საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 7, №1, 2013
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 7, no. 1, 2013

Structural Mechanics

35 Years of the Enguri Arch Dam

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ABSTRACT. The design of Enguri arch dam is recognized to be a striking example of engineering to date. The height of the dam is 271 m, the length of crest is 700 m. 1.1 billion tons of water is accumulated in the reservoir of the dam. For 35-years of service of Enguri hydrosystem, the programs of its rehabilitation were accomplished several times. Unfortunately, some problems planned in the program of rehabilitation were not studied at all. In particular, the assessment of the behavior of the arch dam at strong seismic loading possible in the region was not made. The program of responding to the emergency situation created at possible break of the dam was not developed. These problems were considered to be very important and were discussed at the meetings held in 2004 within the above-mentioned program of renovation. Later they were emphasized in my reviewing paper. Some additional commentaries to the above-mentioned report are presented in the paper. *© 2013 Bull. Georg. Natl. Acad. Sci.*

Key words: *Enguri arch dam, seismic impact, collapse of dam, emergency action plan.*

The paper, actually, represents a response to the technical report "Correlation of the behaviour and analysis of Enguri arch dam safety" [1], carried out by the Consultative Company "Stucky" (Switzerland) in the framework of the Structure Rehabilitation Program. Public discussion of this account was conducted at a special seminar in Tbilisi on 1-2 July, 2004 [2,3].

• As the authors of the report note, the investigations were prompted by the joint report of the company "Stucky & Electrowatt Engineering Service LTD" (1995), wherein it was mentioned: "The conditions of the Enguri Arch Dam are not clear and must be considered as rather unsafe, as long as the monitoring is not fully under control and as long as the assessment of the dam behavior is not made on a continuous basis" [1].

• In the report under review the technical conditions of the Enguri arch dam are assessed under dead weight, hydrostatical pressure of the water, the temperature pattern and, what is especially important, the seismic effect. All this has been performed on the basis of mathematical simulation, using the method of finite elements. The simulation covers the dam body and a part of the river gorge.

• Of course, a number of remarks could be expressed, regarding the study: inaccuracy of some formulations and conceptions. Some propositions cited in the work, can be objected, or alternative opinion could be expressed (account of the geological structure, evaluation of the modulus of elasticity of the material, temperature pattern adopted, con-

sideration of construction joints, selection of calculation seismic effect etc.), but the fact that the authors have managed to correlate dam body displacements, obtained as a result of mathematical simulation with natural displacements (data of monitoring), and the circumstance that the results of determination of stress-strain made at the dam under the basic combinations of loading (dead weight, the hydrostatical pressure of water, temperature effect), almost repeat the results obtained earlier, at designing the dam, confirm that, when calculation of mathematical simulation is made more precise, the inferences will not change cardinally, and consequently, from the viewpoint of global assessment of the condition of the structure, they (inferences) can be discussed right now.

• It will be recalled that the Enguri arch dam was put into operation in 1978. To the present day it remains the highest arch dam in the world. Its height H=271 m, the length along the ridge l_0 =700 m, the cubic capacity of the reservoir is beyond 1 billion m^3. The design and analysis of the Enguri arch dam was carried out by many organizations of the Soviet Union, in particular, by the Institute of Structural Mechanics and Earthquake Engineering of the Georgian Academy of Sciences. The results, obtained by different organizations, were compared to each other, corrected, compared to data of experimental tests, enriching the vast technical project documentation that formed the legal basis for future construction.

• The analysis, carried out by "Stucky" company on global scale, actually, repeats and confirms results, obtained at designing the Enguri arch dam in the part that concerns the determination of the stress-strain mode of the arch dam under basic combinations of acting loads (dead weight, hydrostatical pressure of the water, temperature pattern). The basic result at such acting obtained as before, as by company "Stucky" says: The stresses do not exceed the acceptable values and are in material linear-elastic performance limits. The authors have written: "The dam safety is ensured under the static loading".

• The alarm of the authors is caused by the results of analysis at the action of seismic loading. They have examined two levels of earthquake intensity (the calculation and the possible maximum).

In both cases, even at comparatively weak calculation intensity (OBE), to say nothing of a strong maximally possible one, the authors indicate the possibility of occurrence of unpleasant phenomena - opening of the cracks, damage of the girdle etc.

• What is the matter? Was something missed at the designing? May be we are dealing with a sensational discovery? No – it is an anticipated result. Let us clarify this statement. The earthquake engineering ideology both 30 years ago and today declares that the norms of antiseismic designing allow to design the structure in such a way that at a comparatively weak earthquake, the occurrence of which in the life-time of the structure operation is expected with high probability, it will not suffer visible damage, while at the occurrence of strong earthquake that has a period of recurrence, much exceeding the term of operation of the structure, it will suffer damage, but a limit state will not develop in it. Limit states for different structures are interpreted variously.

• The above-cited propositions of earthquake engineering are declared in the norms, and for their realization it is considered enough to carry out one calculation process, instead of two. The norms assert that the structure is designed for maximum possible (MCE) earthquake, and the damage, occurring at such action that will decrease the seismic loading transferred to the structure, can be considered by the so-called structural coefficient. By this logic, in constructing an object in seismic zone, where the maximum intensity 9 (a_g = 0.4 g) is expected, the design procedure, proposed by the norms of the Soviet Union, defines the technical parameters of the structure that ensure the elastic performance (without damage) of it at intensity 7 (a_g = 0.1 g). As to the behaviour of the structure under the action of a stronger earthquake, the norms say nothing clearly, indicating only that the structure will get "permissible" (?) damage.

• In principle such a procedure was used at designing the Enguri arch dam, therefore, almost elastic performance (without damage) of the dam is ensured at an earthquake of intensity 7.

It is quite clear that, when Swiss specialists increased the calculation acceleration two and even four times more (a_g =0.2 g and a_g = 0.4 g), they obtained a total field of stresses that exceeds the limits of linear performance of the material. This circumstance was clear at the design process as well (30 years ago), and its illustration was possible on the basis of analytical simulation adopted at that time. This is indicated in the analysis carried out by the company "Stucky" as well. Nothing is unexpected here.

• It is quite another matter that at present there exists the possibility to forecast clearer the arch dam behaviour at the occurrence of both weak and strong earthquakes with the intensity 8 and 9, without recourse to the "reduction coefficient". This requires carrying out the calculations on the basis of nonlinear analytical schemes that consider the possibility of crack formation, opening of joints, break of some parts of the structure, and even the breakdown of the pressure front of the dam. In this procedure the real state of the structure is taken into consideration. By the way, in Russia a number of dams, located in seismic regions and designed according to old norms, have been recalculated with account of the new views on the basis of nonlinear dynamic analytical schemes.

• The availability of such calculation results creates a more well-grounded legal basis for taking certain decisions and evaluation of risk: the degree of accepted technical (restoration, strengthening) and procedural (limitation of the operation regime, lowering of the water level) solutions.

Such calculations, do not exist for the Enguri arch dam; therefore the behaviour of the structure at a strong earthquake is not clear. Consequently, neither a legal basis exists for adoption and evaluation of risk degree of solutions taken.

• In conclusion, one more, perhaps, principal point. Calculations on the basis of a nonlinear scheme must be carried out without fail for such unique structures as the Enguri arch dam is. Such calculations will shed additional light on the behaviour of the structure at a strong earthquake. But one can assume in advance that after carrying out nonlinear calculations, implementation of all required recommendations towards increasing the arch dam earthquake resistance will not be feasible, consequently a certain risk of the occurrence of a critical situation will always exist. Therefore, in my opinion, to carry-out an analysis of such events is obligatory with the purpose of elaboration of preventive measures to decrease their consequences, including even the consideration of the scenario of the breaking of Enguri arch dam pressure front. One may start thinking in this direction without waiting for the results of nonlinear calculation.

სამშენებლო მექანიკა

ენგურის თაღოვანი კაშხალი - აშენებიდან 35 წლის შემდეგ

გ. გაბრიჩიძე

აკადემიის წევრი, საქართველოს მეცნიერებათა ეროვნული აკადემია, ბუნებრივ კატასტროფათა მეცნიერული პრობლემების შემსწავლელი კომისია, თბილისი

ენგურის თაღოვანი კაშხლის კონსტრუქცია დღესაც საინჟინრო ხელოვნების ნიმუშად მიიჩნევა. კაშხლის სიმაღლეა 271 მეტრი, თხემის სიგრძე 700 მეტრი. კაშხლის მიერ შექმნილ წყალსაცავში აკუმულირებულია 1,1 მილიარდი ტონა წყლის მოცულობა. ენგურის ჰიდროკვანძის ექსპლუატაციის 35 წლიან პერიოდში რამდენჯერმე განხორციელდა მისი სარეაბილიტაციო პროგრამები და მნიშვნელოვანი სამუშაოებიც ჩატარდა. სამწუხაროდ, სარეაბილიტაციო პროგრამებით დაგეგმილი ზოგიერთი საკითხი არ იქნა შესწავლილი, კერძოდ, არ გაკეთებულა თაღოვანი კაშხლის ქცევის შეფასება ამ რეგიონში მოსალოდნელი ძლიერი სეისმური ზემოქმედებისას. არ დამუშავებულა კაშხლის შესაძლო გარღვევისას შექმნილ საგანგებო სიტუაციაზე რეაგირების პროგრამა. ეს საკითხები უმნიშვნელოვანეს საკითხებად იყვნენ მიჩნეული და მათზე იყო მსჯელობა ზემოთნახსენებ სარეაბილიტაციო პროგრამის ფარგლებში 2004 წელს ჩატარებულ სამუშაო შეხვედრებზე, კერძოდ, გამახვილებული იყო ყურადღება ჩემს სარეცენზიო წერილში, რომელსაც დღეს ვთავაზობ მკითხველს.

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Received December, 2012