# Identification and assessment of geohazards affecting pipelines and urban areas

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**Abstract.** The paper addresses methods and criteria of risk assessment associated with land subsidence threatening pipelines, buildings, and constructions. Currently, there are some practical issues relating to geohazards that should be taken into account while constructing a pipeline. The article provides comparison data on the effects of Spitak earthquake and the natural disaster in Neftegorsk in terms of geohazards impact on the pipeline systems. The suggested risk assessment procedure embraces a wide range of aspects: from soil properties to economic and management issues.

## 1. Introduction

The Russian gas pipeline system crosses the areas with different climatic, geological, tectonic, and hydrogeological conditions that may have negative impact on the pipeline operation and maintenance. Geological or geotechnical factors can lead to the pipeline failure. Regarding South Yakutia, there are a lot of dangerous geological and geocryological processes, such as erosion, swamping, karst, thermokarst, thermal erosion, aufeis formation, bloating, screes, slope displacement caused by thawing of soil, etc. [1].

Geohazards present a separate group of possible threats for the pipeline. Geohazard risk assessment involves evaluating failure frequency of pipelines subjected to geohazards. A geological process is considered «safe» or «dangerous» in terms of its impact on the stability of a buried pipeline. It means that if a dangerous geological process does not cause a threat to the pipeline construction and safety operation, it is regarded as “safe”. However, if a geological process threatens the pipeline integrity and can cause some damage to the construction, it is classified as “dangerous”. At the same time, other occasion can break integrity of pipeline, which considered as damaging event. Thus, geohazards risk assessment for pipelines has its particularities.

## 2. Geohazards and their consequences regarding to a pipeline

The pipeline is considered to be in «safe» condition if there is no factor threatening its integrity or the pipeline can resist all possible stresses. However, some elements of the pipeline system are less reliable than a pipe, thus, they should be evaluated separately (figure 1).

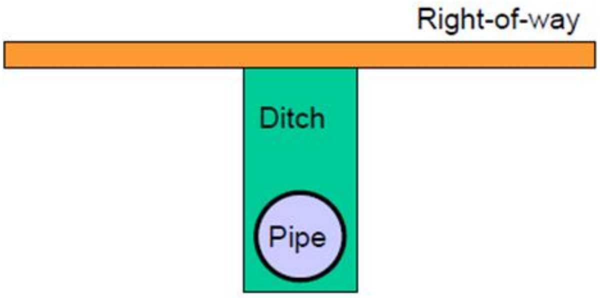


**Figure 1.** Pipeline elements.

Land subsidence has the most significant influence on the pipeline system. The earth's surface subsidence may occur slowly or suddenly due to different causes: oil or gas production, karsting rocks, mining activities, destruction of permafrost, etc. Land subsidence involves a downward displacement of soil that can be accompanied by horizontal movement of the soil. Both land displacements can cause negative effect on the pipeline and generate a compressive stress resulting in pipeline failure and disturbance of the pipeline stability. The deformation of land surface can occur in the form the bending, tilting, or sinkholes. Table 1 shows the list of geohazards and their impacts on a pipeline system [2].

**Table 1.** List of hazards and their impacts on a pipeline.

| Disaster | Effects | Elements affected (directly only) | | |
|---|---|---|---|---|
| | | Pipe | Ditch | ROW |
| Thawing of permafrost under the pipe | It can result in deformation of pipes due to bending in pipes in areas of cavities | Yes | No | No |
| Thawing of permafrost around the ditch | It can induce pipe destabilization and displacement due to soil erosion along the ditch | No | Yes | No |
| Thawing of permafrost above the pipe | It can lead to drainage violation caused by ground subsidence | No | No | Yes |
| Earthquake shocks | It increases dynamic strain on pipe | Yes | No | No |
| Soil liquefaction | It decreases soil strength | Yes | Yes | Yes |
| Soil erosion | It leads to erosion over the pipe | Yes | Yes | No |
| Sinkhole development (karst) | It leads to pipe deformation | Yes | No | No |

## 3. Risk assessment procedure

The table above presents only a part of possible geohazards that can induce a pipeline failure. However, the consequences may lead to significant economic loss and environmental problems. To avoid the negative consequences, it is necessary to evaluate all the risks in order to predict and prevent possible failures. Risk assessment is the determination of quantitative or qualitative estimate of risk related to a certain situation defined as a threat. The procedure implies two specific stages. The first stage is to determine risk frequency; the second one is to identify the influence of the risk, i.e. severity of consequences [3]. Generally, risk management consists of the following steps:

- Risk management planning;
- Risk identification;
- Qualitative and quantitative risk analysis;
- Risk response plan;
- Risk monitoring and control.

Basic principles of response to any threats are shown in figure 2. To avoid any accident associated with hazardous geological processes, it is necessary to assess the possibility of their occurrence and the scale of their negative influence. Then, the probability level is correlated to the scale for each risk category. A certain color corresponds to a specific level of threat. This method allows estimating and predicting consequences of the hazard. In addition, it identifies the value of each situation and provides the solution. The disadvantage of this method is that probability level and scale value are estimated subjectively.

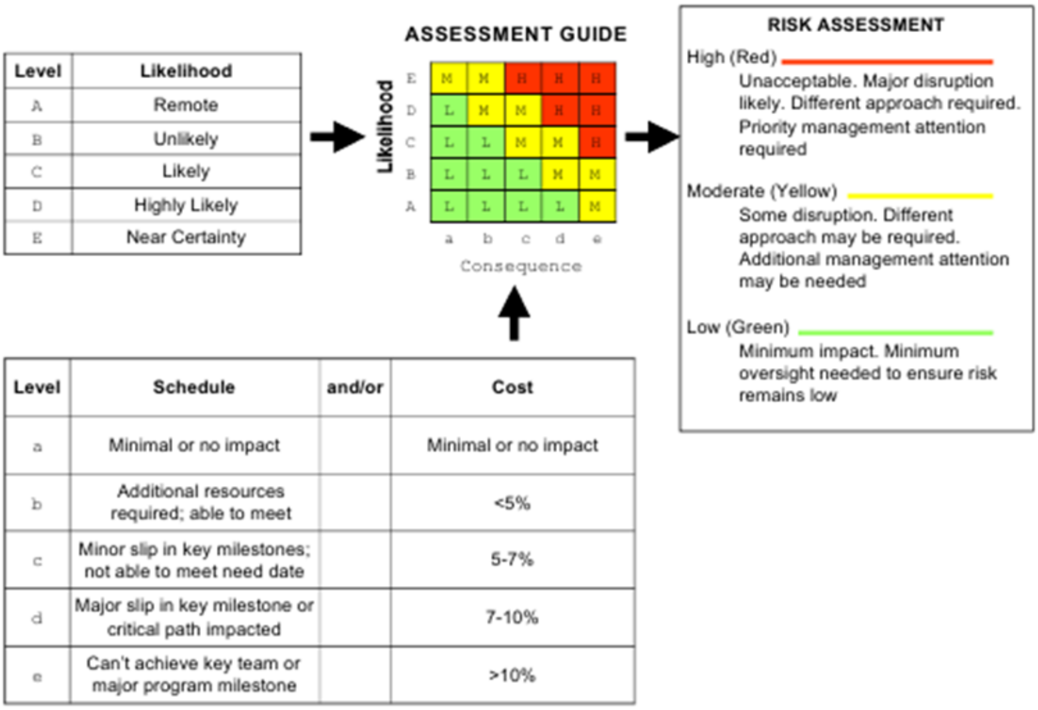


**Figure 2.** Risk evaluation procedure.

## 4. Integrated approach for risk assessment of geohazards

The method and criteria mentioned above may not be enough to predict land subsidence with required accuracy. In this case, it is necessary to use additional parameters such as rock properties, tectonic fractures, morphometric characteristics of the relief, physical and mechanical properties of soils, groundwater characteristic, etc. One of the methods implies taking into consideration geological indicators that are often used in karst research. Rock stratum assessment in terms of engineering-geological conditions implies studying composition, condition, structure and texture of sediments and overlying strata of soluble rocks and their physical properties. Usually, the list consists of 21 parameters divided into 6 group [3]: structural-tectonic, geological, hydrogeological, geomorphological, engineering-geological and geocryological (table 2).

**Table 2.** List of criteria to assess the risk of land subsidence

| Group | Parameters |
|---|---|
| Structural and tectonic | Lineaments density Ll, km/$km^2$ |
| | Number of lineament intersections Ml, $number/km^2$ |
| | Modularity Bl, $km^2$ |
| | Distance from lineaments Rl, $m$ |
| Geological | The of quaternary loose layer thickness |
| | Overburden thickness |
| | Composition of bedrock |
| Hydrogeological | Groundwater level HQ, $m$ |
| | Fissure-karst water level Hk, $m$ |
| | Salinity of groundwater M, $g/dm^3$ |
| | Hydrochemical facies of groundwater |
| Geomorphological | Slope of a terrain , degree |
| | Distance from river network U, $m$ |
| | Watershed slope tg α, u. f. |
| Geotechnical | Density ρ, $g/cm^3$ |
| | Total deformation modulus $E_0$, $MPa$ |
| | Angle of internal friction of soil $\varphi$, degree |
| | Specific cohesion of the soil c, $kPa$ |
| Geocryological | Soil temperature t, °C |
| | Ice content $i_{tot}$, u. f. |
| | Total humidity $W_{tot}$t, u. f. |

One of the most important factor in the development of subsidence is a geological structure of the area, which involves texture and structure of soluble rocks; content and composition of insoluble residue; composition, structure, thickness and nature of bedding layers; genesis and age of karst rocks. Karst is dangerous due to possible underground cavities that are sometimes difficult to identify by engineering geological hazard assessment Currently, geological assessment of subsidence risk is quite an efficient way to determine potential threat and to prevent negative impact.

## 5. Quantitative risk assessment calculations

Quantitative risk evaluation is becoming worldwide the main constituent in decision-making related to risk management activities. Differentiated estimations of economic risks caused by landslides, sinkholes and subsidences resulted from karst development, karst-suffusion and suffusion, liquefaction and mining should be carried out in the form of total and specific (normalized to unit of area) values by the following formulas (1), (2):

$$R_e(H) = P(H) \cdot P_s(H) \cdot V_e(H) \cdot D_e \quad (1)$$

$$R_{s\,e}(H) = R_e(H) S_0^{-1} \quad (2)$$

where $R_e(H)$ and $R_{s\,e}(H)$ - total (€$/year$) and specific (€$/(m^2 \cdot year)$ respectevely, €$/(ha \cdot year)$ or €$/(km^2 \cdot year)$ is risk of loss caused by hazard H of certain nature and intensity; $P(H)$ – is frequency of hazard occurrence $(H)$ within a certain area, which is numerically equal to its statistical probability $(cases/year)$; $P_s\,(H) = S_0/S_t$ - geometric probability of hitting the object in hazardous area; $S_0$ - section of the object $(m^2, ha, km^2)$; $S_t$ – section, where the hazard $H$ can occur $(m^2, ha, km^2)$; $D_e$ - cost of the object before its destruction (€).

$V_e(H)$ - economic exposure of the evaluated object to the hazard $H$.Equation (3) is used for some area (the formula is different for buildings and structures) [5].

$$V_{t\,e}\,(H) = D_{td} D_{te}^{-1} \quad (3)$$

where $D_{td}$ – cost of the destroyed territory, $D_{te}$ – overall cost of evaluated territory.

For better risk assessment, it is reasonable to introduce such parameters as average speed of a geological process and average amplitude of the deformations into the formulas presented above. Differentiated evaluation of loss for buildings and structures should also involve the geological risks of adjacent areas.

Geological risk assessment should be carried out at all stages of geotechnical survey and should result in geological risk maps, reports and conclusion.

## 6. Vulnerability evaluation

A vulnerability assessment is the process of identifying, quantifying, and ranking the vulnerabilities of a system. It may be conducted in the physical, social, economic or environmental fields.

In the simplest case, it may be defined by the following formula (4):

$$V(H) = n_i \cdot n^{-1} \tag{4}$$

where V(H) is the object vulnerability in any sphere of consideration of possible losses (fractions of unit, f.u.); $n_i$ – is the number of destroyed and damaged elements by hazard H or the cost of these elements in object; n – is the total number of elements or the total cost of these elements before disaster.

The equation allows identifying vulnerability of a particular area. For example, the 8-9 magnitude earthquake in Spitak occurred in the area with 1million residents and 120000 houses. It resulted in destruction of 58 settlements and about 61000 houses. According to the equation [6]:

- Physical vulnerability of settlements is $58 \cdot (365)^{-1} = 0.159$;
- Vulnerability of dwelling houses is $61 \cdot (120)^{-1} = 0.51$;
- The population vulnerability is equal to 0.025.

The disaster in Neftegorsk was of the same power. However, the vulnerability of 3-5-storey houses was 1 and that of the population was 0.58 [4].

Today, experimental statistical tables of vulnerability of buildings and their occupants are developed to be applied to earthquakes, karst collapses, subsidence, and underflooding [5-8]. Until recently, the vulnerability evaluation remains a poorly developed element in the general scheme of natural risk analysis.

## 7. Conclusion

The methods described above and the assessment criteria can be used to predict and monitor land subsidence and protect the pipelines and other urbanized facilities from their negative impact. The impact of natural factors on the stability of objects in karst areas should be studied. Such study contributes to the development of petroleum industry in geologically complicated areas and investments in high-tech industry. To ensure effective prediction and monitoring of geological hazards and to manage preventive activities it is reasonable to apply the complex approach that takes into account all the aspects of possible hazards.

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