Numerical analysis of dams

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Theme B:

Seismic analyses of Menta Embankment dam

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Design model

The Menta dam is a bituminous-faced rockfill dam located in Southern Italy, lying in the heart of Aspromonte Massif. A homogeneous rockfill dam, located on a rock mass foundation was considered as a design model. Bituminous screen was not considered in the design model, the upper face was taken waterproof.

The size of the base area was chosen in such a way as to exclude the influence of the lateral boundaries of the area on the static stress-strain state (SSS) of the dam. In dynamic calculations, the lateral boundaries of the base area were assumed to be viscous in order to avoid the reflection of waves from these boundaries.

The calculations were carried out using the Plaxis 2D program. The finite element mesh is shown in figure 1. Number of mesh nodes – 10599, elements – 1283. The calculation takes into account the construction sequence of the dam; three stages of construction are indicated in the figure in different colors.

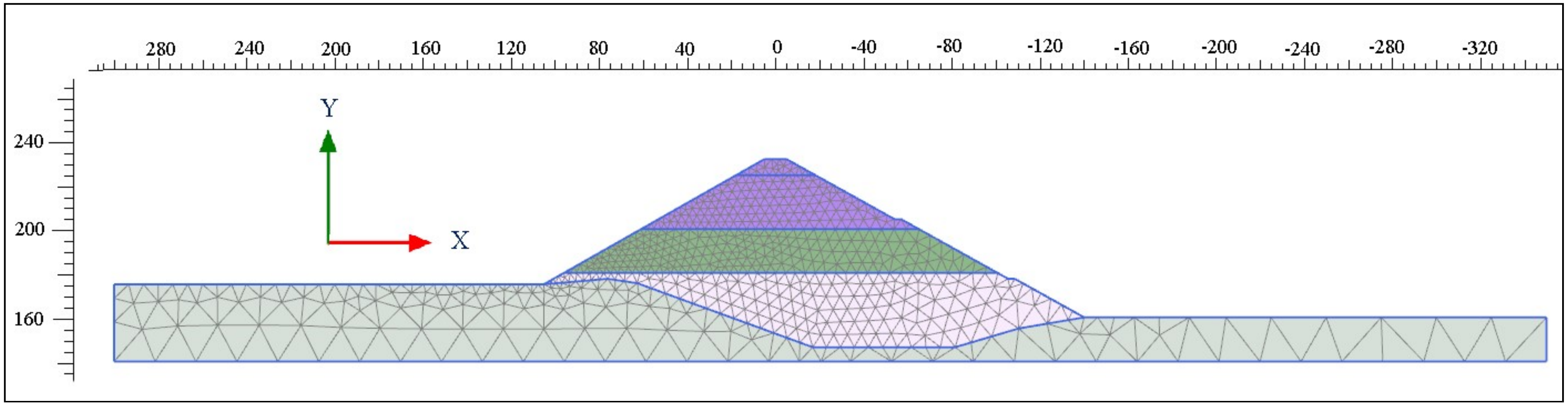

Figure 1: Design model of the dam.

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Characteristics of the dam material

Due to the lack of complete data on the characteristics of the material, the following assumptions were made in the calculation. The dam is divided into 3 zones according to the stages of construction (Fig.1). Static deformation modules of these zones change in the process of erection stepwise during the transition to the next stage of construction (Table 1). The angle of internal friction is also assumed constant for each zone and also changing stepwise. The dynamic characteristics of the rockfill material for the HS small Plaxis model also are taken different in these 3 zones and will be given below.

Table 1. Characteristics of rockfill layers

Stages of construction	**1**			**2**			**3**		
Layers	1	2	3	1	2	3	1	2	3
Friction angle, degrees	44	-	-	42	44	-	40	42	44
Young's modulus, MPa	250	-	-	300	250	-	350	300	250

For an approximate account of the dependence of the characteristics E and φ on the stress-strain state, their values in the layers are assumed to be different when calculating at different stages of construction. Layer number in the Table 1 corresponds to the construction stages.

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Characteristics of the dam material

Upon completion of construction, the deformation and strength characteristics of the dam layers have the values given in column 3 of the Table 1. Bulk unit weight of rockfill is 23 kN/m3 and Poisson's ratio is 0.2.

The rock mass foundation is assumed to be linearly elastic; the characteristics are given in Table 2.

Table 2: Characteristics of rock mass foundation

Foundation	γ, kN/m^3	ν	E, MPa
Rock mass	27,0	0,25	7000

After determining the static stress-strain state of the dam at the end of construction, SSS was calculated when the reservoir was filled to the design level. Hydrostatic water pressure was represented by a corresponding distributed load on the upstream slope and the foundation. The calculation results are presented in Figures 2 and 3.

The SSS of the dam after filling the reservoir

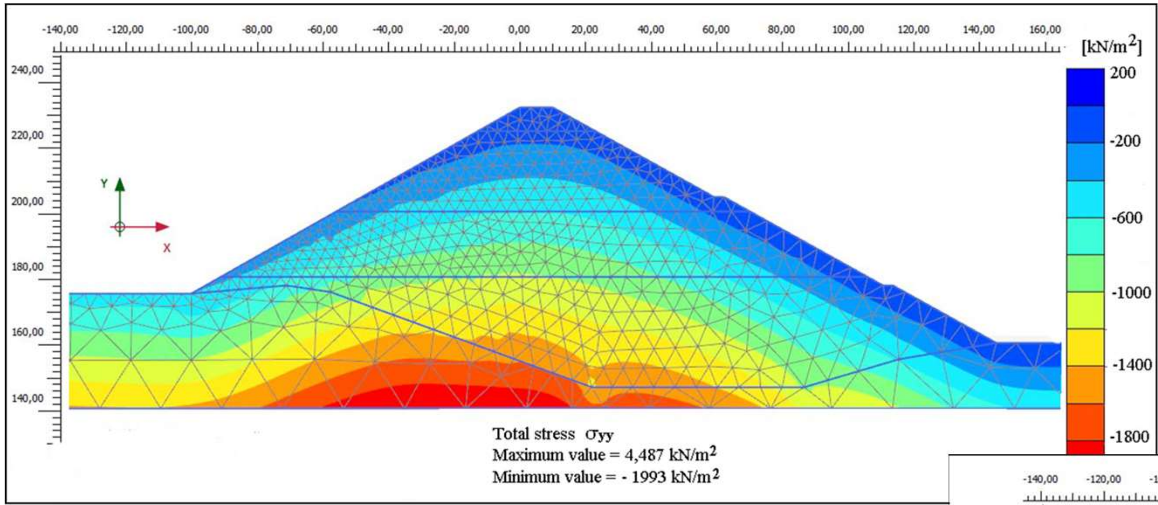

Figure 2. Vertical stresses σ_{yy}

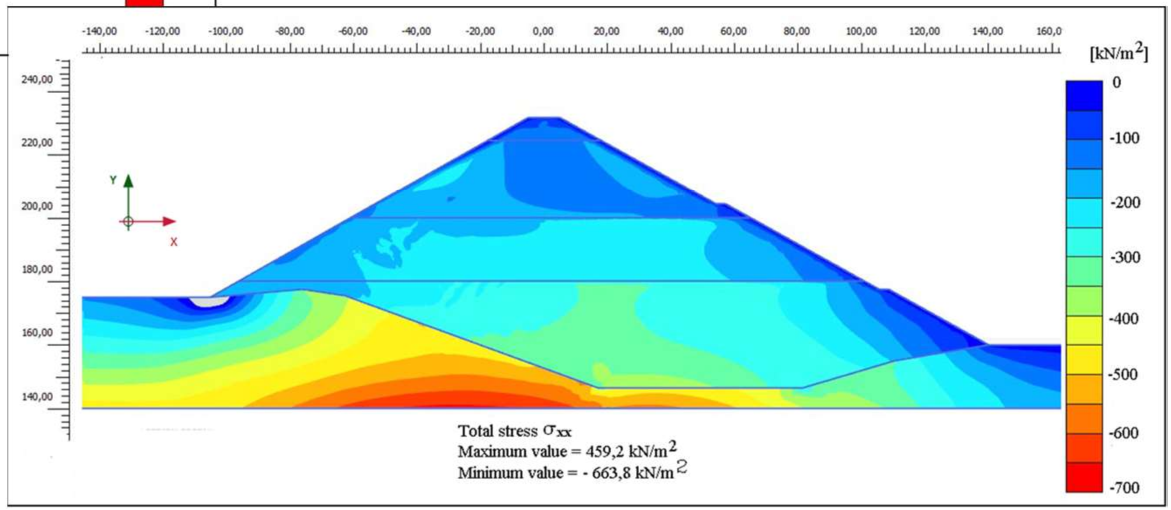

Figure 3. Horizontal stresses σ_{xx}

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Calculation of the dam under seismic impacts

Calculation of the dam under seismic impacts, represented by records of two strong earthquakes that occurred in Italy was carried out. Records are scaled to have a maximum acceleration of 0.26 g.

In the calculations the following assumptions were made. For ease of calculation, it was assumed that the records of accelerograms of earthquakes correspond to the lower boundary of the computational domain.

The rock base is assumed to be weightless, linearly elastic, the Young's modulus is E = 1400 MPa, the damping is 5%.

For the dam material, an elastoplastic model with hardening at small strains, implemented in the Plaxis program, is adopted. The following characteristics of the dam material were taken into calculations (Table 3).

Table 3. The dynamic characteristics of the rockfill material

Layer number	E_{50}^{ref}, MPa	E_{oed}^{ref}, MPa	E_{ur}^{ref}, MPa	G_0^{ref}, MPa	$\gamma_{0.7}$
1	350	350	1050	933	$2{\cdot}10^{-4}$
2	300	300	900	800	$2{\cdot}10^{-4}$
3	250	250	750	670	$2{\cdot}10^{-4}$

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Calculation of the dam under seismic impacts

In Table 3 E_{50}^{ref} is the secant modulus of stiffness in standard drained triaxial test of soil; E_{oed}^{ref} – the tangent modulus of stiffness for primary loading in the odometer; E_{ur}^{ref} – stiffness during unloading/re-loading; G_0^{ref} – the value of shear modulus at very low strains; $\gamma_{0.7}$ – shear strain at which the shear modulus $G = 0{,}722 G_0^{ref}$.

For all layers damping was taken to be 10%. Other characteristics are the same as in static calculation.

Records of the accelerogram were presented for the three coordinates, but only two were used - vertical and one of horizontal, having a larger amplitude.

Accounting for the effect of the reservoir on the SSS of the dam during seismic impact was carried out by introducing the added mass in accordance with Russian standards. The results of the calculations showed that the dynamic interaction of the earth dam with the reservoir has little effect on the SSS of the dam and, in particular, on the magnitude of the crest acceleration. That's why in calculations the presence of the reservoir was taken into account only by the applied load from the hydrostatic pressure on the upstream slope and the foundation.

Results of seismic calculations. *The earthquake Friuli, 1976.*

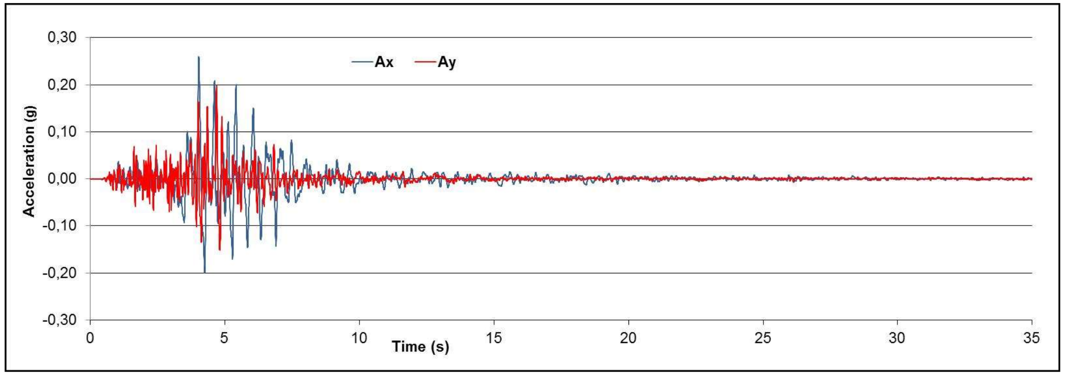

Figure 4. Accelerograms of the Friuli earthquake, 1976.

$$\frac{A_{x,crest}}{A_{x,base}} = 1{,}69$$

$$\frac{A_{y,crest}}{A_{y,base}} = 1{,}59$$

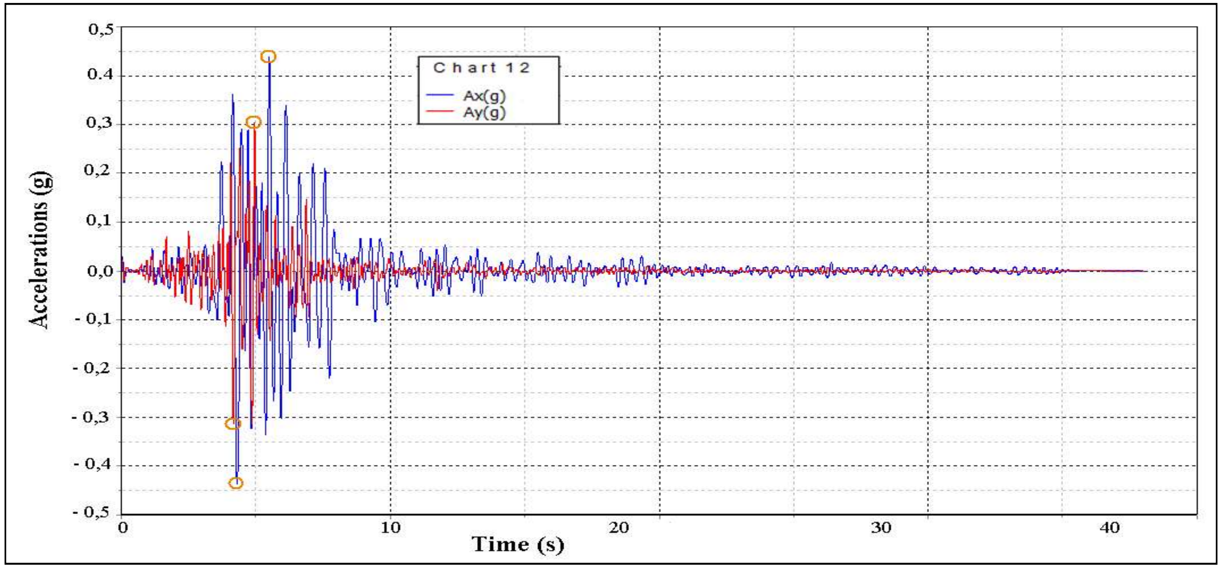

Figure 5. Accelerations of a point on the crest during an earthquake.

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Results of seismic calculations. *The earthquake Friuli, 1976*.

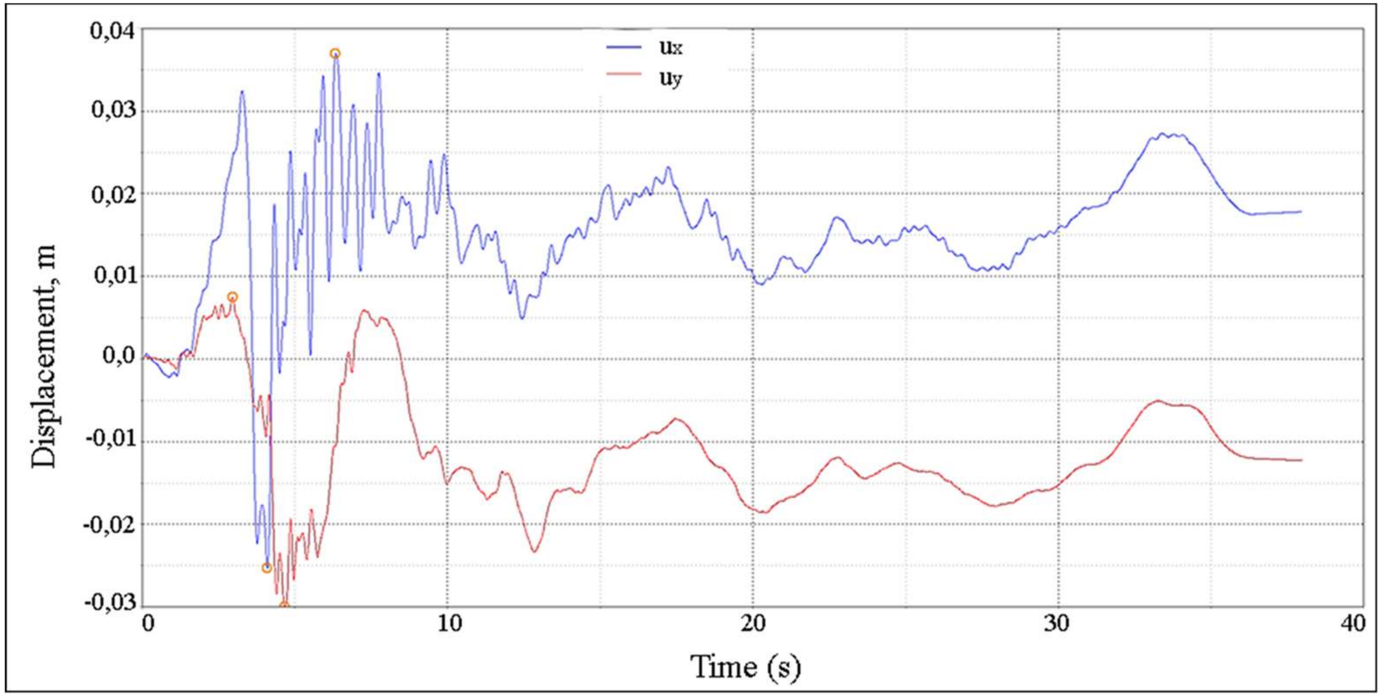


Figure 6. Displacements of a point on the crest during an earthquake.

A residual horizontal displacement of central axis on the crest is 1.78 cm and residual vertical displacement of central axis on the crest is -1.23 cm.

Results of seismic calculations. *The earthquake Friuli, 1976.*

The residual displacements after earthquake Friuli, 1976.

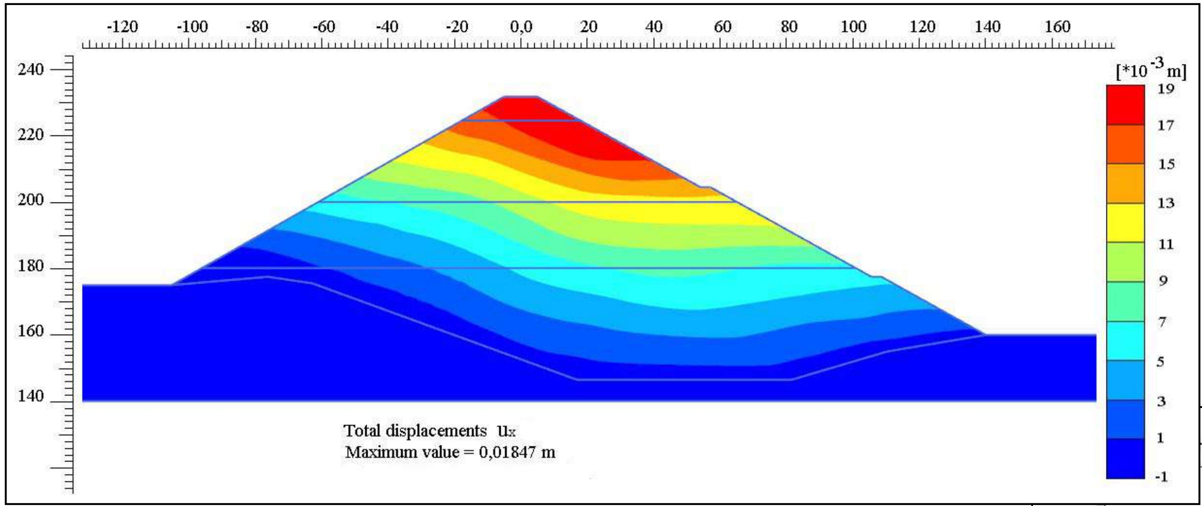


Figure 7. Displacements ux.

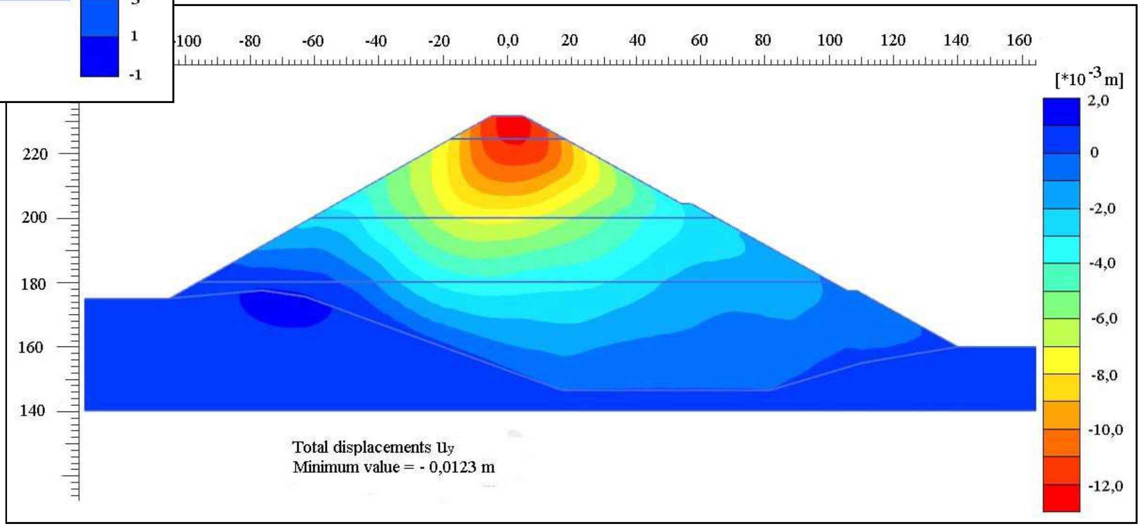


Figure 8. Displacements uy.

Results of seismic calculations. *The Central Italy earthquake, 2016*.

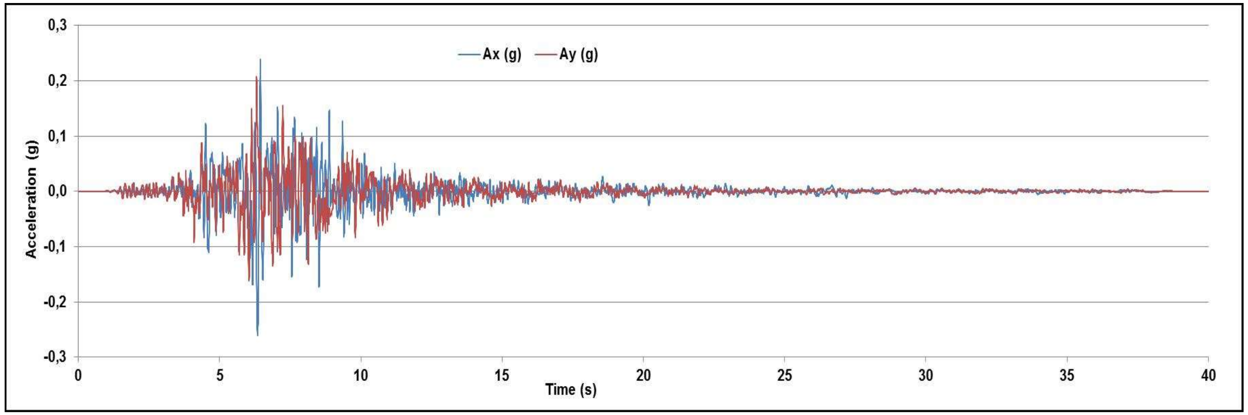
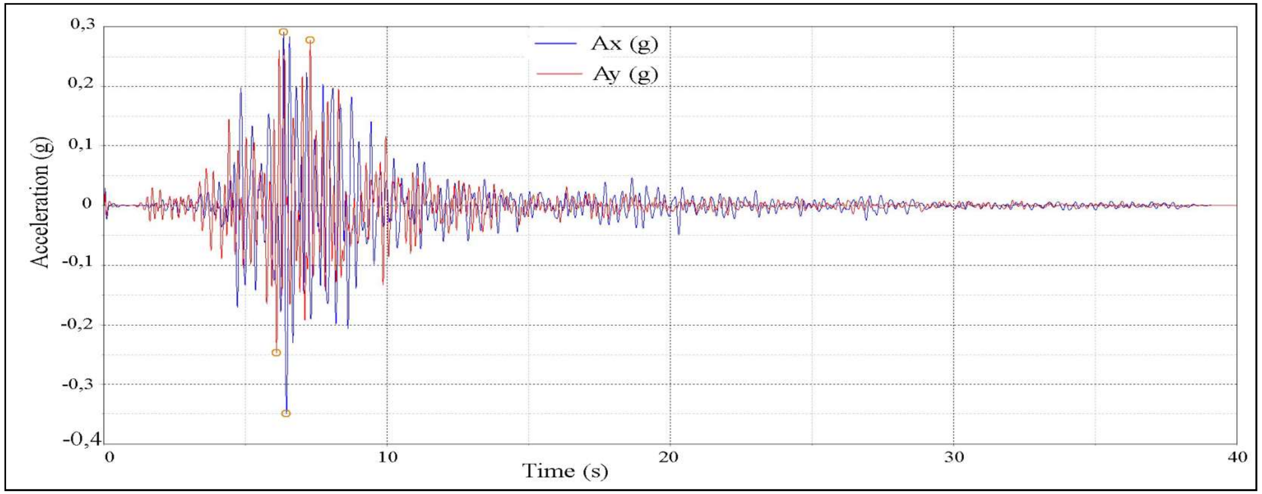


Figure 9. Accelerograms of the Central Italy earthquake, 2016.



$$\frac{A_{x,crest}}{A_{x,base}} = 1{,}34$$

$$\frac{A_{y,crest}}{A_{y,base}} = 1{,}34$$

Figure 10. Accelerations of a point on the crest during an earthquake.

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Results of seismic calculations. *The Central Italy earthquake, 2016*.

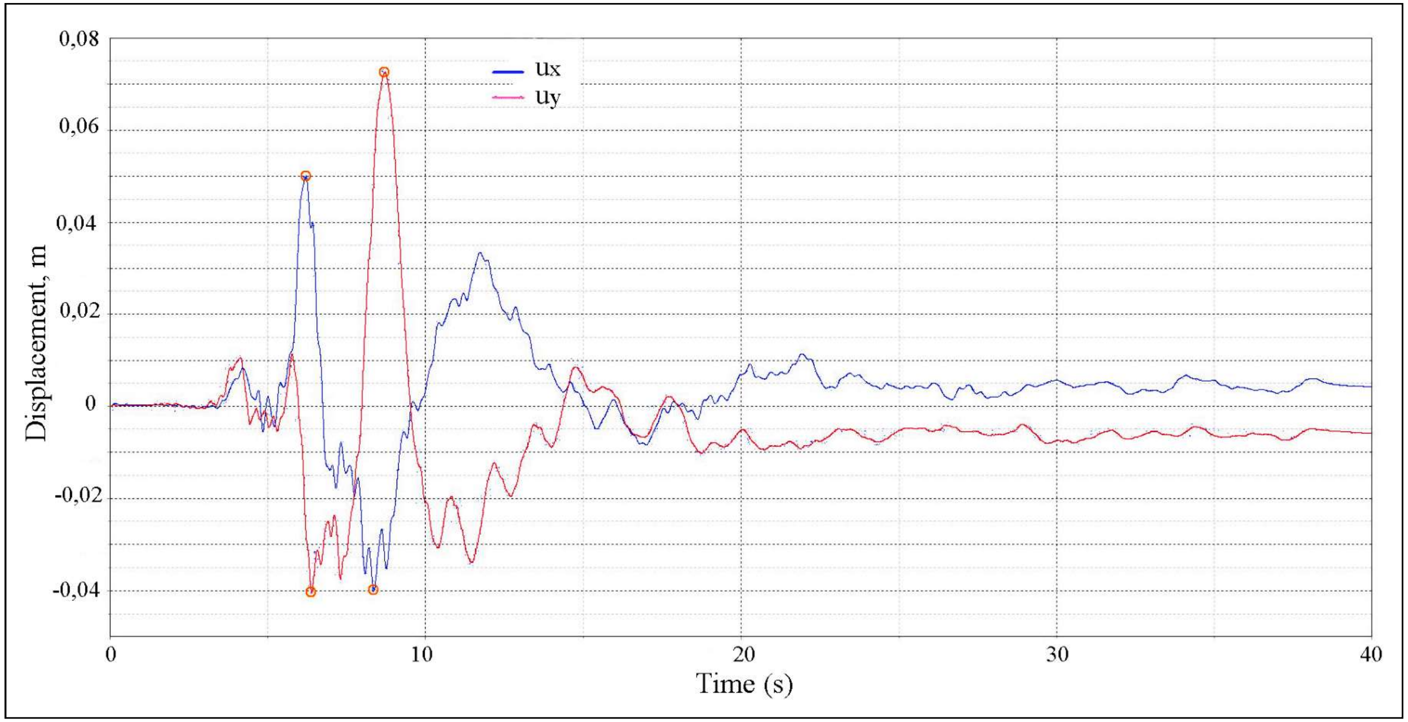

Figure 11. Displacements of a point on the crest during an earthquake.

A residual horizontal displacement of central axis on the crest is 0.43 cm and residual vertical displacement of central axis on the crest is -0.58 cm.

Results of seismic calculations. *The Central Italy earthquake, 2016*.

The residual displacements after the Central Italy earthquake, 2016.

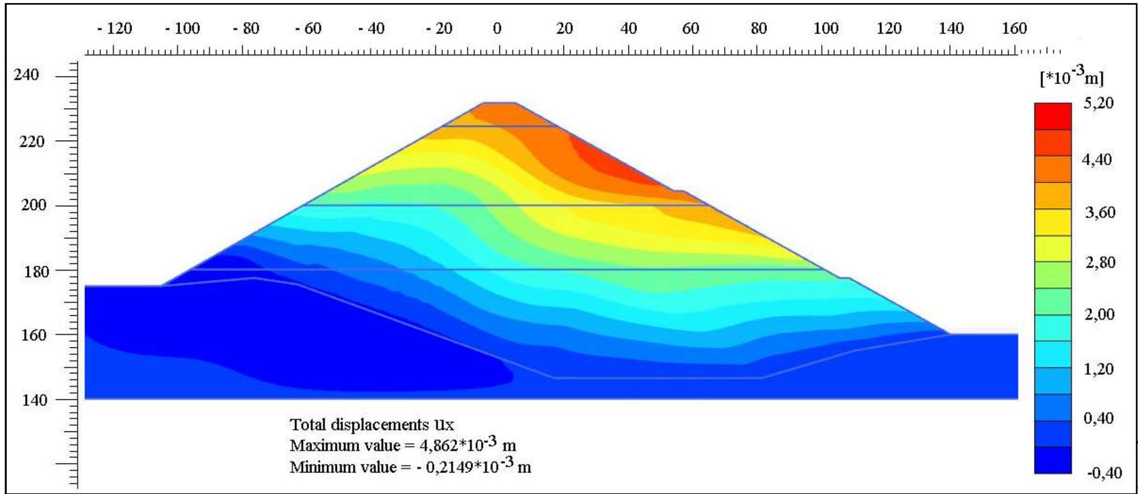

Figure 12. Displacements ux.

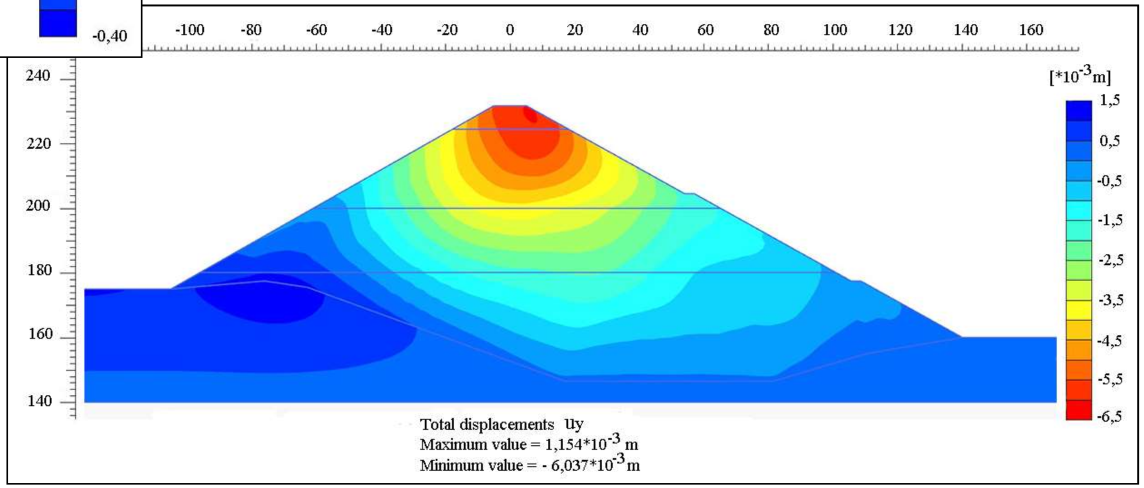

Figure 13. Displacements uy.

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CONCLUSIONS

The results of the calculations show that within the framework of the accepted mathematical model of the dam and the accepted characteristics of soils, the Menta embankment dam is able to withstand the considered earthquakes without significant damage. Due to the lack of complete data on the characteristics of the dam material and the inability to calibrate the model from field observations, the values of soil characteristics were assigned conditionally according general considerations.

In the process of calculation, the insignificance of the reservoir influence on the results of dynamic calculation of the embankment dam was confirmed once again.

Thanks for attention