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Original Research Article

THE RISK ASSESSMENT FOR A SINGLE BUILDING ON THE LANDSLIDE AREAS AND FLOODPLAINS

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Abstract

Mass movements and floods are natural hazards posing a threat to the environment and bring significant economic losses. The flooding and landslide are risks in the municipalities of south-eastern Poland. Long-lasting rains cause initialize process of landslides on the slopes above the river valley, as well as flooding of local infrastructures (buildings, roads, railway tracks) located near water courses. Monitoring of geotechnical and hydrological parameters of the area is the base for the prognosis, as well as the risk assessment associated with them. So, in the paper highlights the issue of the consistency of monitoring and warning systems for these two threats. For landslides work SOPO - System Guards Against Landslides. Hydrogeological bases are defined for floodplains as The Computer System of the National Guard - ISOK. However, notable is the lack of integrity of both systems. In this paper a proposal to determine the overall risk for both threats in case of a single building is presented.

Keywords: landslide, geotechnical parameters, floodplains, risk assessment

1. INTRODUCTION

The use of economically attractive areas for development, which is accompanied by investors' inability to recognize various forms of threats increases the risk of geohazards such as landslides. The studies conducted recently showed [1] that in

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the 20th century floods and landslides have caused more than half of the casualties of accidents caused by natural hazards (Fig. 1).

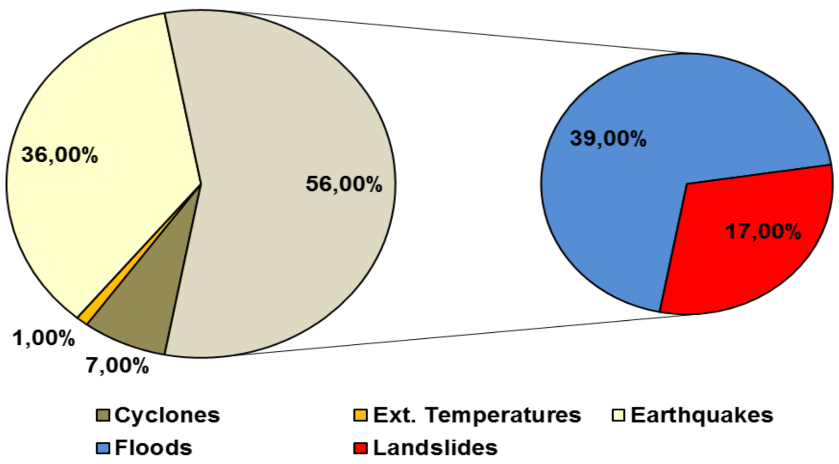

Fig. 1. Comparison of casualties from natural hazards in the 20th century
(own elaboration on the basis of [1])

In the municipalities of south-east Poland, there is both risk of flooding and landslides existing. Long-term rainfall causing flooding of buildings and rad infrastructures located near watercourses, and the landslide processes running on the slopes above the river valley. Knowledge of the hydrogeological conditions and monitoring of geotechnical and hydrological parameters is the basis for the prognosis of these hazards and adequate risk assessment. The damage on the Polish municipal roads caused by the flood and landslides in 2010 was estimated at 426 million euros. Thus, the occurrence of floods and landslides is a real problem dedicated not only to the nature of planning, but also to budgets of local communities [19,20]. A major challenge both of the global and local nature is to estimate the risks assessment associated with geological and hydrological hazards. Very often there are no formal guidelines (relevant legislation acts and norms) and standard procedures determining risk assessment. Nowadays, as far as landslides are concerned the SOPO (System Guards Against Landslides) system works. In case of floodplains ISOK (Computing System of National Guards) system exists.

2. GEOHAZARDS

The investment in the landslide or flood risk areas is possible, if it is combined with technical measures enabling not only identification of the hazards, but also a risk assessment. Risk assessment and the economic calculation concerns not only private buildings, but also public infrastructure, including transport facilities (roads, railways, airports).

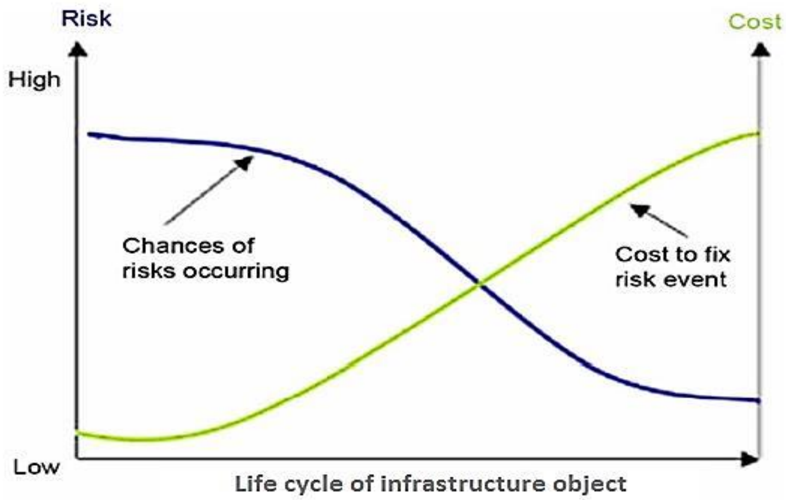

Fig. 2. Risk and cost for the life cycle of the infrastructure object [10]

These facilities should be designed and built taking into consideration the assessment of natural hazards, so that the safety of people and already existing building infrastructure is provided [3, 9].

2.1.Landslides

The significant factors that affect the formation of landslides are the geological history and slope inclination, as well as the occurrence of heavy rains with a large territorial range [3].

An important criterion for spatial planning and development in the areas of landslide appears to be the division, based on their activity, understood as the behavior of the soil or rock masses in time. Landslides are divided as follows [32]:

- periodically active landslide (periodic) - a landslide with signs of activity occurred at irregular intervals over the past 50 years,
- still active landslide (chronic) - a landslide in constant motion until equilibrium of slope is reached,

- inactive landslide (stabilized) - a landslide without observed and documented signs of activity for at least 50 years. Landslide phenomena cannot be easily predicted or prevented, as the main factors contributing to the movement of soil masses belong to the group of random factors. So a very important aspect in the management of landslide areas is the awareness of citizens and local authorities, which will allow to minimize the damage caused by the soil movements. Preventive action is to create an efficient system of information on landslide, appropriate use of land exposed to landslides, reduction of the negative impact of rainwater and groundwater, as well as the improvement of the rocks mechanical properties [2].

2.2. Floodplains

The terrain plays an important role in the risk assessment of flooding. Flat terraces along the banks of rivers, which form part of the river valley, usually flooded during flood periods are called floodplains. Those areas are located directly along the river, flooded during periods of high water, when the water is carried by the river out of the channel. Such area should be excluded from the development, in the event of floods can safely carried out a large amount of water without significant losses, while protecting the intensely urbanized areas. Floodplains can be divided into different zones of flood risk, depending on the assumed probability of floods. According to the draft law, the flood zones are set for the waters of the probability of flooding once in 10, 100 and 500 years [30]. The residential buildings, as well as road and industrial infrastructure are the subject of especially high risk along the floodplains. The consequences of flooding in cities, compared with open or rural areas, are usually very high financial losses and significant damages. Financial losses from the floods in 2010 in Poland amounted to a total of 12.5 billion PLN, including nearly 2 billion PLN of losses in private properties [4]. The principal causes of high losses in relation to flood and landslide areas are as follows:

- density of housing (urban) and placement of technical infrastructure,
- a significant reduction or elimination of infiltration of water, following the trend for sealing of the soil surface (increasing the risk of flooding)
- slopes undercutting during the construction of transportation infrastructure (increasing the risk of landslide)
- excessive and unreasonable belief in the reliability of technical means of flood protection (levees and reservoirs of water) or against landslide (retaining walls, nailing or drainage).

3. LEGAL CONDITIONS

- **Legal conditions concerning with landslide areas**

The most important legislation in Poland regarding the problem of landslides are namely:

- the Act of April 27, 2001. Environmental Protection Law [28] - defining of the mass movements of the earth, and imposing on local prefects obligation to register areas endangered by mass movements of the earth and the land on which there are these movements present,
- the Act of February 3, 1995 for the protection of agricultural lands and forests [29] - requiring owners of agricultural land and forestry to counteract the mass movements of the earth,
- the Act of April 18, 2002 on the state of natural disaster [27] - gives a landslide nature of the disaster, and to prevent or suppress the declaration of a state of natural disaster,
- the Act of March 27, 2003 on spatial planning and development [23] - which imposes on local authorities to take account of landslide areas in the records and show on the maps for urban planning community. The document is obligatory for the entire area of municipality, as well as local spatial plans. Furthermore, the above-mentioned act also obliges the authority performing a study or future plan to request opinions on solutions to the competent authority of a geological survey,
- the Act of July 17, 1994 on construction law [26] and the Act of August 11, 2001 on special rules for reconstruction, renovation and demolition of buildings destroyed or damaged as a result of natural disasters [25] - owe to the construction safety, which is damaged or destroyed as a result of landslides of soil mass.

  Primary source of information on landslides, which is used in the planning process is currently developed as a result of project SOPO - System Guards Against Landslides. It is a cartographic project started in 2006, and carried out by National Institute of Geology and geological companies and research units.

As a result of work Landslides Registration Cards (KRO) and Registration Cards of Areas Threatened with Mass Movement (KRTZ) are developed with the adopted in Phase I of the project pattern and forming an example of a basic registration document landslides collected by local authorities. As part of the SOPO - Maps of Landslides and Mass Movement Endangered Areas (MOTZ) are created, draught on a scale of 1:10.000 summarized within communities - in the case of the Polish Carpathian areas, and counties - except for the Polish Carpathian. The registration cards are collected in SOPO database and available for the users of website: osuwiska.pgi.gov.pl. An important aspect from the point of view of planning is putting in studies the sites excluded from construction work due to environmental hazards including landslides.

- **Legal aspects concerning with areas of flooding**

The spatial planning and management of floodplains areas as landslide is governed by a number of laws. Here are some of them:
– Directive 2000/60/EC of the European Parliament and of the Council of October 23rd, 2000 establishing a framework for Community action in the field of water policy,
– Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks,
– the Act of July 18th, 2001 - the Water Law [24],
– the Act on Spatial Planning and Development of March 27th, 2003 [23].

It should be emphasized that only a part of the flooded area called due to the shape and other geological and hydro-morphological conditions floodplain, is the subject to legal acts.

The legal act contributing to mitigating the effects of floods in EU is the Directive on the assessment and management of flood risks, which sets out the principles of risk assessment and management of flood [30]. Member States are obliged to make a "preliminary flood risk assessment" on the basis of which will be defined "areas where there is a high risk of flooding or likely to occur." The overriding aim of flood risk management is to put a particular emphasis on the reduction of potential adverse consequences of flooding for human health, the environment, cultural heritage and economic activity, and if deemed appropriate, on non-structural elements or reduce the probability of flooding".

4. RISK AND GEOHAZARDS

The risk is situations when making decisions without complete information. Then decisions are not optimal from the point of view of the objectives pursued [12,18,19,31,33]. The risk is identified as the probability of an adverse event [6,7,13,30], or the probability of being evaluated negatively or occurrence probability of loss [18,19]. Another definition determines the risks [22,30] as the quantitative and qualitative risk or level or measure of risk. It is the probability of negative phenomenon and its consequences. In structural and soil mechanics [3,4] risk is a measure of danger defined as a combination of probability and consequences of the occurrence of an adverse event.

4.1. Methodology

PN-EN 1991: Actions on structures (part 7) [16] provides two methods of risk analysis for buildings and structures:

- The qualitative risk as a part of risk analysis, which identifies all hazards and corresponding hazard scenarios. It requires a detailed examination and understanding of the system. It requires also that use of buildings and its implications for safety of use is acceptable. For such a reason a number of techniques of risk analysis have been developed to assist (e.g. Process Hazard Analysis (or, Evaluation) - PHA, Hazard and Operability study - HAZOP [21], fault tree, event tree, decision tree, casual networks, etc [8,13,14,17,21,31],
- The quantitative risk as a part of risk analysis probabilities estimated for all undesired events and their subsequent consequences, as it stands *in ISO 13824 – General principles on risk assessment of systems involving structures* code, it may be given by the following formula [5,31]:

$$R = \sum_{i=1}^{n_H} p(H_i) \sum_{j=1}^{n_p} \sum_{k=1}^{n_s} p(D_j / H_i) p(S_k / D_j) C(S_k) \qquad (4.1)$$

The quantitative analysis of risk calculated as the value of risk in monetary units according to formula (1) should be treated as nominal size, which has no direct reference to the financial outlay incurred in the event of structural damage. Considering, that the maximum tolerable probability of structural damage in the full life cycle cost is equal to $\boldsymbol{C(S)}$, qualified for the relevant class of reliability (RCX ={*RC3, RC2, RC1*}). For the reference period of $\boldsymbol{T_0}$**,** as defined in *PN-EN 1990* [15] as a measure of risk associated with the analyzed exceptional situation, one may take a risk index $\boldsymbol{i_R}$ [31]:

$$i_R = \frac{R}{R_{ac}} \qquad R_{ac} = p_{fd}(RCX; T_0) x(C(S) \qquad (4.2)$$

A common quantitative risk analysis covers:

• an estimation of the probability of the possible risks for fixed intensity;

• an estimation of the probability of various failures and their consequences for the considered threats;

• an estimation of the probability of adverse reaction to local structural damage and the consequences related to it.

Analysis of the causes of damages of structures indicates, that they were scarcely ever associated with insufficient values of parameters adopted in the construction documentation, and their increase would not have prevented the damage [11]. Usually, the reasons of accidents are such factors or circumstances that are not included in the design process and/or an evaluation of the technical conditions. Hence, a clear analysis and risk assessment is recommended as the most appropriate and promising method to ensure a satisfactory level of resistance to accidental load and other impacts acted on the structure, including the risks of landslides and flooding. For building structures built under geohazards risk level decreases by increasing the costs for testing soil, it increases the amount of information to assess the scale of the threat and risk quantification (Fig. 3).

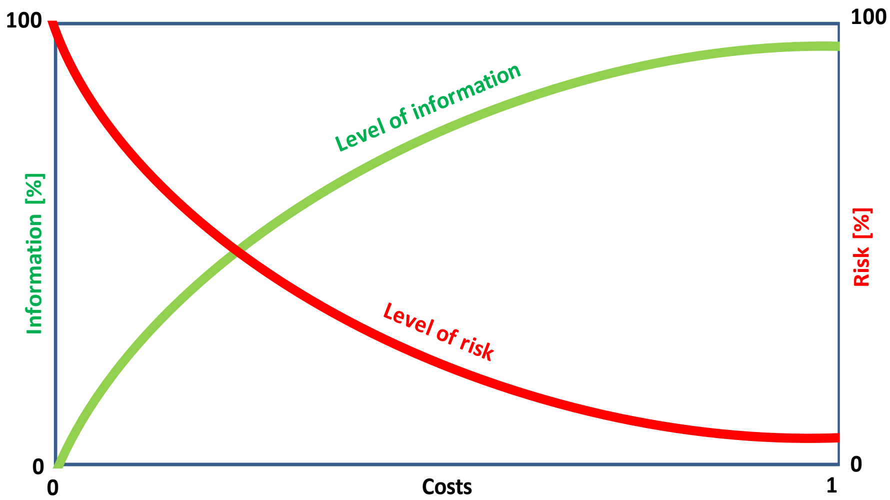

Fig. 3. The curves show the level of risk and information as a function of costs (own elaboration on the basis of [33])

4.3. Case study

The analysis is performed to a building classified due to *the PN-EN 1990* code [15] to the consequence Class 3, with monolithic structure of reinforced concrete columns and slabs built in the landslide zone. Accidental action on the structure is caused by the occurrence of hazard landslide is marked as H_l, (landslide due to heavy rains), which occurs with probability of $p(H_l) = 0.001$, and may cause either the local damage to the of the building D_1 or destruction of the foundation D_2 with the conditional probability equal to: $p\ (D_l\ /H_l) = 0.1$ and $p(D_2/H_l) = 0.01$.

The probability $p(H_l)=0.001$ is determined taking into account Bayesian theorem [18,19] assuming the building will be constructed in the area covered by the geohazards: the probability of a landslide has got the value of *0.01* due to the SOPO guidelines, while the probability of flood is equal to *0.1* due to the ISOK guidelines. Effect of local defects in both entire structure, is defined as the damaged part of the structure S_1 (up to 100 m2 floor or the floor area of 15% [15]), or destruction of larger parts or the entire structure S_2 where the conditional probabilities of occurrence are as follows:

$$p(S_1/D_1) = 0.1;\ \ p(S_2/D_1) = 0.01;\ \ p(S_1/D_2) = 0.5;\ \ p(S_2/D_2) = 0.05.$$

The consequences of the partial damage of building and the whole destruction are estimated, respectively:

$C(S_1)$ = €750 000, and $C(S_2)$ = €15.000 000.

On the basis of formula (1) the risk value is equal to $R = 168.75$.
Acceptable risk of damage to the structure deemed to have reliability class RC3 for the reference period is equal to $T_0 = 50$ years [15], and taking into account the cost of investment in the full life cycle of $C(S)$ = €7.500 000, is equal to:

$$R_{ac} = p_{fd} \times C(S) = 8.5 \times 10^{-6} \times 7.5 \times 10^{6} = 63.75$$

The ratio of risk associated with the destruction of the structure as a result of the present emergency situation and tolerable risk is:

$$i_R = R/R_{ac} = 168.75/63.75 = 2.64.$$

This is nearly three times more than the acceptable level of risk. It is therefore necessary to take appropriate action to reduce it, for example, the application of more effective procedures related to the economic evaluation of the investment or protection of the structure from the effects of landslides through proper foundation construction and increased costs of the investment.

5. CONCLUSIONS

Analysis of the existing legal sources shows that they focus primarily on the designation of areas at risk, but concerning not enough the activities about how regulations deal with the landslides already identified. The problem of obtaining new investment areas is growing. And the end of the current opportunities spatial development areas, allows us to understand that it is impossible to complete exclude buildings on landslide area. The fact that tourists and economically valuable areas shall always be the need for building is evident. But it is important to find the appropriate assessment of the risk and include strict economic calculation.
Another group of problems is the lack of specific and clear rules concerning the obligation of carrying out fieldwork and accurately determine their scope in relation to areas where the investment is planned. There are also no clear guidelines on how the admission of areas threatened by landslides for installation and operational use. It should be emphasized that even SOPO project is based on the study of phenomena already occurring. Still, in the country there is neither continuous monitoring of sites and buildings, even those of strategic trans-regional importance, nor to the residential areas.
The strategy of spatial planning must be done very carefully, in accordance with the principles of sustainable development and procedures for determining risks.

The optimal design and dimensioning criteria and evaluation of the structure in the landslide areas, allowing consideration of quantitative and qualitative requirements how to minimize the risk criterion. Risk measurement is the product of the probability of occurrence of events that may lead to exceeding the specified condition of the structure, usually the ultimate limit state or serviceability limit state. The estimated risk characterizes not only the state of structures, but also a variety of hazard consequences. The standards recommendations associated with quantitative analysis and risk assessment are quite vague and raises a number of concerns, primarily related to the interpretation and quantification of risk factors, i.e. the probability of hazard, local and global effects and consequences of damage.

The paper presents a proposal for extended interpretation of risk factors by defining proprietary risk matrix and presents modified acceptance criterion taking into account the class of structural reliability and designed lifespan. This methodology may be successfully applied in determining investment risk on landslide areas.

The risk assessment in structural design involves the determination of structural reliability class (permissible failure probability), the number of potential victims and the consequences of either financial, or social, or environmental or other nature. A particularly difficult issue is to assess the impact of structural damage. The evaluation in monetary units raise many objections, which are related to the accepted reference scale for the individual person. For a municipality or a county or region, these effects may be more or less severe. This also applies to social impact assessment and the value of life potential casualties of complete destruction of structures.

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OCENA RYZYKA DLA OBIEKTU BUDOWLANEGO NA TERENIE OSUWISKOWYM I ZALEWOWYM

S t r e s z c z e n i e

Ruchy masowe i powodzie stanowią zagrożenie dla środowiska naturalnego i generują znaczne straty gospodarcze. Osuwiska i powodzie są przyczyną ryzyka dla obiektów inżynierskich w gminach południowo-wschodniej Polski. Długotrwałe deszcze powodują inicjalizację osuwisk na zboczach dolin rzecznych, a także podtopienia lokalnej infrastruktury (budynki, obiekty drogowe i kolejowe) położonej w pobliżu cieków wodnych. Monitorowanie parametrów geotechnicznych i hydrologicznych obszaru jest podstawą prognozy pojawienia się zagrożeń, a także oceny ryzyka z nimi związanego.

W artykule podkreślono zatem kwestię spójności państwowych systemów monitorowania i ostrzegania w odniesieniu do tych dwóch zagrożeń. W przypadku osuwisk funkcjonuje System Osłony Przeciwosuwiskowej (SOPO), natomiast dla terenów zalewowych dedykowany jest Informatyczny System Osłony Kraju (ISOK). Systemy te nie są jednak dostatecznie zintegrowane. W niniejszym opracowaniu przedstawiono propozycję określenia łącznego ryzyka na podstawie obu analizowanych zagrożeń dla danego obiektu budowlanego.

Słowa kluczowe: osuwisko, parametry geotechniczne, teren zalewowy, ocena ryzyka

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