DEVELOPMENT OF A METHODOLOGY FOR RISK ASSESSMENT AND SELECTION OF MEASURES FOR THEIR MANAGEMENT AT THE FACILITIES LOCATED IN HIGH LANDSLIDE-PRONE TERRITORIES

Fakhraddin Gabibov[1], Arzu Zeynalov[1], Könül Bayramova[2]

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[1]Azerbaijan Scientific-Research Institute of Construction and Architecture
[2]Azerbaijan University of Architecture and Civil Engineering
farchad@yandex.ru
konulbayramova55@gmail.com

Abstract

As a quantitative measure of risk, an indicator was used simultaneously taking into account two characteristics of a landslide: 1) probability of landslide; 2) the amount of damage caused by the landslide. The probability of suffering damage from a landslide is defined as a conditional probability depending on the probability of the occurrence of an adverse event and the probability of suffering damage from a landslide caused by this event. A graphical methodology for comparing approaches for determining landslide risk parameters with and without protective measures was provided. The condition of combining the risks of various negative events was used for the assessing of integral risk magnitude. A formula was derived with known values of cost indicators for results and expenditures for determining the absolute value of the effect of implementing protective engineering measures to reduce risk at sites located in high landslide-prone territories. The measure of effectiveness was the relative indicator of accident or disaster risk reduction per unit cost of activities aimed at mitigating it.

Keywords: risk, landslide, methodology, probability, engineering measure

I. Introduction

Most of scientific studies describe the concept of "risk", along with the probability of the occurrence of an adverse event, also includes another characteristic associated with this event - the amount of damage caused. This leads to interpretation of a quantitative measure of risk as a mathematical expectation of damage determined on a set of possible adverse events (average risk values).

Assuming that the damage from the landslide is zero, no deformed and destroyed area is at risk. A similar situation occurs with zero probability of a landslide, although the possible damage from it would be enormous. The situation is perceived as dangerous, risky only in cases where the probability of a landslide and the possible damage from its occurrence are different from zero or are real in everyday understanding.

The study of problems of analysis and risk assessment of landslide processes is devoted to the work of I.T. Aitmatov, K.C. Kozhogulov and O.V. Nikolskaya [1, 2], I.O. Tikhvinsky [3], A.L. Ragozin [4], Kh.Kh.Einshtein and K.S. Karama [5], N. Jenny [6], G.P. Postoyeva [7], V.G. Tishina [8], R.I. Choudkhary and P. Felentje [9], K.Sh.Shaduntsa, S.I.Mathsia and E.V.Bezgulova [10, 11] and other researchers.

In a previously published article by the authors [12], a detailed analysis of the above works was carried out and it was revealed that the methodological approaches of various authors differ in originality. Simultaneously, a systematic approach is clearly observed in all studies. Depending on the specialization of various authors, the specifics of system approaches also change (geological engineering, geomechanical, geoecological, geotechnical and mixed), but in almost all cases, applied methods of probability theory are used to one degree or another.

As W. Morris notes [1], one of the main difficulties in management activities is the need to make decisions under conditions of uncertainty or with incomplete knowledge about the possible consequences of the actions taken.

The fundamentals of the science of managing complex systems are presented in the monographs of W. Morris [13], M. Starr [14], E.M. Khazen [15], B. Gurney [16], I.V. Prangishvili [17], S. Yang [18] and et al.

As noted by N.A. Makhutov and R.S. Akhmetkhanov [19], for optimal risk management, the systemic properties of objects and the systemic properties of risks should be taken into account. An analysis of international experience in the development and application of organizational and economic risk management mechanisms shows that there’s a fairly large number of mechanisms aimed at reducing the level of risk [20, 21].

V.N. Burkov [22] studying mechanisms for managing the risk level, as is customary in the theory of active systems, believes, that the structure of ecological-economic system in which the mechanism operates is two-level. The top level is occupied by the control body. In addition, at the top level there may be one or more insurance organizations. The lower level of this system is occupied by objects whose activities pose a potential threat emergency.

II. Description of the developed methodology for determining the risk magnitude of a landslide on a landslide-prone slope

As a quantitative measure of risk, it’s advisable to use an indicator that simultaneously takes into account two characteristics of a landslide: 1) the probability of a landslide; 2) the amount of damage caused by the landslide. Based on the above, the measure of slope landslide risk is the average landslide risk indicator, calculated according to the following formula:

$$R = \sum_{i=1}^{n} P_i X_i, \tag{1}$$

where P_i is the probability of damage from a landslide X_i as a result of one of the possible impacts on a landslide-prone slope; X_i – the amount of damage from a landslide, expressed in cost terms; R – quantitative measure of landslide risk (average landslide risk), expressed in the same indicators as damage; n is the number of possible damage options that can occur during various types of landslide phenomena on a landslide-prone slope.

Thus, for the purpose of determining the risk magnitude of landslide phenomena according to expression (1), it’s necessary to have information expressing the correspondence of the values of P_i and X_i, i=1, 2, ..., n. In the simplest case, such information allows to determine the law of probability distribution in the space of damage from landslide phenomena.

Assuming a continuous dependence of the probability P_i on the values of damage from landslide x, we obtain

$$P_i = P(x), \tag{2}$$

and expression (1) can be presented in integral form:

$$R = \int_{-\infty}^{\infty} xP(x)dx \cdot \tag{3}$$

In general case, when damage from a landslide can occur as a result of various unfavorable and independent events (impacts on a landslide-prone slope), the average risk of a landslide occurrence (process) can be determined according to the following formula:

$$R = \sum_{i=1}^{n}\sum_{j=1}^{m} P_{ij} X_i, \tag{4}$$

where P_{ij} is damage probability of landslide X_i upon the an event occurrence (i.e. impact on a landslide-prone slope) of type *j*.

In the probability of receiving damage from a landslide, formula (4) is defined as a conditional probability according to the following product:

$$P_{ij} = P_j P_i(j), \tag{5}$$

where P_j is the occurrence probability of an adverse event of *j* type (negative impact on a landslide-prone slope), contributing to the development of a landslide, $P_i(j)$ – the probability of receiving damage from a landslide X_i with a negative impact on a landslide-prone slope of *j* type.

Provided that damage from various impacts on a landslide-prone slope is measured on the same scale (for example, in value terms), and taking into account formula (5), to determine the average risk of a landslide, the following formula can be used instead of expression (4):

$$R = \sum_{i=1}^{n}\sum_{j=1}^{m} P_j P_i(j) X_i. \tag{6}$$

Formula (6) represents, that P_i expresses the distribution law of probabilities of negative factors impact on a landslide-prone slope, and $P_i(j)$ – distribution laws of damage from landslides for each of such negative impacts on a landslide-prone slope.

Formulas (1) – (6) determine the average risk of a landslide on a landslide-prone slope, regardless of the activity of an object located on the slope and exposed to a landslide hazard. It's advisable to consider the system "structure + people + technology + biota" as an object on a landslide slope. In the general case, an object represented by a person (who builds, operates structures and controls technology and biota) can perform two types of activities.

1. An object located on a landslide-prone slope can take measures to prevent or reduce losses from an adverse event (this means protective engineering measures). In this case, the object itself does not affect the possibility of its manifestation. The risks of such events are called "pure risks". These measures are associated with certain costs. In this case, in the formula for the average risk of a landslide, it's necessary to link the probability of damage from a landslide $P_i(j)$ with the costs incurred to prevent (reduce) it. In this case, expression (6) will take the following form:

$$R = \sum_{i=1}^{n}\sum_{j=1}^{m} P_j P_i(j, z_j) X_i, \tag{7}$$

where $P_i(j, z_j)$ is the damage probability of a landslide X_i upon the occurrence of a negative impact of type *j* and protective engineering measures taken against the specified negative impact with costs z_j;

The differences in formula (6) on the one hand and (7) on the other can be illustrated by the graph presented in Fig. 1.

In Fig. 1, $P(x)$ means the distribution of losses during a slope landslide in the absence of protective engineering measures, $P[X(z)]$ is the corresponding probability when carrying out protective engineering measures.

$\Delta X = X - X(z)$ - reducing the damage amount from a landslide as a result of implementing protective engineering measures.

2. The facility may take an adventurous position in relation to the development or exploitation of a landslide-prone slope, consciously choosing a situation characterizing different probability of landslide(s) occurring on the specified slope. The facility may choose a more risky situation with a greater likelihood of damage, expecting to receive additional benefits (at the same time, the requirements of regulatory documents for the construction and operation of structures on landslide-prone slopes are partially or completely ignored). In most cases, the object relies on the concept of "may blow over." Often the object consciously tries to compensate for deliberate adventurism by insuring its investments.

The risks of this kind can be called "adventurous speculative risks." Taking into account the possibility of such a choice, the average risk of a landslide is determined on the basis of the following expression:

$$R = \sum_{i=1}^{n}\sum_{j=1}^{m} g_{ij}(V) P_j P_i(j) X_i, \tag{8}$$

where $g_{ij}(V)$ is the probability of an object choosing a situation characterized by the probability of a landslide P_i on a landslide-prone slope with a negative impact on the j-type slope.

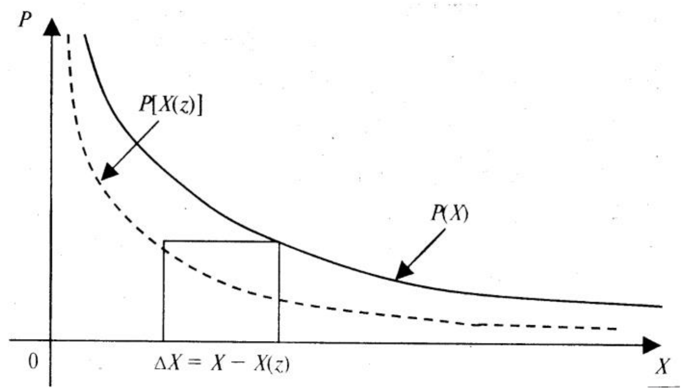

Figure 1: *Comparison of approaches for determination of the risk parameters of landslide manifestations when implementing and not implementing protective engineering measures on a landslide-prone slope*

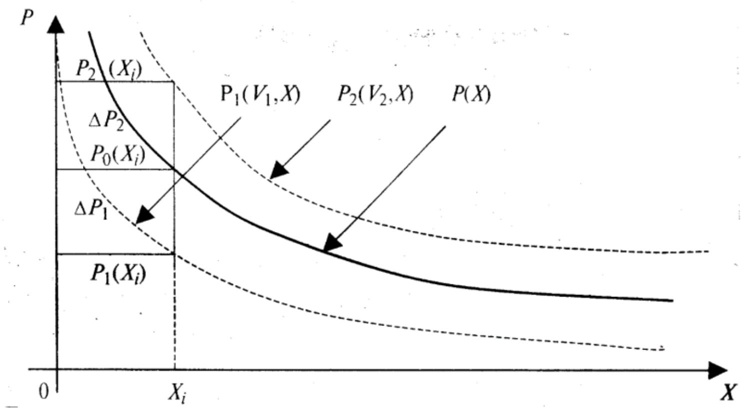

Figure 2: *Comparison of approaches for determination of the risk parameters of landslide manifestations on a landslide-prone slope in the initial state and during "adventurous" development*

The peculiarity of the approach for determining landslide risk on the basis of expression (8) can be illustrated by the graph presented in Fig. 2.

As is evident from Fig. 2, $P(X)$ means distribution law of damage from landslides in the initial state of a landslide-prone slope, $P_1(V)$ distribution law of damage from landslides in a more risky situation (adventurous approach).

As can be seen from Fig. 1 and 2, with different approaches to the development of landslide-prone slopes, it's possible to achieve various types of positive and negative risks of landslides.

III. Selection of risk management measures in high landslide-prone slope

Risk management at facilities located in high landslide risk zone is based on the developments of the general theory of risk analysis and that part of it relating to risk management [23]. In this regard, general principles and approaches are usually used when forming management decisions, the scientific justification of which is developed by the general risk theory.

It should be borne in mind that each of the listed approaches operates within the framework of a certain system of measures regulating management activities to reduce risk at facilities located in landslide-prone areas and the conditions for its implementation. According to their composition, they are divided as follows:

– regulatory measures representing the rights and obligations of parties, objects and other participants in the field of risk management;

– administrative measures related to the implementation of functions of control over the results and financial support of activities (if necessary, with enforcement of their implementation);

– economic measures involving economic stimulation of risk reduction activities at facilities located in high landslide hazard areas, the organization of its financial support, environmental and social interests of public development;

– technical measures determining the scope of possible technical solutions for reducing risk at facilities located in high landslide-prone areas, associated with the implementation of individual work aimed at protecting against the impact of the "field of damage and destruction" caused by a negative event, to reduce the potential damage and suchlike.

It should be noted that regulatory and administrative measures for risk management at facilities located in high landslide-prone areas with a generally form a set of restrictions, unconditional responsibilities for various participants in this activity, and limit the scope of their possible behavior in the socio-economic system. Effectiveness of risk management activities within this framework is determined by the correct choice of the system of permissible measures and the rational use of available economic and material resources in their implementation.

Economic results are taken into account in the vast majority of cases when developing territorial, engineering, technical and economic regulations and using administrative levers to regulate risk management at facilities located in high landslide-prone areas. If the regulatory framework and administrative framework interfere with the adoption of cost-effective decisions, as a rule, they are modified and changed as management experience accumulates.

However, in specific conditions, the management body, development of solutions in the field of risk management at facilities located in high landslide-prone areas, is always within the framework of certain legal, administrative and environmental restrictions, which it should not violate. Effectiveness of the decisions for reducing risk depends on the economic feasibility of the chosen system of management measures, taking into account these limitations.

The set of technical measures to influence risk at facilities located in high landslide-prone areas determines the space of possible solutions that can actually be implemented in each specific situation. Their composition is associated with the accessible level of scientific and technological development of society, since in market conditions the necessary equipment and technologies can be purchased practically without any restrictions, provided financial opportunities.

For the practice of risk analysis, the principle of integral hazard assessment is extremely important, according to which risk management at facilities located in high landslide-prone areas must comprehensively consider the entire range of events and the risks associated with them when developing management decisions. The fact is that negative events that cause damage and the damage themselves in real life can be interrelated.

From the point of view of theory and practice of risk assessment at facilities located in high landslide-prone areas, the simplest situation arises when considering the list of negative independent events. In this case, the integral risk R_{int} can be presented as a simple arithmetic sum of the risks from each negative event:

$$R_{\text{int}} = \sum_i R_i \ , \tag{9}$$

where R_i is the risk from the *i* negative event.

In the presence of interrelated risks at facilities located in high landslide-prone areas, expression (9) isn't suitable for assessing the magnitude of the integral risk. In certain situations this is due to risk absorption effects. Therefore, to assess the of the integral risk magnitude, you should use the formula for combining the risks of various negative events:

$$R_{\text{int}} = \bigcup_i R_i \ , \tag{10}$$

Where $\bigcup_i$ - represents the operation of combining sets.

In the case of non-overlapping risks at facilities located in high landslide-prone areas, expression (10) is equivalent to expression (9).

Note that the simplicity or complexity of the formula for assessing the integral risk at facilities located in high landslide-prone areas doesn't automatically transfer to management decisions. For example, expression (9) in no way means that managing the integral risk in each such case is reduced to a set of measures to manage each of them. It's due to the fact that risk reduction often measures at facilities located in high landslide-prone areas are aimed at blocking the main source of danger.

Taking into account the principle of integral hazard assessment when developing management measures to reduce risk at facilities located in high landslide-prone areas, in practice, can significantly complicate the solution of the problem, taking it beyond traditional optimization problems to maximum efficiency under given restrictions. As a result, in practical studies, control decisions can often be obtained on the basis of the methods, for example, simulation modeling.

It allows us to consider many different scenarios for the development of the consequences of negative events at facilities located in high landslide-prone areas, taking into account the likelihood of each, and compare them with each other in terms of consequences, complexity and effectiveness of using risk reduction methods for each of them. The most "rational" system of risk reduction measures is usually selected on the basis of such a comparison.

It should be noted that general approaches for determination of the effectiveness of any protective measures differ little in different types of life activities. All of them in one way or another involve comparison, comparison of results (*W*) achieved using the set of measures under consideration with the costs of them (*Z*).

With known values of cost indicators of results and costs, the absolute value of the effect from the introduction of protective engineering measures to reduce risk at facilities located in high landslide-prone areas may be determined according to the following formula:

$$E(Z,T) = W - Z = \sum_{t=1}^{T} \left(\sum_{i=1}^{k} W_{it} - \sum_{j-1}^{n} Z_{it} \right), \tag{11}$$

where *T* is the total operating time of the enterprise included in the project; $W_{it} -$ result in the i direction in period *t*; $Z_{jt} -$ costs in the *j* direction in period *t*.

Considering that the results of the implementation of protective measures in the case of pure risks manifest themselves in the form of a decrease in mathematical expectations of damage, expression (11) can be presented in the following form:

$$E(Z,T)=\sum_{t=1}^{T}\left\{\sum_{i=1}^{k}\left[\overline{X}_{it}-\overline{X}_{it}(Z)\right]-\sum_{j=1}^{n}Z_{jt}\right\}, \tag{12}$$

where $\overline{X}_{it}$ – is the average level of damage that occurred in period t, before the introduction of risk-reducing protective measures at the enterprise; $\overline{X}_{it}(Z)$ – the average level of damage determined after the implementation of risk-reducing protective measures at facilities located in areas with a high landslide hazard.
The index

$$\mathrm{I}(Z,T)=\sum_{t=1}^{T}\left(\sum_{i=1}^{k}\overline{X}_{it}+\sum_{j=1}^{n}Z_{jt}\right), \tag{13}$$

represents the total value of risk management costs at facilities located in high landslide-prone areas when implementing a set of control measures Z.
In the case of applying speculative risks at objects located in high landslide-prone areas, expression (11) for the assessment of the effectiveness of measures, the following relationship can be used:

$$E(Z,T)=\sum_{t=1}^{T}\left[\overline{\Pi}_{t}(Z)-\overline{\Pi}_{t}\right], \tag{14}$$

where $\overline{\Pi}_{t}(Z)$ is the expected average profit from an object located in high landslide-prone area in a year t if any protective measures Z are taken in relation to the risk, not necessarily related to its reduction; $\overline{\Pi}_{t}$ - expected average profit in the absence of these measures.

In general, the expected profit should be assessed taking into account the probability distribution of possible methods of operation of an object located in high landslide-prone area, the risk of losses from negative events and the costs of implementing risk management measures:

$$\overline{\Pi}_{t}=\overline{D}_{t}(Z)-R_{t}(Z)-\sum_{j=1}^{n}Z_{jt}, \tag{15}$$

where $\overline{D}_{t}(Z)$ is the expected amount of income in year t, when choosing a risk management strategy, is characterized by a set of costs $Z_{jt,}\ j=1,2,3,...,n;\ R_{t}(Z)$ - the risk level at an object located in high landslide-prone area in year t, estimated by the expected average amount of damage.

Profit is determined in a similar way in the absence of measures Z. In a real situation, the indicators $\overline{\Pi}_{t}$ and $\overline{\Pi}_{t}(Z)$ can change places, for example, in cases where a more risky solution is deliberately chosen for an object located in high landslide-prone area in the hope of getting more profit by refusing from the implementation of known protective measures.

As a measure of efficiency, a relative indicator of reducing the risk of accidents or catastrophes at facilities located in areas with a high landslide hazard per unit cost of costs for measures to reduce it can be used:

$$E(R/Z)=\frac{R_{1}-R(Z)}{Z}=\frac{\sum_{t}R_{1t}-\sum_{t}R_{t}(Z)}{\sum_{t}Z_{t}}, \tag{16}$$

where R_{1} is the risk indicator at the enterprise before the implementation of protective measures; $R(Z)$ - risk indicator at the enterprise after the implementation of protective measures; Z – cost of protective measures to reduce risk at the enterprise; $R_{1t}, R_{t}(Z), Z_{t}$ - values of the considered indicators in the period t.

Expression (16) is based on the indicators of both individual and social risk at a facility located in high landslide- and collapse-prone areas.

IV. CONCLUSION

By the authors for the first time as a quantitative measure of risk of a landslide, an indicator was used simultaneously taking into account two characteristics of a landslide: 1) probability of landslide; 2) the amount of damage caused by the landslide. It was revealed that the probability of suffering damage from a landslide is defined as a conditional probability depending on the probability of the occurrence of an adverse event and the probability of suffering damage from a landslide caused by this event. The authors have developed a graphical methodology for comparing approaches for determining landslide risk parameters with and without protective measures was provided. The condition of combining the risks a landslide by the authors of various negative events was used for the assessing of integral risk magnitude. The authors proposed the measure of effectiveness was the relative indicator of accident or disaster risk reduction per unit cost of activities aimed at mitigating it.

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