of laboratory tests [MGCE, 1998], it was decided to use a combination of 60% clay and 40% sandy gravel as the core material. Further comprehensive studies on composite clays [Jafari and Shafiee, 2004] revealed the high potential for pore pressure build-up in cyclic loading when the aggregate content is equal to or greater than 40% (Figure 2). This indicates the importance of dynamic analysis in the evaluation of the effect of pore pressure build-up on the seismic stability of Karkheh dam.

3. Modeling of Materials Behavior

3.1. Laboratory Testing

In this study, two types of core material, a clay-gravel mixture and a pure clay were used. The clay had a specific gravity of 2.74, liquid limit of 69%, and plasticity index of 38%. The gravel was retrieved from a riverbed and was composed of subrounded aggregates with a specific gravity of 2.66. The mixture was also composed of 60% by weight of the gravel and 40% of the clay. Monotonic triaxial tests were performed on both materials to obtain appropriate soil model. The specimens 50mm in diameter and 100mm in height, were compacted in six layer, with a dry density of 95% of maximum dry density obtained from the standard compaction test method (ASTM1999) and water content of optimum. The specimens were saturated with a Skempton B-value in excess of 95%. Then they were isotropically consolidated under three different effective confining stress of 100, 300, 500 kPa. Following consolidation, undrained cyclic triaxial test were carried out under strain-controlled condition. Figure 3(a) shows stress-strain curve of the mixture tested at various initial confining stresses, $P_0^{'}$. Normalize pore pressure-axial strain for the mixture is also presented in Figure 3(b).

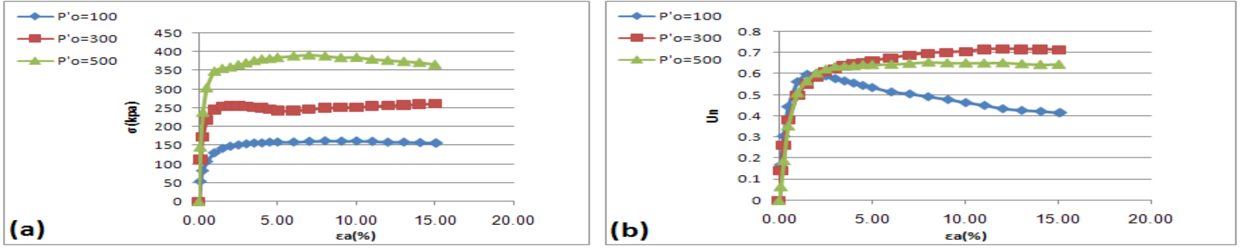

Figure 3 (a)Stress-strain(q-εa)curves and (b)normal excess pore pressure-strain(U- εa) of kaolin-gravel mixtures tested at different initial confining stress($P_0^{'}$)

Table 1 Hardening soil model parameter

Zone	γ_{dry} (kN/m^3)	Permeability (m/s)	E_{50} (kn/m^2)	E_{oed} (kn/m^2)	C (kn/m^2)	Φ (deg)	Ψ (deg)	K_{0Nc}	υ
Core(composite)	16.9	1.5e-8	2.8e4	3.1e4	0.2	31	-0.06	0.67	0.25
Core(pure)	13.5	1e-7	0.6e4	0.6e4	0.2	24.7	-0.25	0.67	0.25

Table 2 soil properties used in analyses

Zone	γ_{dry} (kN/m^3)	Permeability (m/s)	E_{ref} (kn/m^2)	C (kn/m^2)	Φ (deg)	Ψ (deg)	Y
shell	20	1e-3	8.6e5	0.2	38	0	0.25
Foundation(mudstone)	18	5e-6	1.2e6	-	-	-	0.3
Foundation(conglomerate)	21	5e-3	5.6e6	-	-	-	0.25

3.2. Modeling of Material in PLAXIS

The same specimen which was used in the laboratory test was modeled by PLAXIS (Figure 4) utilizing different soil models. The results of this model were compared to result of the test and the best model was used.

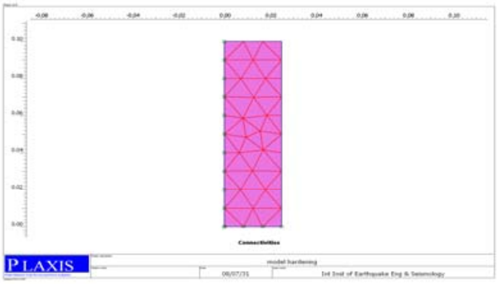

Figure 4 Finite element mesh and Boundary condition of model

In this study the soil hardening model was applied in PLAXIS model and the parameters of this model were obtained by comparing to test result (Figure 5, 6). The results of experimental research program are used to calibrate the results of PLAXIS model. The hyperbolic model has been used extensively in the finite element analyses of different geotechnical problems. This model is very useful, especially when applied to analyses of earth dams, given the difficulties associated with the laboratory testing of material.tis model is based on a hyperbolic function which approximates the stress- strain curve in conventional triaxial compression test. The parameters of this model are given by calibration, are presented in Table 1. These analyses to obtain the core materials model were carried out for pure clay and composite clay and the result of these analyses presented in Table 1. In Table 2 the model of other materials which were used in embankment model by PLAXIS, are presented. These materials were used in dynamic analyses to obtain the pore pressure and acceleration in various points along the sliding surface.

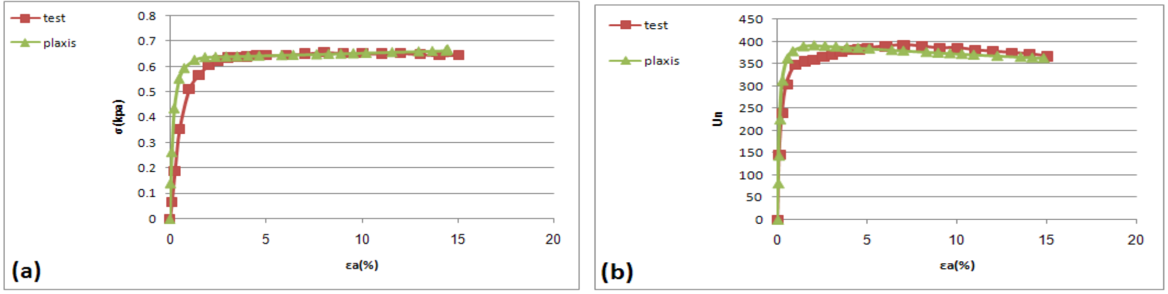

Figure 5 (a)stress- strain curve of test comparing to stress- strain curve of PLAXIS model and (b) normal excess pore pressure- strain curve of test comparing to normal excess pore pressure- strain curve of PLAXIS model at initial confining stress(P_0'=500)for composite clay

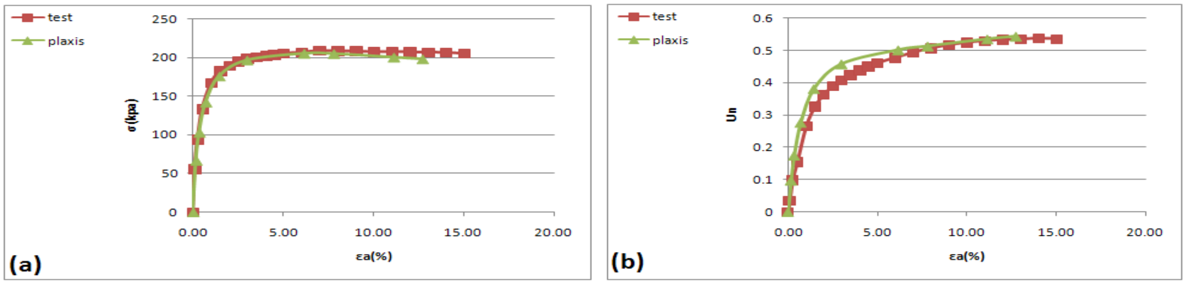

Figure 6 (a)stress- strain curve of test comparing to stress- strain curve of PLAXIS model and (b) normal excess pore pressure- strain curve of test comparing to normal excess pore pressure- strain curve of PLAXIS model at initial confining stress(P_0'=300)for pure clay

4. Dynamic Analysis

To check the effect of core material on the level of permanent deformation dynamic analyses were carried out using eight different earthquake records (Table 3), normalized to 0.4g. The analyses were performed separately for the dam composed of composite clay and pure clay. A typical finite element mesh, with appropriate boundary conditions, used in the analyses is shown in Figure 7. Construction stages of the dam were simulated thrugh twenty five layers, each horizontal layer of element was treated as a construction layer. The foundation and shell material were modelled as linear elastic material and Mohr-Coulomb material respectively (Table 2 (b)). The material on the slip surface was assumed to be a saturated composite clay and pure clay with the undrained shear strength characteristic provided by the laboratory study and modelling in PLAXIS. Analyses consist of consolidated analyses, drained analysis, and dynamic analyses. The results of the dynamic analyses were obtained along slip surface, and then Newmark sliding block model was used to obtain the permanent deformation. In Newmark analyses, acceleration of at least three points along the sliding surface was computed and their average was used in the Newmark model.

One objective of these analyses were to check that the influence of pore pressure build- up on deformation of the embankment during the earthquake. Points B and C were selected along the critical sliding surface, on the composite clay core (Figure 7). The results of dynamic analysis are presented in Figure 8. At point C high pore pressure is generated and the peak acceleration at this point is higher than at the B. In Figure 8, the influence of composite clay on pore pressure build-up is presented.

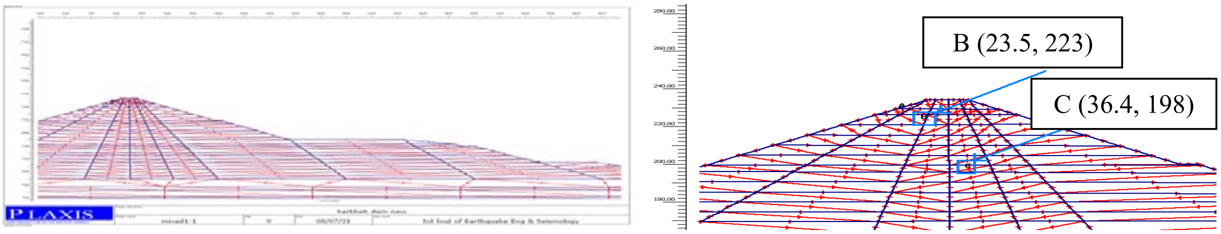

Figure 7 mesh used in finite element model

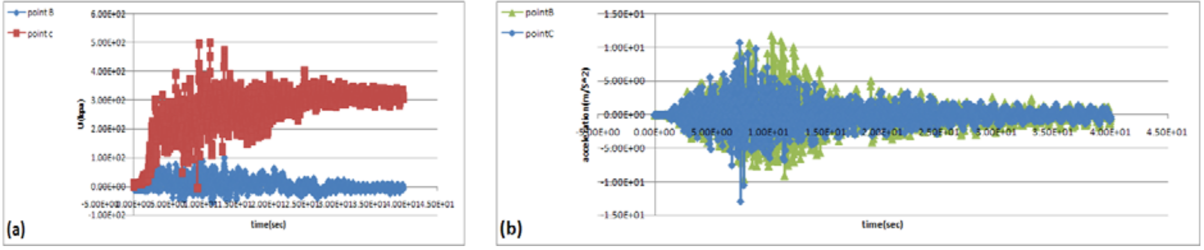

Figure 8 (a) excess pore pressure in B and C versus time (b) horizontal acceleration of B and C versus time for northridge earthquake scaled to 0.4 peak ground acceleration (composite clay).

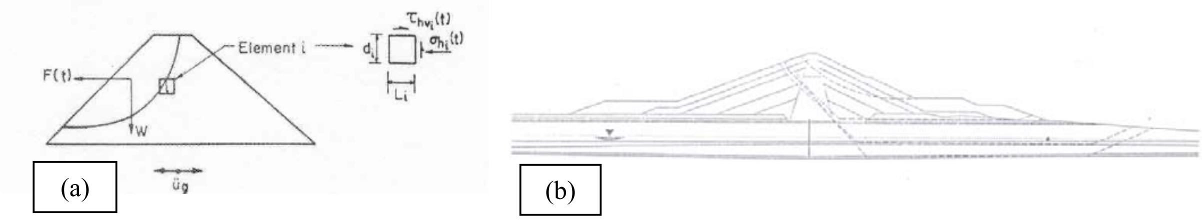

Figure 9 (a)Newmark calculation along critical sliding surface (b)Critical Sliding Surface of Karkheh dam

5. Newmark sliding block model

In this research, the Newmark's method is used to estimate seismic-induced permanent displacements of embankment. The results of dynamic analyses are applied to Newmark estimation. To obtain Newmark displacement, the average of acceleration along the critical sliding surface is computed from the dynamic analysis. Critical acceleration associated with potential failure mechanism is also required. A psudo static method is used to determine the value of critical acceleration (i.e., 0.03g and 0.033g for composite clayey core and pure clayey core respectively). The critical sliding surface was obtained from psudo static analysis. The critical sliding surface was selected in such a manner that which passed the core zone.(Figure 9)

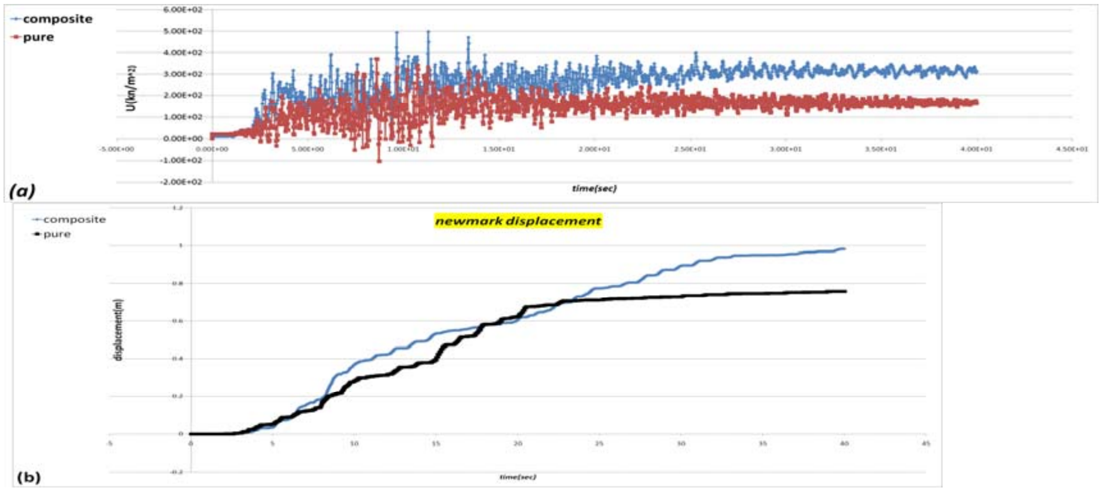

Figure 10 (a) comparison of pore pressure build-up in composite clay and pure clay and (b) comparison of permanent deformation in composite clay and pure clay for Cape Mendocino earthquake scaled to 0.4 peak ground acceleration

Table 3 Result of Newmark Block Sliding Model

No.	Earthquake	Station (direction)	Magnitude	Epicentral Distance (km)	PGA	Permanent deformation (composite clay core)	Permanent deformation (pure clay core)
1	Northridge, 17/01/1994	127Lake (000)	6.7	26.8	0.165	0.98	0.76
2	Northridge, 17/01/1994	127Lake (090)	6.7	26.8	0.217	0.83	0.52
3	LomaPrieta, 18/10/1989	47379 Gilroy (000)	6.9	11.2	0.411	0.81	0.45
4	LomaPrieta, 18/10/1989	47379 Gilroy (090)	6.9	11.2	0.473	0.83	0.60
5	Cape Mendocino 25/04/1992	89005 Cape Mendocino 000	7.1	8.5	1.497	0.76	0.38
6	Cape Mendocino 25/04/1992	89005 Cape Mendocino 090	7.1	8.5	1.039	1.045	0.4
7	Landers 1992/06/28	12206 Silent Valley - Poppet Flat	7.3	51.7	0.05	0.92	0.65
8	Landers 1992/06/28	12206 Silent Valley - Poppet Flat	7.3	51.7	0.04	1.05	0.79

Results of the analyses for eight selected accelerograms are presented in Table 3. Result show that the permanent deformation in composite clay is higher than the value for the pure clay core. Influence of pore pressure build-up and composite clay on the permanent deformation is shown in Figure 10(a) and 10(b) respectively. The remarkable value of deformation can be attributed to the high pore pressure build-up in composite clays.

6. Conclusion

The following conclusion may be drawn on the basis of tme history analyses of Karkheh dam in Iran using PLAXIS finite element software:

1. The influence of the composite clay core on the seismic stability of Karkheh dam was examined, taking in to account the pore pressure build-up within the core. The model used for seismic pore pressure build-up was based on the undrained triaxial tests. The results of the dynamic analyses shown that high shear strain and, consequently, high pore pressure can developed within the core when composite clay is used as the core material. The pore pressure can decrease the undrained shear strength strength of the dam during the earthquake.

As previously mentioned, Laboratory test results have shown that significant pore pressure could build up during cyclic undrained loading such as earthquake in composite clay. This may cause an increase in permanent displacement during the earthquake. Newmark Block Sliding Model was used to estimate the permanent displacement. The results show that increase in pore pressure leads to increase in deformation of the dam. This may be so dangerous if exceeds allowable deformation.

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