NUMERICAL MODELING OF CONCRETE FACE ROCKFILL DAM AT SEISMIC IMPACT

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ABSTRACT :

Many high concrete face rockfill dams (CFRD) have been built in different countries. Russian engineers have been studying the world experience of CFRD design and possibility CFRD construction in the high seismicity regions of Russia. The report considers the behavior of the CFRD of 148 m height on a fractured rock foundation under seismic impact of 7 earthquake intensity (MSK-64 scale). Three soil zones were defined in the dam body: the transition zone under the slab, the central and the downstream parts. The analysis was carried out on the basis of 3D model of the structure - foundation by the finite elements method using ANSYS and LS-DYNA software. Total amount of the finite elements was about 150 thousands. The dam body and foundation were modeled by 8-node, the abutments - 4 and 6-node 3D elements, the concrete slab - by shell elements of variable thickness. There were also used contact elements. Static and seismic analyses were fulfilled. The static evaluation was carried out to determine the initial stress field from the dam dead weight and hydro-static. The seismic evaluations were carried out according to the non-linear dynamic theory; three-component seismic impacts were specified for the low border of the design area. Studied was the influence of the relationship of deformation module values of the central and the downstream parts on the stress-strain state of the dam and concrete slab. A result analysis of the numerical modeling of the dam and slab behavior under seismic impacts was carried out.

KEYWORDS: numerical modeling, CFRD, seismic impact

1. INTRODUCTION

Provision of safe exploitation of earth dams in seismically active regions is only possible if all major features of their behavior in case of an earthquake were taken into consideration in the design for both construction and operational stages. Modern methods and computer procedures providing with reliable behavior prognosis of the ground constructions in various situations allow to model possible scenarios of the constructions' behavior and evaluate their capacities to bear various impacts and possibilities to introduce at the design stage necessary changes in the constructions in order to provide their safe exploitation.

Rockfill dams with reinforced concrete face have a number of specific features which should be taken into consideration in the design and construction of such dams in the high seismicity regions.

A detailed overview of the status of the issue and related problems emerging in the design and construction of rockfill dams with reinforced concrete face in seismic regions is provided in papers (Wieland, 2003, 2005; Wieland and Brenner, 2004, 2005, 2007). The papers point out that so far there are no sufficient monitoring data accumulated for high reinforced concrete dams, especially for the case of forceful earthquakes. This obstacle does not allow to hold identification of the developed mathematical models or to evaluate the degree of the prognosis reliability for high rockfill dams with reinforced concrete faces in case of seismic impact.

This paper is continuing the work results of which had been presented at the previous conference (Glagovsky et al., 2004), it presents some results of the calculation studies of dams with reinforced concrete faces under seismic impact. In particular, influence of the correlation between moduli of deformation of the central and downstream prisms of the dam on the stress strain behavior of the dam and the face.

Calculations of static and dynamic stress strain behavior of a dam with reinforced concrete face, results of which are presented in this paper, are made with the finite element method with utilization of the ANSYS and LS-DYNA software. Characteristics of the dam and seismic impact, major statements and brief description of the factors considered are shown below.

2. ANALYTICAL MODEL OF THE DAM

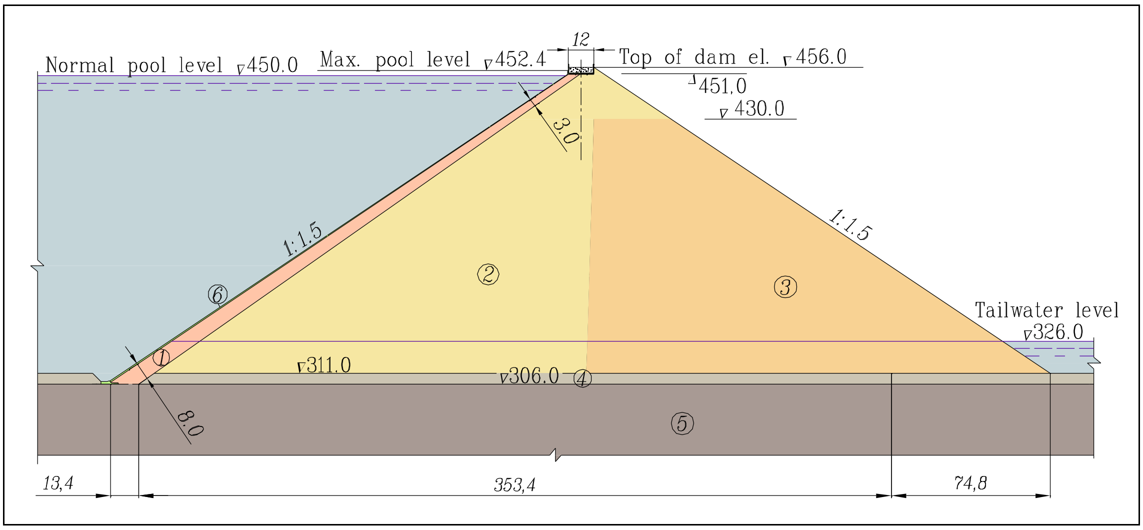
A three-dimensional model of a dam (Figure 1) with the 148m height and the slope ratio from the side of the upper and lower pools 1:1.5 was considered. The body of the dam consists of the rockfill of the central and external prisms, the transition zone and the reinforced concrete face from the side of the water reservoir. The base of the dam and the coastal slopes are laid of the weathered and preserved rock formations (siltstones).

The reinforced concrete face has thickness varying from 0.8 m at the bottom to 0.3 m at the top. The face plates are cut through by vertical deformation seals with the 16 m intervals. A perimeter seal is designed along the dam's contact points with the coasts.

A three-dimensional model of the dam-foundation system with the finite element meshing is shown on Figure 2. Altogether, there were about 150 thousand of finite elements, most of them were the eight-node 3D (brick) elements and partly, four- and six-node 3D elements in the abutment zone. The concrete slab was modeled by shell elements of variable thickness.

The borders of the calculated area of the dam foundation were assigned on the condition of their sufficient distancing from the dam, so that their influence on the construction functioning was insignificant. Conditions of "non-reflection" of the seismic waves were put on the side borders of the foundation model. On the face-dam contact points, in the deformation seals of the reinforced concrete face, and at the dam-coast contact points one-side connections were set. Contact elements of different types were used to simulate interaction between the dam elements and slab deformation joints.

Axis X is oriented towards the lower pool, axis Y goes up and axis Z goes along the longitudinal axis of the construction.



1 – transition zone; 2 – rockfill (central embankment); 3 – rockfill (downstream embankment); 4 – weak rock; 5 – rock foundation; 6 – concrete slab.

Figure 1 Cross-section of the concrete face rockfill dam

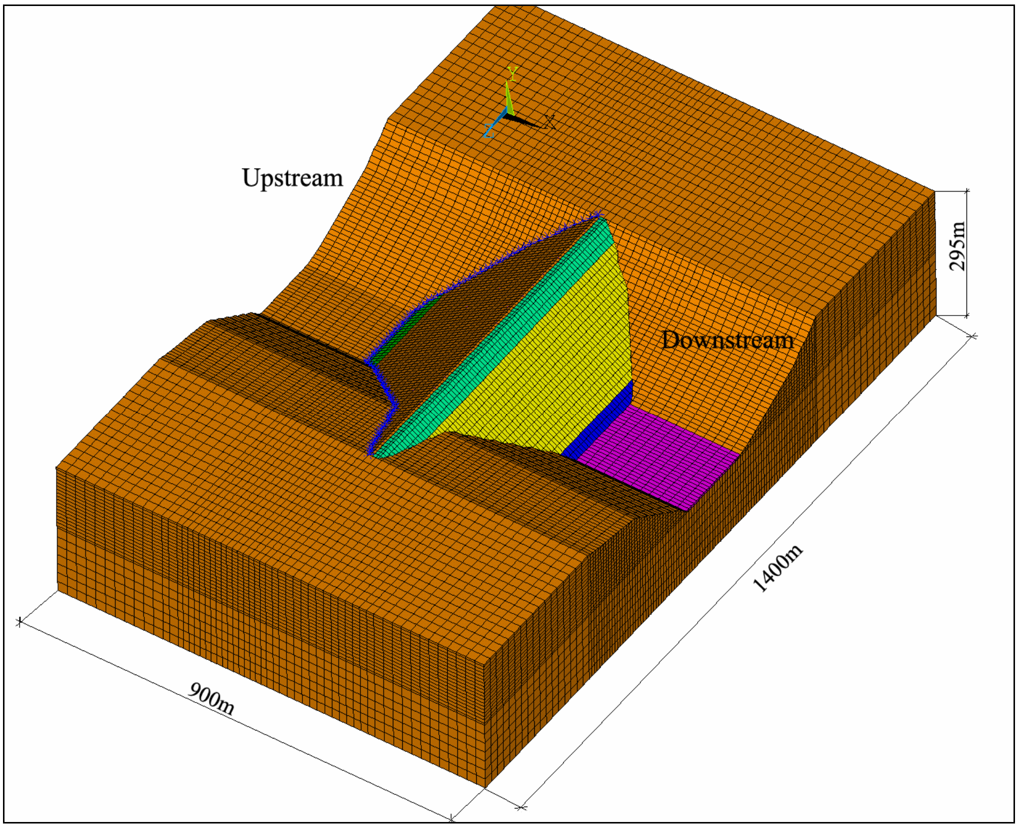


Figure 2 The three-dimensional model of the dam-foundation system

3. CALCULATION METHOD

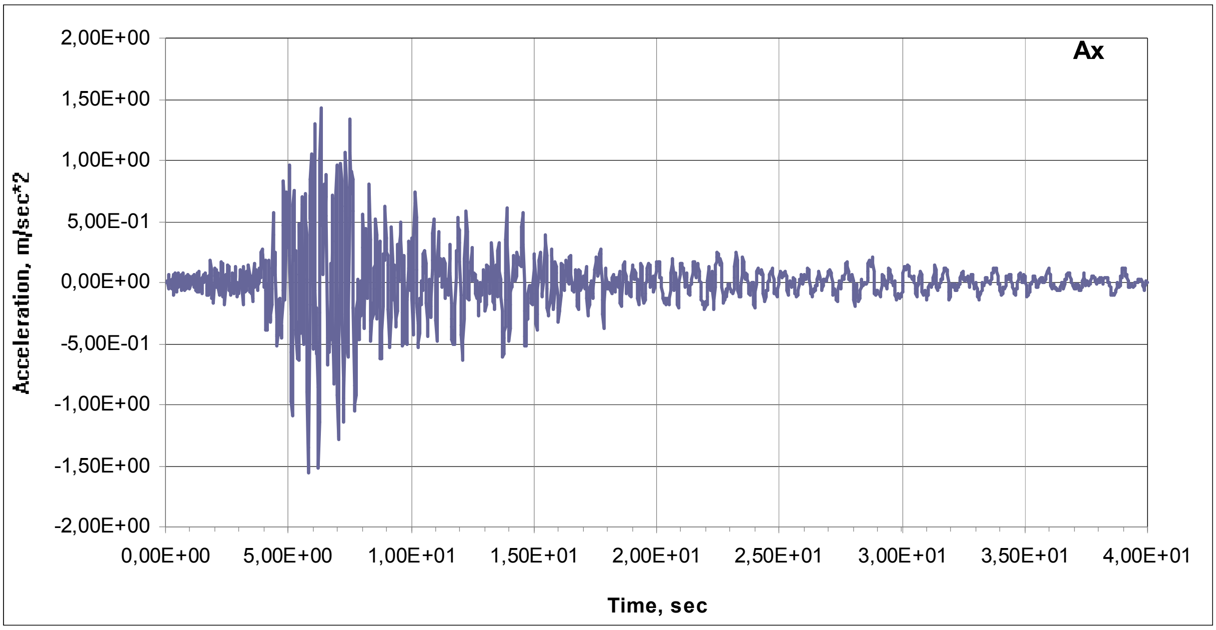
The order of construction and filling of the water reservoir was taken into consideration in the static calculations.
In the calculation of the hydro static pressure of the water the stress-strain behavior of the reinforced concrete face under the impact of its dead weight was considered as its initial condition, formatted prior to the water reservoir filling. It was also assumed that the face was put upon the massive with already established deformations under the impact of the rockfill weight.
In the calculation of the seismic impact, stress-strain state of the structure after the construction completion or some period of its exploitation was considered as the initial one. The water reservoir pressure on the dam was taken into consideration through adding of an associated water mass in accordance with recommendations of the Russian construction regulations.
The seismic evaluations were carried out according to the non-linear dynamic theory. Calculation of the seismic impact was carried out by solution of a system of differential dynamic balance equations with the method of direct step-by-step integration. The stress condition caused by the static loading was taken for the initial stress field.
It should be mentioned that utilization of three-dimensional mathematical CFRD models and three-component accelerograms allows to estimate the actual behavior of a dam with reinforced concrete face in case of seismic impact, particularly, which is especially important, take into consideration the valley geometry and the impact component directed across the canyon.

4. LOADS AND IMPACTS

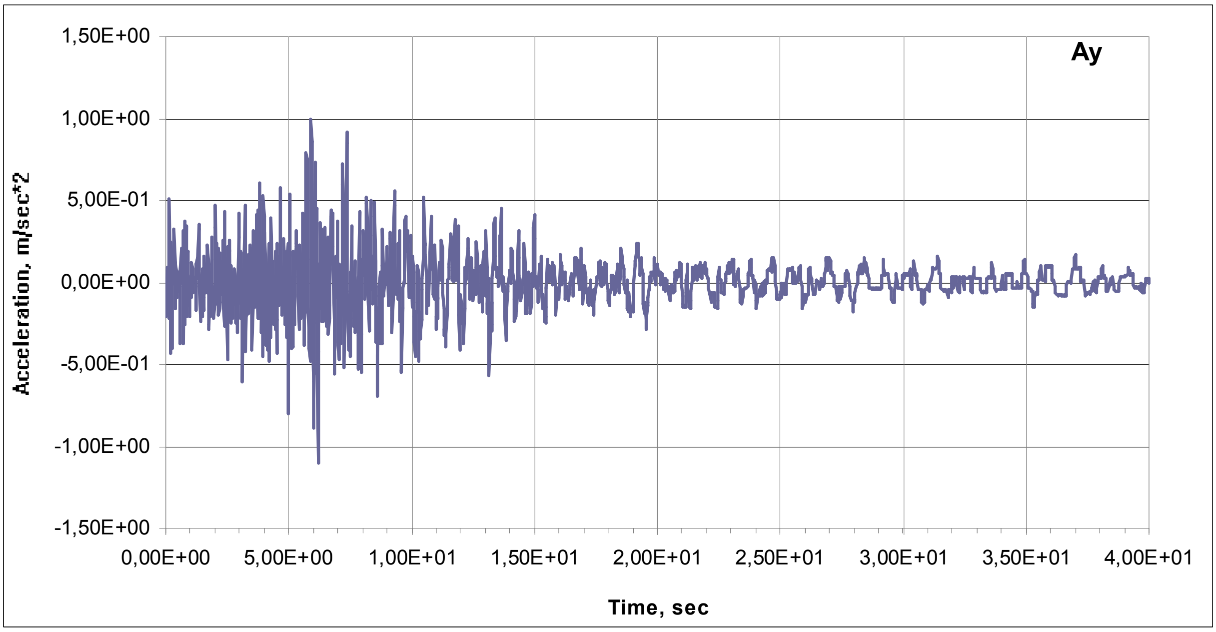
The principal and special combination of the loads was considered: the dead weight of the construction, water pressure from the upper and lower pools, and the seismic impact.
The seismic impact was set by simultaneous three-dimensional accelerograms of the design level earthquake (OBE), applied to the foundation of the calculated area (in the bedding rocks). Whittier Narrows; CA; 1987 accelerograms were taken as initial data, they were standardized in accordance with the actual soil conditions and recalculated for the depth corresponding to the base of the calculation model and of 7 earthquake intensity on the MSK-64 scale (see Figure 3).

5. MATERIAL CHARACTERISTICS

In the development of the finite element model of the structure three zones with different values of the physical and mechanical characteristics of the soils (central and downstream prisms and the transition zone) were singled out in the dam, a reinforced concrete face and reinforced concrete flume, in addition to two zones in the construction foundation. Positions of the zones with different values of the physical and mechanical characteristics are shown on Figure 1. Due to the lack of detailed data on the properties of soils to be laid in the different dam zones, the current calculations were based on the data taken by analogues, particularly, the internal friction angle for the rock mass of the central prism was assumed as 38°. The major soil properties are shown in the table 1.
The calculation deformation and strength characteristics of the dam body were varied, e.g., the static modulus of deformation for the upper zone of the rockfill was assumed in calculations equal to 80 MPa, and the modulus of deformation for the downstream zone varied from 32 MPa to 53 MPa.



a) - The horizontal acceleration component



b) - The vertical acceleration component

Figure 3 Input base accelerogram

Table 1 Material data

Material	E, MN/m^2	ν	ρ, kN/m^3	E_d, MN/m^2
Concrete slab	33750	0.3	23.0	38475
Transition zone	120	0.2	22.1	1800
Rockfill central embankment	80	0.2	21.6	1200
Rockfill downsream embankment	40	0.2	21.2	600
	44	0.2	21.2	660
	53	0.2	21.2	795
Weak rock	1000	0.3	27.4	5000
Rock foundation	6500	0.3	28.2	19500

6. CRITERIA OF THE SEISMIC RESISTANCE OF EARTH DAMS

The capacity to bear a given level of seismic impact without catastrophic wrecking is considered as the major criterion of an earth dam. Full repair ability of the structure for the case of impact of a design level earthquake should be provided.
Ratio between the maximum seismic loads without destruction to the calculation seismic impact can be considered as a factor of safety in case of seismic impact.
Other criteria of seismic resistance can be also used for earth dams, e.g., range of permanent (inelastic) deformations during and after an earthquake, limitation on the residual displacements of the dam and slopes in case of earthquake, etc.
It should be mentioned that destructions of the face (cracks, plate shifts), practically inevitable in case of forceful earthquakes, usually do not lead to catastrophic consequences in case of correctly designed dams of this construction, because in such cases only filtration enhancement through the rockfill but no destruction is taking place.

7. SOME CALCULATION RESULTS

Displacements of several points on the upper slope of the dam, between the face and the transition zone in three cross-sections have been considered. Comparing the results received we can make the following preliminary conclusion: with the 40MPa modulus of deformation of the downstream prism the dam vibrates more near the coasts, the left side displacing for a bigger magnitude than the right one, while with the 53MPa modulus of deformation the maximal displacements are registered in the central part of the dam.
In case of a seismic impact the face mostly had been keeping the permanent contact with its foundation due to squeezing of the face-transition zone contact under the hydro-static pressure of the water reservoir. The cut-off of the face is possible in the upper third of the face.
The total displacements of the dam points (m) under static loads (40 MPa modulus of deformation for the downstream prism) are shown on Figure 4.

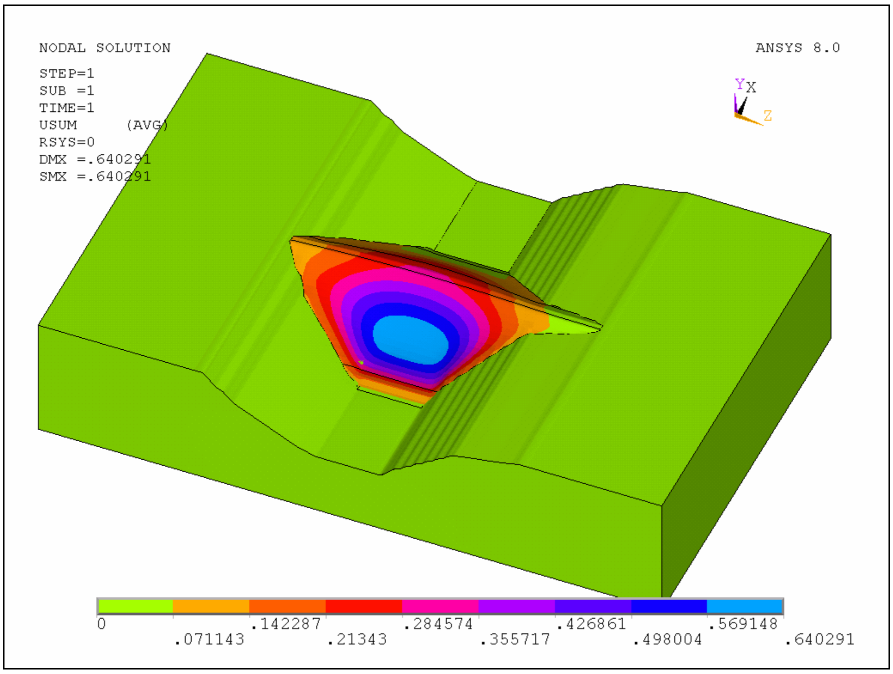


Figure 4 Total displacements

Displacements of the dam points (m) along the Z-axis after 5.9 seconds of seismic impact are shown on Figure 5 (40 MPa modulus of deformation of the downstream prism).

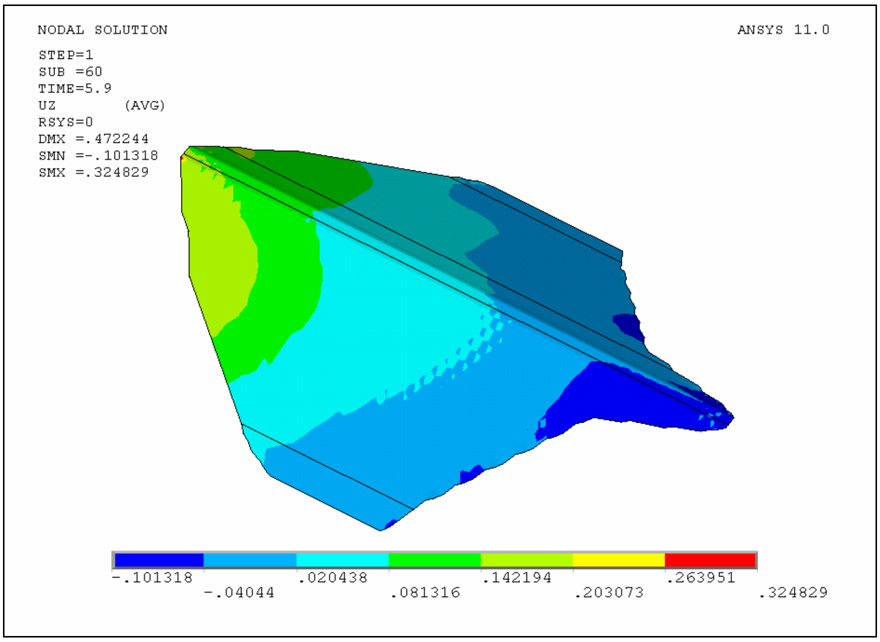


Figure 5 Displacements along the Z-axis

The calculated relatively significant values of displacements of certain parts of the face most likely should not be considered as actual displacements but rather as an indication of the possible mechanism and projected zones of the face plates damage or destruction.

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