Site investigation as tool for elimination of natural hazard impact on construction project

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Abstract. Natural hazards and their impact on traffic structures represent the most risk factor during the construction phase and maintenance of traffic structure. The article deals with the process of site investigation focused on elimination of natural hazards impact on the structure. It is described the importance of gradual assessment especially of rock environment conditions in relation to specific traffic structure. Significant role plays cooperation between foundation designers and investigation workers especially for right classification of geotechnical category and final determination of characteristic values for documented rock formations. Positive and negative role of standardised approaches included in various standards are also.

1. Introduction
High-quality construction process especially in transportation engineering guaranties quality final structure as road/highway, railroad, pipeline etc. Transportation structures has been both very demanding from the point of view of design and construction and vulnerable by natural hazards, accidental and deliberate hazards in all phases of construction and utilization [1].

It is essential to understand basic concepts of the risk analysis and risk management theory including terminology.

A hazard (threat) is a potential threat of an undesirable event occurring in the future. It is a state of endangering by the undesirable event occurrence and resulting in a consequential damage origin. The hazard is a dimensionless parameter. The hazard has not been established as a legal concept.

A risk scenario is a manner in which the undesirable event may occur, circumstances, and conditions, under which the undesirable event occurs, and its development in time.

A hazard source is a factor, which is the hazard originator, which may be an insufficiently investigated rock massive, human factor, untested construction technology, exceedingly daring design of the structure, rapidly changing outer environment at the area of interest, external influences, such as poor weather conditions, or even danger of natural disaster, and the like.

An undesirable event (occurrence) is an aggregate process, an event, the occurrence of which will cause a material or immaterial damage or any other financially expressible detriment to the risk bearer.

A damage (harm) is a legal concept. The damage is a particular material/immaterial detriment caused to the injured party (the risk bearer). They are unforeseen costs related to the surmounting of the undesirable events or removing consequences of their occurrence, lost property benefit, and the
like. The final consequence is mostly a financial loss, which has already arisen, or which is most likely to arise after the undesirable event occurred.

Natural hazards threaten all engineering projects. It is necessary to identify all potential natural hazards in the first phase of the ground investigation. Natural hazards including: Earthquakes (including tsunamis), volcanoes, floods and droughts, windstorms, including hurricanes and tornados, erosion, ground displacements, including landslides, frost heave, and settlement, avalanches, icing, chemical threats (degradation of concrete structures), wildfires, geomagnetism.

Other important concepts of a risk assessment is vulnerability of the particular structure and the system performance. Vulnerability includes the potential for physical damage and loss of life with respect to: Physical facilities, functional systems, environment, administrative/financial activities, human safety.

System Performance includes the consequences resulting from system damage or disruption as measured by: Capital and revenue losses, service disruption and downtime, casualties, hazardous materials release and environmental damage.

In addition to scientific works dealing with natural hazards and their impacts on the natural and urbanized environment [2], [3], [4], [5] and project titled “The Spatial Effects and Management of Natural and Technological Hazards in Europe - ESPON 1.3.1” [6] has been solved as a part of the European Union scientific programs ESPON, which dealt with a territorial assessment of specific regions of all European Union countries in aspect of a possible negative impact caused by the natural and technological hazards.

From the point of view of the natural hazards, especially southern and south-eastern EU countries may be potentially affected by endogenous hazards (earthquake and volcanism).

The main natural hazards in the central European regions affecting structures during their construction and lifetime are certain properties and behaviour of the rock environment and its changes in the course of time (ground displacement). Moreover, also exogenous influences, such as extreme precipitation causing the rock environment erosion, or possibly floods. Recently, drought has also started becoming a problem, affecting the quality of certain types of the rock environment (contraction of some of the rock masses). Storms, avalanches, icing, chemical hazards are local, not regional influencing factors. Furthermore, these events are very random ones. It is geomagnetism that plays a very specific role. The Earth’s geomagnetic field has been continually changing and may affect electronic instruments, and thus have a negative impact especially on the transportation and traffic management in the future. A general classification of the natural hazards for the specific EU regions is shown in Figure 1.

2. Elimination of natural hazards

The natural hazards elimination is a complex process, which must constitute an integral part of every construction project being solved, especially in transportation engineering. This can be achieved through a consistent application of the risk analysis and risk management in the process of the engineering project designing and execution.

2.1. Risk assessment

The risk analysis is a sequence of risk identification and quantification procedures. The risk analysis does not include a decision-making process focused on the risk reduction. It includes a parametric analysis of various possibilities, which can be taken into consideration to reduce the particular risks. (Which tools are taken into account to reduce the probability of the undesired event occurrence? Which actions and under what conditions can be applied to reduce the consequences of the undesired events occurrence, i. e. damage and loss? – and the like). The risk analysis also deals with the analysis of circumstances, under which potential hazards may arise, which result the undesired events, and with their development. It is focused on the assessment of outer as well as random factors, which may influence the course of the undesired events.
The evaluated results of the risk analysis allow for the application of the risk management procedures at the project preparation and above all at the construction. The risk management is the base of optimal variants selection for the design solution and technological procedures in further construction process.

Figure 1. Natural hazard exposure potential. (Source. EU - ESPON 2006 Programme 1.3.1 [6])
2.1.1. Risk identification. The risk sources identification is a procedure resulting in a list of all possible undesirable events, which may occur, and a description of circumstances, under which they may happen. Basically, it is the list of all hazards, which may be taken into account, and a description of scenarios. The risk identification concept is sometimes also indicated as a risk specification.

2.1.2. Risk quantification. The risk quantification is understood to be a procedure, which results in the risk expression in financial or other physical units. The risk quantification is based on determination or estimation of probability of occurrence its impact (Figure 2). The risk quantification is done either directly by calculation, or by expert estimations.

![Risk analysis matrix](image)

*Figure 2. Risk analysis matrix [7].*

The risk analysis finally results in assessment of system performance. The approach is shown in Figure 3.

![Two-phase approach](image)

*Figure 3. Two-phase approach to performance assessment [8].*

2.2. Risk management (risk control)

The risk management is the risk analysis completed with a decision process aiming at the risk reduction to an acceptable level. It is a decision-making process based on the risk analysis result. At the beginning, the decision-making is to define the risk management goals and the risk management strategy. The latter determines the decision-making principles, goals, and criteria. The basic goals are as follows: Protect public safety, maintain system reliability, prevent monetary loss, prevent environmental damage.

A part of the risk management strategy is the acceptable risk level definition for specific risk bearers. The goal of the risk management is to reduce the risk amount under the acceptable level. The
risk management is typically applied to decision-making processes comprising an uncertainty. (Under the conditions when all circumstances influencing the result are not sufficiently known, or they cannot be unambiguously quantified).

2.3. Specific features of decision-making process at risk management in construction engineering
The risk management at the preparation and construction of structures is typical of decision-making under the conditions of uncertainty, when several, or all variables influencing the decision are only partially or insufficiently known. The decision-making is therefore executed at a higher or lower uncertainty rate.

The use of deterministic methods to solve the problems related to the risks is therefore limited and requires a special carefulness.

That is why a probability approach is needed for most of the problems solved in relation to the risk management of construction of structures of various types.

The risk analysis and risk management are integral parts of the preparation and construction of every structure. They condition the structure’s safe and, at the same time, economical construction. They allow for the construction using elements of the observation method when the construction progress is adjusted to the real behaviour of the system “rock environment (foundation ground) versus structure”.

The risk management minimizes the situations, which may result in origination of emergency events, minimizing also the possible consequences of such events. Thus, the occupational safety is enhanced, and extra works, extra costs, and construction term extension due to the emergency events arisen are reduced to minimum. The risk management requires the application of the observation method and the geotechnical monitoring.

![Decision-making process for assuring system performance goals](image)

**Figure 4.** Decision-making process for assuring system performance goals [8].
3. Investigation
Understanding the site and subsurface characteristics of the project site are another key aspect of geo-engineering risk identification. Typically, there are unique risks associated with particular geologic formations or structures such as, presence of sinkholes in karst terrain, and rock gouge and slickensides along fault zones. Regional and local ground water conditions are another key risk factor that must also be considered. Valuable knowledge of the geologic and ground water conditions for a particular site can generally be attained through literature research which usually includes previous geotechnical and ground water studies, geologic and agricultural maps, journals, and research studies. Mining maps, historical data, topographic surveys and aerial photos are other sources used to aid in the identification of potential geo-engineering risks especially those associated with previous man-made features e.g. resulted from mining activities [9], [10].

It is widely recognized that risk identification is best achieved through knowledge and experience. In assessing geo-engineering risks, experience can extend beyond that of the agency's geotechnical engineers or engineering geologists. Local experience of individual contractors, field inspectors, geotechnical design consultants and even adjacent landowners have the potential for providing valuable insight in identifying geo-engineering risks associated with a particular project site [7].

A complex and correct execution of the ground investigation at the area of interest is extremely demanding. It is only the correctly executed ground investigation that is able to eliminate the natural hazards, which may in the future negatively affect the engineering project being designed or under construction. The basis is the creation and gradual improvement of the rock environment 3D model – engineering-geological model.

3.1. Gradual assessment
The effectively executed ground investigation should be divided into several interconnected stages. The terrain works should be preceded by a desk study of archive materials available, then an orientation and preliminary investigation should follow. It should be also followed, for complex structures or structures designed in a complex rock environment, by a detail ground investigation or also by an additional ground investigation)

3.2. Role of cooperation between designer and investigator
Very important is to provide for the information transfer between the ground investigator and the designer.

3.2.1. Determination of geotechnical category. It is the geotechnical category determination at the investigation beginning which should result from the cooperation of the investigator of the area of interest and the engineering project designer. The geotechnical category should be refined as needed in the same way as the selection of the ground investigation methods and refinement of the engineering and geological model.

3.2.2. Determination of characteristic values of the rock environment. In the course of the ground environment the basic engineering and geological types of rock formations and their detail characteristics should be defined on the 3D engineering and geological model. At the end of the ground investigation, derived values and designed characteristic values should be determined of relevant parameters in the meaning of the ground investigation goals and purpose in possible cooperation with the engineering project designer.

4. Positive and negative role of standardised approaches (Standards)
The rock environment ground investigation can be standardized for many engineering tasks. In EU the Eurocode 7-1 a 7-2 have been approved and published, which methodically describe the procedures of the ground investigation. With regard to partial differences both in legislation and especially in composition, properties, and behaviour of the rock environment it is nevertheless necessary to respect
national annexes of the Eurocodes and national standards. In case of the ground investigations at the territory of the Czech Republic it is also necessary for the traffic structures to respect, in addition to the Eurocode, the ČSN 736133 and the newly approved ČSN P 731005. The standardized procedures, however, cannot describe all situations at the specific area of interest. This can be evidenced by the ground investigations and technological procedures executed at the construction of highways in the Czech Republic, such as the rolling D1 highway near Ostrava or the north Bohemian D8 highway buried in a landslide.

5. Conclusion
The ground investigation results should be handed over to the designer in an “understandable” form where an instructive verbal description of all significant parameters and the rock environment behaviour will be supplemented with clearly arranged tabular analyses and measurements results together with a presentation of the 3D model of the rock environment at the area of interest in the form of a digital model (e. g. AutoCad solid) or in the form of an appropriately chosen 2D sections; preferably in the form of such files that could be further used for creation of the geotechnical model simulating the rock masses behaviour under certain marginal conditions.

Problems still remain in certain cases in the ground investigation works organized by investors; their insisting on a possibly cheapest and fastest investigation prevents the observation of fundamental procedures of the quality and quantity risk analysis of the specific rock environment for the particular engineering project. The experience from abroad suggests that more advantageous is a design-build construction method employing an experienced contractor capable of better organization of activities and allocation of finance.

The use of the design-build (DB) procurement process has become increasingly popular in recent years especially in the transportation industry. The allocation of responsibility to a single source (design-builder) gives an agency the ability to define total project costs and to decrease the time for project procurement and delivery. It also reduces the potential for disputes and claims that are commonly associated with the traditional design-bid-build (DBB) projects. The DB contractor has more flexibility in managing costs and schedule during both the design and construction phases [7].

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