Hydrology

The Results of Flood Risk Evaluation for the Village Nakra, Svaneti

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(Presented by Academy Member Avtandil Korakhashvili)

Aiming at securing the local people of village Nakra in Mestia region (Georgia) against floods and mudflows, the work considers the results of the field and theoretical studies carried out in the water catch basin of the River Lekverari, the right tributary of the River Nakra are considered in the paper. The principal geological, hydrological and hydraulic characteristics of the River Lekverari catch basin, as well as GIS and GPS technologies, were used to identify the sensitive sites of the river where landslide processes of various intensities are expected to originate. Mathematical modeling and software Volna-4 were used to identify the relation between the principal hydraulic and hydrological properties of the flood and mudflow wave formed in case of rupture of a 5-meter-high natural coffer solistone barriers in the riverbed and the time and geometry of the flooded area on the example of the River Lekverari. At the following stage obtained data can be used to realize preventive and complex engineering environmental measures to ensure the safety of the population of village Nakra against natural calamities. Such measures, together with other environmental protection measures, shall describe the regulation of the transit portion of both, the talus train and bed of Lekverari River by constructing the cascades of reliable springboard-type structures. *© 2021 Bull. Georg. Natl. Acad. Sci.*

Flood, river, natural barrier, flood risk, safety

Scientists observations made on climate clearly showed that temperature increase observed on our planet is instigating intensive melting of snow cover and glaciers that in its turn represents one of the major components of formation of floods, freshets and debris flows [1-3];

Apart from erosive processes river-bed crossing by the landslide body on the mountain slope in the catchment area of the river and a breach of the natural barrier formed by the water mass accumulated in the headrace of the river bed play a significant role in formation of debris flows [3,4].

Based on the analysis of the monitoring surveys conducted in 2016 -2019 on the sensitive areas observed in the catchment areas of the right tributaries of the rivers Lekverari and Nakra it can be concluded that in the case of formation of surface landslides taking into account climatic factors and engineering-geological conditions the bed of the River Lekverari can be blocked up by ground of 5 m height while in the case of formation of tectonic and seismogenic type landslides the river beds can be blocked up by a natural solistone barrier of 5 m height [5,6].

Materials and Methods

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 [7].

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 large masses of water in the direction of its movement. 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. 1.

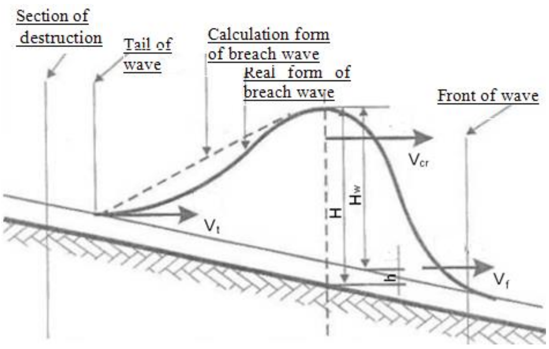

Fig. 1. Diagrammatic longitudinal section of a breach wave. H – ordinary level of water in the river; h – height of wave; H_w – height of stream.

The breach wave is the principal striking factor at 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 the time of arrival at various characteristic points of the wave (front, crest, tail) to the calculation sites lying downstream the hydraulic-engineering scheme (V_f, V_{cr}, V_t and T_f, T_{cr}, T_t), 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 the levels (T_r) and time of fall (T_{fl}) or the difference between (T_t and T_{cr}) [3,5].

The following are the initial data necessary for calculations of the parameters of the breach wave:

The capacity of the reservoir [5,8]

$$W_R = \frac{H_R S_R}{3} \text{ Million m}^3, \qquad (1)$$

where H_R is the depth of the reservoir at the barrier, m; S_R – the area of the surface of the reservoir (area of flowage), m^2; B_W – the width of the reservoir in front of the barrier, m; Slope of the river bottom [8]:

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

where W_R is the volume of the reservoir; h_G – the depth of the river downstream the barrier; M – the parameter describing the form of river cross-section; B_W – average width of the river at the height h_G; *h* – coefficient of river roughness.

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 the principal causes of the formation of floods, freshets and mudflows.

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 [2,5,6], because by means of this method it is possible not only to assess the expected risk but also plan the 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 commenced in 1969 -1987 - 2003 by Acad. Tsotne Mirtskhoulava [9] that are legated to the so-called "aging" of solistone barriers, which reduces the reliable work of barriers and raises the probability of the risk of their collapse.

With a view to predicting the catastrophe of the barrier, the algorithm of the "Volna-4" program was re-worked, allowing calculating the rate of the wave in case of collapse, the distance run and, most importantly, the geometrical dimensions of the inundated territory, with account of the time factor [10].

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

The width of the river is taken from a topographical map. 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 barrier should not exceed 8 sections, the distance between which should be given on the topographical map in advance.

The rate of wave (V) at flooding in the tailrace of the structure is calculated by the following formula [5, 11]:

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

where V_0 is the rate of water in the river in the tail race of the structure (m/sec); H_0 – the height of water in the river in the tail race of the barrier (m); H_1 – 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 dependence [3]:

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

where F_w is the area of the collapse of the bank (m^2); F_0 – the area of the surface (m^2); in our case E_P = 0.75. In addition to the above, the height (m) of river bank, the number of section along the length of the river, the distance between the sections (*km*), the width of the river bed (*m*), the rate of the water stream in the river bed (*m/sec*), the value of the river bed marks (*m*) etc. are considered in the algorithm.

Determination of the height of the parameter [3],

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

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

Determination of the time passage of the breach wave through the site of the destroyed dam (time of complete emptying of the reservoir) [8]:

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

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

Determination of the time of arrival of the breach wave at the 1st site [5,8]:

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

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

Determination of the time of arrival of the breach wave at the 2nd site:

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

where L_2 is the length of the 2nd section, *km* (i.e. from the 1st to the 2nd site); V_2 – the rate of movement of the breach wave at the 2nd section, *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.

By using the methodology provided above we will consider the case of crossing the river bed by the landslide formed in the bed of the River Lekverari while the height of the natural barrier does not exceed 5 m.

With the aim of predicting a disaster in the bed of the River Lekverari, the number of sections on the Lekverari and Nakra rivers up to the confluence of the Enguri river makes up 8 points (Fig. 2.).

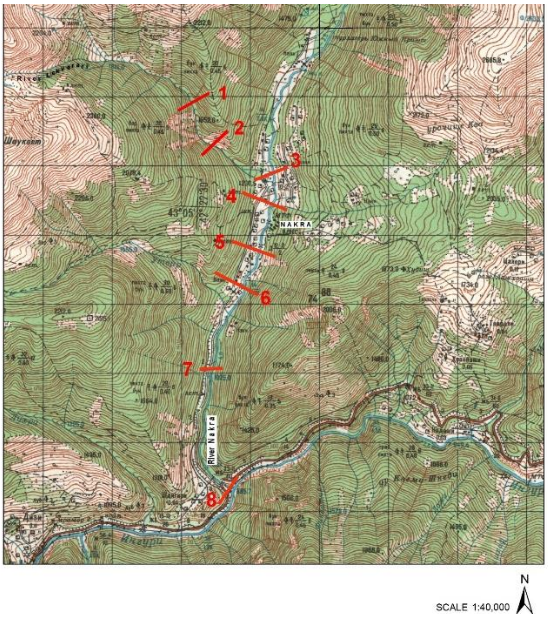

Fig. 2. Calculation sections determined in the bed of the River Lekverari.

Sections from the natural barrier of the River Lekverari were taken in the following sequence: in the bed of the River Lekverari at the site of formation of the barrier – one section, on the transit area of the River Lekverari – one section, while out of 6 sections taken in the bed of the River Nakra 3,4,5,6 sections were taken in the village of Nakra, 7 and 8 sections were taken after the village of Nakra – at the confluence of the Nakra and Enguri rivers.

The calculation sections determined in advance are away from the ground barrier in different distances. Namely:

1 - Calculation section – 0.10 (km);

2 - Calculation section – 0.84 (km);

3 - Calculation section – 1.69 (km);

4 - Calculation section – 2.18 (km);

5 - Calculation section – 2.91 (km);

6 - Calculation section – 3.51 (km);

7 - Calculation section - 4.83 (km);

8 - Calculation section - 6.78 (km);

In the case of a breach of the 5m high barrier in the bed of the River Lekverari, the first stream of the flood (debris flow) wave will run down to relevant sections in the following time (min):

1 - Calculation section – 4.24 (min);

2 - Calculation section – 12.46 (min);

3 - Calculation section – 22.58 (min);

4 - Calculation section – 28.41 (min)

5 - Calculation section – 37.10 (min);

6 - Calculation section – 44.25 (min)

7 - Calculation section – 61.17 (min);

8 - Calculation section – 88.25 (min)

As to the geometrical dimensions of the flooded area from the river axis to the right and to the left in the case of a breach of the 5m high barrier in the bed of the River Lekverari, are as follows:

1 - Calculation section

To the left – 13.11 (m), to the right – 13.67 (m),

Depth of flooding – 4.19(m), wave velocity – 4.59 (m/sec);

2 - Calculation section

To the left – 8.12 (m), to the right – 14.88 (m),

Depth of flooding – 2.85 (m), wave velocity – 3.59 (m/sec);

3 - Calculation seciton

To the left – 8.95 (m), to the right –18.00 (m),

Depth of flooding – 2.15 (m), wave velocity – 2.94 (m/sec);

4 - Calculation section

To the left – 8.00 (m), to the right – 16.62 (m),

Depth of flooding – 2.05 (m), wave velocity – 2.88 (m/sec);

5 - Calculation section

To the left – 9.05 (m), to the right – 15.01 (m),

Depth of flooding – 1.85 (m), wave velocity – 2.75 (m/sec);

6 - Calculation section

To the left – 17.66 (m), to the right – 21.52 (m),

Depth of flooding – 1.32 (m), wave velocity – 1.57 (m/sec);

7 - Calculation section

To the left – 11.44 (m), to the right – 9.77 (m),

Depth of flooding – 2.23 (m), wave velocity – 4.27 (m/sec);

8 - Calculation section

To the left – 9.00 (m), to the right – 10.83 (m),

Depth of flooding – 1.60 (m), wave velocity – 3.04 (m/sec);

The detailed material describing the situation created as a result of a breach of the 5.0 m high barrier in the bed of the Lekverari river is provided in the tables (Tables 1-3) while the geometrical dimensions of the flooded areas in the river bed and on the adjoining territory are provided on the drawings.

According to the calculation, in case of a 5 m high in the River Lekverari, the volume of water in the artificial reservoir is equal to 5 000 m^3, and in the case of the destruction of soil barrier, the flood waves will reach the village in the minus 13 minutes. The rural area is flooded with a width of 27.0 meters, with depth of flooding - 2.15 m and the wave speed is equal to the village entrance – 3.00 m/s.

The obtained results were compared and the methodology of the study was numerical simulation of hydrodynamics using MIKE21 software, data collection and data analysis using surface laser scanning (LIDAR) data and GIS technology [12,13].

The comparison demonstrated that the difference between our calculations and the results obtained by MIKE21 [12] varies between 20 - 25% which can be considered as a result of a satisfactory calculation of hydrological calculations [14,15].

Conclusion

1. A review of methods for the analysis of hazards of various types is provided on the basis of available scientific literature sources. Special note should be taken of the analysis of the statistical data of the catastrophes of solistone barriers (dams) that have occurred in the world, which allows prediction of the risk of possible catastrophes at obsolescent solistone barriers (dams) in Georgia.

2. Taking into account the destruction coefficient (E_p = 0.75) of the village of Nakra in the case of a breach of 5 m high solistone barrier in the bed of the Lekverari river, the geometrical dimensions of territories flooded in the beds of the Lekverari and Nakra rivers and adjoining area, the main dynamic, topographical and hydrological characteristics are determined, with account of the time factor.

3. Implementation in practice of the results obtained allows effective forecasting and preliminary warning of the population of Nakra Village (Georgia) at risk, which will considerably reduce casualties among the population in a possible future accident. Also, it would help to perform risk analysis and management studies.

ჰიდროლოგია

წყალდიდობის რისკების შეფასების შედეგები სოფელ ნაკრაში, სვანეთი

გ. გავარდაშვილი

საქართველოს ტექნიკური უნივერსიტეტი, ც. მირცხულავას სახ. წყალთა მეურნეობის ინსტიტუტი; გარემოს დაცვის ეკოცენტრი, თბილისი, საქართველო

(წარმოდგენილია აკადემიის წევრის ა. კორახაშვილის მიერ)

მესტიის რაიონის (სამეგრელო – ზემო სვანეთის მხარე, საქართველო) სოფელ ნაკრას ადგილობრივი მოსახლეობის წყალდიდობებისა და ღვარცოფებისაგან დაცვის მიზნით განხილულია, მდინარე ნაკრას მარჯვენა შენაკადზე, მდინარე ლექვერარის წყალშემკრებ აუზში საველე და თეორიული კვლევის შედეგები. მდინარე ლექვერარის წყალშემკრები აუზის ძირითადი გეოლოგიური, ჰიდროლოგიური და ჰიდრავლიკური მახასიათებლების, ასევე GIS და GPS ტექნოლოგიების გამოყენებით დადგენილია მდინარის ის მოწყვლადი უბნები, სადაც შეიძლება წარმოიშვას სხვადასხვა სიმძლავრის მეწყრული პროცესები. მათემატიკური მოდელირებისა და კომპიუტერული პროგრამის “Volna-4”-ის გამოყენებით მდინარე ლექვერარის მაგალითზე დადგენილია მდინარის კალაპოტში 5 მეტრი სიმაღლის ბუნებრივი ზღუდარის განგრევის შემთხვევაში წარმოშობილი წყალდიდობისა და ღვარცოფის ტალღის ძირითადი ჰიდრავლიკური და ჰიდროლოგიური მახასიათებლები დროსთან კავშირში და დატბორილი ტერიტორიის გეომეტრიული ზომები. მიღებული მონაცემების გამოყენებით შემდეგ ეტაპზე შესაძლებელია სოფელ ნაკრას მოსახლეობის ბუნებრივი კატასტროფებისაგან უსაფრთხოების მიზნით განხორციელდეს პრევენციული და კომპლექსური საინჟინრო ეკოლოგიური ღონისძიებები, სადაც გარემოს დაცვის სხვა ღონისძიებებთან ერთად წარმოდგენილი იქნება მდინარე ლექვერარის როგორც გამოტანის კონუსის, ასევე კალაპოტის ტრანზიტული ნაწილის რეგულირება ღვარცოფსაწინააღმდეგო ტრამპლინის ტიპის საიმედო ნაგებობების კასკადების მოწყობით.

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