The Semi-quantitative evaluation method and application of the risks of geological disaster of the Shaan–Jing pipeline

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Received 1 March 2014, www.tsi.lv

Abstract

Based on the index scoring method, the semi-quantitative method for assessment of pipeline geological disaster risks calculates the relative risk of a disaster by investing and assessing the objective existence state of index in accordance with pre-determined scores and weights, and meets the requirements of risk prioritizing and ranking at the geological disaster investigation stage so as to guide the development of risk control planning. A geological disaster risk semi-quantitative assessment system and risk grading standards both of which are applicable to oil and gas pipelines have been established. What has been developed also includes the pipeline geological disaster risk management system software, which integrates the risk semi-quantitative assessment technique based on the index-scoring-method, and other techniques such as information management and risk management, and thus provides a platform of information, technology and management for the management of pipeline geological disaster risks. This method has been used for a unified risk assessment of more than 3300 disaster points along the oil and gas pipeline, and satisfactory evaluation results are obtained, thus providing an important basis for the development of planning of pipeline geological disaster risk remediation.

Keywords: oil and gas pipeline, geological disasters, index scoring method, semi-quantitative assessment, risk grading

1 Introduction

Geological disasters are one of the major risks for oil and gas pipelines and even become the NO.1 risk threatening the safety of oil and gas pipelines in mountain areas with complex geological and geomorphic conditions. Due to randomness and unpredictability of geological disasters, pipeline geological disaster risk management has gradually become a major means for prevention of pipeline geological disasters. The risk assessment technique is one of the main supporting techniques for the management of pipeline geological disaster risks, and its purpose is to conduct risk calculation and evaluation of identified risk points, rank risks according to the size of them and provide a basis for risk control planning. Currently, pipeline geological disaster risk assessment methods can be divided into three categories: qualitative assessment, such as the risk matrix method; semi-quantitative assessment, such as the risk index method; quantitative assessment, such as the probability assessment method [1]. For the pipelines laid in mountain areas in Midwest China, each one is faced with different kinds of geological disasters along the line, and the number of disaster points for each pipeline is often as many as several hundreds or even several thousands [2-5]. The qualitative method cannot meet the requirements while the quantitative method is inoperable to rank risks for such a huge number of disaster points, so the semi-quantitative method is the ideal choice.

The semi-quantitative assessment method developed for the GRM system by Canadian BGC Company in 2002 can be used for semi-quantitative risk assessment and risk ranking of landslides, dilapidation and brook & road flood destruction. The West-East Gas Pipeline Environmental Geological Disaster Risk Assessment System [6] developed by West-East Gas Pipeline Company together with Southwest Petroleum University in 2006 can conduct semi-quantitative risk assessment of 9 kinds of disasters faced by the west-east gas pipeline, such as water destruction, collapsible loess, collapse of mined-out area and debris flow.

2 Risk assessment model

The Department of Humanitarian Affairs of the United Nations published a definition of the natural disaster risk in 1992, and used Formula (1) to represent a risk [6]:

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability}. \quad (1)$$

The formula is the rationale for assessment of natural disaster risks. Hong Kong Civil Engineering and Development Department uses Formula (2) to evaluate the annual risk of landslides. This formula also applies to risk assessment of other disasters such as pipeline landslides (with the pipeline as the hazard-bearing body), dilapidation, debris flow, collapse of mined-out area and water destruction.

$$R_{\text{prop}} = P_{\text{L}} \cdot P_{\text{T,L}} \cdot P_{\text{S,T}} \cdot V_{\text{prop,S}} \cdot E_{\text{s}}, \quad (2)$$

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where: R_{prop} is the annual loss of property value, with the unit being a currency or in another form; P_L is the frequency of landslides, dimensionless, ranging from 0 to 1; $P_{T,\,L}$ is the probability of landslides reaching the hazard-bearing body, dimensionless, ranging from 0 to 1; $P_{S,T}$ is the space-time probability of the hazard-bearing body, dimensionless, ranging from 0 to 1; $V_{prop,\,S}$ is the vulnerability of the hazard-bearing body to landslides, dimensionless, ranging from 0 to 1; E_S is the hazard-bearing body (such as value or existing net property value), with the unit being a currency or in another form.

Once laid, the location of the oil and gas pipeline is generally fixed and can be clearly identified, so $P_{T,\,L} = 1$. The probability of disaster occurrence is relevant to the geological disaster's natural state and environment, and will also be relevant to the effectiveness of engineering measures if these measures are taken against the geological disaster; the probability of the disaster reaching the pipeline is related to the spatial locations of the two; the probability of destruction of the pipeline under the influence of disaster is relevant to parameters such as the disaster scale, the length of affected part of the pipeline and the pipeline's strength, and the vulnerability of the pipeline will also be related to the effectiveness of protective measures if these measures are taken against the disaster. Therefore, Formula (2) can be adjusted to Formula (3):

$$R = H\left(1-H'\right)SV\left(1-V'\right)E\,, \tag{3}$$

where: R is the pipeline's risk of a geological disaster with the unit being a currency or in another form; H is the probability of occurrence of a geological disaster under natural conditions, i.e. disaster liability, dimensionless, ranging from 0 to 1; H' is the probability of preventive measures playing a full role (completely preventing occurrence of the disaster), dimensionless, ranging from 0 to 1; S is the probability of a geological disaster affecting the pipeline after its occurrence, dimensionless, ranging from 0 to 1; V is the probability of pipeline failure (strength failure or instability) without any protections against a geological disaster that has occurred, i.e. pipeline vulnerability, dimensionless, ranging from 0 to 1; V' is the probability of pipeline protective measures playing a full role (completely preventing pipeline damages), dimensionless, ranging from 0 to 1; E is the consequence of pipeline failure, i.e. economic losses due to transmission media leaks, service outages and adverse effects of leaked media on the environment after pipeline failure, with the unit being a currency or in another form.

If E, the consequence, is not to be considered. Formula (3) can be adjusted to Formula (4):

$$P_R = H\left(1-H'\right)SV\left(1-V'\right), \tag{4}$$

where: P_R is the risk probability of the pipeline suffering from a geological disaster, i.e. the probability of pipeline failure under the current disaster environment and pipeline state, dimensionless, ranging from 0 to 1.

This model is a quantitative evaluation model, which can be used to calculate the real risk of a pipeline geological disaster, and can be used for semi-quantitative risk assessment. The purpose of semi-quantitative assessment of pipeline geological disaster risks is to prioritize and rank risks. Therefore, semi-quantitative risk assessment only needs to assess the relative risk of a disaster instead of calculating the actual risk of the disaster, and can use a relative value (index) to represent each parameter in Formula (3) to respectively evaluate risk probability and the consequence.

3 Risk probability evaluation

A. Index scoring method

The index scoring method is selected to evaluate the risk probability exponent of a pipeline geological disaster. The index scoring method is a major influence factor for statistical analysis of risk probability. All influential factors are used as evaluation indexes to establish an evaluation index system. Taking into account the impact of each index on risk probability, each index is given an appropriate weight. Then the possible state of each index is analysed to judge the level of risk probability in different states and give a score to each index (Table 1). Therefore, the evaluation system is made up of evaluation index system, weight, score and algorithm. In practical application, after the state of each index is investigated, the risk probability exponent can be calculated based on the weights, the index state score and the algorithm.

TABLE 1 evaluation parameters of different methods

Index u	Weight w	Index State	Score
Index 1	w_1	State 1 State 2 …	u_{11} u_{12} …
Index 2	w_2	State 1 State 2 …	u_{21} u_{22} …
…	…	…	…
Index n	w_n	State 1 State 2 …	un_1 un_2 …

B. Calculation method

According to Formula (4), risk probability assessment can be divided into five assessment parts. An index system is established for each assessment part and the sum of weights in system is one. The maximum score of index state scoring is 10. The value of risk probability is a decimal no greater than 1. According to the index scoring method, Formula (4) can be expressed as Formula (5):

$$P_R = \frac{\sum_{i=1}^{n_1} u_{1i} \times w_{1i}}{10}\left(1-\frac{\sum_{i=1}^{n_2} u_{2i} \times w_{2i}}{10}\right) \frac{\sum_{i=1}^{n_3} u_{3i} \times w_{3i}}{10} \frac{\sum_{i=1}^{n_4} u_{4i} \times w_{4i}}{10}\left(1-\frac{\sum_{i=1}^{n_5} u_{5i} \times w_{5i}}{10}\right), \quad (5)$$

where: n_1 is the number of evaluation indexes for the occurrence probability of a geological disaster under natural conditions; u_{1i} is the score of the state of the i-th (No. i) evaluation index for the occurrence probability of a geological disaster under natural conditions; w_{1i} is the weight of the i-th (No. i) evaluation index for the occurrence probability of a geological disaster under natural conditions.

Therefore, the establishment of a risk probability calculation system needs to determine the risk probability evaluation index system, index weights and the index state score.

C. Establishment of a risk probability assessment index system

To ensure the operability and applicability of the evaluation system and objectivity of the evaluation result, the determination of evaluation indexes and index states shall follow the following principles: selecting main factors having significant impacts on the evaluation result as indexes to form a slimmer but better index system; index states should be intuitive, easy to get, and not experience-dependent to avoid the interference of human factors; indexes and index states should be widely applicable, and can be applied to most disasters of the same category. Based on this, an index system (Table 2) has been established for 6 categories (11 kinds) of disasters, namely landslides (clay landslides, debris landslides, loess landslides, rock landslides), dilapidation, debris flow, collapse of mined-out area, water destruction (slope water destruction, platform & farmland water destruction, brook & road water destruction) and loess collapses. Each index generally has 3 to 4 index states.

TABLE 2 evaluation parameters of different methods

Disaster Category	Number of Indexes
Clay Landslides	21
Debris Landslides	25
Loess Landslides	19
Rock Landslides	21
Dilapidation	27
Debris Flow	23
Collapse of Mined-out Area	25
Slope Water Destruction	13
Platform & Farmland Water	11
Destruction Brook & Road Water	14
Destruction Loess Collapses	14

A. Determination of index weights and index state scores

Index weights are essential for the accuracy of the result. Calculate the weight of each evaluation index using the Analytical Hierarchy Process (AHP) method and according to the relative importance of each index provided by several experts of pipeline geological disasters. Score each index state according to the level of risk in each index state and the score should be between 10 and 0.

Because the evaluation index system varies as the disaster varies, the evaluation results of different disasters cannot be directly compared. To rank risk probabilities of different kinds of geological disasters, a unified standard has been adopted for the scoring of all states of all pipeline vulnerability evaluation indexes, making relative risk probabilities of different kinds of disasters basically comparable.

4 Failure consequence evaluation

The pipeline failure consequence evaluation model established by Muhlbauer W Kent [7] is used for risk consequence assessment. The pipeline failure consequence (expressed as an exponent) is calculated using Formula (6):

$$E = \mathrm{PH} \cdot \mathrm{SP} \cdot \mathrm{DI} \cdot RC, \quad (6)$$

where: PH is the product hazard coefficient, to be selected according to the product type, ranging from 5 to 10; SP is the leakage coefficient, to be selected according to the amount of leakage, ranging from 1 to 5; DI is the diffusion coefficient, to be selected according to the nature of the surrounding environment, the higher the value, the more conducive to diffusion, ranging from 1.5 to 5; RC is the receptor whose value is selected according to factors such as nearby residents, ecological environment and the resulted public opinion, ranging from 0.5 to 4.

The values of all parameters are determined by the corresponding indexes. The greater the value of E, the more serious the losses are.

5 Risk probability evaluation

A risk can be determined based on the risk probability and the consequence. As the calculated results are the risk probability exponent and the consequential loss exponent, a risk is expressed in the risk matrix form and the risk level is determined according to the risk probability exponent and the consequential loss exponent. Generally speaking, the ultimate goal of pipeline geological disaster prevention is to prevent pipeline failure accidents as far as possible, extra emphasis should be placed on classification of risk probabilities when ranking risks. To meet different production needs, the risk probability exponent, the risk consequence exponent and risks are respectively classified into 5 levels: (1) high level of risk, unacceptable, for which risk mitigation measures need to be implemented within the specified time; (2) relatively high level of risk, undesirable, for which preventive measures should be taken to reduce it, but the prevention cost needs to be assessed and limited, and selective inspection, professional monitoring or risk mitigation measures can be adopted; (3) moderate level of risk, conditionally acceptable, for which there should not be a substantial increase in cost of risk control, and selective inspection or easy monitoring can be adopted; (4) relatively low level of risk, acceptable, for which tour-inspection measures can be adopted; (5) low level of risk, negligible, for which no measures need to be taken and no file records need to be kept.

Risk grading standards should be determined based on the risk tolerance of pipeline operators. The risk tolerance, which is changing all the time, is different for different pipeline operators. Therefore, risk grading standards adopted by different pipeline operators are different and can be adjusted at any time. As risk grading is intended to provide a basis for risk control planning, so grading standards need to be developed based on previous prevention and control planning as well to ensure a certain degree of continuity. Risk grading standards are developed according to PetroChina's prevention and control planning for major pipelines in 2008. As the management cost of water destruction and loess collapses is relatively low, the risk probability grading standards are adjusted (in Figure 1, risk grading exponent values outside the brackets apply to landslides, dilapidation, debris flow, collapse of mined-out area, etc. while risk grading exponent values inside brackets apply to slope water destruction, platform & farmland water destruction, brook & road water destruction, and loess collapses) in consideration of risk - cost effectiveness.

TABLE 3 evaluation parameters of different methods

Risk Grading Exponent →

=0.4 (0.2)	High	High	High	High	High	High
0.2~0.4 (0.1~0.2)	Relatively High	Relatively High	Relatively High	Relatively High	Relatively High	High
0.1~0.2 (0.05~0.1)	Moderate	Moderate	Moderate	Moderate	Relatively High	Relatively High
0.05~0.1 (0.01~0.05)	Relatively Low	Relatively Low	Relatively Low	Moderate	Moderate	Moderate
<0.05 (0.01)	Low	Low	Low	Relatively Low	Relatively Low	Relatively Low
		Low <10	Relatively Low 10-90	Moderate 90-300	Relatively High 300-860	High =860

Consequential Loss Exponent →

6 Validation and application

A team made up of several experts of pipeline geological disasters is organized to conduct on-site confirmatory applications on the Shaanxi-Beijing gas pipeline in order to verify the operability and applicability of the pipeline geological disaster semi-quantitative risk assessment method which is based on the index scoring method and to verify the accuracy of the evaluation result. According to the result of applications, this method is easy to operate, and using this method, the field investigation generally takes no more than 20 minutes for a single disaster point; evaluation indexes are easily accessible and the evaluation result is less affected by human factors; (3) the reliability of the result is ensured as there is a high degree of consistency between the grading result worked out by the expert team through qualitative evaluation and the calculation result obtained using this method; (4) this method has considered similarities of disaster points, and therefore applies to most of disaster points.

As there are so many indexes and disaster points in an index system, the computer is needed for data management and computing. The pipeline geological disaster risk management system (software) is developed with the needs of pipeline geological disaster risk management work taken into account. This system, which integrates the index-scoring-method based pipeline geological disaster risk semi-quantitative assessment technique, can conduct semi-quantitative evaluation computing, and have functions such as information management (including information, photos, documents, etc. other than evaluation indexes), quantitative evaluation of landslides and dilapidation, risk control planning and management, and workflow management, thus providing an information platform, a technology platform and a management platform for risk management of pipeline geological disasters. The system is based on browser/server mode (B/S architecture), and authorized users only need to log on the Internet to use it. Currently widely used in the Shaan–Jing gas pipeline, this system evaluates risks of more than 3,000 disaster points along the pipeline in a unified way, and the evaluation result provides an important basis for the development of pipeline geological disaster risk control planning.

7 Conclusion

(1) Pipeline geological disaster risk management is a mainstream method of pipeline geological disaster protection. A risk assessment method needs to be established to make risk control planning for thousands of geological disaster points along the pipeline. The relative risks of disaster points should be ranked and graded.

(2) The pipeline geological disaster risk assessment model, which is established on the basis of the landslide disaster risk assessment model, can perform quantitative risk assessment and can also be used for semi-quantitative risk assessment.

(3) The index-scoring-method based pipeline geological disaster risk semi-quantitative assessment method can be used to calculate the relative risk of a disaster. Not only is the method very simple, but the assessment result is reliable, so it can meet the needs of pipeline geological disaster risk management.

Acknowledgments

Authors wishing to acknowledge assistance or encouragement from colleagues, special work by technical staff or financial support from organizations should do so in an unnumbered Acknowledgments section immediately following the last numbered section of the paper.

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