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A method of quantitative risk assessment for transmission pipeline carrying natural gas

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Abstract

Regulatory authorities in many countries are moving away from prescriptive approaches for keeping natural gas pipelines safe. As an alternative, risk management based on a quantitative assessment is being considered to improve the level of safety. This paper focuses on the development of a simplified method for the quantitative risk assessment for natural gas pipelines and introduces parameters of fatal length and cumulative fatal length. The fatal length is defined as the integrated fatality along the pipeline associated with hypothetical accidents. The cumulative fatal length is defined as the section of pipeline in which an accident leads to N or more fatalities. These parameters can be estimated easily by using the information of pipeline geometry and population density of a Geographic Information Systems (GIS). To demonstrate the proposed method, individual and societal risks for a sample pipeline have been estimated from the historical data of European Gas Pipeline Incident Data Group and BG Transco. With currently acceptable criteria taken into account for individual risk, the minimum proximity of the pipeline to occupied buildings is approximately proportional to the square root of the operating pressure of the pipeline. The proposed method of quantitative risk assessment may be useful for risk management during the planning and building stages of a new pipeline, and modification of a buried pipeline.

Keywords: Individual risk; Societal risk; Natural gas pipeline; Risk assessment; Safety management

1. Introduction

Transmission pipelines carrying natural gas are not on secure industrial site as a potentially hazardous plant, but are routed across the land, i.e., busy city or a network of superhighways. Consequently, there is the ever-present potential for third parties to interfere with the integrity of these pipelines. In addition, the combination of third-party interference and pipeline route might suggest that people around the pipelines are subject to significant risk from pipeline failure. The hazard distance associated with the pipeline ranges from under 20 m for a smaller pipeline at lower pressure, up to over 300 m for a larger one at higher pressure [1]. Therefore, regulatory authorities and pipeline managers have endeavored to improve the level of safety of the pipeline.

Recently, safety regulations associated with the pipeline are moving away from prescriptive approaches. As its alternative way, risk management based on the quantitative risk assessment has been under consideration in many countries. Risk is generally defined as a measure of human death in terms of two quantities: the probability of a pipeline failure occurring and the magnitude of death that arise as a result.

Until now, the failure rate of gas pipeline was estimated with high uncertainty from historical data or hierarchical analysis. Some of the failures are time independent, such as those resulting from external mechanical interference by third parties, earthquake or overpressure, while others are time dependent as in cases as corrosion or fatigue failures. The failure rate varies significantly with design factors, construction conditions, maintenance techniques and environmental situation. Thomas [2] proposed an empirical model to correlate the failure rate of the pipe. This approach relies on estimating the failure frequency for leakage and then predicting the

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Nomenclature

A	area bound by hazard range (m^2)
A_p	cross-section area of pipeline (m)
a	constant
a_k	variable of correction function
b	constant
C	decay factor for the effective rate of gas release
D	thermal dose for given exposure time (s $(J/m^2\,s)^{4/3}$)
d	pipe diameter (m)
F	cumulative frequency of the accident with N or more fatalities (1/year)
f_F	Fanning friction factor
H	distance from gas pipeline to populated area (m)
$\bar{H}$	distance from pipeline to populated area scaled by effective rate of gas release $(m/(kg\,s)^{1/2})$
H_c	heat of combustion (J/kg)
h	distance from pipeline to a specified point (m)
$\bar{h}$	distance from pipeline to a specified point scaled by square root of effective rate of gas release $(m/(kg\,s)^{1/2})$
I	radiational heat flux at the location of interest (J/m^2 s)
K_j	correction function associated with failure causes
L	pipe length from gas supply station to leak point (m)
L_{CFL}	cumulative fatal length of pipeline (m)
L_{FL}	fatal length of pipeline (m)
$\bar{L}_{FL}$	fatal length scaled by square root of effective rate of gas release$(m/(kg\,s)^{1/2})$
$l_{\pm}$	ends of interacting section (m)
$l_{50–1}$	length of pipeline within from 50 to 1% fatality (m)
$l_{99–50}$	length of pipeline within from 99 to 50% fatality (m)
$l_{100–99}$	length of pipeline within from 100 to 99% fatality (m)
N	expected number of fatalities (person)
$\bar{N}$	number of fatalities scaled by release rate and again by population density (m^2 s/kg)
$N_{i,a–b}$	number of people within the range from a to b% fatality (person)
P	probability of death
Pr	Probability unit
p_0	stagnation pressure at operating condition (N/m^2)
Q	rate of gas release from a hole (kg/s)
Q_{eff}	effective rate of gas release from a hole (kg/s)
Q_{peak}	peak initial rate of gas release from a hole (kg/s)
$Q_{steady\text{-}state}$	rate of gas release from a hole at steady-state (kg/s)
Re	operator of complex number
r	radial distance from fire (m)
$\bar{r}$	distance from fire scaled by square root of effective release rate $(m/(kg/s)^{1/2})$
r_1	radius of fatality 1% (m)
r_{50}	radius of fatality 50% (m)
r_{99}	radius of fatality 99% (m)
r_h	hazard distance (m)
t	expose time (s)
u	unit function

Greek letters

α	dimensionless hole size
φ	expected failure rate per unit pipe length (1/year km)
γ	specific heat ratio of gas
η	ratio of total heat radiated to total heat released from fire
ρ_0	stagnation density at operation condition (kg/m^3)
ρ_p	population density ($person/m^2$)
τ_a	atmospheric transmissivity

subscript

i	denotes the accident scenarios such as small, medium and great hole on the pipeline
j	denotes the cause of failure such as external interference, construction defects, corrosion, ground movement and others

rupture frequency. The failure rate for leakage is estimated from global statistics by using an observed correlation of geometric and weld material factor. This estimate is scaled by other factors such as plant age. The failure rate of ruptures is evaluated with a given failure rate of leakage, partly by using a fracture mechanics model. The Thomas model may be suitable for estimating failure rate of pipes or vessels in a chemical plant. However, it is inappropriate to use it for transmission pipelines carrying natural gas because some of the most serious pipeline accidents resulting in ruptures have been caused by third-party activities which are not included in the Thomas model. In this work, the failure frequencies are estimated simply from the historical data of the European Gas Pipeline Incident Data Group (EGIG) and BG Transco [3,4].

The consequences of accident depend on its scenarios of the elements, such as hole size on the pipeline, time to ignition, meteorological condition and environmental condition at the failure point. In risk assessment, therefore, different results may be obtained depending on the assumptions of accident scenarios. Tedious calculations are sometimes unavoidable because of many accident scenarios and the distribution of hazard sources along the pipeline. However, investigation of real accidents associated with natural gas pipelines shows