International Symposium
Qualification of dynamic analyses of dams and their equipments
and of probabilistic assessment seismic hazard in Europe
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Session :

Prediction of gravity dams behavior under strong eartquakes

SUMMARY

1. Occurrence of Irreversible displacements and plastic deformations

2. Calculation of irreversible displacements

3.Evaluation of impact on the leakages at the contact with the rock foundation or within the rock

4.Impact on uplift pressures and on the post eartquake stability of the dam

5. Conclusion

Irreversible displacements, plastic deformations

For the *Safety Evaluation Earthquake* it is generally accepted that the storage capacity of the dam should be maintained. However, cracks, plastic deformations, irrecoverable displacements are tolerated as far as they don’t threat the capacity of the dam to control the reservoir.

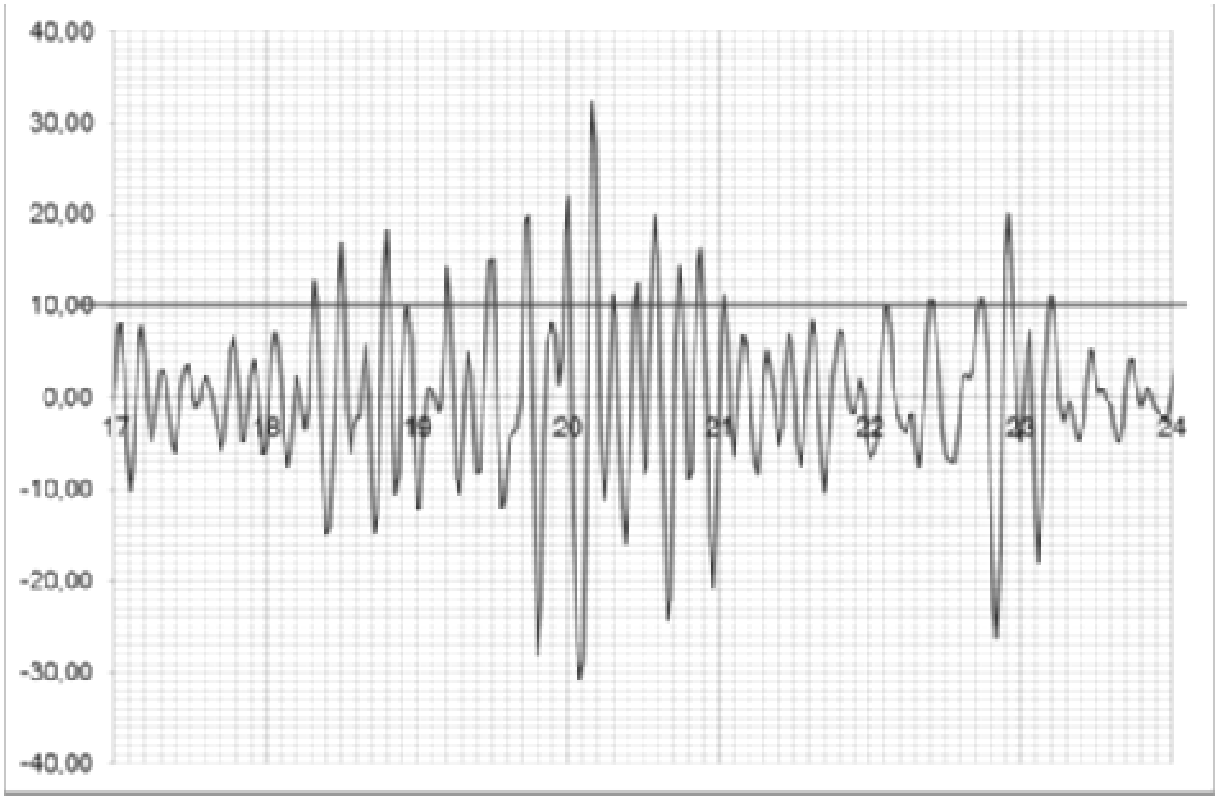
Calculation of the irreversible displacements

- Movement along an horizontal contact joint in the concrete or at the contact with foundation under rigid body principle
- Finite element calculation with theoretical frictional joint (no tension, φ max)
- Finite element calculation taking into account the rock foundation with its modulus and damping ratio
- In any cases, the joints have an **angle of dilatancy**. Shear movement is associated with opening of the joint(s)

1. Rigid Body Movement

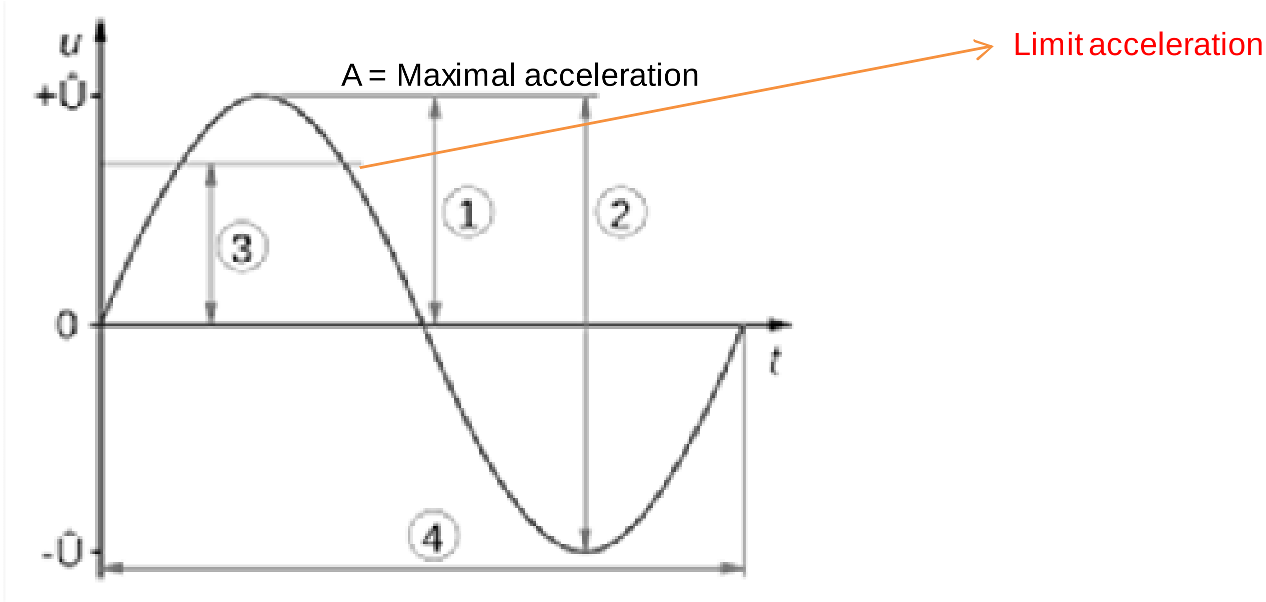
Newmark method. Exemple of the top part of a gravity dam:

limit acceleration = g.tgφ



Newmark method. Exemple of top part of a gravity dam: limit acceleration = g.tgφ

$$D = \frac{aT^2}{4\pi \;(1 - 2\;\pi\;\text{Arcsinus}(\gamma_1 / A))}$$



period

One peak at 32,3 m/s/s, 4 peaks at 20 m/s/s, 6 peaks at 15 m/s/s
>>> ~ 0,15 meters

2. Elastic body, theoretical frictional joint at the contact on the rock foundation or within the concrete mass

The joint behaves locally (opening, shear movement), and not as a rigid body.

The calculated shear plastic movement is larger than with the first method.

N.B. The calculated displacement is highly dependent of the choice of the accelerogram (with the same PGA).

3. Third method, the foundation is included in the modelling with its modulus and damping ratio.

- The accelerogram is calculated at the centroid of the dam
- The Newmark method is applied at the centroid.
- The shear movement is supposed distributed within the upper part of the foundation

This method gives generally the smallest irreversible displacement due mainly to the damping of the foundation

Necessity to know the dynamic modulus and the damping ratio of both concrete and rock

Impact of the irreversible displacement on the drainage efficiency and the uplift pattern

- Calculation of the leakages through the active joints:
- Methode 1: a unique joint opened under dilatancy effect
- Methode 2: includes the foundation. The displacement is distributed in a thickness of rock under shear movement.

Methode 1 Unique dilatant joint

The flow is “turbulent and very rough”

The velocity of the water is:

$$V = -(4(eg)^{0,5} \ln(1,9/Rr)\, J_f^{0,5}\, F$$

Where

e= opening of the joint = displacement x tg i (i=angle of dilatancy)

Jf = hydraulic gradient

Rr = relative roughness ~0,5

F=degree of separation of the crack ~0,75

The velocity of the water in the open joint is

$V = 17\,(e\,J_f\,)^{0,5}$ >> Flow through the joint to be collected by the drainage system

- The velocity of the water depends essentially on the plastic displacement and of the hydraulic gradient.
- The hydraulic gradient depends on the distance of the drainage curtain from the upstream face.
- The flow is proportional to the opening of the joint and the length of the joint.
- The drainage system should collect the flow
- If the drains are saturated, the uplift pattern is modified and the safety factor decreases strongly

Methode 2 involving the rock foundation

- Choose a thickness of involved “multicrack” rock i.e 10 metres corresponding to consolidation grouting for instance
- Equivalence cracked/porous medium
- $K = e^3 \; F g / 12 \; Vc \; b \; C$
- Where
- e = opening of the cracks
- b= distance between the cracks
- Vc = cinematic viscosity of water
- $C = 1+8{,}8 \; R_r^{1{,}5}$
- *So* **$K \sim 0{,}124 \, . \, 10^6 \, . \, e^3/b$**

This resulting permeability K modifies the flow of water within the rock

And then efficiency of the drainage system

thus the uplift pattern underneath the dam

and subsequently the safety factor of the dam after the end of the earthquake.

We suggest that the main danger of the dam is not during the earthquake, but after the earthquake, on a new permanent basis.

We suggest that the main danger of the dam is not only during the earthquake, but after the earthquake, if the uplift pattern is modified.

The safety factor is no longer acceptable.

Conclusion for the dam design

- Both methods show the fundamental impact of the change of the water flow at the contact or just beneath the contact with the foundation as a consequence of the permanent displacement
- The location and the design of the drainage system is of utmost importance
- It should be not to close to the upstream face (avoid high hydraulic gradient)
- It should include several lines of defense namely close to geological features (faulty zones, dense crack system)
- Large diameter of holes are highly recommended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