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COMPUTATION ANALYSIS OF CONCRETE FACE ROCKFILL DAM UNDER STATIC AND SEISMIC LOADING

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SUMMARY

The report is dedicated to the numerical investigation problems of system of the rockfill dam with reinforced concrete screen – its foundation being under static and seismic action. On the example of the specific construction there have been considered such problems as the development of the numerical three-dimensional model of the system taking into account contact and physical nonlinearity of its deformation, simulation of seismic action, interpretation of numerical investigation results.

INTRODUCTION

In the nearest 10-15 years in the Russian Federation it suggested to construct a significant number of new hydrotechnical systems in such regions as Siberia, Far East and North Caucasus Laschenov [1]. It is planned to build a cascade of electric power stations on the river Lower Angara (tributary stream of the river Enisey), Katun hydro-electric power station (the river Katun in Altai), Lower-Zeisk hydro-electric stations (the river Zeya, the tributary stream of the river Amour), Soth-Yakutsk hydro-electric power complex (the river Uchur), Mocks hydro-electric power station (the river Vitim, Siberia), Andiyskaya hydro-electric power station (the river Andiyskoye Koisu, North Caucasus) and et.al.

The analysis of natural conditions of possible regions of hydro-electric power station construction demonstrated their conformity, in some cases, with the conditions at which there were constructed a great number of rockfill dams with reinforced concrete screens all over the world. In Russia the dams of such type are not used nearly 50 years. The study of international experience showed that this direction of dam construction is promising for the Russian region.

The review of the problems arising at projecting the dams with reinforced concrete screen, methods of their designing and the analysis of the behavior of some high dams of such construction type is given in [2], [3], Giudici [4], Kashiwayanagi [5], Zeping [6], Yuezhan[7], Humes [8]. The detailed analysis of

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static behavior of the dams with reinforced concrete screen and of peculiarities of their calculating proof is given in Anthiniac [9]. The analysis of behavior of the dams with reinforced concrete screen being under seismic action has been carried out on the base of two-dimensional calculations Matsumoto [10], Noorzaei [11], Mahabadi [12], Johannesson [13], of three-dimensional Harita [14].

In the B.E.Vedeneev VNIIG in the period of 2002–2003 there have been carried out the numerical investigations of the considered type dams to work over the methods to substantiate the design and performance objectives.

There were considered and evaluated the possibilities of the existing computer software for modeling the dam deformation taking into account the contemporary concepts of the processes in the system “structure-foundation” at static and seismic actions. There were analyzed the following computer programs– ANSYS [15], LS-DYNA [16], Cosmos/M [17], SCAD [18] and others realizing the solution of the static and dynamic tasks by the method of finite elements. The main part of the numerical investigations is carried out using the program LS-DYNA [16].

The investigations allowed to develop principal statements of the method of calculated substantiation of constructive solutions of rockfill dams with reinforced concrete screen on the base contemporary computer programs.

STATEMENT OF THE PROBLEM FOR NUMERICAL ANALYSIS

Described is the computation analysis of the concrete face rockfill dam under static and seismic loading.

The analysis is performed by the finite element method using the “LS-DYNA” software. For the purpose of the analysis there was developed a 3D model of dam-foundation system. The body of the dam and its foundation is modeled by 3D elements; the concrete slab is represented by variable thickness shell. The contact elements modeling unilateral type of contact are provided at the interfaces of the dam with the foundation and the banks, the slab with the rockfill, and inside the functional joints. Account is taken of the friction over the interface surfaces. The rockfill was treated as non-linear.

The structure is analyzed for the seismic impacts. The seismic impact is idealized by three component accelerograms applied to the rock massif at 150 m depth from the dam base. The nonreflecting condition is prescribed at lateral boundaries of the foundation area.

The calculation at seismic action was carried out by the method of solving the system of differential dynamic equilibrium equations using direct step-by-step integration. When the structure was investigated at seismic action the static computation results involving the dam weight and the hydrostatic pressure were considered as its initial stress field.

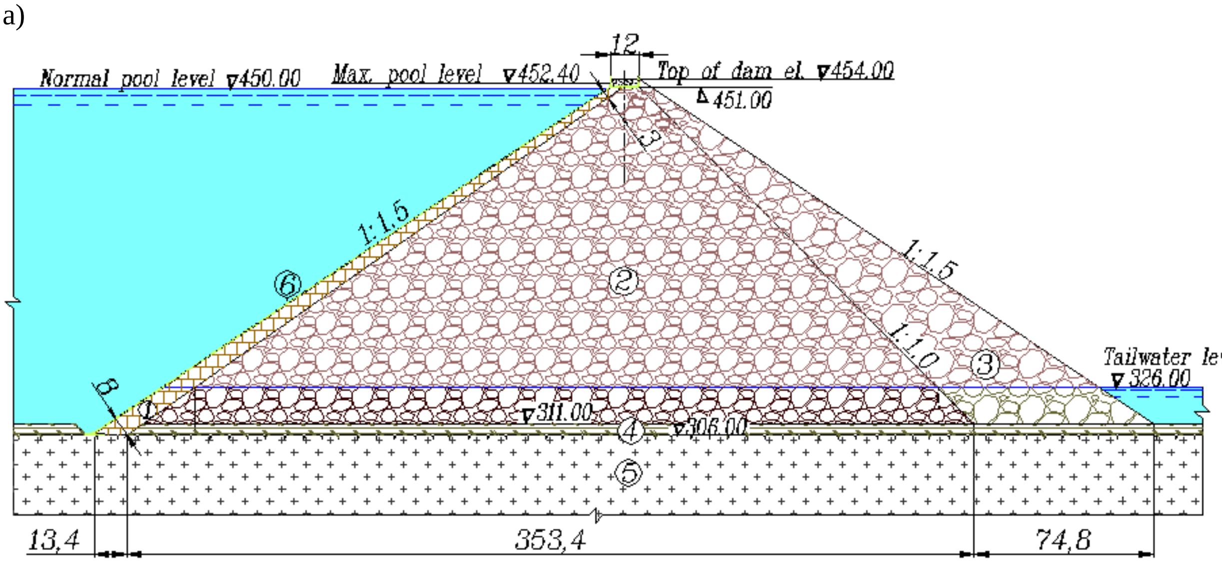
The analysis deals with such problems as the dependence of the stress-strain state of the dam and the concrete slab from the mechanical properties of the structure and its foundation, from the layout chart of joints of the slab and the conditions at the concrete - rockfill interface. The influence of the dam on the vibration process in the foundation is analyzed as well as the influence of the inertia forces in the foundation on the stress-strain state of the structure. The studies make it possible to work out recommendations for the design.

Further there are described the numerical investigations of one of the variants for the project of the rockfill dam with reinforced concrete screen (applied to Urgalskiy hydro-system, Far East), under static and seismic loading.

MODEL OF THE "DAM – FOUNDATION" SYSTEM

In Fig. 1 there is shown an example of the dam project of 148 meters high with inclination of slopes from the side of head water and tail water of 1:1.5. The dam body was made up of rock fill central and external prisms, under the screen layer and reinforced concrete screen from the side of the reservoir. Dam foundation and bank slopes are consisted of weathered and non-weathered rocks (siltstone).

a)



Notation:
1 – filter zone (chipping); 2 – rockfill (central embankment); 3 – rockfill (outer embankment); 4 – weak rock; 5 – rock foundation; 6 – concrete slab.

b)

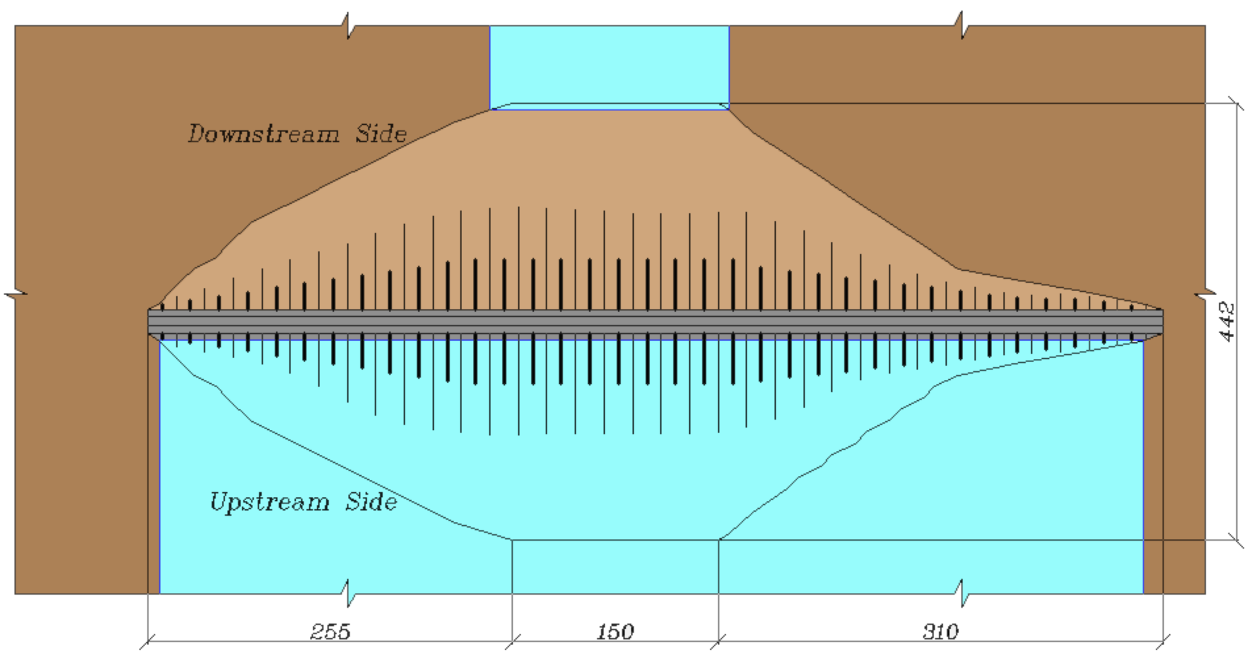


Fig. 1. Rockfill dam with reinforced concrete screen:
a) cross-section of the dam; b) top view of the dam; (dimensions in meters).

The reinforced concrete screen was of variable thickness – from 0.80 m up to 0.30 m. The plates of the screen were cut by vertical deformation junctions in every 16 meters. The conditions of conjunction of the screen with the foundation and dam cap were being changed during investigations. On the contact of the dam with banks there was suggested the existence of junctions along the perimeter.

In these investigations the rockfill dam with reinforced concrete screen and the foundation was considered as integral, mutually deforming three-dimensional system.

Figure 2 demonstrates a three-dimensional model of the system "dam – foundation", its division on finite elements. All in all there were a number of finite elements about 150 thousands, mainly – eight nodes three-dimensional elements and partially – four-six nodes three-dimensional elements in the areas of attaching the dam to banks. The screen was modeled by three-dimensional shell elements.

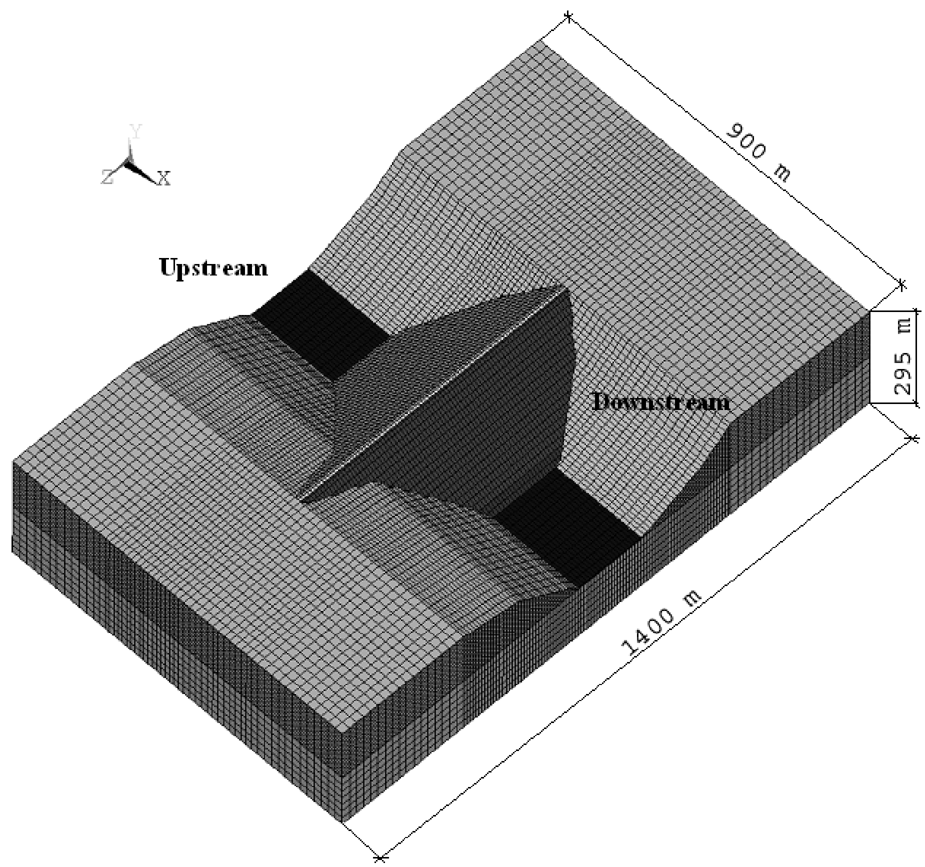


Fig. 2. Dam model to calculate the 3D stress-strain state.

The certainty extent of investigation results significantly depends on plausibility of the stated conditions on system element joints. Unilateral constraints (joint working only for compression) taking into account friction between media were installed on the area of contact of the dam with the foundation, on the attachment of the dam to banks, on the contacts of the reinforced concrete screen with rockfill and in expansion joints between screen slabs.

Boundaries of the design area of the dam foundation were chosen from the condition of quite long distance from the dam not to influence significantly on the structure functioning. Conditions “not to reflect” the seismic waves were stipulated for the boundaries of foundation model Lysmer [19], Lysmer [20]. Up-to-date programs permit to lay down conditions “to pass through” or “to absorb” seismic waves on the boundaries of the chosen design area.

Some points of the investigations were preliminary worked out on plane models. If it was necessary there had been carried out the structure detailing by extracting the interesting parts of the structure taking into account the boundary conditions of the fragments.

The calculation of the structure in two-dimensional statement was carried out only on the first stage of the object investigation because to substantiate the structure of the whole construction and its separate elements is possible only by complex investigations of the whole tree-dimensional system on main and specific combination of loads.

Taking into account the three-dimensional character of the construction functioning influenced on the calculated values of screen joints opening, on the state evaluation of dam body insets into embankments, on behavior of the inspection galleries and on general view of displacement and stress fields.

For the investigators there was also a problem to choose materials deformation models of the system “structure – foundation”. During investigations there were realized the models of linear-elastic, non-linear-elastic and elastic--plastic behavior of the construction materials.

The design deformation and strength characteristics of the construction materials were varied in quite wide ranges. So, the static deformation module under the screen layer was taken in the calculations from 80 MPa up to 200 MPa. The dynamic modules of deformation and dissipation characteristics were changed in a wide range as well. This approach is justified if we take into account considerable difficulties in determining quite reliable mechanical and physical performances of such media as rockfill.

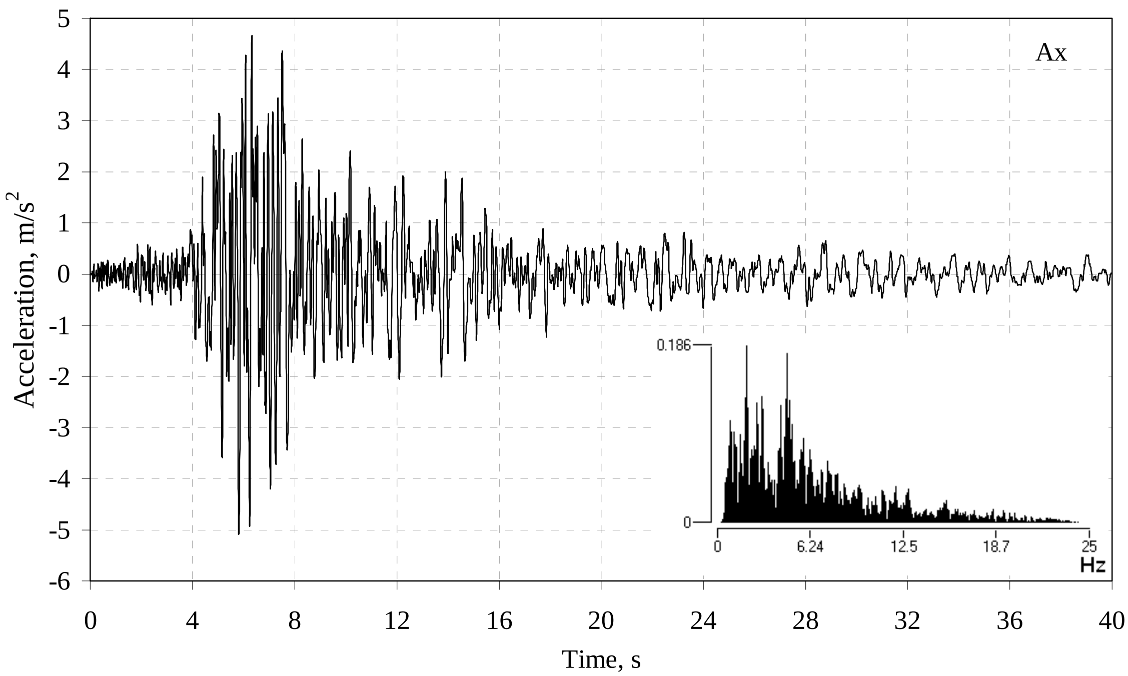
LOADING AND IMPACTS

There were considered main and specific combinations of loads consisting of water pressure of the reservoir, self-weight of the structure and seismic action.

Stress state of the reinforced concrete screen because of its self-weight was considered here as its initial state formed before filling the reservoir. The influence of stress state of the rockfill being under its own weight on screen deformation was not taken into account, it was suggested that it is placed on the massif with completed deformations.

Seismic action was specified simultaneously by three-component accelerograms applied to the lower boundary of the calculated area (in basic rock) Clough [21], Birbraer [22]. For the report as the original accelerograms there were chosen the accelerograms of the earthquake “Whittier Narrows; CA; 1987” standardized conformably to the present rock conditions and recalculated for the depth corresponding to the foundation of the design model (see Fig.3). Seismic pressure of reservoir water on dam was taken into account. According to Russian Building Codes added mass was calculated in nods on wetted screen surface.

a)



b)

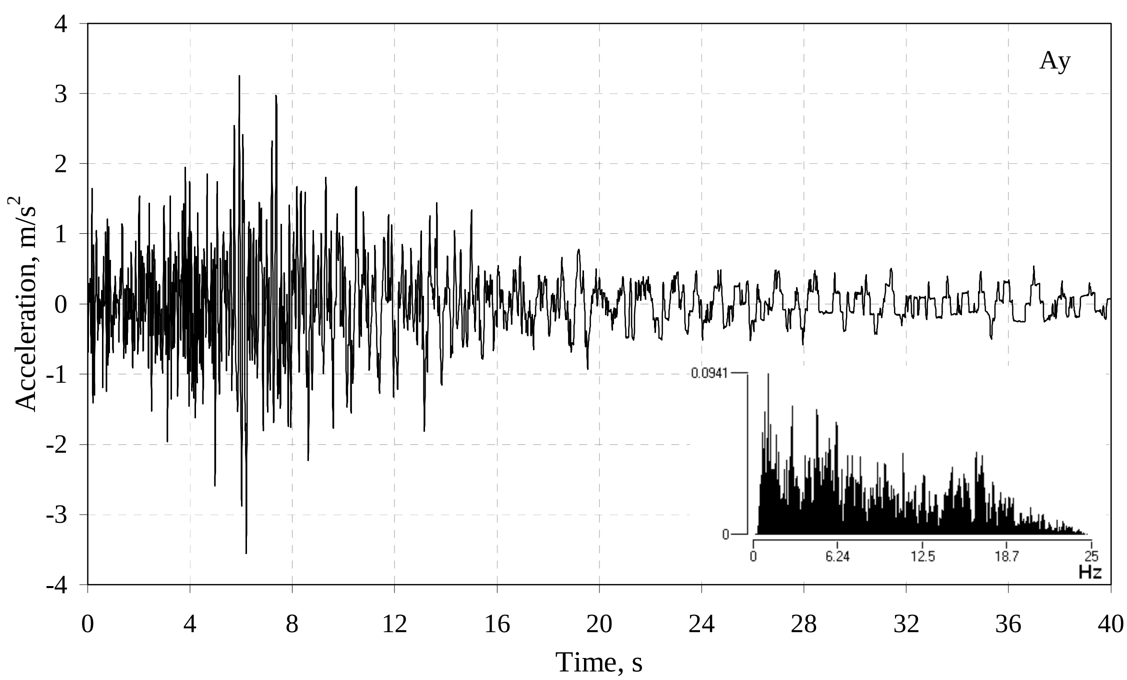


Fig. 3. Input base accelerogram and spectrum: a) - horizontal component; b) - vertical component.

INVESTIGATION RESULTS, THEIR INTERPRETATION

In the result of the fulfilled investigations, by variation of construction parameters and material characteristics of the system there was received necessary information to substantiate the dam construction and its reinforced concrete screen. Having valuable information the development of the construction solution of the structure is a matter of engineering art.

Figure 4-a demonstrates reinforced concrete screen deformation under the static water pressure of the reservoir. The screen was cut by vertical junctions after every 16 meters. As it can be seen from the Figure the central part of the screen has been squeezed under the water pressure, and the deformation junctions have been opened in the riverside areas. There was fixed the maximum junction opening of 10 mm.

Figure 4-b shows deformation of the reinforced concrete screen on different stages of the earthquake. The upper area of the screen in its central part (area A) is marked out. Here we can observe the "opening – closing" process of screen deformation junctions during the earthquake. Maximum junction opening of 165 mm could be seen on the 9-th second of the earthquake in the middle of the dam on its crest. The forecast of junction opening is necessary to project their width and design of sunk keys.

The screen at seismic action had, mainly, the constant contact with its foundation (rockfill) because of squeezing the "screen – dam body" contact by hydrostatic pressure of the reservoir. Screen separation from the rockfill can occur on the very upper part of the dam where there will be needed the design requirements to provide strength of this node.

The investigations showed quite significant calculated bending moments in the middle part of the screen. The insufficiency only of the vertical deformation junctions is obvious. The screen demands to be unloaded by horizontal deformation junctions in longitudinal direction.

Evaluation of possible displacements, non-compactness the rockfill on the dam joining with bank massif is demanded to develop construction design of their joining.

Figure 5-a illustrates evolution of dam "detachment" from bank slopes on the eighth second of the earthquake (view from the side of the reservoir). Figure 5-b shows probable propagation of "detachment" on the 12-th second of the earthquake in central longitudinal cross-section of the dam (approximately under its crest).

At calculating dams on seismic action, in some cases it is modeled only the dam applying disturbance to its foot. Such approach can be accepted if the calculated action has been determined also taking into account the existence of the structure by solving of the auxiliary task.

Figure 6 shows seismograms on the surface of the foundation when there is no dam, and in case when the earthquake occurs after construction has been finished. As it can be seen the displacements at the structure existence are nearly two times less than they were without the dam, at that the excitation along the foot is not uniform. Naturally the greatest difference in the displacements is observed in the middle of the dam cross-section (under the crest).

At that the massif with inertial forces is cut off and deformation of the free surface out of the foot boundaries is not taken into account. To solve the problem of organizing conjunction of the dam with the foundation and also the conjunction of the reinforced concrete screen with the foundation it is preferable to simulate a system "construction – foundation".

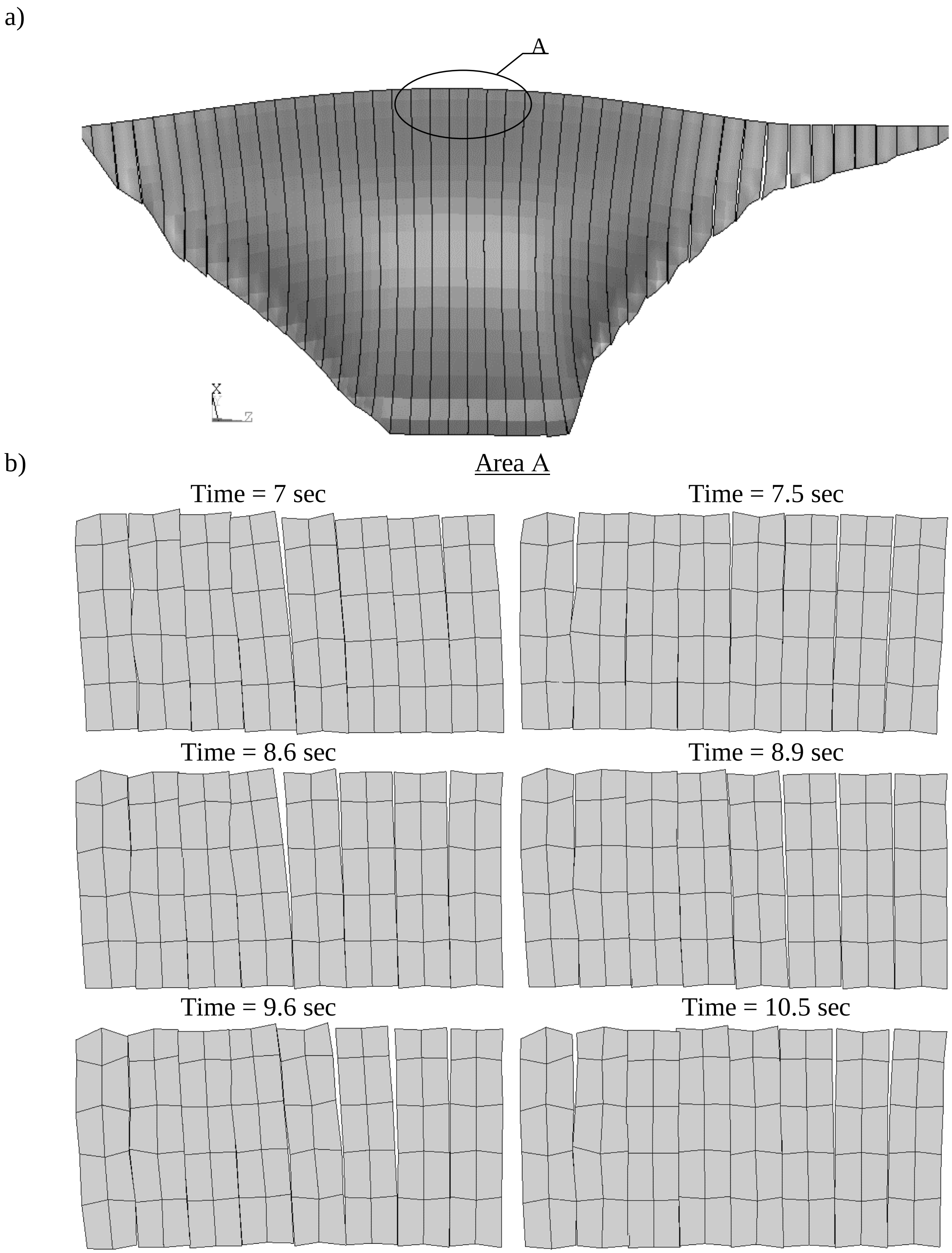


Fig. 4. Deforming junctions opening in the reinforced concrete screen:
a) - at static load; b) - at earthquake in the area A of the screen.

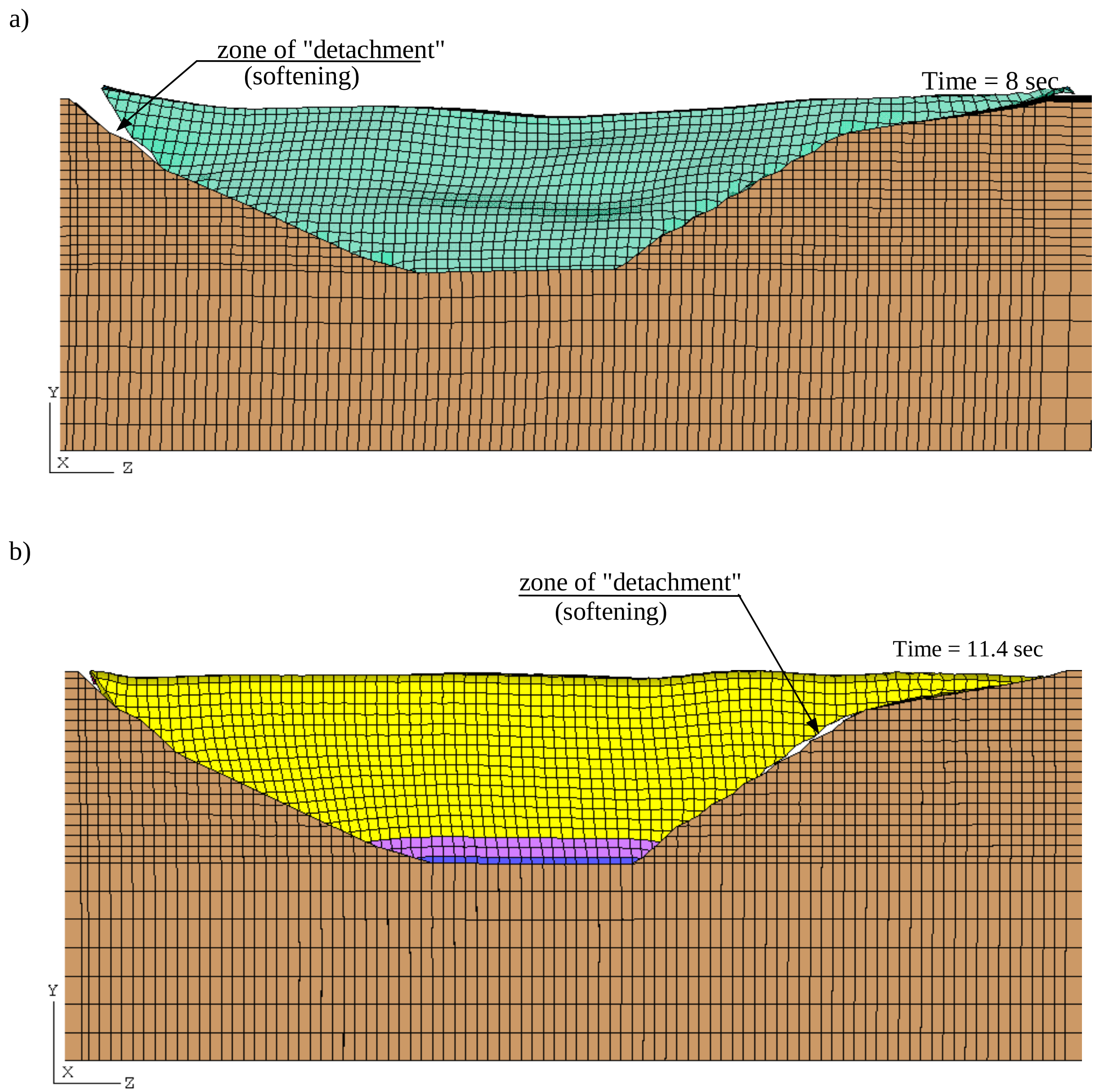
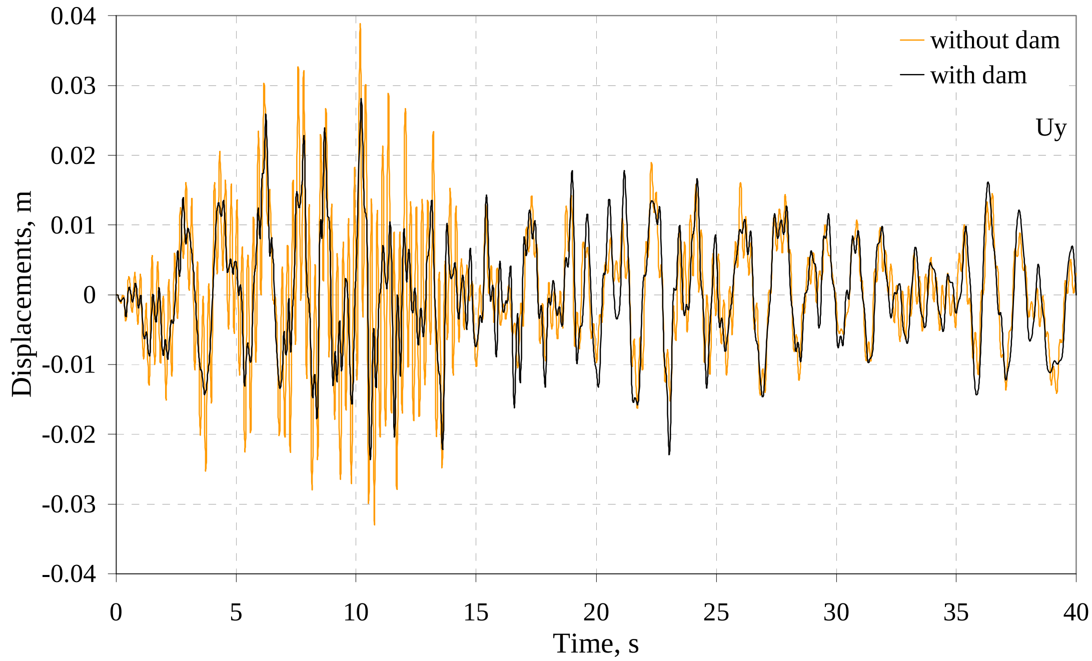


Fig. 5. Deformation of the construction at seismic action:
a) - view from the side of head water, t = 8 s;
b) - deformation of the central longitudinal section of the construction, t = 11.4 s.

a)



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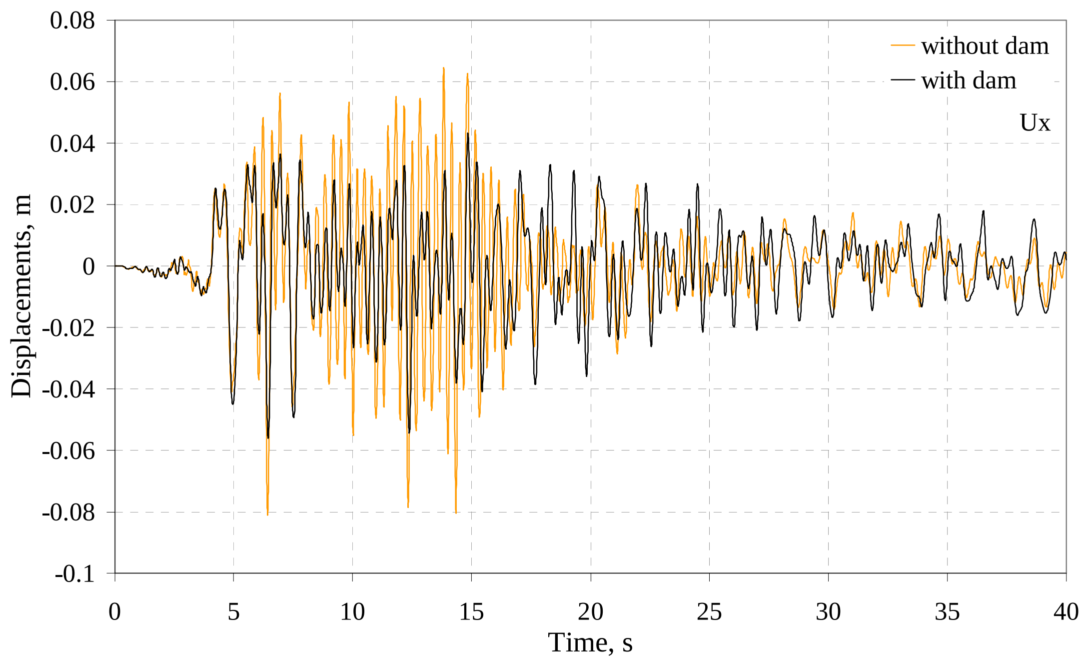
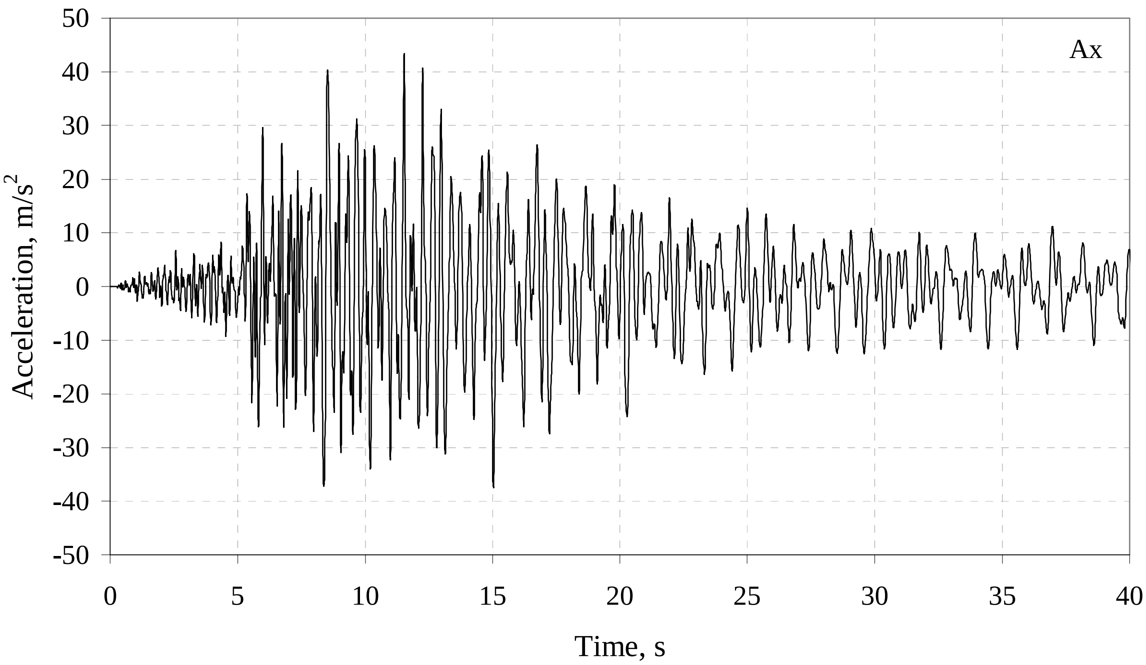


Fig. 6. Seismograms on the embankment foot in the absence or at the presence of the dam: a) - horizontal component; b) - vertical component.

Special attention was paid to the investigation of the reinforced concrete screen functioning. Together with that there was carried out evaluation of stress-strain state of the dam body and stability of its slopes. Figure 7 shows accelerogram on the dam crest. Investigation showed that maximum of acceleration on dam crest exceed in 3-4 times corresponding acceleration on foot of dam.

a)



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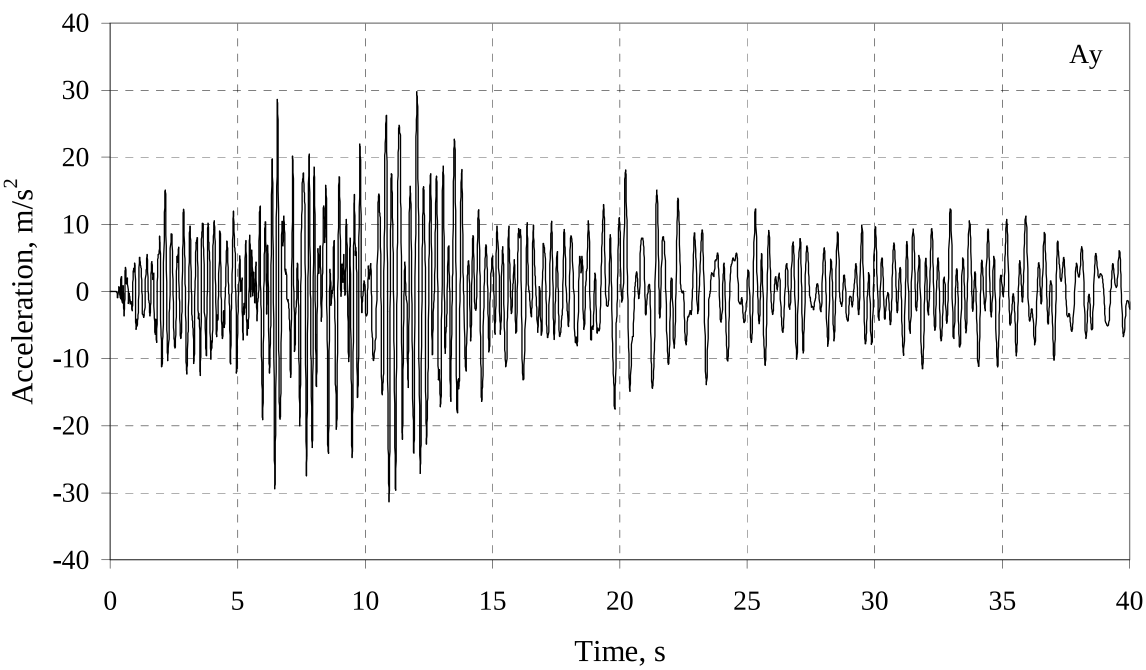

Fig. 7. Output accelerogram on the dam crest: a) - horizontal component; b) - vertical component.

CONCLUSIONS

Thus, the rockfill dam with the reinforced concrete screen is a complicated hydro-technical construction demanding complex approach during its projecting. A great variety of problems to be solved at designing arises the necessity of scientific research in the field of numerical investigations, rock mechanics and seismology.

Full statement of the task demands to solve a package of problems. In this case it is demanded to develop a three-dimensional numerical model, in the calculations to take into account the geometrical (contact) and physical non linearity of the system "dam – reinforced concrete screen – foundation". At calculating the system at seismic action it has to be taken into account the static initial field of stresses, to simulate "non-reflecting" boundaries in the foundation massif, to fulfill the non-linear calculation by the method of solving dynamic differential equations system, to choose optimal integration method, efficient computation method and so on.

It should be noted that to carry out full calculated investigations it is necessary to have a certain qualification of the specialists and corresponding software and hardware. A considerable labor expenditure can also be notified.

Besides, now there are significant difficulties to assign quite proved calculated deformation and strength dynamic performances, energy dissipation factors of the materials of the system "dam – foundation".

At last, the specific problem – to assign initial seismic excitation solving of which demands to engage specialists on seismology.

In conclusion it can be noted that in B.E.Vedeneev All-Russian Scientific Research Institute of Hydro-Engineering (St.Petersburg, Russia) there are successfully carrying out the numerical investigations of rockfill dams with reinforced concrete screens in spite of the difficulties accompanying the investigations.

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