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THE CONSEQUENCES OF PARTIALLY GROUTED JOINTS UPON THE ARCH DAM SEISMIC BEHAVIOUR

L'EFFECT DE L'INJECTION PARTIELLE DES JOINTS SUR LE COMPORTEMENT SISMIQUE DES BARRAGES-VOÛTES

DIE EINWIRKUNG DER TEILEINPRESSUNG VON BAUFUGEN AUF DAS ERDBEBENVERHALTEN DER BOGENSTAUMAUERN

Radu Priscu*, Adrian Popovici**, Constantin Stere***

SUMMARY-RÉSUMÉ-ZUSAMMENFASSUNG

By partially grouting some contraction joints, several favourable changes in arch dam seismic behaviour may occur. In this paper, a numerical study of the seismic behaviour of a large arch dam in Romania is being carried out, through the finite element method, following the hypotheses of a monolithic-continuous structure and, comparatively, of different dam joints grouting schemes. Some remarks related to the seismic behaviour of this large dam during the recent Vrancea Earthquake of March, the 4-th 1977 are also included.

L'injection partielle des joints entraîne des modifications favorables sur le comportement sismique des barrages-voûtes. Dans l'ouvrage, tout en employant la technique des eléments finis, on analyse le comportement sismique d'un grand barrage en Roumanie à partir d'une hypothèse sur la structure monolithe et comparativement en différentes variantes d'injection des joints. On y fait également des remarques sur le comportement de ce grand barrage au recent tremblement de terre Vrancea, 4 mars, 1977.

Die Teileinpressung von Baufugen führt zu vorteilhaften Änderungen beim Erdbebenverhalten der Bogenstaumauern. Auf Grund der Methode der finiten Elemente, wird in der Arbeit das Erdbebenverhalten einer grossen Talsperre in Rumänien untersucht, unter der Voransetzung einer einheitlichen Manerwirkung und vergleichend für verschiedene Einpressvarianten der Fugen. Gleichzeitig wird eine Diskussion über das Verhalten dieser grossen Talsperre bei dem kürzlich stattgefundenen Erdbeben (in Vrancea), vom 4 März 1977.

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THE CONSEQUENCES OF PARTIALLY GROUTED JOINTS UPON THE ARCH DAM SEISMIC BEHAVIOUR

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One usually considers, through a current static and dynamic analysis, the arch dams as being monolithic structures with a linear-elastic behaviour [1], [2], [3]. However, the arch dam constructive make up of blocks separed by grouted joints leads to some peculiarities somehow differing frome of the current adopted model; thus, although grouted, the joints have a limited capacity of taking over the tensile and shear stresses. Therefore, when the state of stresses in the arch dam joints exceeds their tensile or shear strength, o reciprocal sliding of the joints or their opening may occur and, consequently, the dam structure is being deprived of its monolithic character.

Recently, several papers [4], [5] have dealt with the consequences of partially grouted joints upon the arch dam seismic behaviour. Following some model experimental research, they have put into evidence the antiseismic efficiency of a dam constructive system characterized by preserving about 4 ÷ 5 ungrouted joints over the upward one fourth of the dam height, the dam continuity at its crest being performed through a reinforced belt. The above system has shown some higher damping capacities against the dam structure with completely grouted joints (increasing 2 ÷ 3 times the fraction of critical damping) and a more favourable distribution of the dam response seismic stresses [4] .

In this paper, the behaviour of a Romanian large arch dam is numerically simulated through the finite element method, by examining several dam constructive solutions with completely and partially grouted joints. Also, some interesting aspects related to this large dam seismic behaviour during the Romanian earthquake of Vrancea, 4 March 1977 are being commented upon.

1. THE COMPUTING MODEL

By the details of Figure 1 one presents the mapping plan and several geometric elements of the Vidraru arch dam, taken up as a physical support for simulating the different constructive variants of our study. The Vidraru double curvature arch dam, built up on the Arges river and put into operation in 1965, is at present, the highest dam in Romania. It has the maximum hight of 166m and the crest length of 292 m. The dam body has a slight geometrical skewness, being more developed at its upper part next to the left bank.

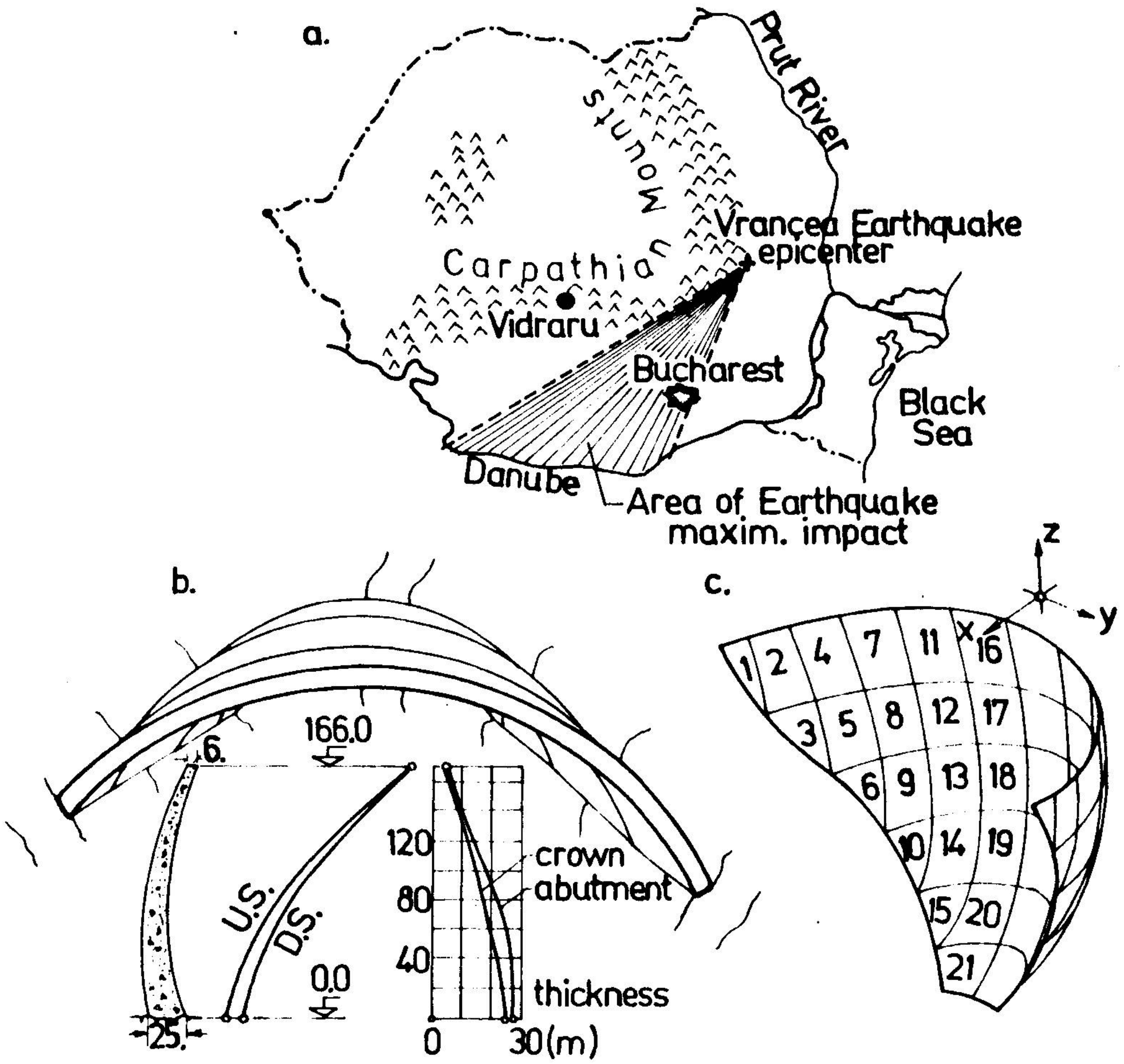

Fig. 1 Vidraru dam: a-the dam site related to the Vrancea earthquake epicenter, b- dam mapping plan and specific geometrical elements, c-thin shell-type finite element discretization network.

The discretizing of the structure has been carried out with finite elements of C.FELLIPA-R.W.CLOUGH thin shell type [6] which reproduce the dam mean surface (Fig.1,b). The quadrilateral element of an arbitrary geometry may be obtained by assembling four compatible triangles. Finally, the finite element used has 20 degrees of freedom, 5 degrees on each node, defined with respect to the element local coordinate system (one disregards the local torsion within the element).

The considered constructive variants of joints grouting and the corresponding discretization networks are presented in Figure 2. In fact, the folowing three cases have been accurately investigated: dam joints completely grouted, 5 ungrouted joints between the elevations 166 and 102 and reinforced belt at the dam crest, 5 ungrouted joints between the elevations 166 and 102. In nature, the considered structure has got complete grouted joints. The latter case has mainly served as testing model, by comparing its computed stresses and displacements with the Vidraru dam field measured ones; the relative changes which occur in the partially grouted structure have also been related to the monolithic dam case. The ungrouted joints have been reproduced by using double neighbouring nodes connected with beam-type elements of a reduced stiffness. Thus,the contiguous dam blocks work independently under tension loads and jointly concur in taking over compressions.

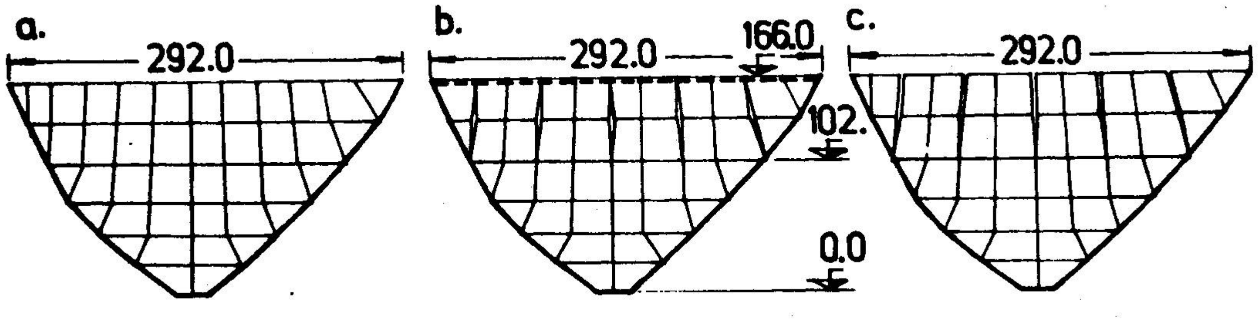

Fig. 2 Dam joints grouting schemes: a-complete grouting, b-partial grouting and crest stiffening belt , c-partial grouting.

The reservoir water effect has been considered on the additional masses principle, by following the incompressible water hypothesis. Those additional masses (M_i), perpendicularly applied on the dam surface, have directly been determined from the velocity potential function (ψ): $[M_i] = [\rho \int_{S_i} \psi \, ds]$, where ρ is the water density and S_i is the i-node affected part of the dam upstream face.

The velocity potential function has numerically been determined through the finite elements method on a spatial elaborated network which reproduces the geometry of the reservoir-arch dam system. The dam upstream face is approximated with a cylindrical surface and the lake being with a prismatic shape. The ψ function is strongly dependent on the earthquake direction and dam-reservoir system geometry as well [7] . The velocity potential function variation is presented in Figure 3, for the Vidraru dam symmetrized halfstructure; the plotting is given for horizontal earthquakes both directed along and transverse the valley and for vertical earthquake as well.

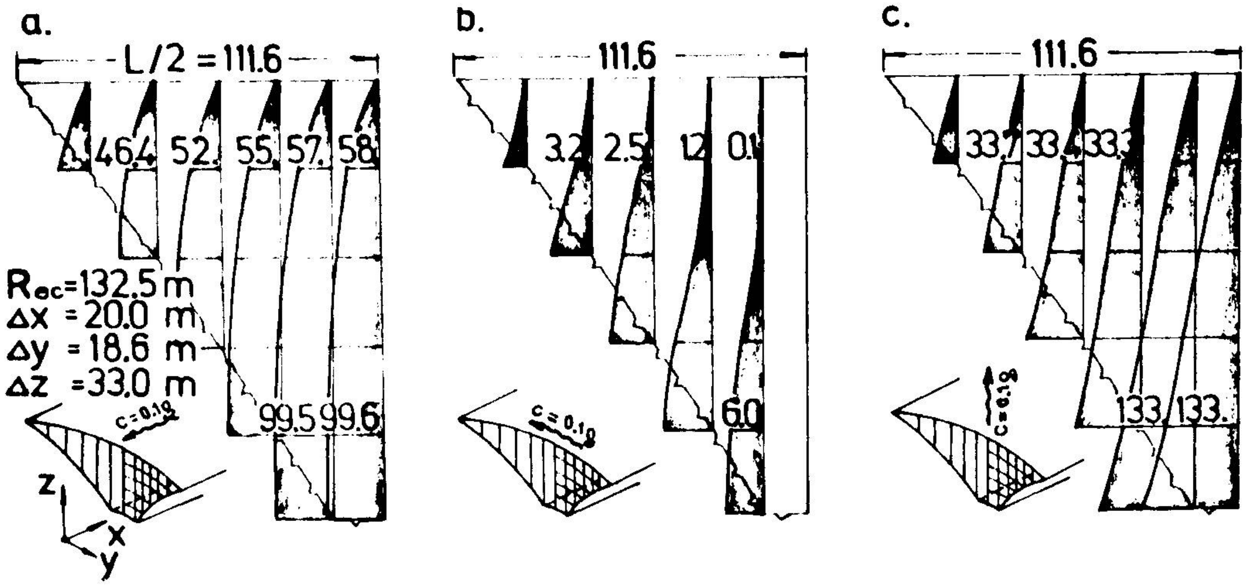

Fig. 3 Variation of velocity potential function ψ on the Vidraru dam halfstructure subjected to earthquakes on the directions: a-horizontal, along the valley, b-horizontal, transverse the valley, c-vertical.

The seismic analysis of the already mentioned variants has been carried out through the modal analysis with response spectra, by following the structure linear - elastic behaviour hypothesis. In the dynamic analysis, the rotatory degrees of freedom are being eliminated by static condensation at the computing level of the total stiffnes matrix; no translatory degrees of freedom on the vertical are being considered. The additional masses are computed for the direction of the dynamic degrees of freedom; the dam masses matrix and the additional masses matrix are both considered as being diagonal. The dam total response is computed through the Rosenblueth probabilistic relationship.

The excitation of the studied systems is being considered under the form of response seismic spectra, scaled up with a computing acceleration of 0.1 g according to the seismic standard in Romania. Comparatively, computations have been carried out with the response spectra set out on the basis of Bucharest recordings of the Romanian earthquake of Vrancea, March the 4-th 1977(Figure 4). In conjunction with the Romanien above mentioned earthquake its slow oscillatory character should be noticed (seismic oscillatory periods of 1.0 ÷ 1.5 s). This aspect could be explained by the relatively weak ground (sands and clays, the groundwater table close to the surface) in the area where records were carried out 8.

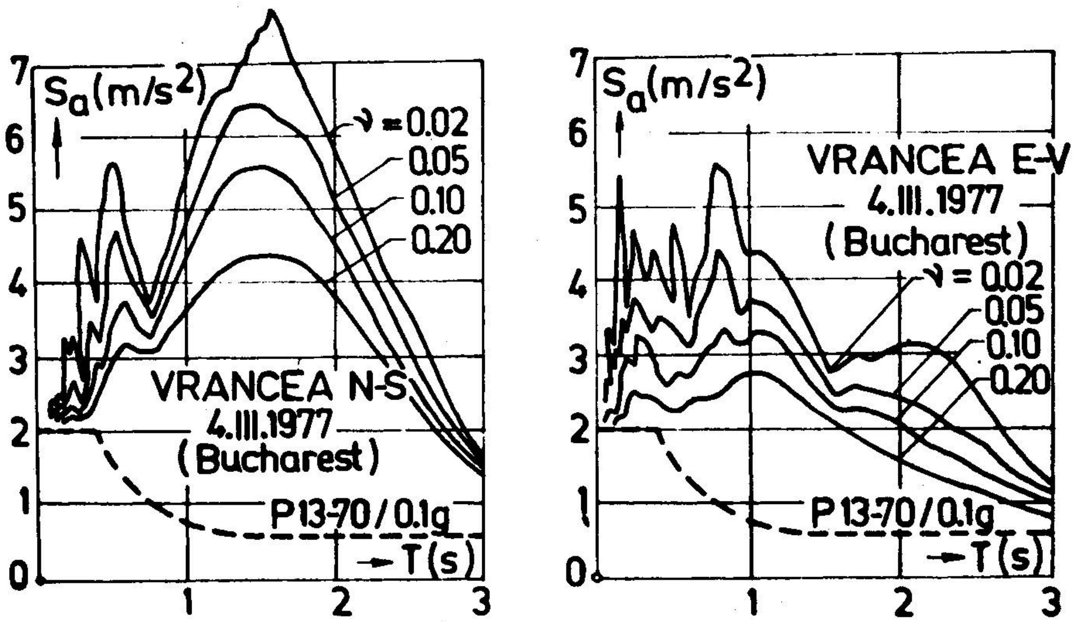

Fig. 4 The average spectra of the Bucharest recorded Vrancea earthquake of March, the 4-th 1977 (full line)and the Romanian in force standard response spectrum (dotted line).

2. THE SEISMIC ANALYSIS OF VIDRARU DAM

With the view to making the seismic analysis, the dam structure has been symmetrized and the analysis was carried out over the dam halfstructure with 40 horizontal dynamic degrees of freedom. Both cases of empty and full reservoirs have been considered each for the input ground acceleration directed along the valley and transverse to it.

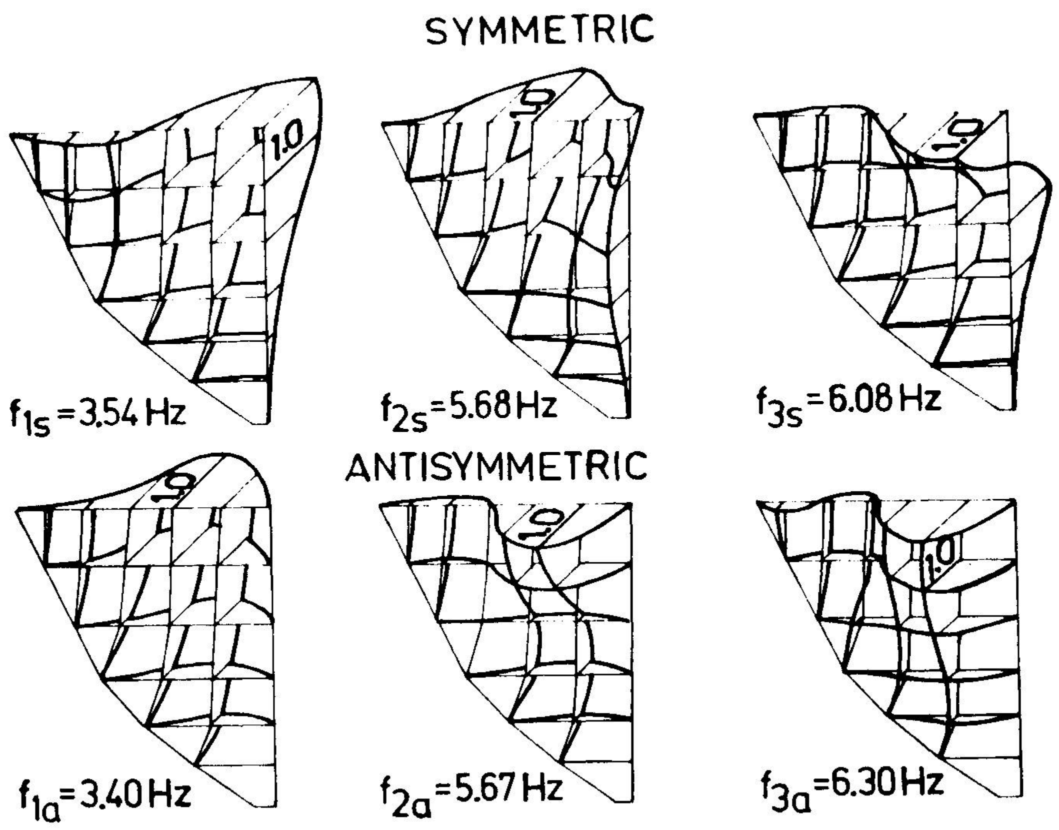

Fig. 5 Symmetric and antisymmetric eigenmodes of Vidraru dam for the empty reservoir condition (E_b = 370000 daN/cm^2, μ =0.15)

In figure 5, the first three symmetric and antisymmetric vibration modes are presented for the dam halfstructure and empty reservoir condition. When full reservoir condition is considered, the first eigenfrequencies have values of 1.95 Hz for the earthquake along the valley and of .21 Hz for the earthquake transverse the valley. However, the obtained eigenfrequencies and eigenmodes are within a range of values normally met with this type of structures;"in situ" measurements have confirmed them out. The Vidraru dam first eigenfrequency, as measured out in situ for the reservoir water level situated at about one half of the dam height, was 2.63 Hz.

Some results with respect to the dam maximum seismic stresses are presented in Figure 6. Thus, for an input of the Romanian actual standard seismic response spectrum, scaled up to 0.1g and directed along the valley, the maximum seismic stresses are σ_h= 22 daN/cm^2, σ_v=26 daN/cm^2 with the empty reservoir condition, and σ_h=31 daN/cm^2, σ_v=30 daN/cm^2 with the full reservoir condition. The same response seismic spectrum but transversally applied has given out more reduced unit stresses as σ_h=6 daN/cm^2, σ_v=5 daN/cm^2 with the full reservoir condition and σ_h=4 daN/cm^2, σ_v=5 daN/cm^2 with the empty reservoir condition.

Regarding the dynamic input of the Vrancea 4 March 1977 earthquake response spectrum, N-S component and ν = 5%, as registred in Bucharest, maximum seismic unit stresses of magnitudes σ_h=70 daN/cm^2 and σ_v=51 daN/cm^2 have been computed for the earthquake applied along the valley. The Vrancea earthquake N-S component accelerogram, on the basis of which the response spectra have been set up, presents the maximum value of 0.24g. By normalizing the Vrancea N-S response spectrum up to a maximum acceleration of 0.1·g, the maximum seismic unit stresses have come out to be σ_h=29.2 daN/cm^2 and σ_v=21.3 daN/cm^2. The differences between the unit stresses which correspond to both input response seismic spectra, explain themselves through the quite important differences existing between the dam structure eigenfrequencies range and the Vrancea earthquake maximum spectral values range.

The examination committee which thoroughly inspected the Vidraru dam after the Vrancea earthquake of 4-th of March, 1977 estimated the ground motion intensity at the dam site in the range of VII-VIII M S K [8] ; this estimated seismic intensity would normally correspond to a maximum acceleration of about 0.1·g. Therefore the seismic unit stresses, as computed through our study, have been about 25-30 daN/cm^2 for full reservoir. However , one should expect the dam real seismic stresses to be less than those computed, due to viscous-elastic-plastic actual behaviour of the concrete and to some structure dissipative capacities not taken

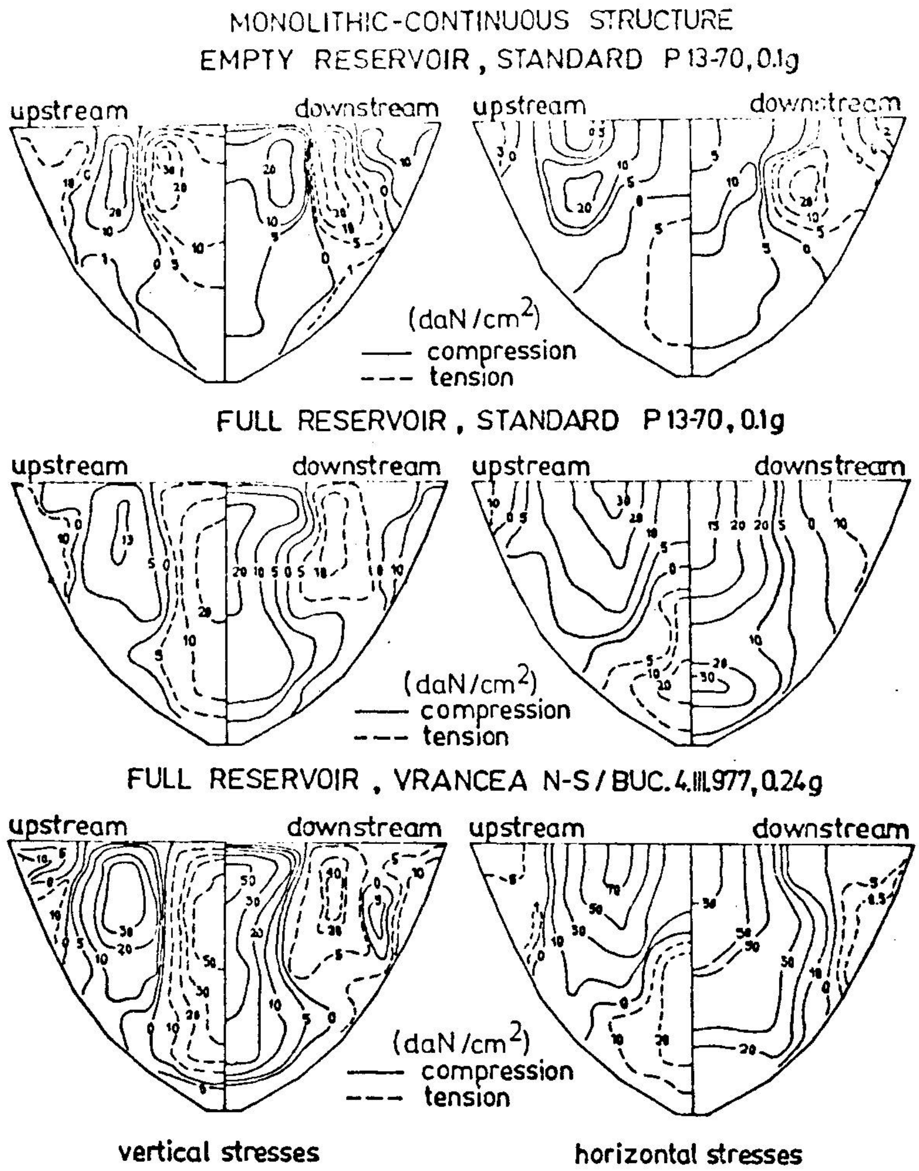

Fig. 6 Vidraru dam, the monolithic-continuous structure: Isolines of horizontal and vertical normal seismic stresses.

into consideration in our numerical model. Furthermore, at the Vidraru dam site, consisting of sound crystalline rocks, it would be less probable that the Vrancea earthquake accelerograme and, consequently, its response spectra should have oscillatory characteristics like those recorded in Bucharest. Unfortunately, excepting the Bucharest recorded accelerograme, there are no other recordings of the Vrancea earthquake of March, the 4-th 1977. Nevertheless, it has been remarcable that the Vidraru arch dam should withstand the Vrancea earthquake under best conditions, without any damages.

3. THE CONSEQUENCES OF PARTIALLY GROUTED JOINTS

The schemes of the dam with partially grouted joints which are to be investigated have been presented in Figure 2 b,c. In view of assessing the new state of stresses in the structure, due to constructive changes brought in by the proposed grouting schemes already given, a comparative study was carried out as a preliminary, refering to the dam main loadings of hydrostatic pressure and dead weight. In Figure 7, the diagrams of normal unit stresses σ_h and σ_v due to hydrostatic pressure are comparatively illustrated in the Vidraru dam central crossection. The stresses in the dam monolithic - continuous structure do agree with those stresses computed by some other methods [9] and are confirmed by in nature recordings. By comparison with monolithic structure, both a reduction of catilever stresses and variations within broad limits of arch stresses over the dam ungrouted parts have been ascertained; however, the unit stresses present a unique grouping tendency over the dam lower and central parts, for all three variants. Following that previous static analysis, the case of partially grouted joints and without the upper monolithic belt has been ruled out because of the unacceptable stress distributions over the dam subjected to hydrostatic pressure ; the arch compression stresses run up to 110 daN/cm^2 over the dam ungrouted part as the tensile stresses reach 45 daN/cm^2.

The seismic analysis of the variant with five partially grouted joints and with a crest stiffening belt has shown up the dam structure become more flexible in comparison with the monolithic dam. In Table 1 one comparatively presents the first four eigenfrequencies of the monolithic continuous structure and the structure with partially grouted joints and crest belt as well. The computations have pointed out that no signifioant differencies would appear in between the geometrical configuratons assigned to first eigenmodes of the two above mentioned variants.

Table 1

Hypotesis	Variant	First four eigenfrequencies (Hz)			
Empty reservoir, symmetric	monolit	3.54	5.68	6.08	7.17
	partially grouted joints and crest belt	2.67	3.15	3.68	5.11
Full reservoir, symmetric	monolit	1.94	3.41	3.72	4.48
	partially grouted joints and crest belt	1.39	2.21	2.75	3.92

In figure 8 there are given out the seismic stresses which taking place in the structure with partially grouted joints and crest belt when subjected to a dynamic input of Romanian standard response spectrum, applied along the valley. An evident tendency of increasing the stresses towards the crest belt is steadily visible. At the dam lower part some generally small stress variations are found, by comparing with the similar case of the monolithic-continuous structure. For the full reservoir condition, the structure with partially grouted joints and crest belt has registred maximum seismic unit stresses σ_h=44 daN/cm^2, σ_v=34 daN/cm^2,thus, increases of about 1.1 ÷ 1.5 confronted by the equivalent condition of the monolithic structure. For the empty reservoir condition, the maximum seismic stresses are σ_h=43 daN/cm^2,σ_v=47 daN/cm^2, thus increases of about 1.6 ÷ 2.0 confronted by the similar condition of the monolithic structure. The stress increase is occuring mostly towards the crest belt and, therefore, the need of reinforcing that crest belt comes out to be most suitable

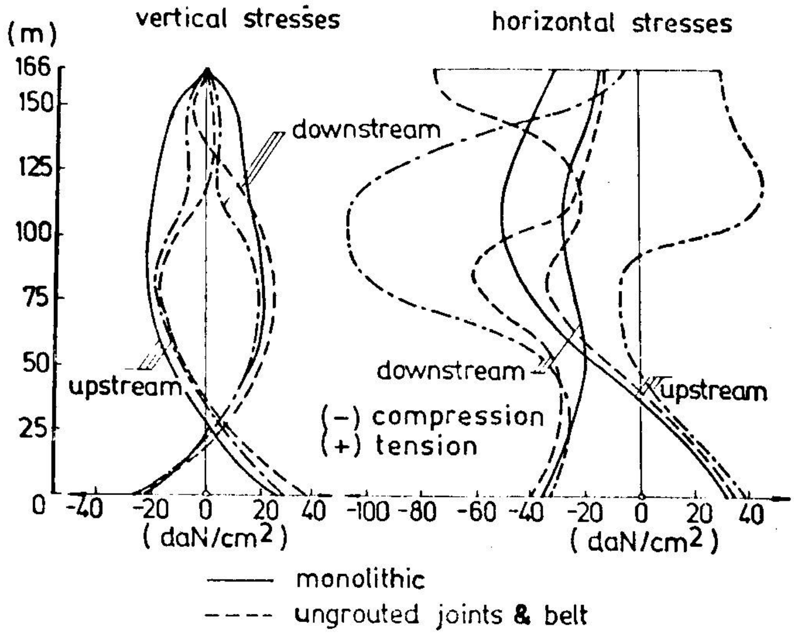

Fig. 7 Vidraru dam, different studied joints grouting schemes: horizontal and vertical normal stresses in the dam central crossection, subjected to hydrostatic pressure.

Within this study, the influence of some additional dissipative capacities of the structure with partially grouted joints hasnot been considered. Model tests had previously put into evidence some increases of the damping logarithmic decrement with respect to the first vibration eigenmodes ; thus, these increases did ranged from $\delta = 0.12 \div 0.17$ for the monolithic structure to $\delta = 0.30 \div 0.50$ for the structure with ungrouted joints over 1/4 of the arch dam height [4] . It seems these damping increasings may give some rather important reductions of seismic stresses without modifying yet their overall distribution.

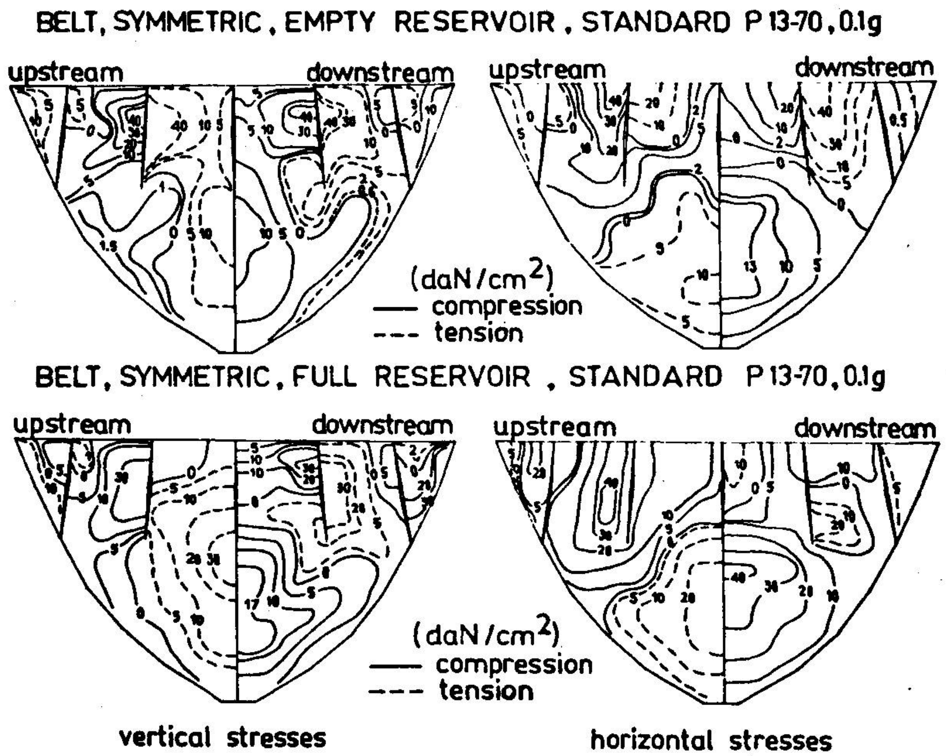

Fig. 8 Vidraru dam, the structure with partially grouted joints and crest belt: Isolines of horizontal and vertical normal seismic stresses.

4. CONCLUSIONS

By taking into account the facts mentioned up to now, the following conclusions may be formulated:

. The constructive solution with 4-5 arch dam shrink joints being partially ungrouted over the upper 1/4 of the dam height offers some advantages with respect to dam seismic behaviour against the solution of the dam structure with complete grouted joints; that proposed solution permits securing some arch dam higher dissipative capacities and an improved dam flexibility.

. The constructive solution already mentioned should be associated with providing for a dam crest stiffening belt, which prevents the cantilever separate vibration; it will also prevent some unfavourable modifications of stresses within the dam structure subjected to permanent loads (hydrostatic pressure, dead weight) and seismic loadings as well.

. The dam crest stiffening belt seems to undertake some important pulsating stresses during seismic loadings; therefore, the belt adequate reinforcement should be necessary.

. The good behaviour of the Vidraru arch dam during the Vrancea earthquake of March, the 4-th 1977, do practically prove once more the arch dams outstanding capacity of accomodating themselves to earthquakes.

REFERENCES

1. OBERTI,G.: Effects of earthquakes on dams (lectures ISMES), Bergamo, 1968.
2. PRISCU,R.,POPOVICI,A.,ILIE,L.: Earthquake analysis of double curvature arch dams. Proc. International Symposium on Discrete Methods in Engineering, Milan, September, 1974.
3. CASTELLANI,A.,CASTOLDI,A.,IONITA,M.: Numerical analysis compared to model analysis for a dam subject to earthquakes. Proc. of the Fifth International Conference on Experimental Stress Analysis, Udine, 1974. Publication ISMES No.83.
4. BAHTIN,B.M.,CERNIAVSKI,V.: About the importance of preserving some nonmonolithic parts in arch dams upon their dynamic behaviour (in russian), Buildings and Architecture, vol. 16,No.3, Moskow, 1973.
5. POPOVICI,A.: Contributions to the seismic analysis of arch dams (in Romanian), Ph.D.Thesis, Bucharest,1975.
6. BATHE,J.,WILSON,E.L.,PETERSON,F.E.: SAP IV Structure Analysis Program for static and dynamic response of linear systems.EERC 73-11, University of California, Berkeley.
7. PRISCU,R.,POPOVICI,A.,ILIE,L.,STEMATIU,D.: New aspects in the earthquake analysis of arch dams.Proc.International Symposium, Criteria and Assumptions for Numerical Analysis of Dams,Sept.1975.
8. PRISCU,R.: The behaviour of Romanian dams during the Vrancea earthquake of March,the 4-th 1977(in Romanian),Hidrotechnics, no.5, Bucharest, 1977.
9. PRISCU,R.: Some modern conceptions applied in constructing the arch dams in Romania (in Romanian), Hydrotechnics,no.8, Bucharest, 1964.