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DAMAGE AND NUMERICAL SIMULATION OF ACCIANO (ITALY) EARTH DAM DURING 1997 UMBRIA-MARCHE EARTHQUAKE

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SUMMARY

Finite element analysis of the seismic behaviour of earth dams is presented. The earth dam and its foundation are considered to be a porous medium and described as a multiphase continuum. The medium is hence constituted by a solid skeleton with open pores filled by water or by water and air, this last one at atmospheric constant pressure. The macroscopic balance equations of the mass and momentum are derived within the hybrid mixture theory. These equations are integrated in space and in time using Galerkin's procedure and Newmark's scheme respectively. The solid skeleton is considered to be elasto-plastic in which the Mohr-Coulomb and Pastor-Zienkiewicz laws are used for cohesive and granular materials respectively. The water flow is assumed to obey to the Darcy's law. The partially saturation conditions are described using the Safai-Pinder's law. Numerical computations are performed analysing the earth dam in Acciano, (Perugia, Italy) subjected to the Umbria-Marche earthquake of Sept. 97 as seismic input excitation. Comparison between the damage measured on the dam after the earthquake and the finite element analysis reveals the validity of the proposed approach.

INTRODUCTION

The earth dams are important structures that have to be protected against earthquakes. Usually the limit analysis is used to design this kind of structures, but this method doesn't take into consideration the water pressures and consider a rigid-plastic behaviour of materials. In this paper, after a description of the mathematical model, a numerical simulation of Acciano (Perugia, Italy) [Briseghella, 1999] earth dam dynamic behaviour is presented. The dam and the surrounding soil are discretised with triangular isoparametric finite elements. The principal material parameters used in the computation are obtained from the data of the in situ geotechnical analysis. The others are estimated by direct comparison between the given materials and similar well known soils. First an initial, elastic static analysis is performed assuming the gravity and external water pressure to be applied without dynamic effects. The phreatic line is hence obtained, revealing the existence of a zone above it where capillary pressures develop. The cohesion resulting from these capillary pressures is hence taken into account in the model. Then a full non-linear dynamic computation is performed, using a vertical and horizontal accelerations of the Umbria-Marche earthquake of September 97 (Nocera Umbra registration) as seismic input excitation [Briseghella, 1997].

MATHEMATICAL AND NUMERICAL MODEL

Mathematical model

The earth dam and its foundation are considered to be a porous medium and described as a multiphase continuum [Lewis, 1998]. The medium is hence constituted by a solid skeleton with open pores filled by water or by water and air, this last one at atmospheric constant pressure. The solid skeleton is deformable and the constituents are considered to be compressible. The macroscopic balance equations of the mass and momentum are obtained by systematic application of averaging procedures to the relevant balance equations of the constituents at microscopic level.

$$\mathrm{div}\left[\boldsymbol{\sigma}' - \mathbf{I}(1-n)S_w p^w\right] + \rho\,(\mathbf{g} - \mathbf{a}^s) = \mathbf{0} \tag{1}$$

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$$\left(\frac{\alpha-n}{K_s}S_w^2+\frac{nS_w}{K_w}\right)\frac{\partial p^w}{\partial t}+\alpha S_w \mathrm{div}\mathbf{v}^s+$$
$$+\left(\frac{\alpha-n}{K_s}p^w S_w+n\right)\frac{\partial S_w}{\partial t}+\mathrm{div}\left\{\frac{\mathbf{k}k^{rw}}{\mu^w}\left[-\mathrm{grad}p^w+\rho^w\left(\mathbf{g}-\mathbf{a}^s\right)\right]\right\}=0 \qquad (2)$$

with:

σ'	efficacy stress;
n	porosity;
S_w	ratio of saturation;
ρ	porous medium density;
g	gravity acceleration;
a^s	solid acceleration;
K_s, K_w	rigidity bulk moduli;
$\underline{k}k^{rw}$	permeability coefficient.
p^w	water pressures.

The independent variables are the solid displacements and the water pressures. The constitutive laws for the solid skeleton and for the water close the resulting coupled model. In particular the solid skeleton is considered to be elasto-plastic in which the Mohr-Coulomb and Pastor-Zienkiewicz laws are used for cohesive and granular materials respectively. The water flow is assumed to obey to the Darcy's law. The partially saturation conditions are described using the Safai-Pinder's law.

Finite element model

The independent variables are the solid displacements and the water pressures [Zienkiewicz, 1999]. The balance (1) and conservation (2) equations of mass are integrated in space and in time using the Galerkin's procedure and the Newmark's scheme respectively. The algebraic system, written in matrix form, is:

$$\begin{pmatrix} \mathbf{M}+\mathbf{K}_T\beta_2\Delta t^2 & -\mathbf{Q}\,\theta\Delta t \\ -\mathbf{Q}^T\theta\Delta t & -\frac{\theta}{\beta_1}\left(\mathbf{H}\,\theta\Delta t+\mathbf{S}\right) \end{pmatrix}\begin{pmatrix}\Delta\ddot{\mathbf{u}} \\ \Delta\dot{\mathbf{p}}\end{pmatrix}=\begin{pmatrix}-\Psi^u \\ -\frac{\theta}{\beta_1}\Psi^p\end{pmatrix} \qquad (3)$$

with:

M	mass matrix;
$\mathbf{K_T}$	elastic-plastic constitutive matrix;
Q	coupling matrix;
H	*permeability matrix;*
S	*saturation matrix;*
$\boldsymbol{\beta_1}$, $\boldsymbol{\beta_2}$, $\boldsymbol{\theta}$	coefficients for temporal discretization.

NUMERICAL SIMULATION OF ACCIANO EARTHDAM

The Acciano dam is an earth dam with a clay nucleus and sides of melted materials, there is a central concrete diaphram to limiting the flow of water too. The main characteristic are:

- height dam	28.50	m
- water height	25.50	m
- top height on sea	521.50	m
- top length	182.00	m
- dam bulk	193360	m^3

- water volume 1.93×10^6 m^3
- basin area 21.4 km^2

Fig. 1 Localizzazione dell'evento

Data evento: 26-9-97
Tempo origine: 11 40 00
Magnitudo: 5.8
Fonte coordinate: Ing
elaborazione S.S.N.: 26-SEP-1997:16:46:57.00

Coordinate epicentrali: Long: 12.9 Lat: 43.00
Comune epicentrale: SERRAVALLE DI CHIENTI
Tipo di magnitudo: .....

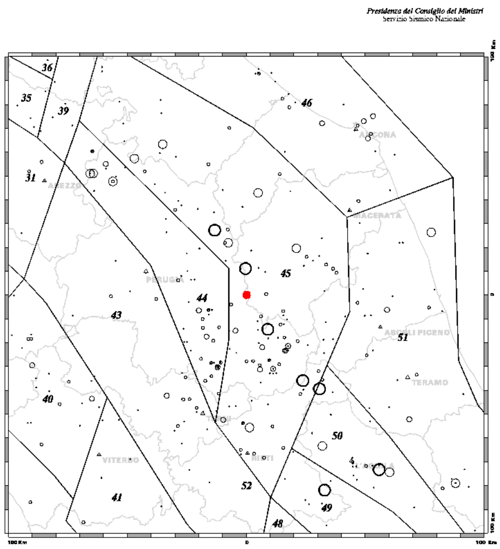


Fig. 18 Catalogo GNDT - NT4. Estrazione per Intensita' MCS >= 5

5.0 <= I < 7.0
7.0 <= I < 8.0
8.0 <= I < 9.0
9.0 <= I < 10.0
10.0 <= I < 11.0
I >= 11.0
Fonte: GNDT - 1996
Scala 1:1.100.000
zone sismogenetiche (Scandone zs4 1996)

The dam was heavily damaged during the Umbria-Marche earthquake (1997).

Figure 1: Location of seismic event, MCS intensity.

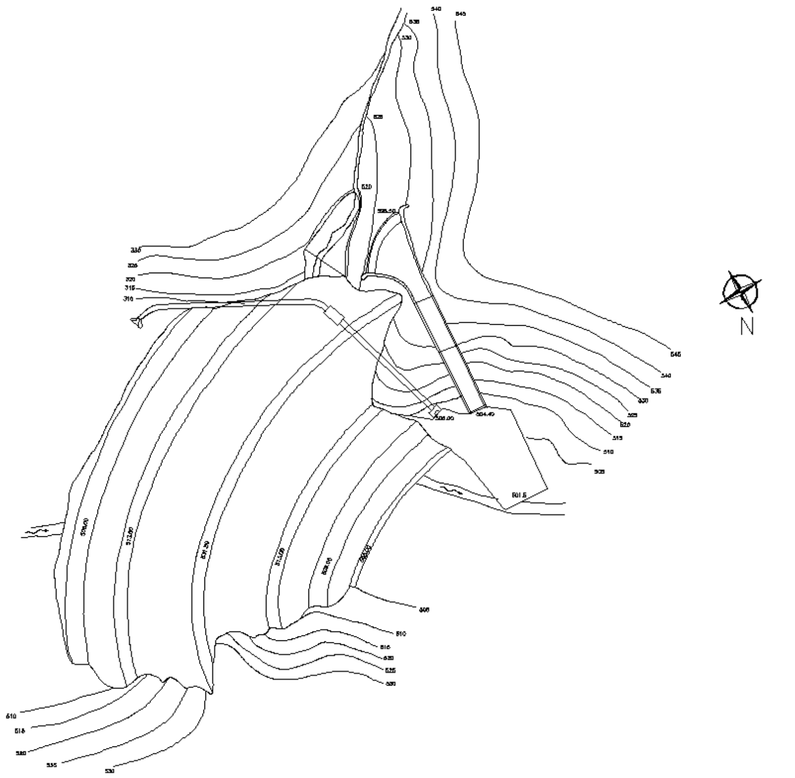
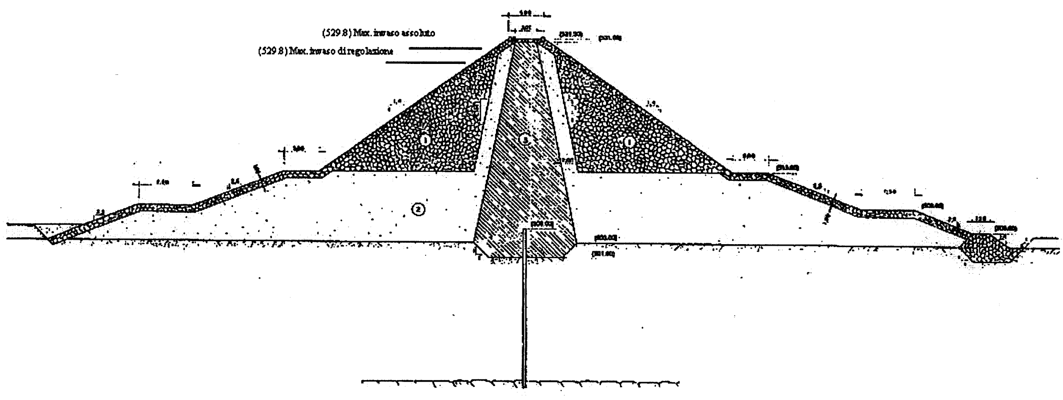


Figure 2: Acciano (Perugia, Italy) earth dam, plant.



.Figure 3: Acciano (Perugia, Italy) earth dam, section.

Figure 4: Views of Acciano (Perugia, Italy) earth dam.

Figure 5: Damages of Acciano (Perugia, Italy) earth dam.

The displacements of some points of the dam measured during the Umbria-Marche earthquake, see table1, are similar to the results of the finite element analysis, see Figure 6.

Table1: Measured displacement on the top of the dam after Umbria-Marche earthquake.

Point	Horizontal displacement	Vertical displacement
3	0.079 m.	-0.247 m.
4	0.114 m.	-0.250 m.
5	0.071 m.	-0.150 m.

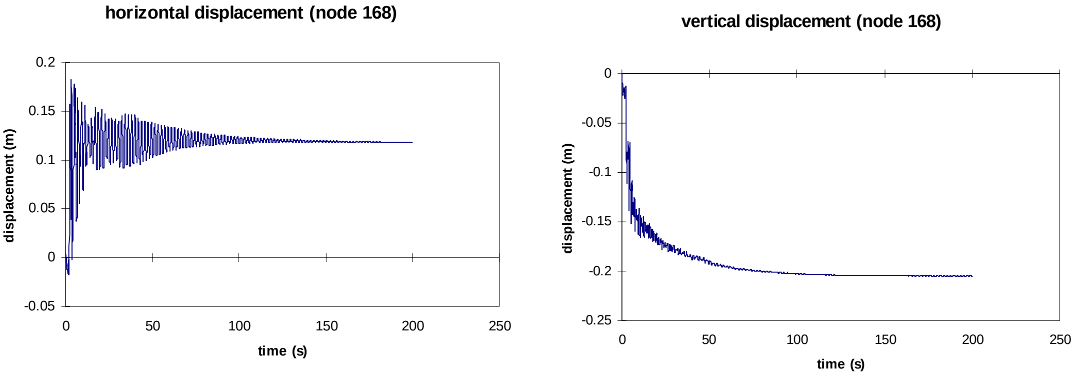


Figure 6: Horizontal and vertical displacement of the top node of dam.

The distribution of equivalent plastic deformations , see figure 7, shows the damage of the dam during the earthquake, in particular the cracking of the concrete under the clay nucleus and of the foundation soil, who caused a increase of the permeability.

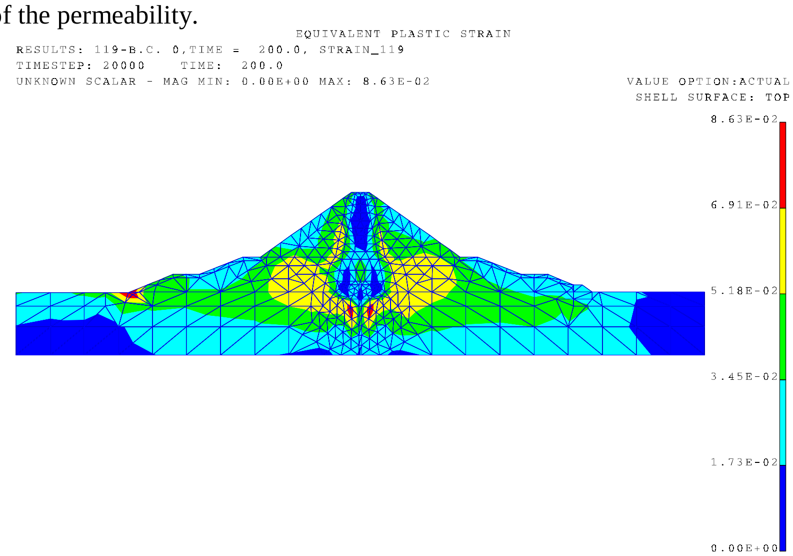


Figure 7: Equivalent plastic deformations of the dam.

The water pressures after 200 s, see figure 8, reveal the existence of a zone above the phreatic line where capillary pressures develop.

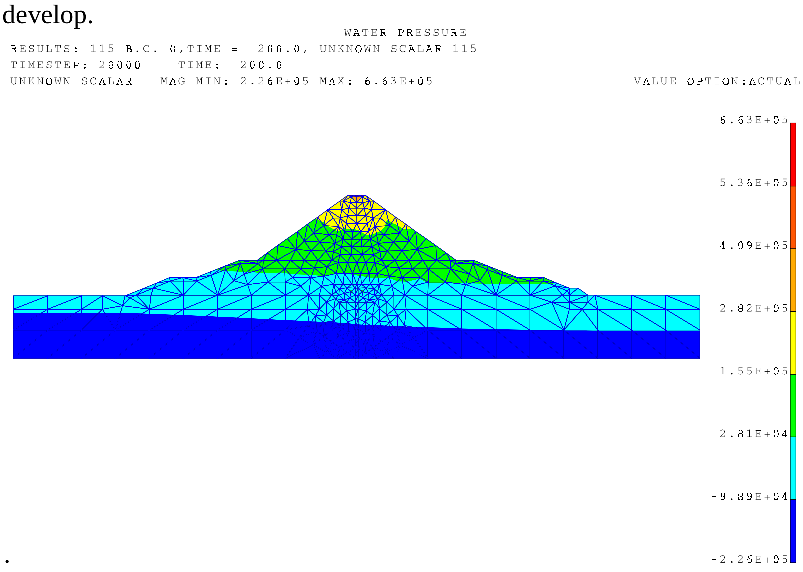


Figure 8: Distribution of water pressure after 200 s.

CONCLUSIONS

A dynamic non linear analysis of Accianos' earth dam subjected to the Umbria-Marche (1997) earthquake is here presented. The comparison of the finite element analysis with the damage of the dam during the earthquake show the consistency of the proposed approach. The numerical simulation shows the damage of the foundation concrete and the variation of water pressure in time.

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