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SEISMIC ANALYSIS OF LOS REYUNOS DAM USING GENERALIZED PLASTICITY MODEL

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SUMMARY

The paper describes the application of a generalised plasticity model to the seismic security analysis of Los Reyunos earthdam. A modified version of Pastor – Zienkiewics model was used to evaluate dam deformation under seismic loads for undrained conditions. The model was modified in order to represent more accurately the steady state strengths of the dam materials. The parameters used for the model were estimated from cyclic triaxial tests. Comparisons of these tests performed on the shell material with model response and some results of dam deformation are presented.

INTRODUCTION

Los Reyunos is a 132-m high dam located in Department San Rafael, Mendoza Province Argentina, which is a zone of moderated seismic risk. The dam section that was used for a seismic security analysis is shown in Figure 1. Shell material is gravel (GP) compacted to a relative density of 70%.

Gravely soils compacted at high relative densities have high residual or steady state strength after liquefaction since shear straining causes dilation and drop of the pore pressures. This fact determines that the final stability of dams built with such materials is ensured for most earthquakes. However, the seismic security assessment of these structures requires not only the final stability check but also the evaluation of the seismic caused deformations and cracking. Deformations can cause loss of freeboard with overtopping hazard and cracking can lead to erosion due water flow.

The simulation of earthdams dynamic behaviour should consider the pore pressure generation phenomenon due to cyclic loads, the stiffness and strength degradation in contractive materials or the stiffness degradation in materials of dilatant behaviour and the post-earthquake dissipation of the pore pressures. This highly complex non-linear coupled problem requires a suitable mathematical treatment and a constitutive model, which represent the granular material features.

The following methodology was used to evaluate the seismic assessment of Los Reyunos Dam:

- Selection of the verification accelerogram. This was derived for a 6.8 Ms magnitude earthquake at a short epicentral distance. (Figure 2).
- Evaluation of materials properties from cyclic triaxial tests.
- Simulation of dam construction and reservoir filling.
- Limit equilibrium check under gravity load using steady state strengths.
- Estimation of dam deformations using fluid coupled non-linear dynamic analysis of a finite element model.

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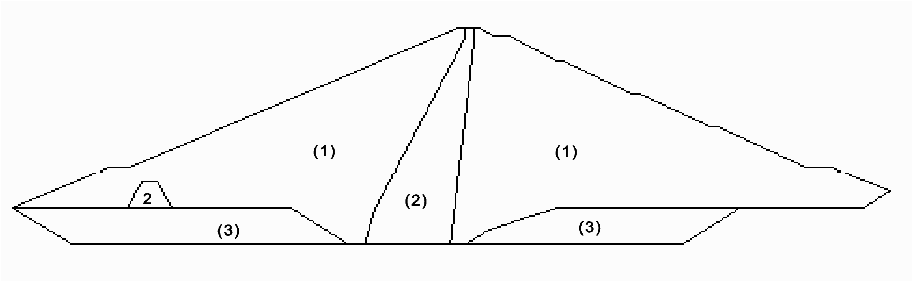

Figure 1. Los Reyunos dam analysis section. Gravel shell, (2) clay core, and (3) foundation

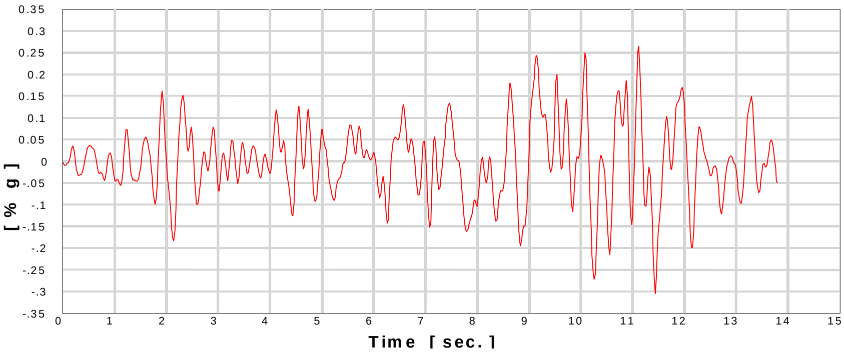

Figure 2.Verification Accelogram.

CYCLIC TRIAXIAL TESTS

Series of cyclic triaxial test were performed in order to identify some characteristics of the shell material. Figure 3 shows curves of axial tension vs. axial deformation and curves of effective pressure p’ vs. deviator q for one of the tests. Once the material reached 5 % of axial deformation, the tests were continued as deformation controlled until the residual strength is developed. Comparisons of different test results of stress paths are shown in Figure 4. Critical state line and steady state strengths were estimated from these tests.

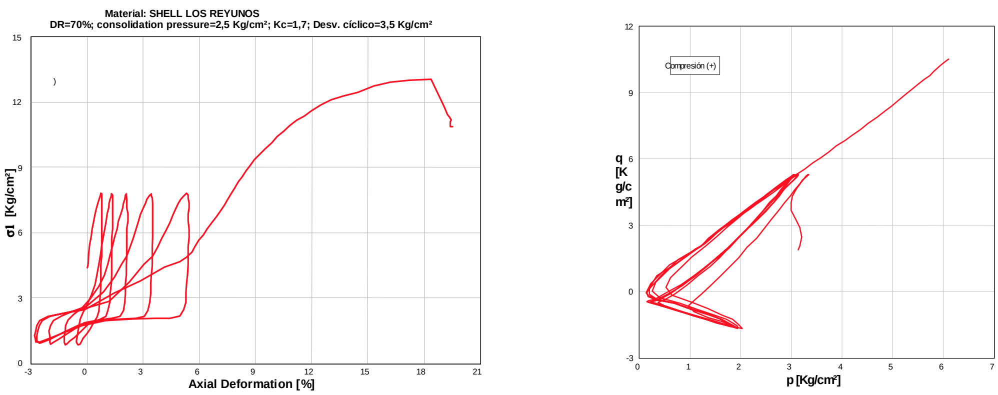

Figure 3. Cyclic triaxial tests of shell material

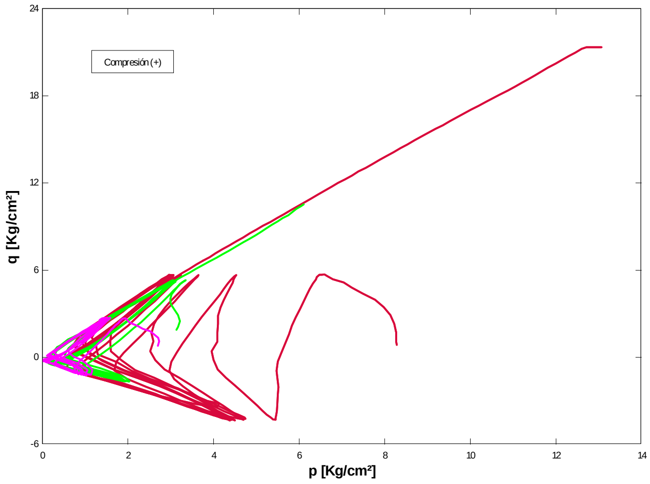

Figure 4. Different tests stress paths

PASTOR-ZIENKIEWICZ MODEL

Pastor – Zienkiewicz model (Pastor, et al, 1990) for sands was used for the analysis. This model is formulated in the frame of generalised plasticity. This theory postulate at every point of stress space one direction that serves to distinguish between loading and unloading and another direction for the direction of plastic flow. Constitutive matrix is defined as:

$$D^{ep} = D^e - \frac{D^e n_g n_f{}^T D^e}{n_g D^e n_f (1+H)}$$

The scalar value H called plastic modulus is a hardening parameter that is a function of effective stress ratio, effective pressure and accumulated strain. The model is formulated in terms of the three invariant: effective mean pressure p', deviatoric stress q, and Lode angle. The flow direction is a function of dilatance d, for loading and unloading.

$$n_g = (n_v, n_s, n_\theta) \qquad \mathrm{d} = (1+\alpha)(\mathrm{Mg} - \eta)$$

eta=q/p' : stress ratio

α= material constant

M_g = slope of the critical state line

$$n_v = \frac{d}{\sqrt{(1+d^2)}} \qquad n_s = \frac{1}{\sqrt{(1+d^2)}}$$

The loading direction vector is defined in a similar form:

$$n_{L/U} = (n_p, n_q, n_\theta) \qquad \mathrm{d_f} = (1+\alpha)(\mathrm{Mf} - \eta)$$

$$n_q = \frac{1}{\sqrt{(1+d_f^2)}} \qquad n_p = \frac{d_f}{\sqrt{(1+d_f^2)}}$$

and the plastic modulus H for loading

$$H_L = H_0 p'(H_v + H_s) H_F H_{DM}$$

Modification of P-Z model.

The model was modified due to the difficulties founded on selecting appropriate parameters that can represent accurately the material steady state strength for a great number of applied cycles.

The model was modified using:

$$H_f = 1 - \frac{\eta}{\eta_f}$$

$$\eta_f = \left[\mathrm{Mg} - (1 + 1/\alpha)\mathrm{Mf}\right](\mathrm{p'}/\mathrm{p_{cr}})^{\mathrm{m}} + (1 + 1/\alpha)\mathrm{Mf}$$

This stress ratio is a limit that causes H=0 and p'cr is the maximum effective pressure that the material can reach under steady state conditions.

The unloading plastic modulus was modified also as

$$Hu = Hu_0 \exp(-Bu\xi)$$

SIMULATION OF TRIAXIAL TESTS.

Shown in Figure 5 are pore pressure increment and axial deformation vs. number of cycles for one of the tests. The green curve was traced using actual test results and the blue one corresponds to the simulation. The model was checked with one set of parameters to the available tests. As can be seen the model simulates with good approximation the observed behaviour. Figure 6 shows deviator q vs. axial deformation q vs. effective pressure p' curves for the same test: green for the test and blue for the model response.

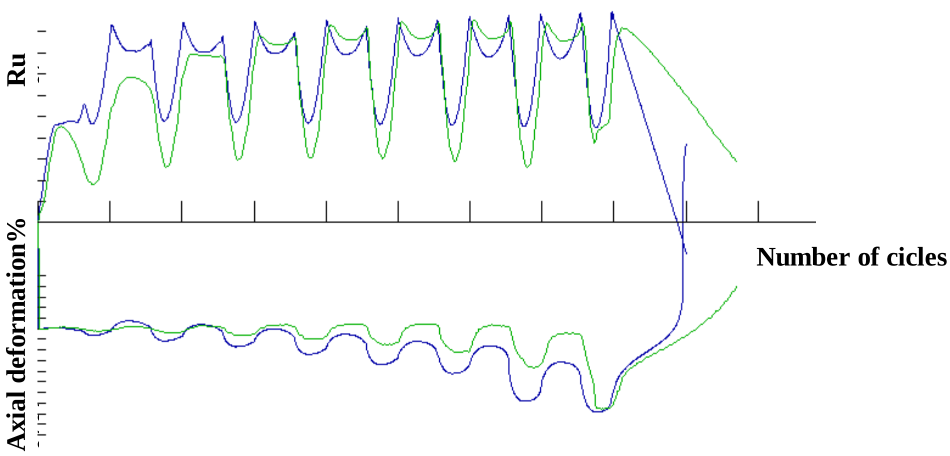

Figure 5. Comparison of model prediction and test results: pore pressure increment and axial deformation vs. Number of cycles

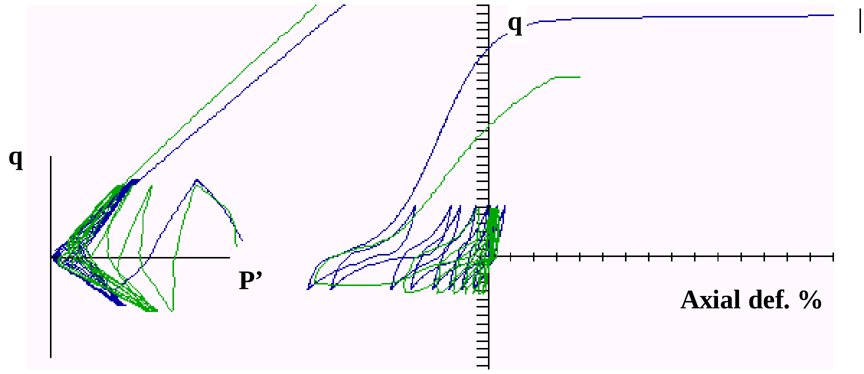

Figure 6. Comparison of model prediction and test result: q vs. Axial def. and q vs. p’

RESPONSE ANALYSIS RESULTS.

The model was implemented in a finite element program developed at the Instituto de Investigaciones Antisismicas de la Universidad de San Juan . This program can simulate dam construction and reservoir filing. The dynamic analysis is carried out using Wilson scheme of step by step integration. Figure 7 shows the mesh displacements computed at the end of the input accelerogram amplified by 50.

CONCLUSIONS

An attempt is made for modelling the post-liquefaction displacements of an earthdam with the purpose of checking its seismic security. In this study, the influence of residual or steady state strength and the loss of stiffness due to cyclic mobility were considered. The parameters of the generalised plasticity model used were chosen using cyclic triaxial test performed on shell material.

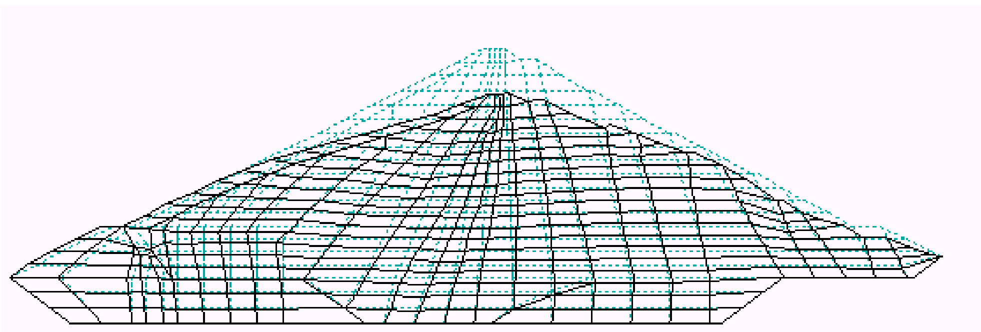

Figure 7. Mesh displacements at the end of the earthquake

REFERENCES

Banerjee,N.G.; Seed,H.B.; Chan,C.K. (1979,Junio)."Cyclic Behavior of Dense Coarse-Grained Material in Relation to the Seismic Stability of Dams".Earthquaqe Engineering Research Center, Report No. EERC 79-13, University of California, Berkeley.

Castro,G.; Keller,T.; Boynton,S. (1989,Septiembre). "ReEvaluation of the Lower San Fernando Dam. An Investigation of the February 9, 1971 Slide", Report 1, GEI Consultants Inc., Winchester, Massachusetts.

Clough,R.W.; Penzien,J. (1975)."Dynamics of Structures", Ed. Mc Graw Hill.

De Alba,P.; Seed,H.B.; Retamal,E.; Seed,R.B. (1987,Septiembre). "Residual Strengh of Sand from Dam Failures in the Chilean Earthquake of March 3, 1985", Earthquaqe Engineering Research Center, Report No. UCB/EERC 87-11, University of California, Berkeley.

Ishihara,K.; Kuwano,J.; Lee,H.C. (1990)."Characteristics of Permanent Deformation of Earth Dams Caused by Earthquake", International Training Course on Earthquake Engineering and Disaster Mitigation Planning, Japan International Cooperation Agency.

Markuson,W.F.; Hynes,M.E.; Franklin,A.G. (1990,Agosto). "Evaluation and Use of Residual Strengh in Seismic Safety Analysis of Embakments", Earthquake Spectra, Vol.6, No.3, Earthquake Engineering Research Institute.

Pastor M. (1990);Zienckiewics,O.C. and Chan A.H. "Generalized plasticity and the modelling of soil behavior". International Journal for numerical and analytical methods in geomechanics" vol 14. Ed.John Wiley and Sons.

Seed,H.B.; Kenneth,L.(1966,Noviembre)."Liquefaction of Saturated Sands During Cyclic Loading", Journal of the Soil Mechanics and Foundations Division, ASCE, Vol.92, No.SM6.

Seed,H.B. (1981,Mayo). "Earthquake-Resistant Design of Earth Dams", International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, Vol III, St. Louis, Missouri.

Siddiqui,F.;Seed,R.;Chan,C.;Seed,H.B.;Pyke,R. (1987,Diciembre). "Strengh Evaluation of Coarse-Grained Soils", Earthquaqe Engineering Research Center, Report No. UCB/EERC 87-22, University of California, Berkeley.

Zienckiewics,O.C.;R.L. Taylor. "El Método de los Elementos Finitos", Ed. Mc Graw Hill- CINME. (1994)

Zienckiewics,O.C., M.Pastor. " A general model for sand/soil behavior". Constitutive Laws for Engineering Materials Theory and Aplications. C.S. Desai- E. Krempl

Zienckiewics,O.C., Chan C.;Pastor,M; Paul D.K. and Shiomi T. " Static and Dynamic Behavior of soils: a rational aproach to quantitative solutions" I. Fully saturated problems. Proc. R. Soc. London