UDC 626:627.81

RISKS ASSESSMENT OF KHACHEN RESERVOIR USEFUL CAPACITY INCREASE

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Khachen reservoir as brought into service in 1954. The annual average flow of the Khachen river is 116x106m3and the useful capacity of the reservoir is 20x106m3. The culvert aqueduct of the reservoir is calculated for a hydrograph of one per cent probability. It is planned to increase useful storage capacity of the reservoirby 3.8x106m3at the expense of transformation volume. To this end it is foreseen to install valves of automated regulation on the shaft spillway and keep elevation of water on high retaining level (HRL)The capacity of the dam to withstand internal erosion and stability of slopes for different levels of the water have been checked and hydraulic calculations have been performed for spillway structures and storm water flows.

***Key words**: reservoir, water balance, stability, dam, storm water sewer, spillway, shaft spillway*.

Introduction

The Khachen reservoir of seasonal regulation was commissioned in 1964 designed for 1000 ha agriculture land irrigation.The reservoir is located in submountain steppe landscape zone, where lukewarm climate conditions are characterized by dry winters and humid summers.The annual average flow is 116,4x10^{6}m^3. Full storage capacity of the reservoir is 23x10^{6}m^3, of which 20x10^{6}m^3 is useful one. The plan of the reservoir is shown in Fig.1.

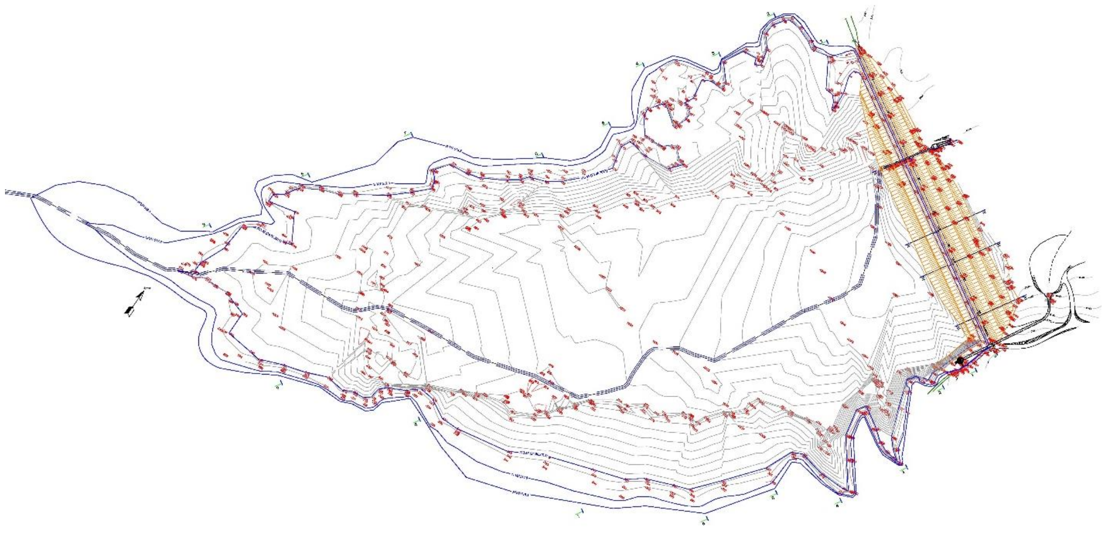

Figure 1. The plan of the dam and bowl of Khachen reservoir

Table 1 shows water balance of the Khachen reservoir. Results of field and laboratory investigations were used in calculations [1, 2].

Khachen reservoir, as all reservoirs, except annual flow regulation for irrigation purpose also regulates storm water maximum flow. To regulate storm rainfall flow on the reservoir surface a shaft spillway was constructed for 168m^3/s capacity. D.Kocherin simplified formula [1,2] was used to evaluate spillway structure capacity

$$q_{\max} = Q_{\max}\left(1 - {V_\phi}/{W_n}\right) \tag{1}$$

where $q_{\max}$ is the spillway flow, $Q_{\max}$ is the maximum flow of water pouring the reservoir, $V_{ф}$ is the 3,8x10^{6}m^3 volume of accelerated spillway is obtained from $V = f(H)$ curve, W_n is the volume of storm water flow. calculations are performed for one per cent probability flow

$$q_{1\%} = 204 \times \left(1 - {}^{3.8}\!/_{21.7}\right) = 168.3\ \text{m}^3/\text{s}$$

Table 1

Khachen reservoir annual water balance (m^3) of 50 and 75 percent probability

Probability, P	Entry end			Outlet portion						Remnant in the reservoir	Downstream of the spillway
	River flow	Atmospheric precipitates on reservoir surface	Total	1200 ha new agricultural land water demand	water demand of existing 1000 ha agricultural land	Seepage losses	Evaporation	Environmental flow	Total		
50%	113.54	0.86	114.4	5.69	23.0	0.69	1.01	6.94	37.33	3.0	74.07
75%	87.36	0.86	88.22	7.4	29.9	0.90	1.31	9.02	48.53	3.0	36.69

Thus, performed calculations show that the storm water sewer provides free passage of the estimated flow of one per cent probability to downstream portion. Fig.2 shows flood hydrograph of one per cent probability, which shows that storm water flows passage to the downstream through the existing shaft spillway practically is impossible.

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Regardless of the fact that maximum flows of the Khachen river are formed also in snowmelt period, however they for the most part are formed by torrential rains. The largest of flow rates 121m^3/s was reported at water inspection station located below the Khachen-Kolatak river mouth, and at Khachen-Vank water inspection point it was 91,5m^3/s.

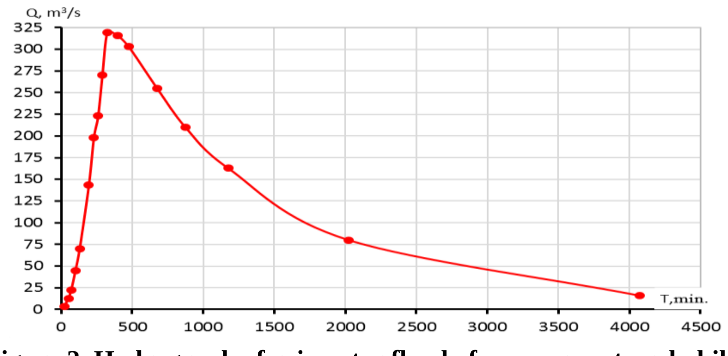


Figure 2. Hydrograph of rainwater flood of one per cent probability of the reach of river of Khachen reservoir dam

Over five decades of Khachen reservoir operation the volume of accumulated sediment amounts to 1,5x10^{6}m^3. At that this volume is located along the entire length of the reservoir and in its different parts the thickness of deposited sediment layers is different: at the dam toe it is 9-10 m, in the middle part of the reservoir – 6-7m, and at the tail it is about 1-2m. Thus it should be noted that today the total capacity of Khachen reservoir reduced from the design capacity not more than seven per cent, and useful capacity only 3-4 per cent, that is half of the dead storage.

Table 2

Maximum flows of different probability

River reach	Maximum flows (m^3/s) according to probability P%					
	0.1	0.5	1	3	5	10
Khachen reservoir	319	235	204	152	126	92

As a result of field measurements and laboratory developments morphologic actual curves have been plotted (Fig.3) and silts' actual volumes shown on them.

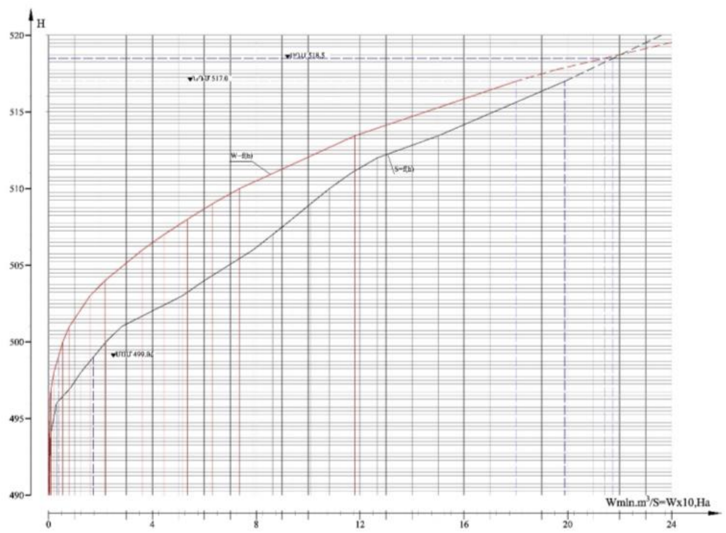


Figure 3. Dependence of volume and area of Khachen reservoir and its water level

Conflict setting

This study is aimed to increase the useful volume of the Khachen dam reservoir using $3{,}8x10^6m^3$ transformation volume between low retaining level (LRL) and HRL setting up valves of automatic regulation on the shaft spillway. In such case, quite natural that both the values of porous pressure and mode of deformation are changed. As it was pointed out above the transformation volume and the flow of the shaft spillway make removal of flood flow to downstream. For this reason total capacity of spillway should be added to $272m^3/s$ or the transformation volume should be added to $11{,}8x106m^3$, which will lead to lowering LRL by 3,4m and the useful volume will become $12x10^6m^3$ [1,2]. According to international norms the spillway capacity should be increased, or NRL decreased. Actually, in recent years the other way about has been done. If in the past capacity of irrigation spillway was around $35m^3/s$, then today after its rehabilitation its capacity plus the capacity of the siphon system does not exceed $7m^3/s$. During rehabilitation of the regulation tower in the irrigation tunnel gallery a pipe of 820mm diameter was installed having 5m3/s capacity (Figs. 4 and 5).

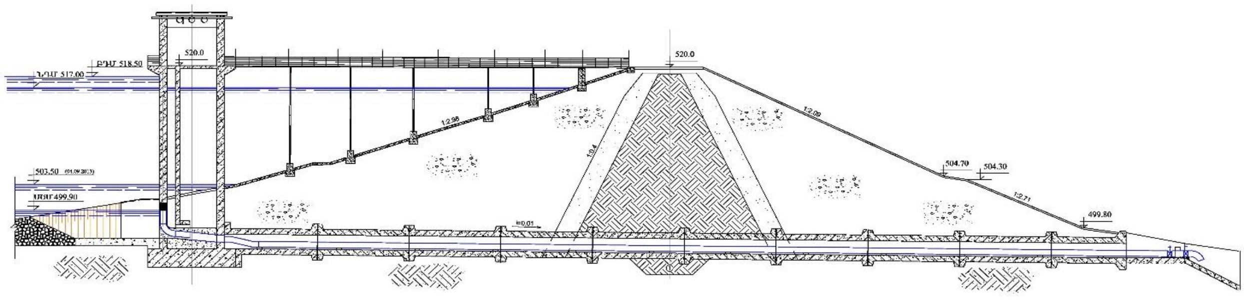


Figure 4. Khachen reservoir irrigation spillway after rehabilitation

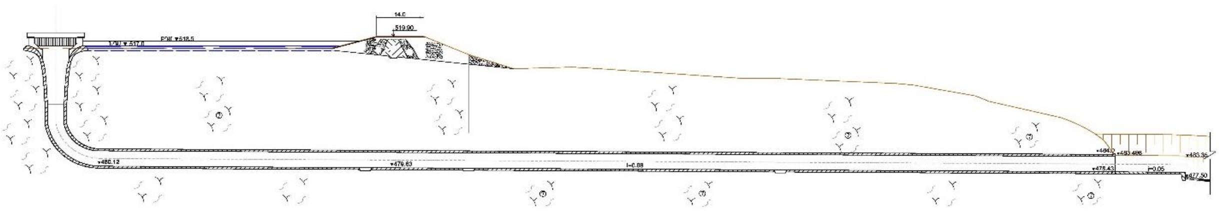
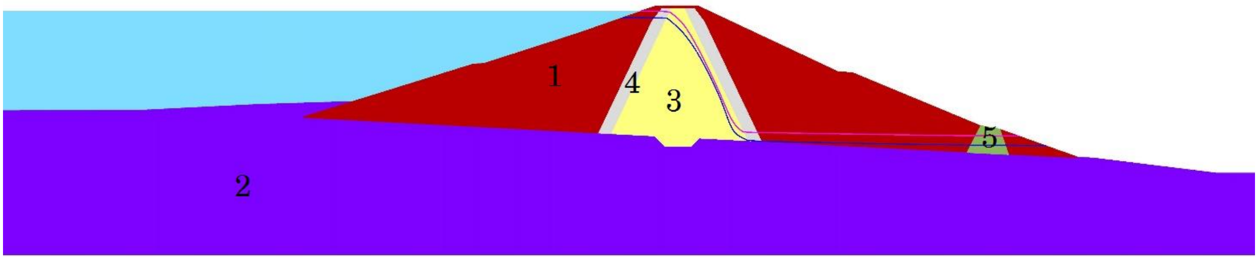


Figure 5. Khachen reservoir emergency shaft spillway

Research results

Strength and stability test carried out for Khachen reservoir in case of water LRL and HRL various calculation methods and techniques have been used. As a calculation section the most dangerous plane section was considered (Fig. 6) on which depression levels are placed (Fig. 7).

Design parameters of static calculation have been defined as a result of laboratory investigations analysis, and design parameters of dynamic calculation were taken from reference books [3]. To determine shear module of soil and Poisson coefficient empirical formulas based on velocities of propagation of dynamic waves have been used



1.Pebble-gravel formation with up to 10% sand filler (dam body)
2.Pebble-gravel deposits with up to 20% sand filler (base)
3.clay loams mixtures up to 5% (dam body)
4. Sand grains of different size (transition prism)
5. Stone banket

Figure 6. Calculation section selected for strength and stability calculations

$$G = \rho \times V_s^2 \tag{2}$$

$$\mu = \frac{0.5 - \gamma_v^2}{1 - \gamma_v^2}, \quad \gamma_v = \frac{V_s}{V_p} \tag{3}$$

where if $\sigma_z > 0.2$ MPa, then $V_s$and V_p, of which zero values are listed in table 1, are determined by the below formula

$$V_{p,s} = 1.3 \times V_{p_0,s_0} \times \left(\frac{\sigma_z}{\sigma_{z_0}} \right)^{1/6} \tag{4}$$

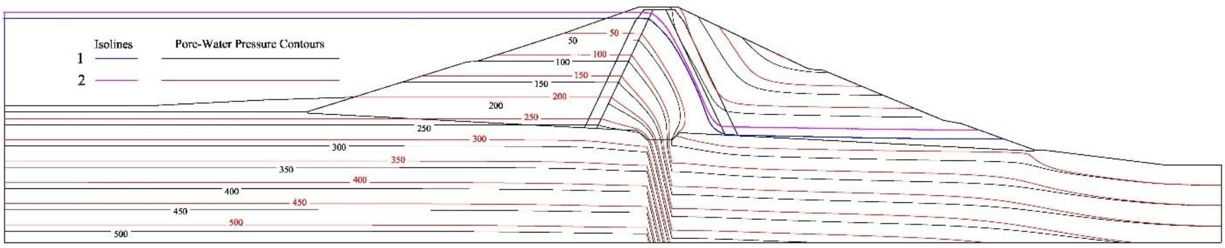


Figure 7. Porous pressure contours and depression curves

Except for the principal loading, as a design case another two loading cases have been considered:
seismic loading and quick lowering of the water level from LRL to MM. In case of seismic loading the problem is solved by two different methods.

In case of seismic loading the normative value of horizontal acceleration was accepted A=0.3g. Taking into account normative documents on seismic construction of the Republic of Armenia and the Republic of Nagorno-Karabagh [4] the design values of the horizontal acceleration were calculated K_0=1.0, K_1=0.3, K_2=1.0, $A_{hաշ.}$=0.09g. Then according to Building Code for earth dams design [3, 4, 5] coefficients of the dam stability have been calculated in cases of principal and special loadings.
Thus, for principal loading

$$Ks = \frac{\gamma_n \times \gamma_{fs}}{\gamma_c} = \frac{1.2 \times 1.0}{1.0} = 1.2$$

and special loading

$$Ks = \frac{\gamma_n \times \gamma_{fs}}{\gamma_c} = \frac{1.2 \times 0.9}{1.0} = 1.08 \tag{5}$$

Khachen dam slopes comparison stability testing for principal and special loading cases were carried out applying the circular cylindrical method. To determine the slope's stable angle of inclination the slopes stability assessment circular cylindrical method was used. The following Ordainar, Bishop, Janbui, and Morgenstein-Price four techniques were used. This method enables to consider stability of a mass of arbitrary surface and satisfy three equations of static equilibrium. Boundary values of shear stresses are defined by Cauchy law and the function of internal forces dependence is considers by $X = E\lambda f(x)$ law where λ is a scale factor and is determined during iteration, and $f(x)$ arbitrary function characterizes X stresses propagation regularity on separate layers is preselected by the user.

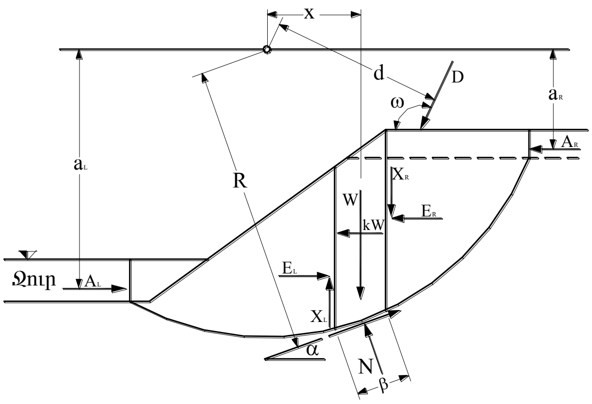


Figure 8. Cylindrical surface of shear

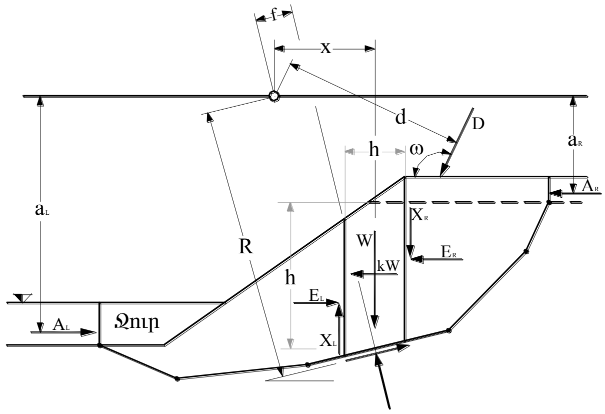


Figure 9. Arbitrary polygonal surface of shear

The above figures show a sliding down mass and forces acting on it where W is the total weight, x and e are horizontal and vertical distances between the centre of mass and centre of rotation, N is the normal reaction and f is its arm, S_m is the tangential reaction and R is its arm, α is the slope angle, E and X are normal and tangential reactions on the layer internal surface, D is the pin load and d is its arm and ω is the slope angle, A is the hydrostatic load and a is its arm, kW is the horizontal seismic load.
On each layer's internal surface a sliders training resistance is developed which is determined by the following formula

$$S_m = \frac{\tau \times \beta}{K} = \frac{\beta \times (c' + (\sigma_n - u) \times tg\varphi')}{K}, \tag{6}$$

Where $\sigma_n = \frac{N}{\beta}$ is the normal stress on the layer bed, K is the safety factor, β is the length of the layer base.

Table 3

Stability testing of Khachen dam slopes in case of primary and special loading and for different water levels in the reservoir

<table>
<tr><th rowspan="2"></th><th rowspan="2">Loading</th><th rowspan="2">Reservoir water level</th><th colspan="4">Stability factor values (K) calculated by different methods</th></tr>
<tr><th>Ordinary</th><th>Bishop</th><th>Janbu</th><th>Morgenstern-Pruse</th></tr>
<tr><td rowspan="8">Upper slope of the dam</td><td>principal (under the action of static forces)</td><td>is empty</td><td>2.452</td><td>2.487</td><td>2.449</td><td>2.488</td></tr>
<tr><td rowspan="2">principal (under the action of static forces)</td><td>N=517.0 m</td><td>2.104</td><td>2.417</td><td>2.292</td><td>2.452</td></tr>
<tr><td>MFL=518.5 m</td><td>2.156</td><td>2.545</td><td>2.425</td><td>2.422</td></tr>
<tr><td>special (under the action of seismic forces)</td><td>is empty</td><td>1.91</td><td>1.941</td><td>1.894</td><td>1.951</td></tr>
<tr><td rowspan="2">special (under the action of seismic forces)</td><td>NFL=517.0 m</td><td>1.438</td><td>1.586</td><td>1.543</td><td>1.591</td></tr>
<tr><td>MFL=518.5 m</td><td>1.456</td><td>1.603</td><td>1.571</td><td>1.605</td></tr>
<tr><td>principal loading</td><td>water horizon instantaneous lowering</td><td>1.262</td><td>1.317</td><td>1.287</td><td>1.322</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="6">Lower slope of the dam</td><td>principal (under the action of static forces)</td><td>is empty</td><td>1.817</td><td>1.846</td><td>1.79</td><td>1.858</td></tr>
<tr><td rowspan="2">principal (under the action of static forces)</td><td>NFL=517.0 m</td><td>1.795</td><td>1.898</td><td>1.781</td><td>1.901</td></tr>
<tr><td>MFL=518.5 m</td><td>1.795</td><td>1.898</td><td>1.781</td><td>1.901</td></tr>
<tr><td>special (under the action of seismic forces)</td><td>is empty</td><td>1.441</td><td>1.479</td><td>1.425</td><td>1.49</td></tr>
<tr><td rowspan="2">special (under the action of seismic forces)</td><td>MFL=517.0 m</td><td>1.465</td><td>1.511</td><td>1.473</td><td>1.519</td></tr>
<tr><td>MFL=518.5 m</td><td>1.465</td><td>1.511</td><td>1.473</td><td>1.519</td></tr>
</table>

Comparison testing of Khachen dam slopes stability under seismic loading in case of the damped forced oscillations problem solution for an earth body dynamic equilibrium is expressed in a matrix form

$$[M]\{\ddot{a}\} + [D]\{\dot{a}\} + [K]\{a\} = \{F\}, \tag{7}$$

where $[M] = \int_s \rho\{N\}^T\{N\}dS$ is the matrix of the mass, ρ is the specific weight, $[D] = \alpha[M] + \beta[K]$ is the matrix of damping characterizing resistive capacity of the material (damping forces), $[K] = \int_s [B]^T[C][B]dS$ is the matrix of stiffness, $\{F\} = \{F_b\} + \{F_L\} + \{F_n\} + \{F_g\}$ is the nodal force vector, $\{F_g\}$ is the gravity force vector, $\{\ddot{a}\}$ is the nodal acceleration vector, $\{\dot{a}\}$ is the nodal velocity vector, $\{a\}$ is the nodal displacement matrix [6].

Since real earth materials have nonlinear properties constructive matrix is calculated for each loading phase.This change is conditioned by the change of mechanical properties of the materia. As show experimental investigations carried out on a spatial experimental facilityhyperbolic dependence exists between the soil's deviation stress and strains.

$$\sigma_n = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x - \sigma_y}{2}\cos 2\theta + \tau_{xy}\sin 2\theta, \tag{8}$$

$$\tau_m = \tau_{xy}\cos 2\theta - \frac{\sigma_x - \sigma_y}{2}\sin 2\theta, \tag{9}$$

$$S_r = \tau\beta = c' + (\sigma_n - u)tg\varphi', \; S_m = \beta\tau_m, \tag{10}$$

Applying final elements method [9] stability factors of slopes are determined by the following formula

$$K_{FEM} = \frac{\sum S_r}{\sum S_m} \quad : \tag{11}$$

To evaluate the mode of deformation of the dam and stability of the slopes under seismic impact in the dam calculation section forced oscillations equation has been solved on the basis of the finite methode. [10]. As a model oscillogram was used the oscillogramme of San-Fernando quake of 9 February, 1971 according to Richter magnitude 6,6 earthquake[11].

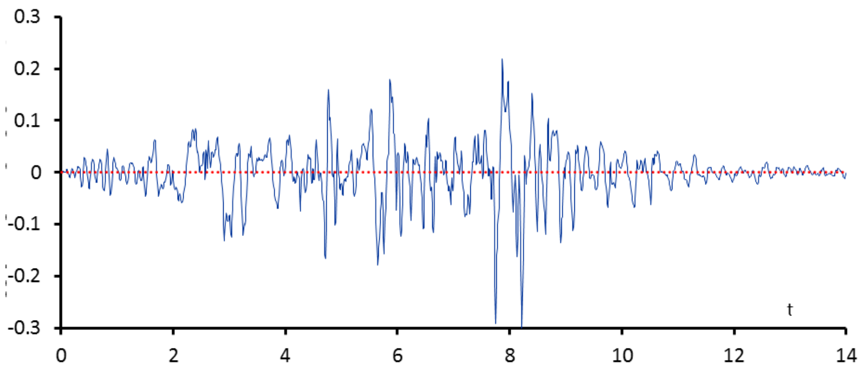


Figure 10. Oscillogram of San-Fernando 9 February 1971 earthquake

Computations have been made for design normal andhigh water retaining levels. For these cases also depression surfaces have been calculated.

For the dam crest and the base for the reservoir water two levels horizontal time-dependence displacements were calculated during the earthquake (Fig.11). Then in case of LRL and HRL for the upper (Fig.12) and lower (Fig.13) slopes stability factor dependence on time.

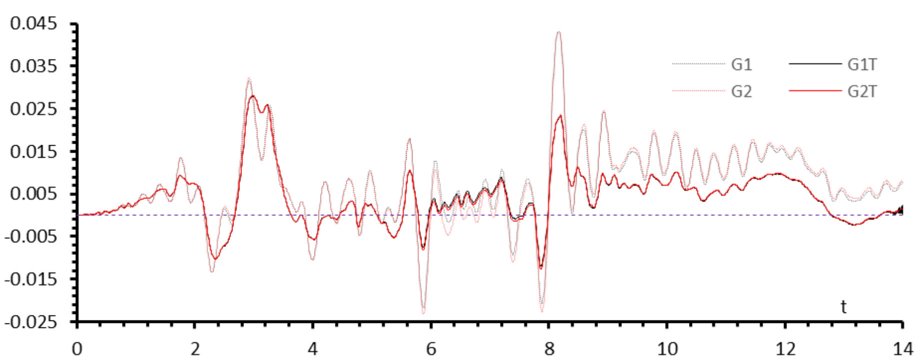


Figure 11. Horizontal displacements of the reservoir dam design section base and the dam crest in the water LRL and HRL levels in the reservoir (LRL-G1T-base, G1—crest || HRL- G2T-base, G2- crest)

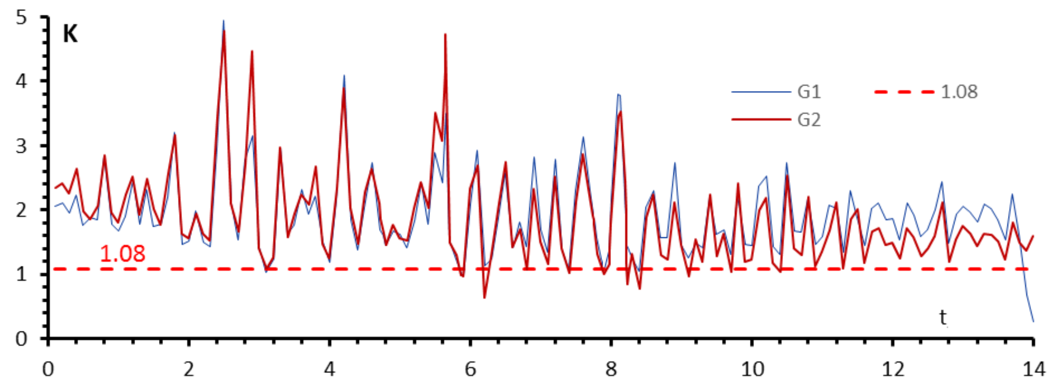


Figure 12. Upper slope stability factor dependence on time (LRL-G1 || HRL-G2)

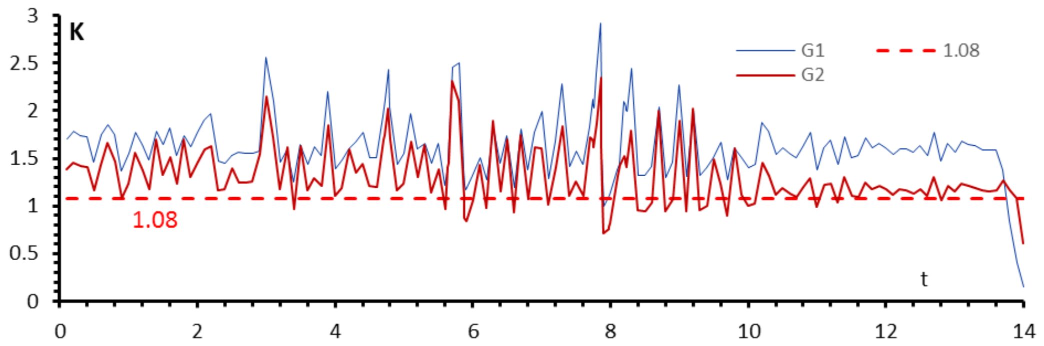


Figure 13. Lower slope stability factor dependence on time (LRL-G1 || HRL-G2)

Determination of the dam failure wave and area subject to inundation.

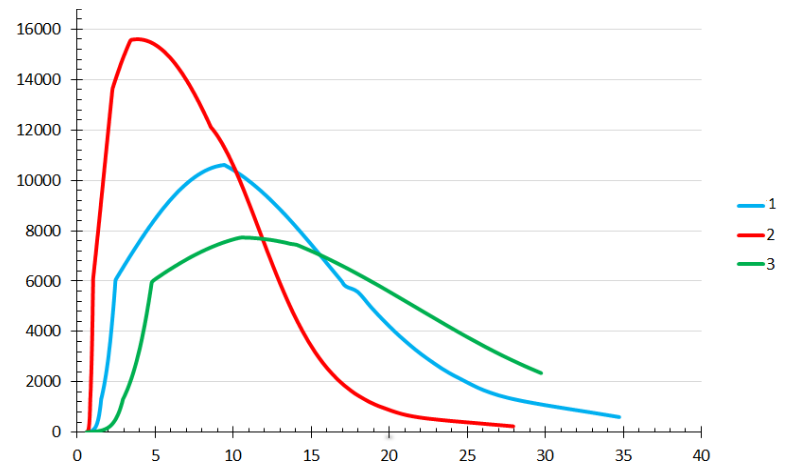


Figure 14. Characteristic curves for the water outflowing through the washed out opening

1- $Q_{ж} = 2Q_T$, 2- $Q_{ж} = 0.5Q_T$, 3- $Q_{ж} = 5Q_T$

The main reason of dams failure is impermissible amount of filtration through the dam body or water flow over the dam which in time washes out ground particles causing increase of filtration flows. The fluid running over the top of the dam washes out the soil gradually widening the opening in the dam body. This process deepens into the dam body and gradually widens the slit. The transversal growth of the opening is conditioned by the penetration depth $\Delta b_i = \Delta y_i \dfrac{y_i}{y_i + \Delta y_i}$ where Δb_i is the transverse growth of the opening when the depth growth is Δy_i .

Using the above plotted flows and taking into account morphologic structure of the river bed areas subject to inundation and the obtained results have been mapped in Fig.15.

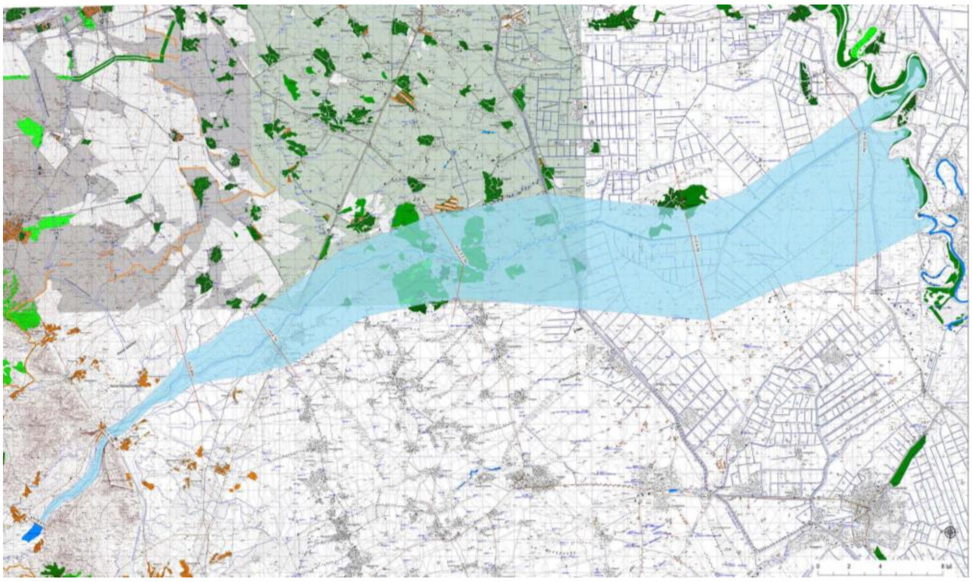


Figure 15. Areas subject to flooding on 1:50000 topographic map

Conclusion

Increase of effective capacity of the Khachen reservoir due to transformation volume does not essentially increase risk of the reservoir operation for the reservoir operation presently is equally dangerous. Later on it is necessary to add capacity of emergency spillway by construction of a riverside emergency spillways.

Increase of water level does not influence on sand boil and stability of the dam both for the main and special loading cases. In case of dynamic loading computations performed using circular cylindrical method unambiguously prove stability of the dam. According to solution of the plane problem of forced damping oscillations values of stability factors are ambiguous which is conditioned by roughness of initial calculation parameters and high horizontal acceleration.

Increase of the useful capacity of the reservoir by the above technique will raise effectiveness of the dam, irrigated land will be expanded by another 2000ha. However, in future the useful capacity of the reservoir can be doubled by adding the height of the dam and planning a new riverside emergency spillway.

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Գ.Գ. Վերանյան
Շուշիի տեխնոլոգիական համալսարան

Խաչենի ջրամբարը շահագործման է հանձնվել 1964թ.: Խաչեն գետի տարեկան միջին հոսքը կազմում է 116.0մլն մ^3, իսկ ջրամբարի օգտակար ծավալը՝ 20մլն մ^3: Ջրամբարի հեղեղային ջրթողը հաշվարկված է 1% ապահովվածությամբ հիդրոգրաֆի համար: Նախատեսվում է ավելացնել ջրամբարի օգտակար ծավալը 3.8մլն. մ^3 – ով տրանսֆորմացիայի ծավալի հաշվին: Այս նպատակով նախատեսվում է հորանային ջրթողի վրա տեղադրել ավտոմատ կարգավորման փականներ և ջրամբարում ջրի նիշը պահել

ԲԴՄ-ի վրա: Ստուգվել է պատվարի սուֆոզիոն ամրությունը և շեպերի կայունությունը ջրի տարբեր մակարդակների դեպում, իրականացվել է ջրթող կառուցվածքների և վարարահին ելքերի հիդրավլիկական հաշվարկ:

Բանալի բառեր. ջրամբար, ջրային հաշվեկշիռ, կայունություն, պատվար, վարարային ելք, հեղեղատար ջրթափ, հորանային ջրթող:

ОЦЕНКА РИСКОВ УВЕЛИЧЕНИЯ ПОЛЕЗНОГО ОБЪЕМА ХАЧЕНСКОГО ВОДОХРАНИЛИЩА

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Хаченское водохранилище сдано в эксплуатацию в 1964 году. Средний сток р.Хачен составляет 116 млн. м^3, а полезный объем – 20 млн м^3. Катастрофический водосброс рассчитан для гидрографа 1% обеспеченности. За счет объема трансформации намечается увеличить полезный объем водохранилища на 3,8 млн. м^3. С этой целью на гребне шахтного водосброса намечается установить автоматические затворы и уровень воды в водохранилище сохранить на уровне НПУ.

Проверены суффозионная прочность плотины и устойчивость откосов при разных уровнях воды в верхнем бьефе, проведены гидравлические исследования водосбросных сооружений.

Ключевые слова: водохранилище, водный баланс, устойчивость, плотина, паводковый расход, водослив, шахтный водосброс.