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Methods for karst hazard forecast and pipeline protection in South Yakutia

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Abstract. The objective of this paper is to consider the ways of monitoring and protecting the pipeline «The Power of Siberia» from karst hazards. The method of protection with bored piles has been recommended and the forecasting methods have been overviewed. Thus, ground penetrating radar allows discovering a soil cavity when the overburden layer is not very deep and predicting sinkhole collapse when used in combination with a balance arch model. Monitoring of triggering factors is widely used to forecast karst collapse when the opening is caused by pumping as the data on dynamic groundwater conditions can be obtained in real-time. However, the suggested protection method is expensive and some forecasts might be difficult to make. The authors have suggested the ways to improve the current situation and to reduce the damage caused by karst collapse.

1. Introduction

1.1. Problem statement

Currently, in the field of hydrocarbon transportation, there is a challenge of constructing the pipeline through the areas of severe climatic and environmental conditions. These areas are the regions with a great number of bogs and ever-frozen ground. However, the most complicated challenge is to construct the pipeline through karst areas. As for the geologically unfavorable regions described above, we have found the ways to solve problems possible in oil and gas pipeline operation, but the karst areas are an exception since there is a lack of applicable and reliable to prevent and eliminate probable accidents. Often transporters do not have an opportunity to build a pipeline through a more preferable route, because it is economically inadvisable or due to environmental requirements, etc. Therefore, firstly, we have to study karst areas and then identify the factors, which can reduce karst risks in the potentially dangerous regions the pipeline runs through.

1.2. Rationale of the research

Karst is dangerous especially because of possible underground cavities, which might represent a challenge in terms of engineering geological assessment. The process of voids development starts under the three co-occurring conditions:

1) soluble fraction;
2) capability of water to dissolve;
3) diverting of ground water.

Subsequently, due to the growth of cavity space at the threshold tension, the surface may collapse and form a sinkhole. This destroys the base of the pipe reducing the pipe resistance and its load-bearing capacity [1]. As the diameter of the sinkhole can be from a few meters to more than 150 meters and the depth is greater than 20 meters [2], the most unfavorable effect in the loss of pipeline integrity. Figure 1 represents the pipeline in the area of karst cavities which correspond to thermokarst (upper picture), in the sinkhole (lower picture), [3].

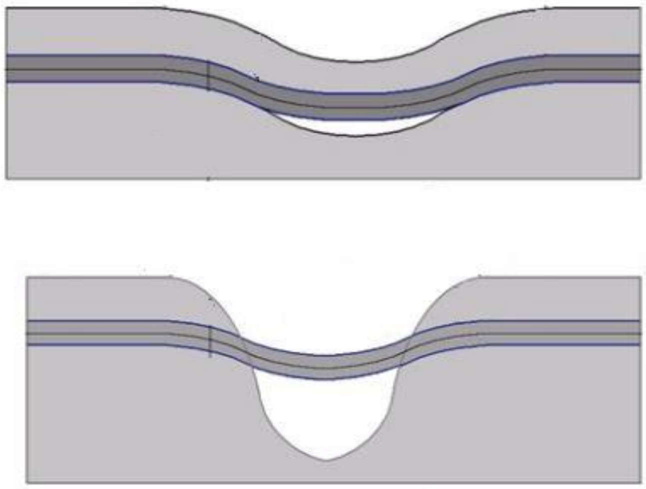

Figure 1. Condition of the pipeline.

1.3. Object of study
The Russian gas pipeline system is one of the largest in the world. In 2012, the length of the main pipeline was more than 175 thousand kilometers. According to the official statistic data represented by «Gazprom», 42% of all gas pipeline accidents are directly or indirectly caused by natural factors.

One of the major problems is «The Power of Siberia» pipeline. The length of the potentially dangerous part is 160 kilometers. This section starts from Chayandinskoye deposit. The pipeline stretches through the territory of Lensky Ulus of the Sakha Republic (Yakutia). The climate conditions are severe, for example, the temperature in the winter can changes from -25 °C to -62 °C, the spring comes quickly, with significant differences between the night and day temperatures. Moreover, many karst regions are located within this area. Every year new sinkholes are developing. Development of karst is connected with rock fracturing. Ground water circulates through the rock dissolving and removing soluble minerals. Therefore, the area is characterized by severe climatic and environmental conditions and tends to be even more dangerous because of the karsts [4].

To start solving this problem, firstly, it is necessary to predict the deformations of the pipelines on the basis of the karst hazard forecast. However, often it is impossible to predict when exactly a sinkhole will open, so secondly, it is important to monitor bending pipeline sections to prevent the pipeline failures and accidents. The efficient solution is to apply the advanced methods of pipeline monitoring and protection.

2. Methods of detection and protection

2.1. Pipeline protection with bored piles
The invention is relevant for pipeline construction and operation and can be used to prevent accidents in pipelines caused by karst failures (figure 2).

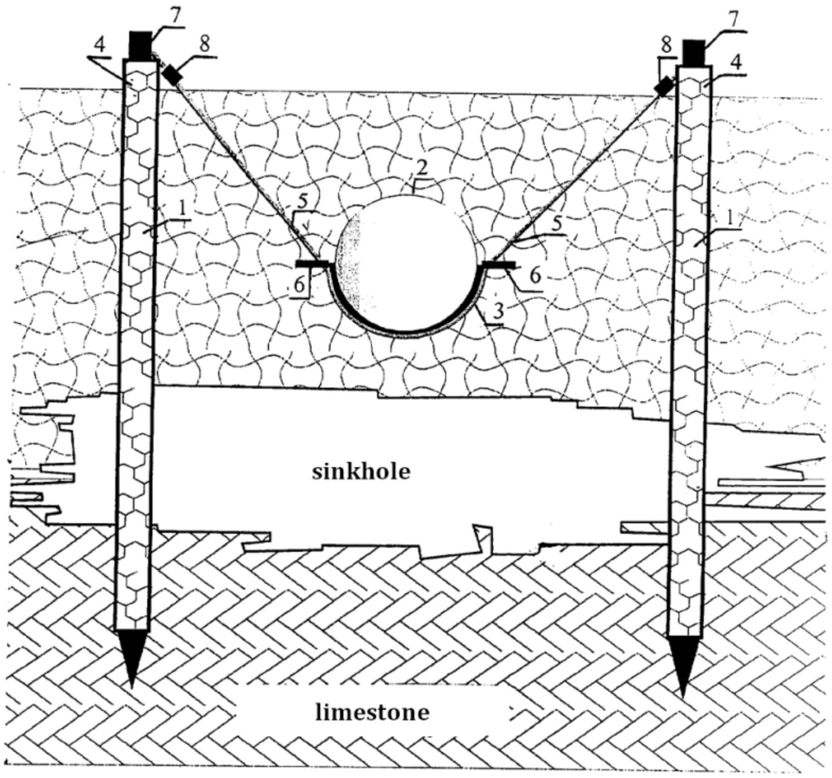

Figure 2. Protection with bored piles.

The bored piles 1 are placed on the both sides of the pipeline 2 and connected with the metal lodgement 3. The construction is fixed in such a way that the pile heads are above the earth's surface, the metal lodgement and the bored piles are connected with the steel cable rope 5, which bypasses the pipe, and the ends of the rope are fixed on the tip piles 4 with the help of the tension clutches regulating the tension of the cable rope. At the ends of the rope before the tension clutches there are the compression couplings sensors 8 (figure 2 [5]).

The disadvantage of this method is that the prototype is difficult to construct since the metal beam is connected with the bored piles through welding. Another disadvantage is the large quantity of metal per structure and the absence of visual control over the construction during the operation.

The advantage of the invention is that the pipeline is independent from any movements, which might occur in the ground.

2.2. Ground Penetrating Radar (GPR) Surveys

This simplest and most popular method for forecasting karst collapse is very popular in China. GPR can directly identify soil cavities. The Ground penetrating radar modeling for predicting the sinkhole is based on an idealized balance arch as shown in Figure 3, where σ_v is the natural vertical stress; h is the height of the arch; b is the half span; and f is the Protodyakonov coefficient.

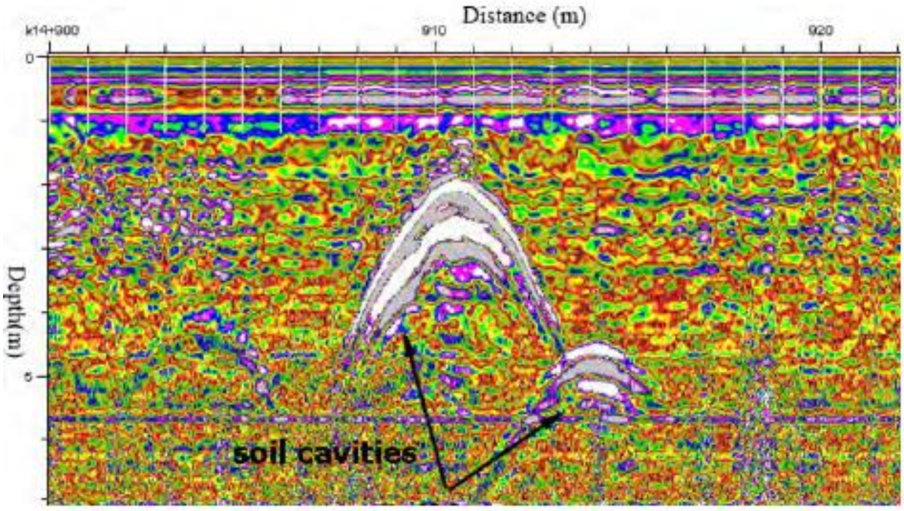

Figure 3. GPR image of a highway and the idealized model of its balance arch [6].

Basically, the equilibrium equation of the arch is

$$\text{—} \tag{1}$$

Thus, if

$$h \quad \text{—} \tag{2}$$

then the arch will be stable, but the hole will develop further when

$$h \quad \text{—} \tag{3}$$

until a sinkhole opens.

The disadvantage of this method is as follows: frequent scanning is necessary to monitor changes in the arch, which might result in high costs when the survey is large. Moreover, GPR fails to be accurate in case of deep cavities because of technological limitations.

The advantage of this method is the time since it is the fastest way to identify the potentially dangerous zones [6].

2.3. Monitoring triggering factors

The aim of this method is to monitor changes in the groundwater through the karst conduit (Figure 4).

Determining the forecasting threshold is the most important stage of this method. First, the soil samples are obtained to be tested in the lab. The main purpose of test is determination of the hydraulic gradient.

If the hydraulic gradient in the laboratory tests is greater than in the field, deformation will generate in the soil, and a karst collapse will open at the surface.

The disadvantage of this method is that the accuracy of forecasting is low due to discrepancies in the structures and physical-mechanical properties of soil even within the same layer, and the test results may be different from the real data.

However, to improve the accuracy, a new method was developed. This method is based on the residual analysis of groundwater pressure. It is important to control relationships between the time that anomalous monitoring data were recorded and the time of karst collapse. The times of maximum, minimum and most anomalous values and the time of the sinkholes opening have a linear correlation. Between the time of the most anomalous value and the time of the sinkhole opening was

. Basically, when an anomalous value fits the equation following monitoring then the time of the sinkhole opening can be predicted.

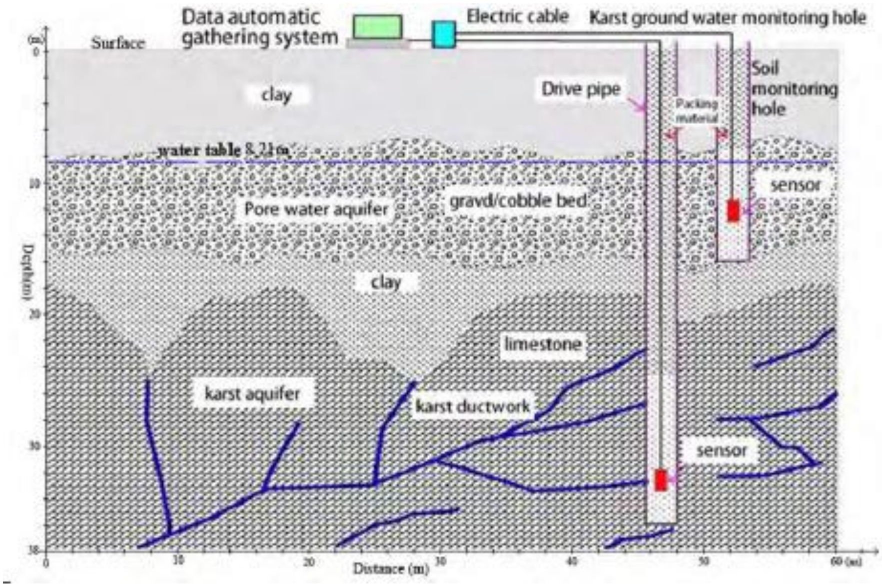

Figure 4. Monitoring of groundwater pressure [6].

The advantage of this method that it is more accurate and provides additional data to analyze the situation: for example, this sensor can obtain the data on the chemical composition of the ground water, etc. [6]

2.4. Barkhausen noise sensor

This method is one of the most reliable and efficient way to identify deformations. The Barkhausen effect is an indirect evidence of the magnetic domains existing within the ferromagnetic materials. When domains grow, under the applied magnetic field, the movement of the domain walls occurs by discontinuous and abrupt Barkhausen jumps. The jumps in magnetization of a ferromagnetic material can induce a voltage in a winding coil of wire that in turn can produce Barkhausen noise [7].

The overhead sensors are used for excitation and detection of magnetic Barkhausen noise (figure 5).

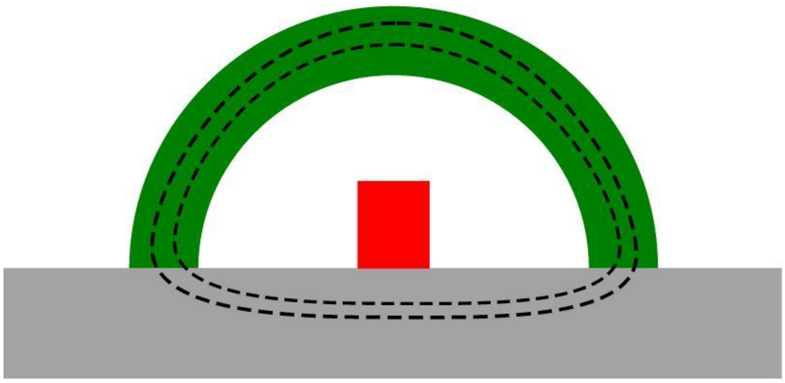

Figure 5. A set-up for non-destructive testing of ferromagnetic materials: arc – magnetising yoke, square – inductive sensor, rectangle – sample of pipeline under test.

Transverse field dipole magnet of the sensor generates varying magnetic field in the study area. This magnetic field creates jumps of magnetization resulting in noise signals in the receiving coil of the sensor which are registered by the device. The level of the magnetic noise depends on the properties and state of the crystal lattice and mechanical tension.

In most types of steel under the tension the intensity of the Barkhausen noise increases while under compression it decreases. The control of the pipe's deformation is provided on the basis of this property.

Moreover, this kind of sensors may be used in hard conditions. In particular, the working temperature is from -70 °C to +70 °C. It is very important for Chayandinskoye region.

The disadvantage is that the method cannot be applied for the pipelines made of non-metal materials.

3. Conclusion

There are different methods to detect sinkholes, as well as the ways of predicting and monitoring the growth of cavities and protecting pipelines against their negative impact. However, karst hazard is still a great challenge for particular regions. Unfortunately, there is no optimal solution that satisfies all needs of the humanity yet. Karst problem is a serious challenge for the safe oil and gas transportation and as a result, it is still the issue researched all over the world. The impact of natural factors on the stability of pipelines in karst areas influences the development of petroleum industry, as well as contributes to investment in the knowledge-intensive field. The analysis of all methods overviewed in the paper demonstrates that the sensors based on Barkhausen effect is the best way to monitor pipelines deformations since the method is applicable at different temperatures.

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