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PREDICTION OF FLOODED TERRITORIES IN CASE OF POSSIBLE BREAKDOWN OF THE SIONI EARTH DAM

Givi GAVARDASHVILI[(*)(**)1]

[(*)]Water Management Institute of Georgian Technical University 60, Ave. I. Chavchavadze, 0162, Tbilisi, Georgia
E-mail: givi_gava@yahoo.com - Phone: + 995 32 2 224 094
[(**)]Ecocenter for environmental Protection Varketili 3, 2 m/r, bull. 29-a, App. 17, 0163, Tbilisi, Georgia
E-mail: ecocenter1985@gmail.com - Phone: + 995 32 2 796 796

ABSTRACT

In order to carry out a computer simulation of a flood originating in the case of a possible breakdown of the Sioni earth dam, the author has re-worked the algorithm of the Volna-2", which allows, in the case of a possible breakdown of the dam, to calculate the wave velocity, the run-out distance according to the topography of river.

In the case of a possible breakdown of the Sioni earth dam the population of the Iori valley as well as the areas adjoining the Iori River comes under great flooding.

As to the spread of the waters it occurs in the north - eastern and south - western directions.

Key words: *earth dam, imitation of a flood, prediction, break down*

INTRODUCTION

Floods, with their recurrence, frequency and generated rank are the first among the natural calamities in the world. By the UN data, in the past century (1900-2000) floods took away the lives of approximately 10 million people in the world if not talking about the damages caused by them (Gavardashvili *et alii*, 2009).

Among the various natural reasons causing floods, particular attention should be paid to the faults or knocking down of waterworks facilities, which on their turn can be caused by different natural calamities, such as earthquake, as well as by the accidents of outdated hydraulic structures. Dam breakdown is also possible through terrorist acts.

In practice, the reliability of dams of different designations has been the subject of interest for the mankind since the ancient times, evidenced by the water-retaining facilities of different heights built in Babylon, China, Egypt and Italy several thousand years ago.

The specialists have considered the little depth of the material laid in a dam foundation as the main reason for dam failures with the second most widespread reason being the overloading of an earth dam above the acceptable level and so on.

Besides, studying the effect of seismic impact is one of the central issues when considering the stability of slopes. Earthquakes with the magnitude of over 5,5 are capable of causing the landslide of natural and artificial slopes.

For instance: the 1920 earthquake caused more than 100.000 victims; the Alaska earthquake in 1964 with large-scale destruction; the landslide in the basin of Vajont arched Dam in Italy in 1963 having taken away the lives of 2.300 people (Gavardashvili, 2010a) and the landslide in Philippine in February 2006 with 2.000 victims.

Below, we report some dam failures in the world with

1 Experience within the NATO SfP 983833 project entitled "Risk-Based Security Analysis of the Hydraulic Systems in the River Network in the South Caucasus Regions (Armenia, Azerbaijan and Georgia)" great numbers of human victims (Gavardashvili, 2011).

- In 1864, the failed Bradfield earth dam in the USA. The dam upstream wall was faced with concrete tiles, and clay-loamy ground was placed in the dam center. The dam accident took away the lives of 239 people.
- On May 31, 1889, the 92-metre-high South Fork earth dam in the State of Pennsylvania (USA) failed and took away the lives of 2.500 people.
- On February 22, 1890, the 33,6-metre-high embankment dam in the State of Arizona (USA) failed and taking away the lives of 129 people.
- On April 27, 1895, the 22-metre-high Bouzev embankment dam failed in France, and 156 people died.
- On September 30, 1911, a concrete dam near the city of Austin (State of Pennsylvania, USA) failed taking away the lives of 100 people.
- On August 13, 1935, a 16,5-metre-high concrete dam in the village of Zerbino (Italy) failed causing the death of over 100 people.

Dam accidents also happened in the former Soviet Republics, but due to the Soviet politics, the cases of accidents were never published. Therefore, the information about the number of victims is unknown. For instance, in 1955, an accident happened at Gorki hydroelectric power plant dam; in 1956, there happened an accident with Luzhskyi dam (Leningrad oblast), in 1958, an accident happened with Irkutsk dam and so on.

Some of the most recent failures are given hereafter:

- The failure of the earth dam in the basin of the Tangjiashan River caused by the earthquake of 2008 in China (Sichuan Province), thousands of hectares of the area got flooded because of the ground block-up in the riverbed.
- The failure of an earth dam (built in 1930) in the city of Jakarta in March of 2009 took away the lives of over 20 people.
- The failure of Saino-Shushenskyi dam in Russia on August 17, 2009, which took away the lives of 17 people (the newspaper "Vzgliad") and so on (Gavardashvili *et alii*, 2009).

As for Georgia, there is only one accident of an earth dam happened on the night of May 14, 1987, in settlement Tskneti, near Tbilisi. The dam height was 11.9 m. The catastrophe happened 30 years after the dam was built as a result of a 3-hour-long downpour. 3 people died (Gavardashvili, 2010b).

The problem is further complicated by the impossibility of making an accurate forecast or arresting of a natural calamity - wreckage of a dam and its resultant flood. Reduction of the damages and improvement of the population safety need accurate forecasting of floods and risk-factor assessment of natural calamities, as well as continuation of the diagnostic and intensifying the scientific-practical studies of the outdated hydraulic structures.

As it is known, an accurate forecast of flood is possible if the data and characteristics of hydrographic networks, topography of the study area, natural barriers and factors capable of changing the hydrological regime, as well as technical data of the outdated hydraulic structures in the area are known in advance.

The cadastre of reservoirs, carried out in Georgia in the 1960-1980, recorded 64 large and small reservoirs on the entire territory of the country. As is known, along with the basic economic purpose of reservoirs, special role is assigned to dams as one of the means of regulating natural disasters, including floods and freshets.

Scientific observation of the world climate has shown that rise of temperature is noticeable on our planet, facilitating intensive melting of glaciers, which in turn is one of principal causes of the formation of floods, freshets and many different types of instabilities.

In the modern world a frame treaty based on risk analysis is given special attention by scientist for the analysis of various types of hazard (Ayyub, 2003; Gavardashvili, 2010b; Gavardashvili, 2011a; Gavardashvili, 2011c; Gvelesiani *et alii*, 2003) for by this method not only the expected risk is assessed but it becomes possible to plan measures for averting or mitigating the expected catastrophe. With account of all these factors, loads are gradually increasing on water-management facilities, including obsolescent dams. Account should also be taken of the studies started in 1969 by Acad. Tsotne Mirtskhoulava (Mirtskhoulava, 1993; Mirtskhoulava, 2003) that are related to the so-called "aging" of dams, which reduces the reliable work of dams and raises the probability of the risk of their collapse.

To assess the damages caused by the destruction of Sioni earth dam (Georgia) (Fig. 1) and analyze the expected results of hydrodynamic calculations, by con-

Fig. 1 - General view of Sioni earth dam upstream wall

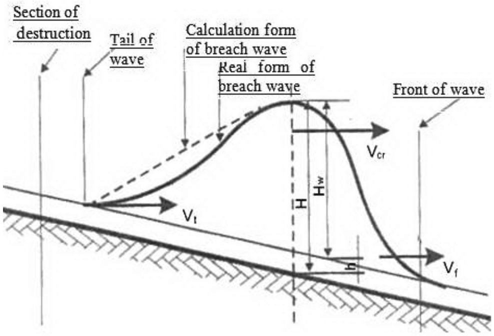

Fig. 2 - Diagrammatic longitudinal section of a breach wave

sidering the hydro-geological and morphological characteristics, the calculation models for the considered area have been designed. As for the assessment of the risk-factor of a natural calamity, this was done by considering various cases of different degrees of damage of hydraulic structures (0.25%, 0.50% and 1.0%).

The article considers a concrete example, in particular, the case of the total wreckage of Sioni earth dam with the destruction coefficient of 1.0%.

METHODOLOGY FOR ESTIMATING THE LOSSES IN THE CASE OF AN ACCIDENT AT THE SIONI EARTH DAM

The main striking factors of catastrophic flooding are: breakthrough wave (height of the wave, rate of movement) and the duration of flooding.

The breakthrough wave is one formed at the front of the water rushing through the breach. It has a considerable height of crest and rate of movement, possessing a great destructive force and energy.

From the hydraulic point of view, a breach wave is a moving wave which, unlike wind waves rising on the surfaces of large reservoirs, has the capacity to transport in the direction of its movement large masses of water. Therefore, a breach wave should be considered as a definite mass of water moving downstream the river and continuously changing its form, dimensions and rate. A longitudinal section of such wave is schematically shown in Fig. 2.

The breach wave is the principal striking factor for the destruction of a hydraulic-engineering structure, hence in order to determine the engineering situation it is necessary to define its parameters: the height of the wave (H_w), depth of the stream (H), rate of movement and time of arrival at various characteristic points of the wave (front, crest, tail) at the calculation sites lying downstream the hydraulic-engineering scheme, as well as the duration of the passage of the wave through the indicated sites (T), equal to the sum of time of rise of levels (T_r) and time of fall (T_{fl}) or the difference between (T_t and T_{cr}).

The following are the initial data necessary for calculations of the parameters of the breach wave (SHTERENLIKHT, 1984):

- The capacity of the reservoir, W_R:

$$W_R = \frac{H_R S_R}{3} \text{ million m}^3 \quad (1)$$

where H_R - is the depth of the reservoir at the dam (m); S_R - is the area of the surface of the reservoir (area of flowage) m^2;

- Slope of the river bottom:

$$i = \frac{B_w h_G^2}{W_R M(M+1)} \quad (2)$$

where h_G - is the depth of the river downstream the dam; M - is the parameter describing the form of river cross-section, assumed according to Fig. 3; B_W - average width of the river at the height h_G; h - water river depth in downstream (SHOIGU, 1998).

In order to predict the catastrophe of the Sioni earth-fill dam, the algorithm of the "Volna-2" program was re-worked, allowing calculating the rate of the wave in case of collapse, the run-out distance and,

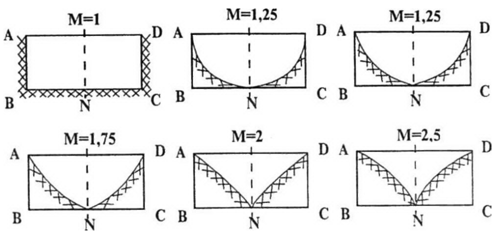

Fig. 3 - Values of the parameter M related to the form of the cross-section of the river-bed

most importantly, the geometrical dimensions of the inundated territory.

The initial data were divided into two parts: first - constant values, and second - variables. Parameters taken into consideration in constant values do not depend on any condition; as to variable values, they depend on the degree of the destruction of the dam, flood, and so on.

The width of the river is taken from a topographical map (1:200.000). As to the number of points, they should not exceed 3 points on one side of the river axis (in all 6 points on both sides).

To determine the area of the flooded territory the number of sections from the dam should not exceed 8 sections, the distance between which should be given on the topographical map in advance.

The rate of wave (V) flooding in the tail-race of the structure is calculated by the following formula (GAVARDASHVILI, 2010[b]; GAVARDASHVILI, 2011[a]):

$$V = V_0 (H_1 / H_0)^{2/3} \quad (3)$$

where V_0 - is the rate of water in the river in the tail race of the structure (m/s); H_0 - is the height of water in the river in the tail-race of the dam (m); H_1 - is the height of water in the river at the time of flooding (m).

The degree of destruction of the dam (E_P) is determined by the following relation (SHOIGU, 1998; SHTERENLIKHT, 1984):

$$E_p = F_w / F_0 \quad (4)$$

where F_w - is the area of the collapse of the bank (m²); F_0 - is the area of the surface (m²); in our case $E_P = 1.0$.

In addition to the above, considered in the algorithm are: the height (m) of river bank, the number of section along the river, the distance between the sections (*km*), width of the river bed (*m*), the rate of the water stream in the river bed (*m/sec*); the width of bed of the river (*m*), etc.

ORDER OF CALCULATIONS OF THE PARAMETERS OF THE BREACH WAVE

1. Determination of the height (H_{BI}) (SHOIGU, 1998):

$$H_{BI} = 0.6H - h_G \quad \text{(m)} \quad (5)$$

where H - is the depth of the reservoir at the dam (*m*); h_G - is the river depth downstream the dam (*m*).

2. Determination of the time passage of the breach wave through the site of the destroyed dam (time of complete emptying of the reservoir; SHOIGU, 1998):

$$T_1 = \frac{W_R A}{3600 \mu B_i H \sqrt{H}} \quad \text{(hour)} \quad (6)$$

where W_R - is the reservoir capacity; A - is the coefficient of the reservoir curvature; for approximate calculation it is assumed to equal 2; μ - is the parameter characterizing the shape of the river-bed; B_i - is the width of breach, *m*; H - is the depth of the reservoir in front of the hydroelectric scheme.

3. Determination of the time of arrival of the breach wave to the 1st site

$$t_1 = \frac{L_1}{V_1} \quad \text{(hour)} \quad (7)$$

where L_1 - is the distance of the 1st river section (km); V_1 - is the rate of movement of the breach wave at the 1st section (km/h).

4. Determination of the arrival of the breach wave at the 2nd and site

$$t_2 = \frac{L_2}{V_2} + t_1 \quad \text{(hour)} \quad (8)$$

where, L_2 - is distance from the 1st to the 2nd site, in km; V_2 - is the rate of movement of the breach wave at the 2nd section, in km/h.

To obtain the parameters of the breach wave at the subsequent sites, an analogous method is used. According to the results obtained of the breach wave at all sites, a graph of movement of the breach wave is built.

FORECASTING SIONI EARTH DAM ACCIDENT BY CONSIDERING THE RISK-FACTOR

Sioni water reservoir is located near the village of Sioni, Tianeti Region (70 km from Tbilisi), in the valley of the river Iori. An earth fill dam is built across the river Iori, at an elevation of 415 m above sea level, with its upstream wall faced with concrete tiles. Data of the dam are reported in Tab. 1 (HYDROELECTRIC STATIONS OF GEORGIA, 1989).

N	Sioni dam (E_P=1,0 %)	Unit	Quantity
1	Reservoir capacity at normal filling level	$m^3 x10^6$	433
2	Depth of reservoir at dam (normal filling level)	m	62
3	Area of water surface at normal filling level	$m^2 x10^6$	12,8
4	Width of dam at normal filling level	m	850
5	River depth at tail-race of dam	m	0,88
6	River width at tail-race of dam	m	75
7	Rate of river at tail-race	m/c sec	1
8	Depth of reservoir at the moment of dam accident	m	62
9	Degree of destruction of dam	-	1
10	Height of river bed bank breach	m	1
11	Mark of normal filling of reservoir	m	1068
12	Quantity of calculation sections in river bed	cal	8

Tab. 1 - Initial data on the hydro scheme

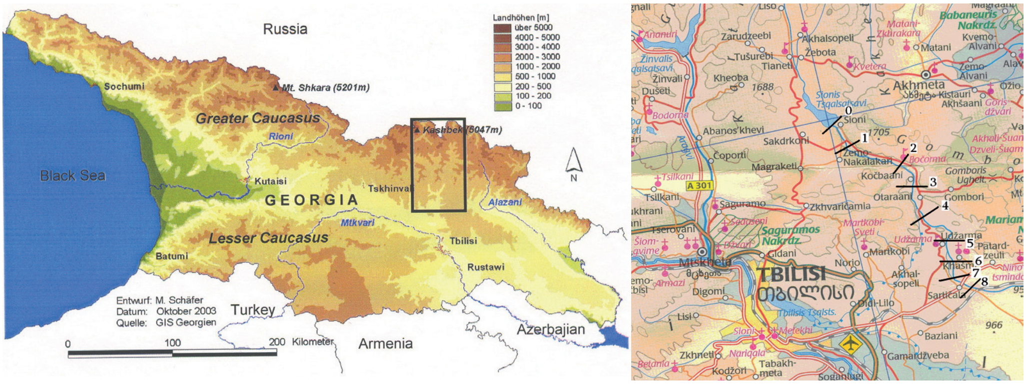

Fig. 4 - Location of the area (a) and of the estimated cross-sections (b)

The volume of Sioni water reservoir is about 433 x 10^6 m^3.

Aiming at specifying the flooded area as a result of a possible accident of Sioni dam, the cross-sections near the settled areas were selected (Fig. 4).

Distances and arrival times are given in Tab. 2.

By considering the sections selected across the river Iori, hydraulic and hydrological characteristics of Sioni earth dam, volume of the water reservoir and topographic characteristics of the river, "Volna-2" program algorithm was used (Shoigu, 1998) and the following values were acquired: the geometry of the flooded area on the right and left sides off the river, wave speed, depth of water, etc. in case of an accident of Sioni dam across the river Iori.

The major hydraulic and hydrological characteristics of the wave in case of an accident of Sioni dam are given in Tables 3 and 4, and the graphs of the flooded cross section are referred to in Figs 5-13 showing the data of Sioni dam accident with the degree of the facility destruction of E_p = 1,0% provision.

The results obtained for the case of breach of Sioni dam are given in tables (see Tab. 2), while the geometric dimensions of the territories flooded in the river bed and adjoining territory are given in Tables (see Tabs 3 and 4). The transverse view of Sioni dam at the initial section is shown in Fig. 5-13.

The calculated geometry of the flooded area was plotted on the map shown in Fig. 14.

Thus, by considering the degree of destruction of Sioni earth dam (E_P = 1,0 %), have established the geometry of the water-flooded areas in the bed of the river Iori and its adjacent area, where is possible water mass flooding.

N	Settlements (Village)	Distance of section from the dam (km)	Arrival time of wave
1	Nakalakari	5,0	8,0
2.	Bochorma	13,0	18,0
3.	Sasadilo	19,5	29,0
4.	Paldo	25,5	40,0
5.	Ujarma	34,0	59,0
6.	Khashmi	36,0	63,0
7.	Mughalno	39,0	70,0
8.	Sartichala	41,5	77,0

Tab. 2 - Statistical and calculated indices of wave

N	Description of the calculation section	Unit	Sec. N1	Sec. N2	Sec. N3	Sec. N4	Sec. N5	Sec. N6	Sec. N7	Sec. N8
1.	Distance from dam	km	5	13	19,5	25,5	34	36	39	41,5
2.	Mark of under- flooding	m	990	940	880	835	758	730	710	690
3	Depth	m	1	0,5	0,6	0,5	0,5	0,5	0,4	0,4
4	Width	m	35	30	30	20	120	60	80	80
5	Rate of stream	m/sec	1,2	1,2	1,2	1,2	1,2	1,2	1,1	1,1
Left bank										
6	Height of river bank breach	m	0,8	0,7	0,1	0,4	0,5	0,5	0,1	0,1
7	Width of river bed	m	30	35	500	20	5	40	500	450
8	Mark 1	m	1000	960	900	840	780	740	720	705
9	Distance from river axis to mark 1	m	420	175	600	175	480	450	1350	850
10	Mark 2	m	1020	980	920	850	790	760	740	710
11	Distance from river-bed to mark 2	m	500	350	650	1550	980	800	1450	1350
12	Mark 3	m	1040	1000	960	860	800	780	745	734
13	Distance from river axis to mark 3	m	600	825	750	2100	1480	1350	1500	2250
Right bank										
14	Height of river bank breach	m	0.8	0.7	0.1	0.4	0.5	0.5	0.1	0.1
15	Width of the river-bed	m	30	35	5	20	5	40	100	500
16	Mark 1	m	1000	960	900	840	760	740	720	700
17	Distance from river axis to mark 1	m	420	225	75	140	570	110	350	1500
18	Mark 2	m	1020	980	920	860	780	760	730	709
19	Distance from river axis to mark 2	m	520	275	500	340	820	1200	1250	2650
20	Mark 3	m	1040	1000	940	880	800	780	750	726
21	Distance from river axis to mark 3	m	700	325	725	490	1270	1350	2200	4650

Tab. 3 - Data calculated for the case of breach of Sioni dam

Parameters of the breach of dam	Unit	Sec. N0	Sec. N1	Sec. N2	Sec. N3	Sec. N4	Sec. N5	Sec. N6	Sec. N7	Sec. N8
Distance of section from dam	km	0	5	13	19,5	25,5	34	36	39	41,5
Maximum water flow discharge section	m^3x10^3/s	155	123,3	70,3	51,8	42,5	34,2	32,6	30,4	28,9
Time										
Of the lowering of wave front	min	0	9,58	32,4	49,4	71,8	106	114	128	141
Of the lowering of wave	min	0	8,31	18,1	29,5	39,6	58,9	63,2	70,4	76,9
Of the lowering of wave tail	min	57,2	126,6	238	328	411	529	557	603	641
Of flooding	min	57,2	117	205	279	340	423	443	474	499
Maximum rate of stream	m/sec	15,2	9,97	11,1	7,44	6,52	6,79	5,93	5,13	4,42
Height of wave	m	36,3	20,58	20,9	11,4	9,36	7,73	6,95	5,27	4,23
Maximum depth of flooding	m	37,2	21,58	21,4	12	9,86	8,23	7,45	5,67	4,63
Maximum mark of flooding	m	1044	1011	961	891	844	766	737	715	694
Maximum height of flooding on the left bank of river	m	318	462,3	183	563	772	205	328	963	590
On the right bank of river	m	318	472,9	227	51,3	184	642	770	250	940

Tab. 4 - Data calculated for the case of breach of Sioni dam

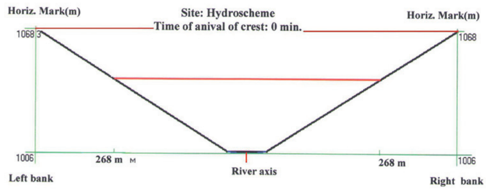

Fig. 5 - Initial section of Sioni hydro scheme

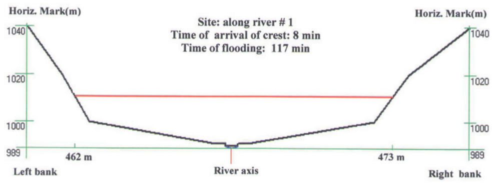

Fig. 6 - Section N1 - v. Nakalakari.
Time of arrival of wave front: 8 min; time of flooding: 117 min; max. height: 22 m; max rate: 10 m/s; mark of under flooding sea level: 1011 m a.s.l.

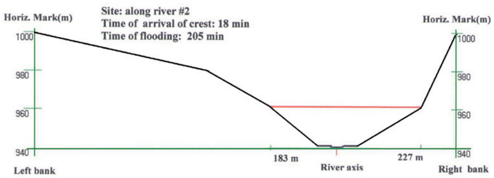

Fig. 7 - Section # 2 - v. Bochorma.
Time of arrival of wave front: 18 min; time of flooding: 205 min; max. height: 21 m; max rate: 11 m/s; mark of under flooding sea level: 961 m a.s.l.

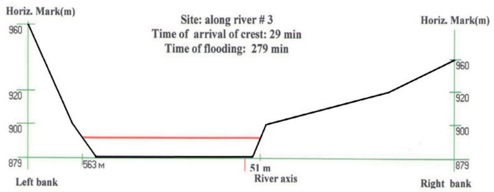

Fig. 8 - Section # 3 - v. Sasadilo.
Time of arrival of wave front: 29 min; time of flooding: 279 min; max. height: 12 m; max rate: 7 m/s; mark of under flooding sea level: 891 m a.s.l.

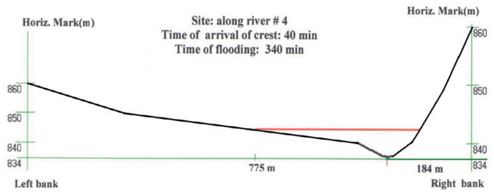

Fig. 9 - Section # 4 - v. Paldo.
Time of arrival of wave front: 40 min; time of flooding: 340 min; max. height: 10 m; max rate: 7 m/s; mark of under flooding 844 m a.s.l.

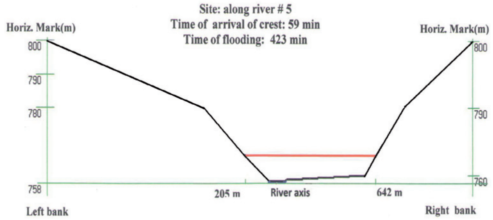

Fig. 10 - Section # 5 - v. Ujarma.
Time of arrival of wave front: 59 min time of flooding: 423 min; max. height: 8 m; max rate: 7 m/s; mark of under flooding 766 m a.s.l.

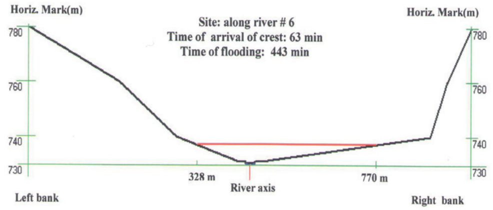

Fig. 11 - Section # 6 - v. Khashmi.
Time of arrival of wave front: 63 min; time of flooding: 443 min; max. height: 7 m; max rate: 6 m/s; mark of under flooding 737 m a.s.l.

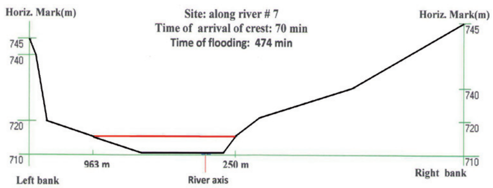

Fig. 12 - Section # 7 - v. Mughalno.
Time of arrival of wave front: 70 min; time of flooding: 474 min; max. height: 6 m; max rate: 5 m/s; mark of under flooding 715 m a.s.l.

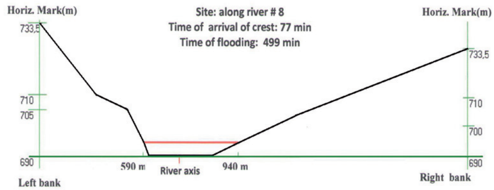

Fig. 13 - Section # 8 - v. Sartichala.
Time of arrival of wave front: 77 min; time of flooding: 499 min; max. height: 5 m; max rate: 4 m/s; mark of under flooding 694 m a.s.l.

CONCLUSION

- Based on the published scientific literature, a risk analysis-based upon CAPRA model (AYYUB, 2003) for the analysis of different hazards. The analysis of the statistical data of dam accidents worldwide is of particular interest allowing forecasting the risk of possible catastrophes of old earth dams in Georgia.

- By considering the degree of destruction of Sioni earth dam ($E_p = 1,0$ %), the geometric sizes of the water-flooded areas in the bed of the river Iori and its adjacent area were specified by considering the major dynamic and hydrological characteristics of a wave and topographic and time factors.
- Thus, the introduction of the gained results in practice allows to effectively forecast the preventive measures for the population, which, if realized, will significantly reduce the number of possible human victim in case of the wreckage of Sioni earth dam.

Fig. 14 - Layout of the areas flooded as a result of Sioni earth dam accident (scale 1: 1 000 000)

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