SOME ASPECTS CONCERNING THE SEISMIC INELASTIC RESPONSE OF LOCAL MATERIAL DAMS

Alexandru Negeiţă[I] and Virgil Breabăn[II]

SUMMARY

In the paper are presented some aspects on the nonlinear seismic response calculus of the local material dams. The constitutive non-linear low problem is analised. For this purpose, the concepts of plastic flow and flow potential function of solids are used. The generalised elasto-plastic modulus is obtained by applying the Drucker-Prager yield criterion, together with Ramberg-Osgood hysteretic model. Finally, the seismic response of a dam to the Bucharest (4.03.1977) earthquake is illustrated by several numerical results. The results of linear analysis and non-linear analysis are compared and several conclusion are obtained.

INTRODUCTION

The seismic analysis of local meterials dams performed by applying the "residual deformations"criterion is capable to furnish better results than other concepts that in seismic analysis of earth structures are used.

The magnitude of residual deformations gives a better image on the stability of earth dams, because the earthquake forces act for a short time and alternate in direction.

The determination of residual deformations in earth structures by considering a linear behaviour of material is inadequate [1]. A physical model of material that is capable to consider non-linear behaviour is necessary. To establish this physical model must account for several characteristics of material : nature of material, consolidation degree, water content, structure of material, drenage conditions, loading time and loading history.

A very important factor in dynamics non-linear analysis is the behaviour of materials to the cyclecal loading, namely the hysteretic characteristics.

In this paper are presented some aspects on the earthquake non-linear analysis of the local material dams by applying a procedure with concepts of yield theory and a procedure with an explicit non-linear stress-strain relation.

NON-LINEAR CONSTITUTIVE LOW

In the dynamic non-linear analysis is used so far very much the plastic deformation theory. In this theory, the plastic strain tensor is directly dependent upon the stresses tensor, i.e., may be expressed by a relation in the form :

I-Professor and Head of the Structural Mechanics Department, Polytechnic Institute of Jassy, Jassy, Romania

II-Lecturer in Engineering, Hydrotechnic Constructions Department, High Technical Institute of Constanţa, Constanţa, Romania

$$\varepsilon_{ij}^{p} = \varepsilon_{ij}^{p}(\sigma_{kl}) \qquad (1)$$

This theory is much prefered because the computing time is less and it yields more simple stress-strain relation [4, 7] . But, this theory has several disadvantages, because it does not account for history of loading-unloading process.

The plastic flow theory offers a better alternative because stress-strain relation can be expressed in terms of strain increments, current stresses and stress increments. The plastic strain increment may be expressed in tenserial form, as :

$$\delta\varepsilon_{ij}^{p} = \delta\varepsilon_{ij}^{p}(\sigma_{kl}, \delta\varepsilon_{kl}, \delta\sigma_{kl}) \qquad (2)$$

This relation is generale and accounts for history of deformation process by including the states of stress and strain as well as their increments. The constitutive low of plasticity can be written in incremental form as :

$$\delta\sigma_{ij} = E_{ijkl}^{*} \; \delta\varepsilon_{kl} \qquad (3)$$

where:

$$E_{ijkl}^{*} = E_{ijkl}^{*}(\sigma_{mn}, \varepsilon_{mn}^{p}, E_{mnpq}, \Psi_{m})_{p} \qquad (4)$$

In these equations, σ_{ij} is the stress tensor, ε_{ij} the plastic strain tensor, E_{mnpq} the elastic constants in the generalised Hooke's low, E_{ijkl}^{*} the elasto-plastic moduli, and Ψ_m characterizes the history of plastic deformations. The symbol δ is an infinitesimal increment.

For a finite increment Δ , Eq.4 can be written as :

$$\Delta\sigma_{ij}^{n} = E_{ijkl}^{*n} \; \Delta\varepsilon_{kl}^{n} \qquad (5)$$

where :

$$E_{ijkl}^{*n} = E_{ijkl}^{*n}(\sigma_{mn}^{n-1}, \varepsilon_{mn}^{n-1}, E_{mnpq}, \Psi_{m}) \qquad (6)$$

and "n" represents the increment number.

In accordance with the plastic flow theory, to establish a relation of form of Eq.3, is necessary to traverse the next three phases [3] :

- to establish an initial yield condition, specifying the state of stress for which the plastic flow first sets in;
- to establish a flow rule, connecting the plastic strain increment with the stress and stress increment;
- to establish a hardening rule, specifying the modification of the yield condition in the course of plastic flow.

To establish an initial yield condition, is necessary to find a function F ( ) defining the limit of elasticity under any possible combination of stresses. For differents materials exist in literature differents forms of yield function. For soils, the Drucker-Prager yield criterion extended to include the work-hardening effects, gives reasonable results 5 .

The Drucker-Prager yield function is defined by the relation :

$$F(\sigma_{ij}) = \alpha I_1 + J_2^{\frac{1}{2}} - \Psi = 0 \qquad (7)$$

where I_1 and J_2 are the first stress invariant and the second deviatoric stress invariant, respectively; α and Ψ are positive constants.

Making use of Coulomb criterion, Drucker has derived the next relation :

$$c = \frac{\Psi}{(1-12\alpha^2)^{\frac{1}{2}}} \quad \text{and} \quad \sin\varphi = \frac{3\alpha}{(1-3\alpha^2)^{\frac{1}{2}}} \qquad (8)$$

where c is the cohesion and the angle of internal friction.

The flow rule can be derived by making analogy between the yield function $F(\sigma_{ij})$ and the potential function of plastic flow of solids. Hence, it may be written that the plastic strain increment tensor is equal with the derivative of potential function of plastic flow (i.e., of yield function):

$$\delta\varepsilon_{ij}^{P} = \lambda \frac{\partial F}{\partial \sigma_{ij}} \qquad (9)$$

where λ is a positive scalar proportional to the amount of work required to produce a set of plastic strain increments $\delta\varepsilon_{ij}^{P}$

The hardening rule allows to determine evolution of yield surface as plastic flow proceeds. This rule is included implicitly in the expression of yield function $F(\sigma_{ij})$. From the form of this function (Eq.7), appears that the flow rule is a rule of isotropic hardening. This rule is characterised by a uniform and simetric expansion of the initial yield surface. The parameter Ψ is the work-hardening, depending on the history of plastic deformation process.

By following the methodology here presented, a relation of form of Eq.3 is obtained. In this relation, the parameter E^{*}_{ijkl} depends on the ratio φ:

$$\varphi = \frac{G_t}{G}$$

where G and G_t are the initial shear modulus and tangent shear modulus, respectively (Fig.1).

The ratio is to be determined from a hysteretic model of material. The authors have considered adequate to use the Ramberg-Osgood model, that is more generaly (Fig.2).

NON-LINEAR EARTHQUAKE RESPONSE

The algorithm for the non-linear seismic response calculus uses the concepts of finite element method, together with the step-by-step integration approach of the motion equations [6]. A computer program (ASBAR 2), based on the algorithm explained early has been prepared [2]. This program enables the attaching of different appropriate subroutines for the constitutive low implementation. For the purpose of this paper, the authors have used the Ramberg-Osgood hysteretic model together with the Drucker-Prager yield criterion.

NUMERICAL RESULTS AND CONCLUSIONS

For the purpose of illustrating the kinds of results that may be obteined using the non-linear analysis described above, two examples are presented. The linear and non-linear seismic response of an earthdam (Fig.3) are compiled. The accelerogram recorded in Bucharest (4.o3.1977) has been used (Fig.4).

For analysis purposed the Cross-section was divided into 131 finite elements giving 149 nodal points.

In the Figures 5, 6 and 7 are presented the seismic responses for stresses (element M in the Fig.3), accelerations and displacements (nodal point A in the Fig.3). The responses have been computed by a linear analysis and by a non-linear analysis using the Ramborg-Osgood stress-strain relation. In the Fig. 8 is presented the non-linear response by applying the plastic flow theory for solids.

The results graphical illustrated show no significant differences in acceleration responses as obtained from the three solutions, namely, the linear and the non-linear solutions. Also, no significant differeces in the shear stress responses. From the Fig.8 it appears that the shear stress response calculated by applying the plastic flow theory is more mitigate that in the cases of the linear analysis and the non-linear analysis with an explicit stress-strain relation. The displacement response show that the differences between the relative displacements are quite obvious. In the non-linear analysis, the maximum displacements are more great. The maximorum displacements from the Fig.8 are more great that those from the Fig.7.

From the graphical presented results, it appears that the seismic non-linear analysis performed by applying the plastic flow theory leads to the more mitigate results than those from the non-linear analysis performed with plastic deformation theory.

REFERENCES

1. Negoiţă,Al., Breabăn, V. - Complete Earthquake Analysis of the Dam-Foundation Ground System, Proc.of the VI-th E.C.E.E., Sept., 1978, Dubrovnik, Yugoslavia
2. Breabăn, V., Arsenie, D., Moroianu, A. - Determinarea prin calcul a răspunsului seismic neliniar al barajelor din materiale locale, Contract de cercet. nr.11/1979, I.I.S.Constanţa
3. Dibaj, M., Penzien, J. - Nonlinear Seismic Response of Earth Structures, Earthquake Engineering Research Center, Barkeley University of California, Report No.EERC 69-2, Jan., 1969
4. Watanabe, H. - Analysis of Non-Elastic and Non-Linear Vibration of Rock Fill Dams Using Finite Element Method, Proc.of the V-th W.C.E.E., Roma, 1973
5. Drucker, D.C., Gibson, R.E., Henkel, D.T. - Soil Mechanics and Work-Hardening Theories of Plasticity, Transaction ASCE, Vol. 122, 1957
6. Clough, R.W., Penzien, J. - Dynamics of Structures, Mc Grow-Hill Book Company, New York, 1975
7. Finn, W.D.L., Miller, R.I.S. - Dynamic Analysis of Plane Non-Linear Earth Structures, Proc. of the V-th W.C.E.E., Rome, 1973

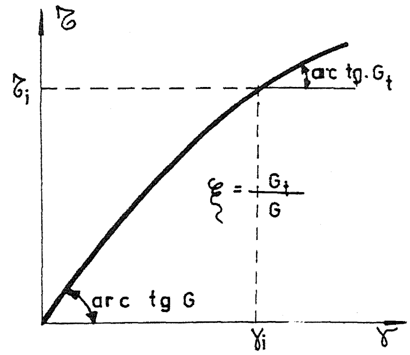

FIG.1. SIMPLEASHEAR–STRAIN CURVE

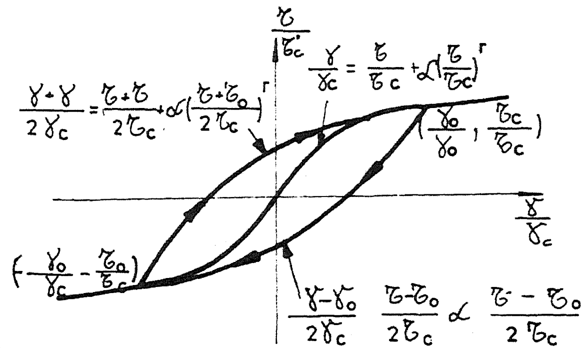

FIG.2 .RAMBERG-OSGOOD HYSTERETIC MODEL

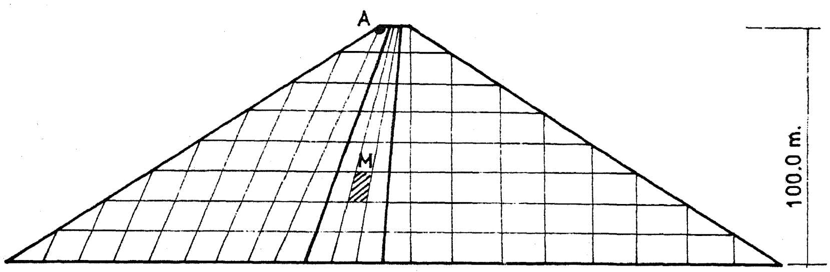

FIG.3 . FINITE ELEMENT MODEL OF DOM

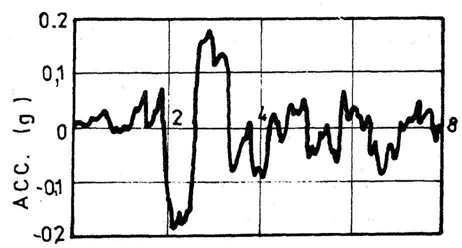

FIG.4 . BUCHAREST ACCELERATION, N S comp

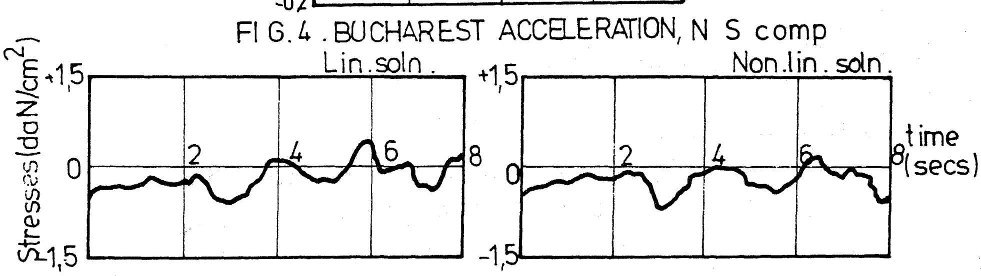

FIG.5 EARTHQUAKE RESPONSE (τ_{xy} within el.M)

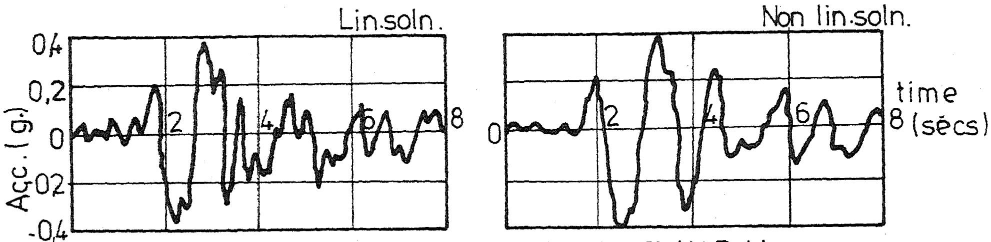

FIG.6. ACCELERATION RESPONSE (N.P.A)

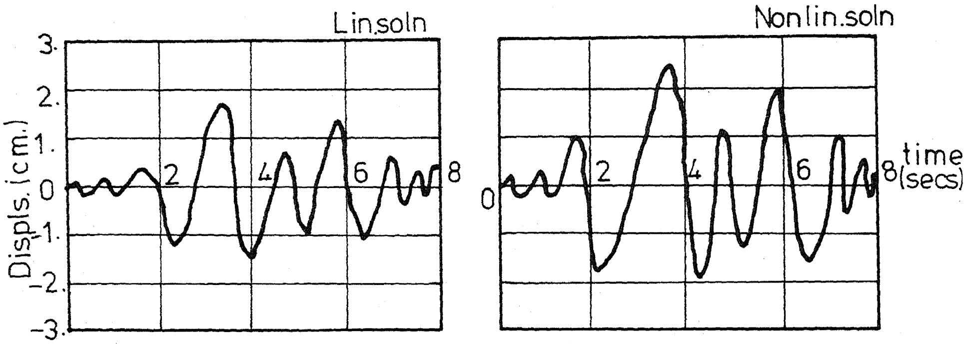

FIG.7. DISPLACEMENT RESPONSE (N.P.A)

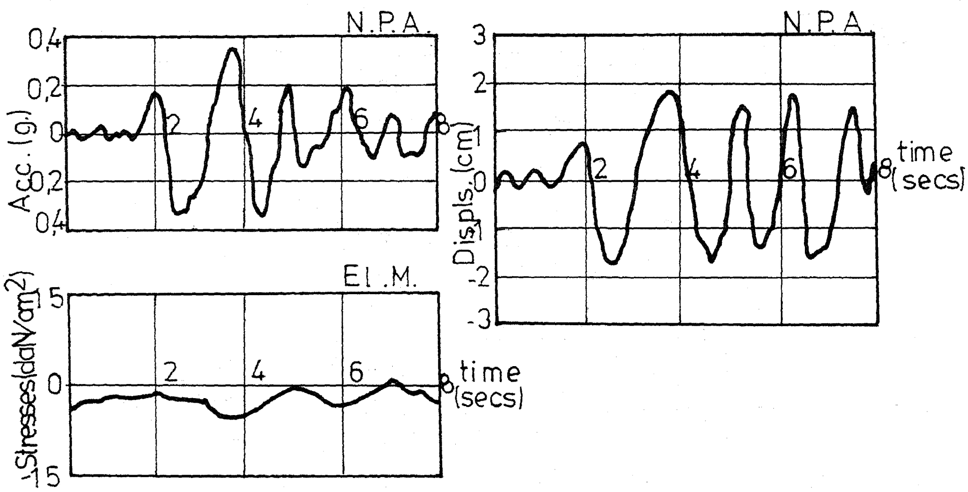

FIG. 8. EARTHQUAKE NON LINEAR RESPONSE
(plastic flow theory)