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EARTHQUAKE ANALYSIS OF AN OLD CYCLOPEAN CONCRETE DAM AND ITS SEISMIC RETROFIT WITH POST-TENSIONING ANCHORS.

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Summary

The dynamic analysis and especially the seismic design of dams are an important area of research in the past years. This research has, however, focused on concrete or embankment dams. There are a significant number of dams in the world, which have been built of rough masonry, mainly in the early 20th century when the use of concrete was not yet widespread. The dynamic behavior of these dams was not thoroughly investigated, and the seismic calculations in seismicity areas were carried out often under simplified assumptions. After about a century, many of these dams are still in use and must fulfill the requirements of the current anti-seismic standards. Using the finite element method, these structures can now also be investigated in order to obtain important information about the seismic behavior of such structures during an earthquake.

The constitutive law of the material

The cyclopean concrete consists of huge rubble stones, with a size of 50-60 cm, bonded with truss-lime mortar. The stones cover about 60% of the volume of the compounded material.

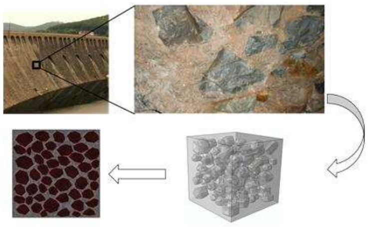

Figure 1: The Representative Volume Element

TABLE 1: MECHANICAL CHARACTERISTICS OF THE RVE

	Stones	Mortar	ITZ
E (MPa)	40.000	8.000	4.800
v	0,25	0,20	0,20
f_c (MPa)	-	17,6	10,6
f_t (MPa)	-	5,0	0,3

The determination of the size dependent fracture energy of the compound material was carried out with numerical splitting test.

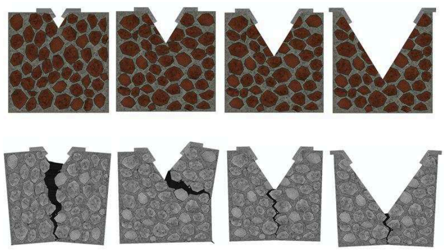

Figure 2: The numerical splitting test

TABLE 2: MECHANICAL CHARACTERISTICS OF THE HOMOGENIZED CONCRETE

	Cyclopean Concrete
E (MPa)	15.600
v	0,20
f_c (MPa)	23,4
f_t (MPa)	1,0
G_F (N/m)	26

Calculation of the size depended fracture energy.

$$G_f(a) = G_F \cdot \frac{W-a}{2 \cdot a_l} \text{, for} \quad a \geq W - a_l$$

$$G_f(a) = G_F \cdot \left[1 - \frac{a_l}{2 \cdot (W-a)}\right] \text{, for} \quad a \leq W - a_l$$

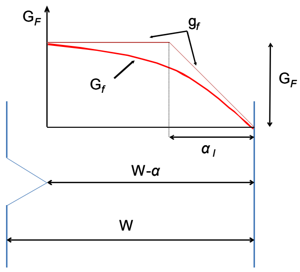

Figure 3: Illustration of size depended fracture energy

TABLE 3: MECHANICAL CHARACTERISTICS OF THE FINITE ELEMENT MODEL

Model Part	Young Modulus E (GPa)	Poisson v	Density (kg/m^3)	Permeability k_f (m/s)	Conductivity (J/m·K·s)	Specific Heat (kJ/kg·K)	Expansion (1/K)
Rock	5	0,25	2773	from $1 \cdot 10^{-5}$ to $1 \cdot 10^{-7}$	3,10	1000	$66 \cdot 10^{-6}$
Cyclopean Concrete	15,6	0,20	2200	$1 \cdot 10^{-6}$	3,10	1000	$6 \cdot 10^{-6}$
Blanket	-	-	-	$5 \cdot 10^{-7}$	3,10	1000	$6 \cdot 10^{-6}$
Anchors	210	0,29	-	-	43	500	$12 \cdot 10^{-6}$
Water	K=2,2	-	1000	-	-	-	-

The finite element model

The finite element analysis carried out with the commercial finite element program ABAQUS. The dam and the rock foundation was modeled with two types of continuum plain strain elements with additional temperature and pore pressure degrees of freedom respectively. The overlay technique was used to combine these two types. The reservoir was modeled with acoustic elements to take into account the compressibility of the water. The interface of the dam-reservoir was modeled with acoustic interface elements. Infinite acoustic and infinite continuum elements were used to represent the infinite extent of the reservoir and the foundation respectively. A second analysis includes the post tensioned anchors, which were modeled using truss elements.

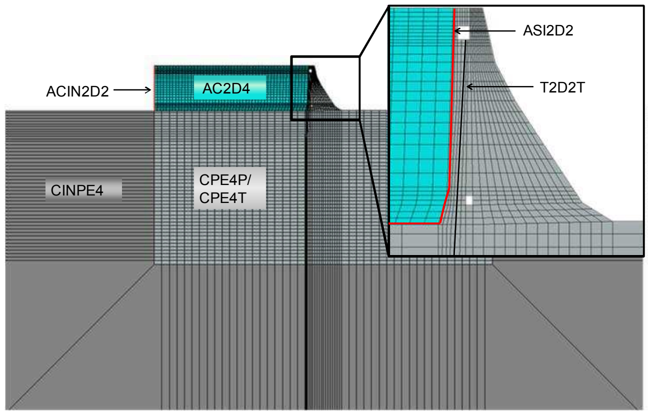

Figure 4: The finite element model and types

The analysis steps

The analysis included the following cases: a geostatic step for the equilibrium of the initial stresses of the foundation under its self-weight, the self-weight of the dam, the water pressures on the dam and the foundation, the pore pressure distribution in the dam and the rock, the post tensioned anchors with a post tensioning force of 2000 kN (optional – as seismic upgrading), the thermal loading and the seismic excitation. The time histories were artificially generated following the requirements of DIN EN 1998-1. As peak ground acceleration a hypothetical value of 0,36g was assumed. The time histories were deconvoluted and applied as shear stresses at the foundation – infinite domain interface.

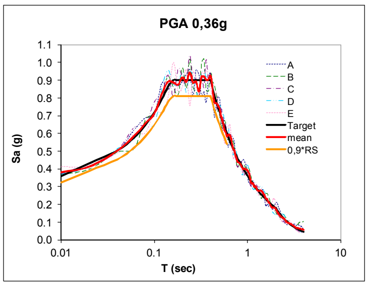

Figure 5: The time histories according to EC-8

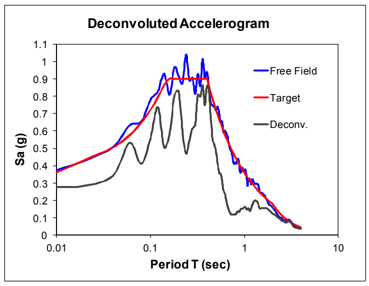

Figure 6: Deconvoluted time history

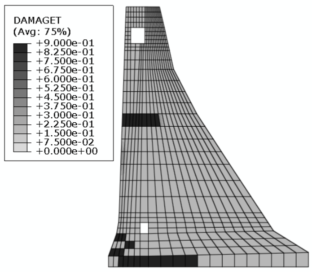

Figure 7: The tension damage without post-tensioning

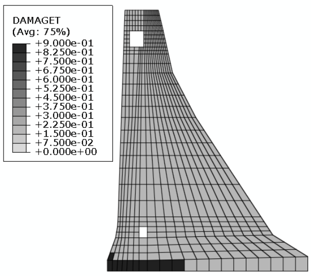

Figure 8: Tension damage with post-tensioning upgrading

Conclusions

The seismic upgrading of an old cyclopean concrete dam with post tensioned anchors was shown to be effective up to a grade. The damage is limited to a smaller region of the dam. The advantage of the post tensioning as a seismic upgrading method is that the anchors add negligible weight to the dam, so no additional inertial forces are developed. The compression stresses due to the anchors eliminate a big part of the tension stresses caused by the overturning moment.

Acknowledgements

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