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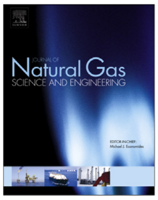

Overall reliability analysis on oil/gas pipeline under typical third-party actions based on fragility theory

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ABSTRACT

Based on fragility and internal & external hazard, an overall reliability model can be established as a theoretical basis for quantitative risk assessment on oil and gas pipeline systems.

In this paper, overall reliability is regarded as conditional probability, including probability of third-party hazard and pipeline fragility. Third parties refer to all individuals, organizations and mechanical tools that cause unexpected damages to pipelines when they are carrying out operations either relevant or irrelevant to pipelines.

By analyzing the propagation, waveform and frequency spectrum of natural seismic waves, the acceleration waveform of an artificial seism is simulated. Also a finite element model of pipeline's seismic response is established. Various pipelines' reactions simulated by ANSYS software are analyzed. Then the fragility probability of pipelines under blasting seismic actions is determined by normal distribution model.

The overall reliability model is established and quantitatively evaluates the risks of Petro-China Gang-Zao product oil pipeline. By comparing the calculation results from algorithm software with the actual situation, the confidence interval of this model is [95%, 100%]. This model can precisely calculate the risk probability of certain pipe sections and then decide which section should be preferentially maintained and protected, increasing the efficiency of pipeline management.

1. Introduction

Over the last few years, the occurrences of pipeline leaks, explosions, fires and other accidents from third-party actions have resulted in great losses of lives, property of the state, and civilians all around the world, thus causing a serious negative impact on both public security and stability. The term “third-party-role” refers to pipeline damages accidentally caused by employees, as well as natural roles such as pipeline deformation caused by soil movement (landslides, mudslides, foundation collapse and floods) and surface load (caused by blasting construction, illegal buildings compressing pipelines and ground live loads). According to United States Department of Transportation (DOT), pipeline accident data shows that between 20% and 40% of pipeline failures are caused by third-party activities (Taolong et al., 2011). During the last few years, 80 people were killed and 250 more were severely injured as a result of just one type of third-party action-excavations. In China, from 2006 to 2016, the total death toll is beyond 100 due to third-party activities, these deaths represent a large negative impact on human lives and overall economic development (Weihe et al., 2015). For example, in 2010, there occurred an explosion in Nanjing due to the breakage of a gas pipeline by improper excavation operations of a house construction group, and over 13 people died in this accident (Liguo et al., 2015). In 2014, because of the improper execution by a road construction team, a huge accident of gas leakage from pipeline cracking took place in Lanzhou, causing the economic loss of nearly 0.7 million dollars (Zijuan et al., 2015).

These occurrences can also impact the advancement and development of the petroleum industry. As a typical third-party action, artificial blasting is a form of destruction posing serious threats to the safety of pipelines. For example, artificial blasting affects the intersection of the ZhangShi highway LJ-N7 section and the Shanxi-Beijing gas pipeline. The Western oil pipeline and the West-East gas transmission line need blasting because of excavations. Such large-scale blasting construction inevitably affects oil and gas pipelines nearby by causing changes in the stress and strain

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on them, which can lead to internal axial vibration and a large amount of displacement in a short period of time. These changes can be shown to have a noticeable impact on the reliability of the pipelines. In this article, a quantitative risk assessment model is established to evaluate overall reliability of pipelines, deciding which pipe section should be preferentially maintained and protected (Steinbrugge, 1969) (Lei and JiamuZhanggao, 2015).

2. The overall reliability analysis of oil & gas pipeline hazards and fragility

Traditional risk evaluations, reliability tests on oil and gas pipeline failure possibilities, and computing methods typically include statistical and analytical methods.

However, for some failure reasons (e.g., illegal construction above pipelines and agricultural tillage), the corresponding failure model and historical failure data have not yet been established, so the failure probability cannot be calculated by using currently available analytical methods (Yang et al., 2011). Thus the fuzzy analysis method of fault tree needs to be adopted to these situations.

However, the results of fault tree analysis are not a pipeline's failure probability, but rather the occurrence probability of hazardous events from third parties and corrosion systems. It does not directly reflect the destruction probability after hazardous events. Thus, it is necessary to analyze pipeline fragility probability when pipelines are experiencing different stages of disaster-causing factors (Zhao and Song, 2016). Failure probability models based on hazard probability and fragility probability of disaster-causing factors must be analyzed as well. After analyzing capacity requirements of probabilistic fragility under different situations, the fragility method will analyze the safety responses under certain hazard strength, as well as failure probability under different stages of disaster-causing factors (Mei, 2014).

2.1. The pipeline dangers - hazard probability analysis

According to fault tree principle, first choose “third party hazard happens” as the top event of pipelines' harmfulness analysis for third-party failure. The most direct reasons for third-party harm include: illegal buildings above pipelines, farming activities, malicious damage, stealing of oil, gas pipeline holing, and compression along pipelines. Any of these causes can lead to leakage and potentially a rupture of a pipeline. Secondly, choose two of the direct reasons as secondary top events, and use a similar procedure to complete a thorough analysis until the basic events are reached (Ge et al., 2015). And Fig. 1 is the fault tree of third-party harm. Table 1 is the corresponding basic event list (see ANNEX).

2.2. Pipeline fragility — analysis on fragility probability

2.2.1. Definition 1: pipeline fragility (Ozaki et al., 1998)

Pipeline Fragility refers to the conditional probability of pipelines transcending a destruction limit when pipelines are under a certain hazard strength. In pipeline risk analysis, the action level parameters of pipeline hazard strength include peak ground acceleration of the seismic blasting near pipelines, dynamic compaction strength and pipeline corrosion velocity, etc. The conditional probability of pipelines transcending the destruction limit state is shown as following:

$$F_{R_i}(a_j) = P[LS_i|A = a_j] \tag{1}$$

where: LS_i—event that is reaching or transcending limit state.-A—pipe hazard strength;$P[LS_i|A = a_j]$—the probability of pipeline transcending limit state “i” when the detrimental effect $A = a_j$.

2.2.2. Definition 2: pipeline fragility demand analysis

Pipeline fragility demand analysis determines the lowest level of security, economical efficiency and applicability ability of pipelines. It is also the strongest reaction aroused by a hazardous event and the probability of that event transcending a given harm level. The demand model of pipeline fragility probability can be defined as the probabilistic statistical relationship between Intensity Measures (IM) and Engineering Demand Parameter (EDP), which is shown as following:

$$P_{EDP|IM}(edp) = P(edp|IM = im) \tag{2}$$

The difference between fragility probability demand analysis and fragility analysis is this: demand analysis only studies pipelines' reactions (displacement reaction or strength reaction) under different hazard levels, while fragility analysis additionally studies the pipeline fragility capacity. Therefore demand analysis is a fundamental premise of fragility analysis.

2.2.3. Definition 3: pipeline fragility capacity analysis

Pipeline fragility capacity is the probability that destruction of a certain level occurs, or that a pipeline transcends a certain capacity level. It represents an attribute of pipelines as being able to resist a certain level of destruction. According to different principles, it can be deformation capacity, residual strength capacity or even energy consumption capacity.

$$G_{DM|EDP}(dm|edp) = P\left(edp > C^{LS}|EDP = edp\right) \tag{3}$$

where: C^{LS}—the boundary value of capacity parameter under destruction states.

Even though different pipelines are under the same destruction state or the same performance level, their capacity of prohibiting the largest reactions may be different. In other words, different pipelines are likely to go into different states though they generate the same reactions.

As to a certain limit state, as long as the probability distribution of C^{LS} is known, the probabilistic anti-destruction capacity of pipelines can be determined, and then the transcending probability can be calculated. Fragility analysis is essential to ascertain the pipelines' reaction capacity limit after the pipeline transcends the destruction state and when experiencing hazards from different conditions and at different levels. This is also the probability of “Demand” being greater than “Capacity”. As long as probability distribution models are determined, the fragility under different levels of harm, which is presented as a fragility curve, can be determined as well (WangCheng, 1979).

2.3. Pipeline overall reliability analysis

Based on the model above, when considering the actions of a third-party, general overall loads generated by the hazards and general overall resistance generated by pipeline fragility are the key components of pipeline risk analysis and overall pipeline reliability analysis. Thus, the risks under the third-party role can be presented by Formula (4), and the basic model of overall reliability analysis can be depicted in Fig. 2.

$$Risk = P_e \times P_f(f|e) \times S \tag{4}$$

where, P_e—Hazard probability under the third party role.P_f—-Fragility probability under the third party role.S—Consequence of pipeline failure under the third party role.