ANALYSIS OF THE SEISMIC BEHAVIOR OF KEDDARA DAM USING STRONG MOTION RECORDS

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ABSTRACT :

On May 21, 2003 the Keddara rockfill dam was shaken by Boumerdes earthquake (M_L=6.8) which epicenter was located at 20 km from the dam. Accelerographs, installed on the crest and the right abutment by the Algerian National Centre of Applied Research in Earthquake Engineering, have measured the motion during the main shock. Nonlinearities may have affected the behavior of the dam during this event. In this study, we provide an analysis of what took place during the main shock, and on the basis of the strong motion records, we investigate the possible development of nonlinearities in the dam materials and the importance of loss coherency effects.

KEYWORDS: Boumerdes earthquake, strong motion, nonlinearity, coherency loss, cyclic loading, shear modulus degradation, hysteretic damping

1. INTRODUCTION

Algeria is one of the most seismically active regions in the world. The Northern part of the country is structurally crossed by numerous faults. Keddara dam located no far from one of these faults was shaken by May 21, 2003 Boumerdes earthquake with a magnitude M_L of 6.8. The dam was equipped with accelerometers that recorded the dam response during the main shock and the aftershocks. The aim of this work is to evaluate degree of reduction in shear modulus and an increase of damping with an increase in shear amplitude of materials, constituting Keddara dam. Ramberg-Osgood is selected to simulate the behavior of a column of soil materials under sinusoidal excitation of variable amplitude.

2. DESCRIPTION OF KEDDARA ROCKFILL DAM

The Keddara dam, located on the Boudouaou River in Boumerdes region about 35 km east of Algiers, was completed in 1985. This dam is 106 m high above its rock foundation, consisting of schist, and 426.26 m width at the base. The crest has a width of 12 m and a maximum length of 486 m. Figures 1 and 2 show respectively the plan view of the dam and the vertical cross section of the dam at mid length, which has an impervious inclined clay core covered by the filters and transition zones. The dam shoulders are of limestone rockfill. The transition zones between core and shoulders are consisting of sand and gravel down to bed rock. The upstream and downstream slopes are of 3h/1v. The material properties used in the dam construction are given in Table 2.1. In this study, a 2D finite difference program, FLAC^{2D}, was used for the analysis.

Table 2.1. Material properties used in Keddara dam construction (monographic report).

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Dry unit weight (kN/m^3)	24.6	19.5	20.4	20.7	27.0
Friction angle (°)	45	14	37	38	38
Cohesion (kPa)	200	55	0	80	0
Bulk modulus × 10^6 (kPa)	30.8	1.1	1.9	2.5	19.2
Shear modulus × 10^6 (kPa)	15.4	0.5	0.9	1.2	9.6

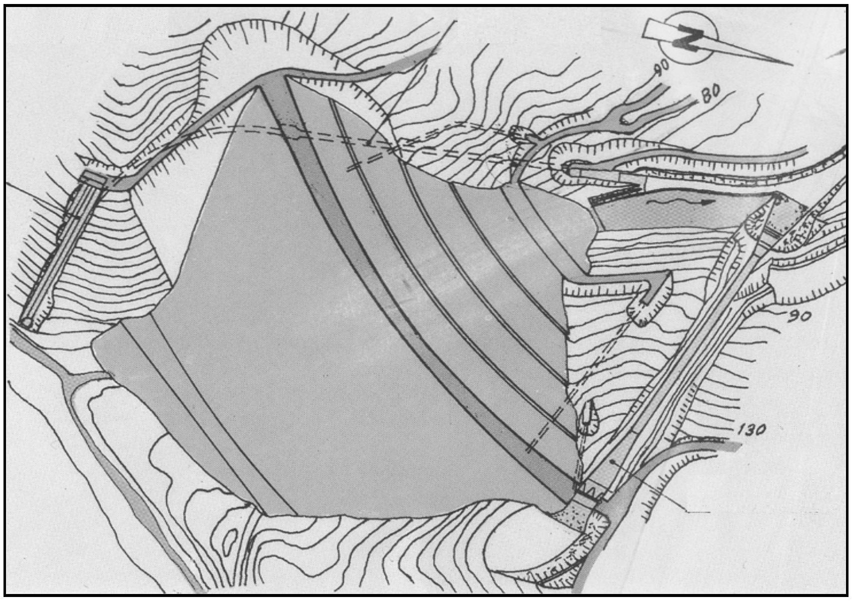


Figure 1. Plan View of Keddara rockfill dam site.

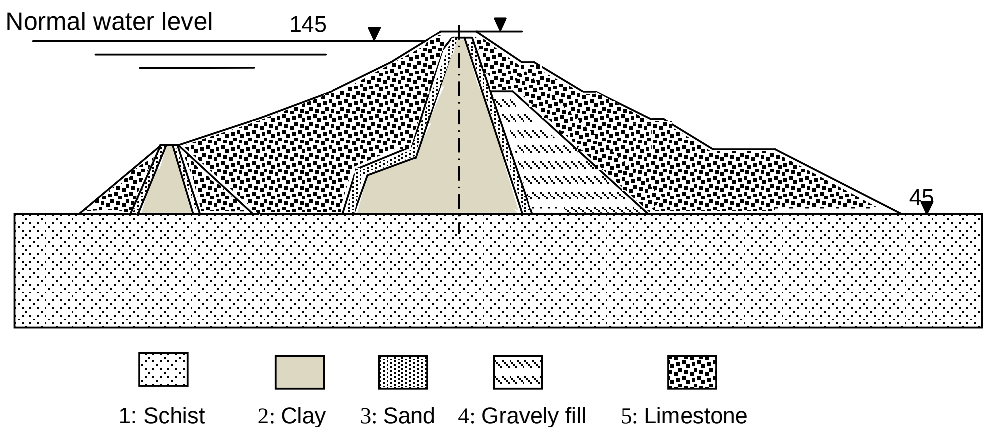
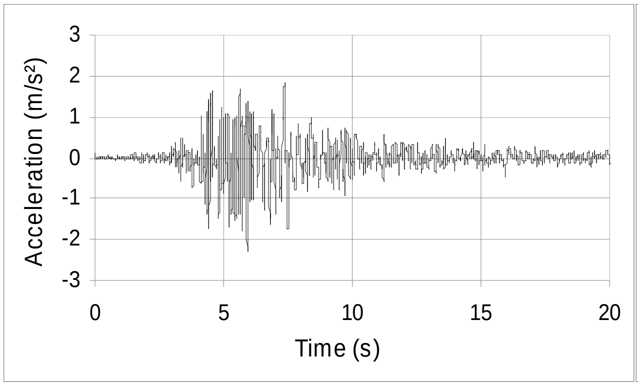


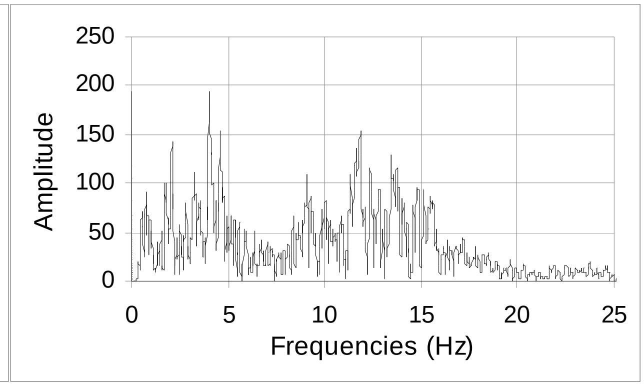
Figure 2. Typical cross section of Keddara dam.

3. ANALYSIS OF THE RECORDED MOTIONS DURING MAY 21, 2003 MAIN SHOCK

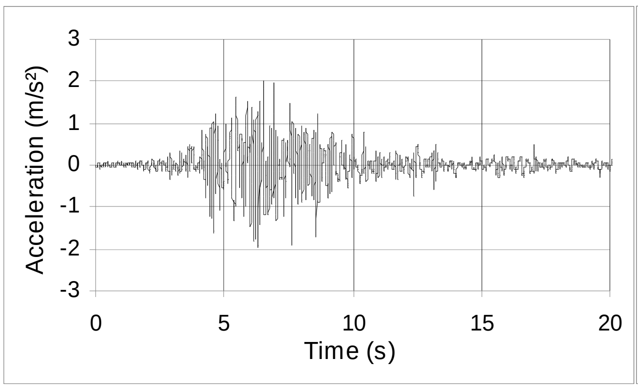
The Fourier spectra of the motions recorded on May 21, 2003, (time history shown in Figures 3 and 5), are presented in Figures 4 and 6 for the left abutment and the crest respectively. The computed Fourier spectra indicate that the seismic energy is mainly concentrated in a range of frequencies lower than 20 Hz. It should be noted that two wavelets are present in the spectral representation of the motions at the bed rock in the transversal and longitudinal directions. The first one corresponds to content lower than 5 Hz and was found highly amplified at the crest. The second one, greater than 5 Hz, was not significantly amplified. However, in the vertical direction, the spectral content is spread over a large range of frequencies while amplification only took place for frequencies lower than 5 Hz.



(a)



(a)



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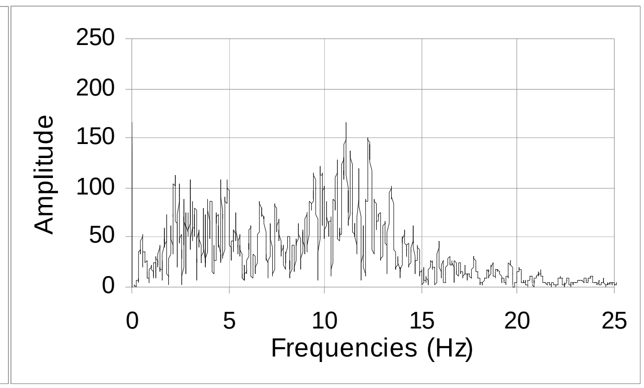

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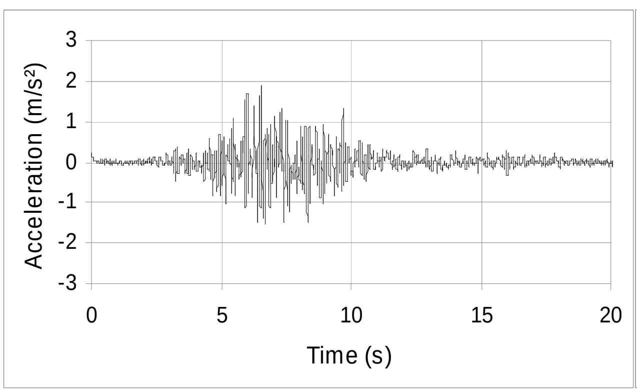

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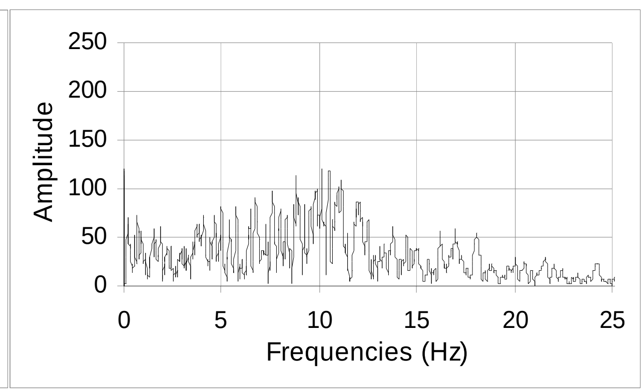


(c)

Figure 3. Left abutment records during 21/05/2003 main shock: a) transversal component; b) longitudinal component; c) vertical component.

Figure 4. Fourier Spectrum of left abutment record motions during 21/05/2003 main shock: a) transversal component; b) longitudinal component; c) vertical component.

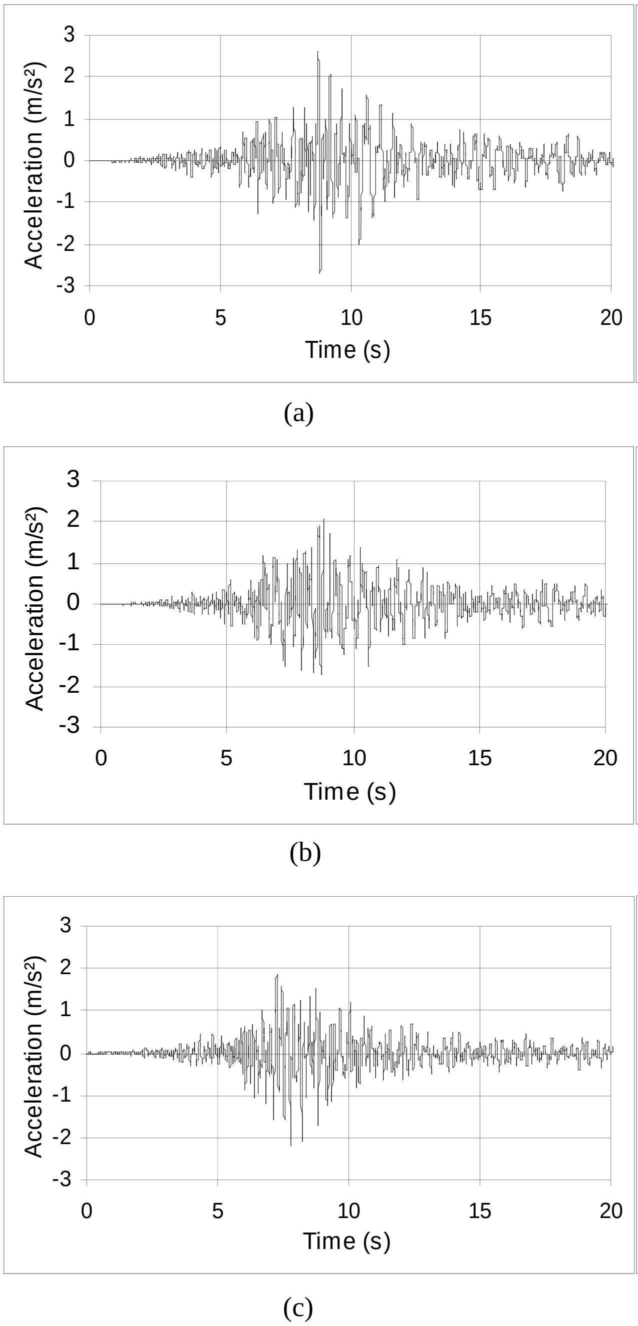


Figure 5. Crest records during 21/05/2003 main shock: a) transversal component; b) longitudinal component; c) vertical component.

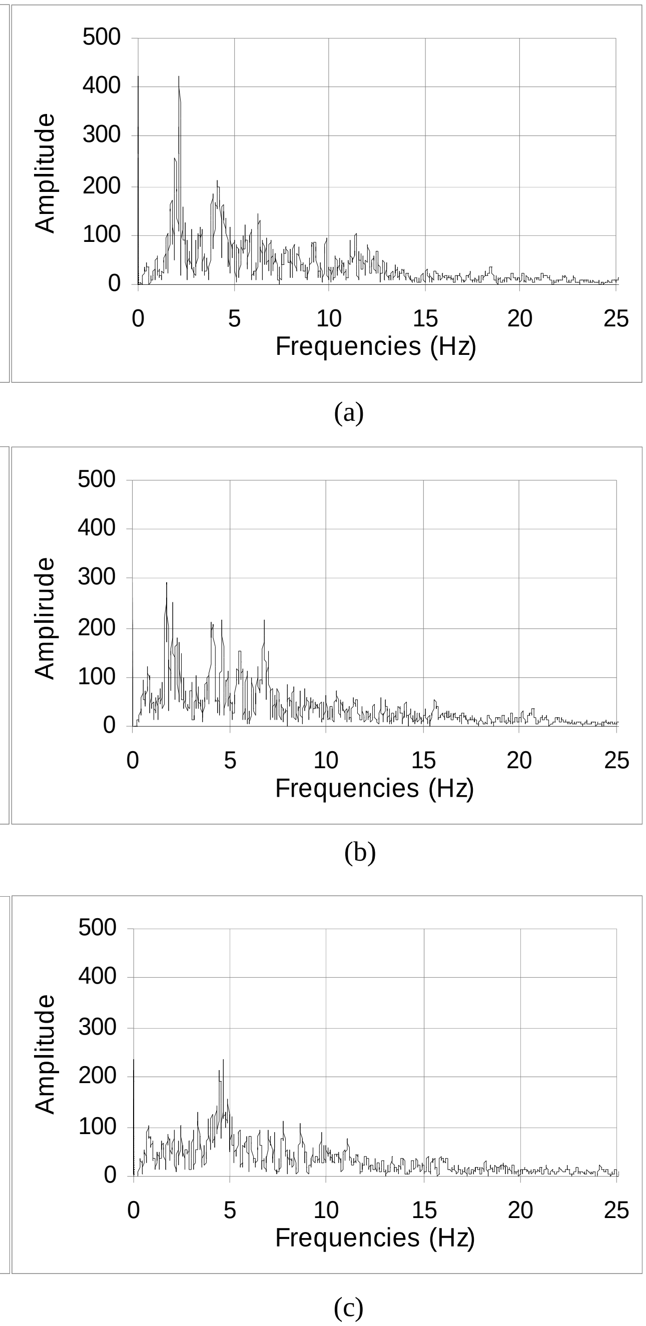
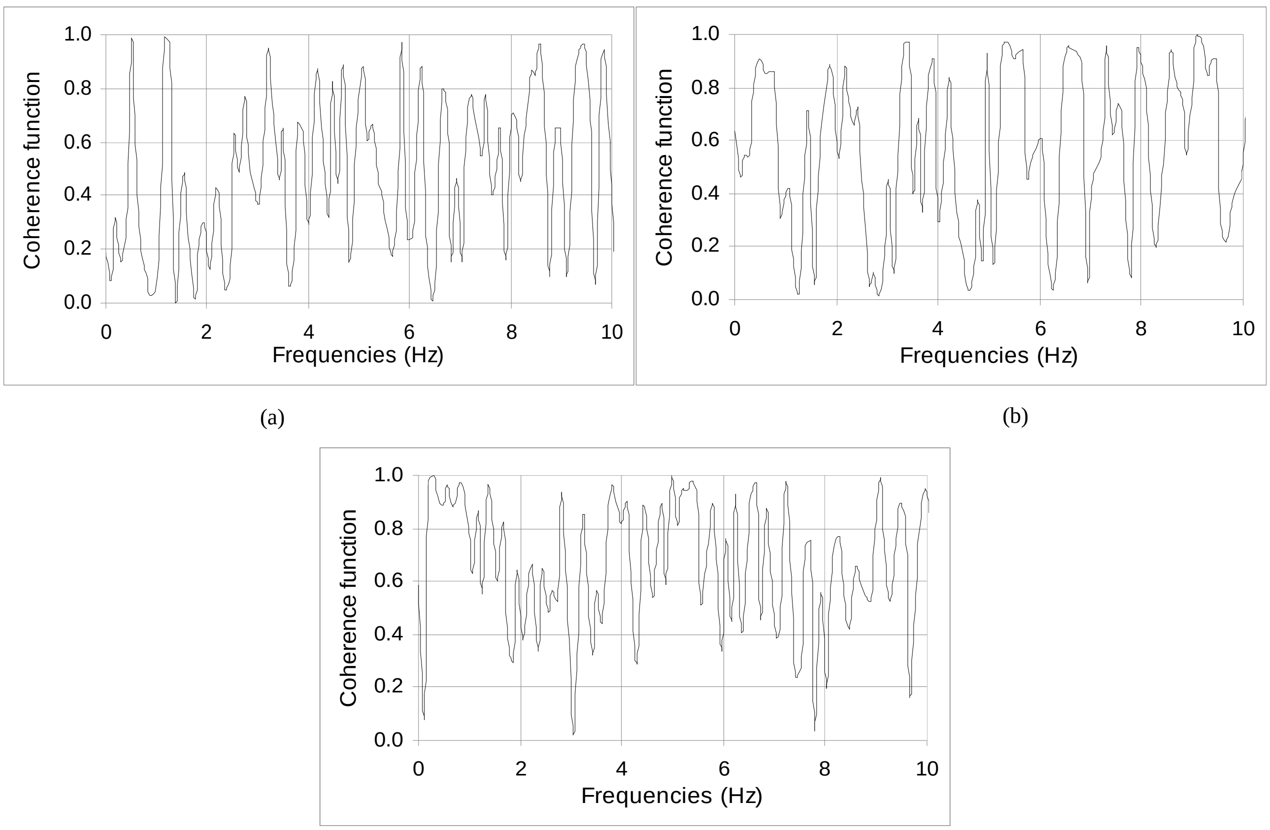


Figure 6. Fourier Spectrum of crest record motions during 21/05/2003 main shock: a) transversal component; b) longitudinal component; c) vertical component.

4. DETECTION OF NONLINEARITY AND LOSS COHERENCY IN MOTIONS RECORDED ON MAY 21, 2003 MAIN SHOCK

The coherence function is estimated to assess whether the experimental data include information relevant to the nonlinear behaviour of Keddara dam during the earthquake. It is well known that for the idealised case of a linear system subjected to a uniform excitation, the coherence function between excitation and response is equal to unity for all frequencies. However, when the coherence function is lower than unity, it can be attributed to noisy measurements, system nonlinearities, or spatially varying excitation (Bendat and Piersol 1980). The spectral analysis of the records during the main shock reveals a low coherency between structural input and output in the three directions (Fig. 7). It can be attributed either to a nonlinear behaviour of the materials or to a spatially varying ground motion.



(a) (b)

(c)

Figure 7. Coherence function between structural input and output records during 21/05/2003 mainshock : a) transversal component; b) longitudinal component; c) vertical component.

5. IDENTIFICATION OF G-γ AND D-γ CURVES FOR SAND AND CLAY USED FOR THE DAM CONSTRUCTION UNDER CYCLIC LOADING

The purpose of this section is to evaluate the degree of reduction in shear modulus and the increase of damping with the increase in shear strain amplitude for sand and clay used in the dam construction, using a non-linear pattern proposed by Ramberg - Osgood (1943). It is a relationship stress-strain with three parameters that reflects the deterioration of the module and takes into account the concept of loading cycle. We present below this formulation. Once implemented in software analysis FLAC^{2D}, this model will be used on a column of soil subject to a shear loading.

5.1. Presentation of Ramberg-Osgood model

5.1.1. Shear modulus

The formulation of Ramberg-Osgood hysteresis between stress and shear distortion can simulate elastic and non-linear behaviour of materials. The shear modulus depends on shear stress and position in the cycle and hence the distortion. The classic formula Ramberg-Osgood writes:

$$\gamma-\gamma_c=\frac{1}{G_{\max}}\left[1+\alpha\left(\frac{|\tau-\tau_c|}{n\tau_y}\right)^{r-1}\right](\tau-\tau_c) \quad (5.1)$$

where n = 1 in the first loading and then n = 2, τ_c et γ_c are respectively the shear stress and shear strain at the last change of direction of loading, G_{max} is the initial tangent shear modulus. r, α are the parameters of the model, τ_y is the larger shear stress, γ_y is related to τ_y by the relationship :

$$\tau_y=G_{\max}\times\gamma_y \quad (5.2)$$

The constant r is a parameter controlling the rate of increase of non-linearity of the stress-strain relationship. The constant α is defined by the ratio between the maximum shear modulus and shear modulus at $\tau = \tau_y$. The formulation of Ramberg-Osgood is bounded by the plastic Mohr Coulomb shear yield criterion.

As proposed, the formulation (5.1) is given in the form stress-strain model, to use it; it is interesting to transform it into a relationship of degradation G/G_{max}. The module shear follows the Ramberg-Osgood formula (equation (5.1)) and degrades as follows:

$$G=\frac{d\tau}{d\gamma}=\frac{G_{\max}}{1+\alpha.\left(\frac{|\tau-\tau_c|}{n.\tau_y}\right)^{r-1}} \quad (5.3)$$

The G_{max} and K_{max} modulus are depending on the average effective stress and follow the Hertz law. The shear secant modulus depends on both the pressure and shear strain.

5.1.2. Damping ratio

The damping ‘D’ is defined by the energy dissipated by the material in a closed cycle by the formula:

$$D=\frac{2}{\pi}\cdot\frac{r-1}{r+1}\cdot\left(1-\frac{G}{G_{\max}}\right) \quad (5.4)$$

5.2. Detection of cycles

The formulation of Ramberg-Osgood requires knowledge of the "distance" between the current state of stress and that corresponding to the last change of loading direction $|\tau-\tau_c|$. It is set during a half-cycle. Once the half-cycle detected, the updated mechanical properties of materials are taken into account.
The distance $|\tau-\tau_c|$ is defined as the projection of the current stress tensor $\left(s_{ij}-s_{ij}^c\right)$ on the one, corresponding to

the earlier half cycle $\left(s_{ij}^{c}-s_{ij}^{cp}\right)$. The distance $\left|\tau-\tau_{c}\right|$, is written:

$$\left|\tau-\tau_{c}\right|=\frac{0.5\left(s_{ij}-s_{ij}^{c}\right)\cdot\left(s_{ij}^{c}-s_{ij}^{cp}\right)}{\sqrt{0.5\left(s_{ij}^{c}-s_{ij}^{cp}\right)\cdot\left(s_{ij}^{c}-s_{ij}^{cp}\right)}} \tag{5.5}$$

where: s_{ij} is the deviatoric tensor stress, s_{ij}^{c} is the deviatoric tensor stress at the first peak, s_{ij}^{cp} is the deviatoric tensor stress at the penultimate peak.

During a half cycle, the distance $\left|\tau-\tau_{c}\right|$ is increasing, passes through a maximum when a peak is detected. Reversing the direction of the solicitation requires an updating of mechanical properties. The deviatoric stress tensors s_{ij}^{c} and s_{ij}^{cp} must be updated.

5.3. G-γ and D-γ curves

5.3.1. Modelling the shear test of a drained column of soil

To represent shear phenomenon, FLAC^{2D} does not properly represent the boundary conditions on a single element of ground. Therefore, we modelled a column of soil, discretized into several elements, subject to a shear movement. Initially, the column is subject to a confinement stress. It then applies a cyclic movement at the base of the column, which can represent the movement caused by a seismic wave for example. The function, chosen to represent this movement, is a sine wave, which can be of a varied range. The tests represented are in drained conditions. The results are presented in Figures 8 and 9 for the sand and in Figures 10 and 11 for the clay.

a- Case of a soil column consisting of sand used for filter and the transition zone in the dam

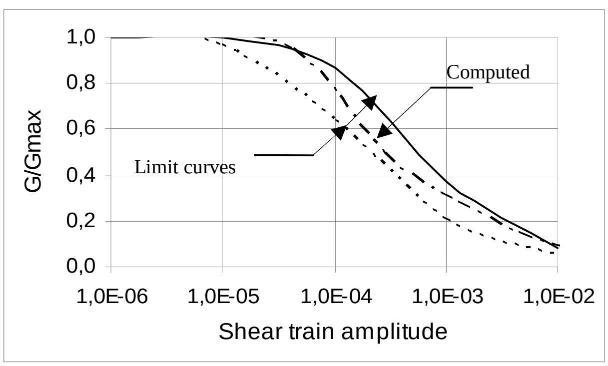


Figure 8. Variation of shear modulus for sand; the limit curves are those set by Seed et al. (1970).

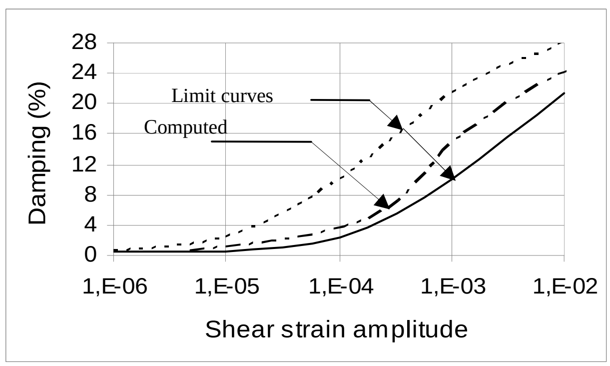
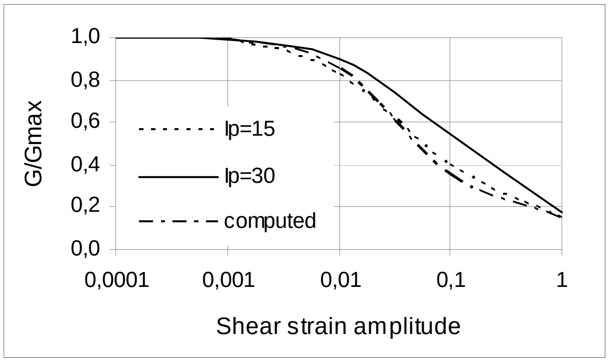


Figure 9. Variation of damping ratio for sand; the limit curves are those set by Seed et al. (1970).

b- Case of a soil column consisting of clay used for core zone in the dam



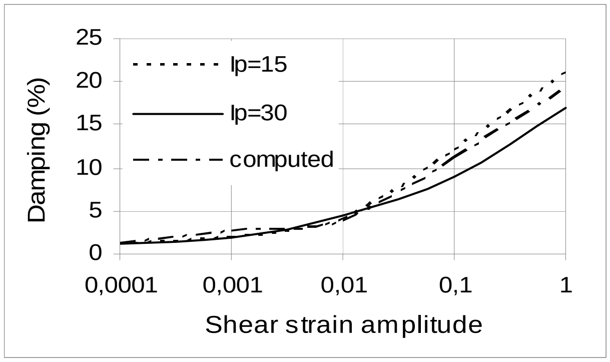


Figure 10. Variation of shear modulus for clay; the limit curves are those set by Vucetic and Dobry (1991).

Figure 11. Variation of damping ratio for clay; the limit curves are those set by Vucetic and Dobry (1991).

6. Conclusion

In this paper, the recorded motions during Boumerdes earthquake on May 21, 2003, at the left abutment and crest of Keddara rockfill dam are used and the spectral analysis is performed. This dam was strongly shaken by the main shock without any damage. Analysis of coherence function between structural input and output records during the main shock revealed lower values. This can be attributed either to a nonlinear behaviour of the materials or to a spatially varying ground motion.
To evaluate the degree of reduction in shear modulus and the increase of damping with increase in shear strain amplitude for sand and clay used in the dam construction, a non-linear model, proposed by Ramberg - Osgood is used. This relationship with three parameters reflects the deterioration of the modulus and takes into account the loading cycle concept in a more appropriate manner.

7. REFERENCES

Agence Nationale des barrages (1987). Monographie du barrage de Keddara, 1-141.
Bendat, J.S., and Piersol, A.G. (1980). Engineering application of correlation and spectral analysis, John Wiley and Sons, New York, N. Y.
Seed, H.B. and Idriss, I.M. (1970). Soil muduli and damping factors for dynamic response analysis. Report EERC 70-10. Earthquake engineering research center, University of California, Berkeley.
Vucetic, M. and Dobry, R. (1991). Effect of soil plasticity on cyclic response. Journal of the geotechnical Engineering Division, ASCE, 117:1, 89-107.