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Seismic vulnerability analysis

The case study of the 3rd Azerbaijan gas pipeline in Iran.

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Abstract

Seismic vulnerability analysis is an important issue in post-earthquake decision making. Therefore, as a consequence of seismic activity in Iran, one of the existing routes of natural gas pipelines was selected for the seismic analysis. The seismic faults around the pipeline (150 Km distance in each side) were identified and their seismicity parameters were obtained. Probabilistic Seismic Hazard Analysis (PSHA) for the case study was performed and leads to a hazard map on the study region. By knowing the natural gas network components, their respective fragility curves through the HAZUS technical manual were established. Different data layers including geometrical property of seismically active faults, hazard map, pipeline joints, compressor stations and seismicity parameters were combined and provide an appropriate seismic vulnerability model on the basis of Geographical Information System (GIS). Finally, by implementing the HAZUS methodology and the practices of National Iranian Gas Company (NIGC) experts, the financial losses of the probable seismic scenarios were determined. The results reveal the financial consequences of different earthquake scenarios and highlight the necessity for reasonable risk mitigation plan.

Background

Seismic risk vulnerability is one of the important analyses in the reliability management in any lifeline system. It is the matter of the both mechanical characteristic of the structure and the earthquake excitation specifications. This study will be divided into two major parts:

- Discussion related to the strong ground motion and its characteristics,
- Discussion related to gas network components.

Now a brief history of previous studies and results is presented here:

A study on natural gas transmission pipelines was conducted by Portante (2009), in order to simulate the local and downstream impacts of the New Madrid and Wabash Valley seismic scenarios which are wide-areas of distributed systems.

In 2008, Song and Chang performed a case study about the natural gas network of the Shelby county of Tennessee using the HAZUS methodology. They aimed to assess possible seismic damages to the gas network owned by MLGW Company. To reduce the complexity of the large scale urban infrastructure system, the matrix-based system reliability analysis was used.

In 2007, Toprak and Taskin studied a case to estimate earthquake damage caused by ground shaking using Geographical Information System (GIS) and HAZUS methodology for the city of Denizli, Turkey.

Wong et al. (2005) conducted a seismic loss assessment project, for the lifeline systems of the South Carolina state. One of the major objectives in their study was to provide a reliable basis for strategic planning issue using the HAZUS methodology.

A similar project was conducted by Xie et al. (2000) for the Daqing oil field, oil transmission pipeline to assess its possible earthquake losses. The main issue in this project was to provide a reliable basis for an intelligent decision making system to be applied in emergency situations.

In 2004, different ground motion intensity measures were taken into account as an independent variable. The study was performed by Hwang et al. for Chi-Chi earthquake in Taiwan.

Yamin et al. (2004) was performed a seismic loss assessment for the gas pipeline in Colombia. They considered natural hazards including earthquake, landslide, liquefaction and volcano.

Great east Japan earthquake (2012) was a start point for the Mori et al. to analyze a gas transmission pipeline. Finally, they developed a seismic safety assessment method for pipeline for different damages based on a field survey.

A recent study performed by O'Rourke et al. (2014) showed the underground pipeline network response to the Canterbury earthquake sequence in Christchurch, NZ. This study was included the response of gas distribution system to 7.1 Mw in the case of 4th September 2010, 22nd February and 13th June earthquake events. They concluded that the excellent performance of the gas distribution network was the result of using high ductility polyethylene pipes.

In the current study, the seismic vulnerability assessment was performed for the existing route of the 3rd Azerbaijan gas pipeline in Iran.

Aim

A brief definition of the case study and methodology

In the high seismic potential zones in the world, seismic risk management and disaster prevention activities are very important to the officials. The main purpose of such studies is to produce loss estimations for use by state, regional and local governments in planning for earthquake risk mitigation, emergency preparedness, response and recovery. Also it will cause feeling safe and comfortable of domestic and industrial customers.

Seismic performance assessment of the gas distribution network is a very important issue especially in Iran because of its crustal structure with high potential seismic activity. The 3rd Azerbaijan gas pipeline is one of the suppliers of the green energy source in the north-west of Iran. This 48 inches diameter pipeline has been built in 2007 by National Iranian Gas Company (NIGC).

This study in the hazard estimation model is based on the HAZUS methodology developed by FEMA (Federal Emergency Management Agency). This methodology is one of the validated methods for seismic hazard analysis, risk assessment and producing loss estimation model.

Methods

An Introduction to the FEMA Loss Estimation Methodology (HAZUS)

The HAZUS-MH Earthquake Model has been tested against the judgment of experts and, to the extent possible, against records from several past earthquakes. The overall approach for the project is based on the following "vision" of the earthquake loss estimation methodology. The methodology may be implemented using geographical information system (GIS) by application of the theory documented in the HAZUS Technical Manual.

The HAZUS methodology has divided lifelines into two main categories:

1- Transportation system
2- Utility system.

Natural gas network is a part of the utility systems. Damages to a lifeline system will cause both direct and indirect losses. Based on the HAZUS Technical Manual, the required data for the natural gas system analysis are

1- The geographical location,
2- Classification of system components,
3- Peak Ground Acceleration (PGA),

4- Peak Ground Velocity (PGV),

5- Permanent Ground Deformation (PGD),

6- The replacement cost for system components.

Discussion related to the strong ground motion:

Seismic Hazard model

During a ground motion, lots of parameters are measured and calculated to recognize the earthquake characteristics. PGA, PGV and PGD are the most important parameters. In order to determine PGA, PGV & PGD, Probabilistic Seismic Hazard Analysis (PSHA) is used. The main prerequisites for the PSHA are:

(1) Seismic source type and geometry,

(2) Source seismicity,

(3) Attenuation relations.

Seismic source type and geometry

Seismic sources in Iran are typically line sources which known as "Fault". The geometry of each major source was defined based on the available fault maps (Berberian 1976, 1994) as shown in (Figure 1).

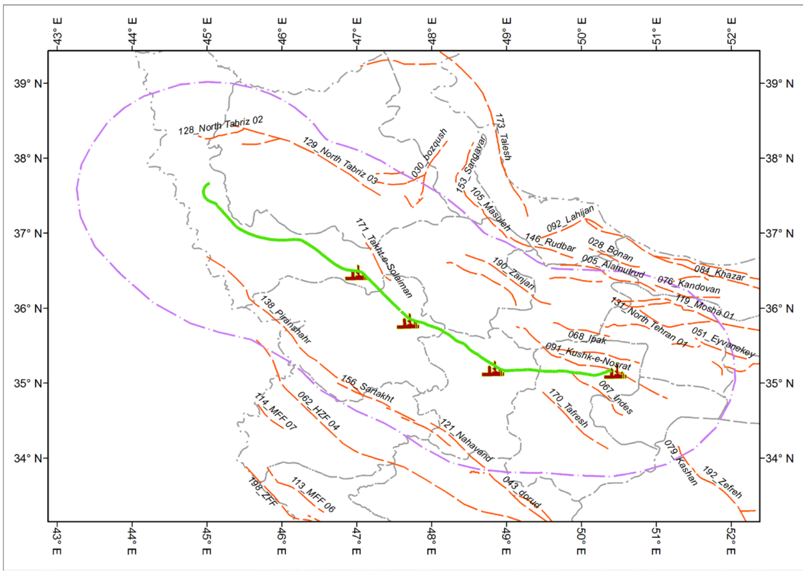

Figure 1: Geometry of seismic sources and the overall view of the pipeline route under investigation.

Source seismicity parameters

The possible potential of earthquake magnitude of any seismic source is known by these parameters. The source seismicity data is based on the previous studies conducted by seismic researchers, after modelling all recorded seismic events by means of the historical and instrumental records. Earthquake engineers established several seismically clustering models for Iran as indicated in Table 1. In current study, a clustering model which was introduced by Tavakoli and Ghafory-Ashtiany (1999) was chosen in order to assign the seismicity parameters.

Seismicity parameters were applied using "Poisson model with Guttenberg-Richter parameters" instead of "Characteristic earthquake model" in CRISIS2007 software which was used for PSHA. An area of 150 kilometers radius around the pipeline is considered as seismically active region. Seismicity parameters for the selected zones of Tavakoli and Ghafory-Ashtiany model (λ and β indices of the Guttenberg-Richter relations and $M_{(observed)}$) are shown in Table 1. The chosen seismic provinces as well as the 150 km band pipeline are shown in Figure 2.

Table 1 : Different models for seismically clustering and seismicity parameters for the selected seismic provinces by Tavakoli et al. 1999.

Clustering Model	Year	Number of seismic Provinces
Stocklin	1968	9
Takin	1972	4
Berberian	1976	4
Nowroozi	1976	23
Tavakoli	1999	20

Province number	β	M_{max}	$M_{(observed)}$	λ
8	1.34	7.4	7.2	0.16
9	1.4	7.3	6.8	0.27
11	1.59	7.6	7.4	0.48
12	1.98	7.2	7	1.7
15	1.19	7.9	7.7	0.37
16	1.83	7.6	7.4	0.14
17	1.68	7.5	7.3	0.53

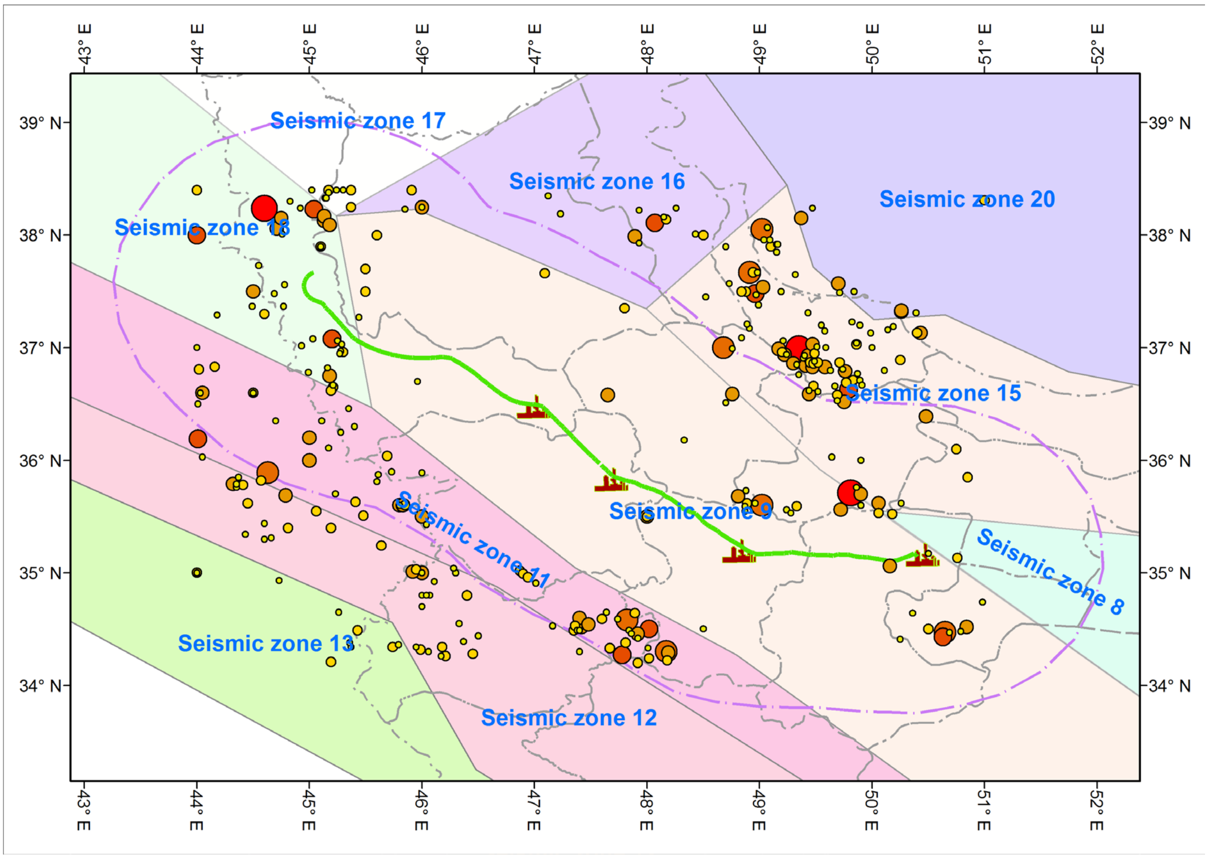

Figure 2: study region and the contributing seismic provinces.

Attenuation relationship

Attenuation relationships are developed to implement the distance and earthquake magnitude at source and the ground type effects on the observed magnitude at site. Using logic-tree combination in attenuation relation leads to better accuracy, so eight attenuation relations, which have good fits to the Iranian database, were used with their respective weights (Mousavi et al. 2012) (Table 2). The output parameter of the PSHA is determined by means of the given attenuation relationships.

Table 2: The applied attenuation models and the assigned weights.

Model name	Assigned Weight
Zafarani et al. (2011)	0.182
Ghasemi et al. (2009)	0.174
Sharma et al. (2009)	0.174
Akkar and Bommer (2010)	0.098

Abrahamson and Silva (2008)	0.096
Boore and Atkinson (2008)	0.087
Chiou and Youngs (2008)	0.097
Kalkan and Gulkan (2004)	0.092

Calculation of the required seismic hazard parameters.

1- **PGA** commonly derived as an explicit result of PSHA and could be used in calculating damages to compressor stations and also in calculating PGD.

2- **PGV calculation:** Some of the attenuation relationships don't have the ability to explicitly calculate PGV. To deal with this problem, HAZUS recommends to use an empirical relationship to calculate PGV as a function of Spectral Acceleration at T=1 sec (Sa1) as written in Equation [1].

$$PGV = \left(\frac{386.4}{2\pi} * S_{a1} \right) \Big/ 1.65 \qquad \textbf{[1]}$$

3- **PGD calculation:** The PGD parameter is the resultant of three types of ground failure: liquefaction, surface rupture and landslide. Since the co-seismic fault slip at depth does not usually propagate to the earth's surface in the Zagros region (Talebian and Jackson 2004), therefore, this source of PGD was neglected in this study. The landslide hazard was also ignored due to the soil/geologic conditions of the studied region. The geological investigations showed that the soil is dry and also the slope angle is below five degrees in the majority sections of the route. Thus, the liquefaction was assumed as the only source of the probable PGD.

The probability of liquefaction occurrence, at a given site, is primarily affected by the susceptibility of the soil and the amplitude of ground motions. Based on the statistical modelling of the empirical liquefaction catalogue, presented by Liao et al. 1988, Equation [2] has been proposed thoroughly estimate the conditional liquefaction probability for the moderately susceptible zones at a specified level of PGA:

$$\begin{gathered} P[Liquifaction | PGA = pga] = 6.67\,pga - 1 \\ 0 \le P[Liquifaction | PGA = pga] \le 1.0 \end{gathered} \qquad \textbf{[2]}$$

The above Equation has been developed for M=7.5 earthquake moment magnitude, and for five feet ground water depth. The chance of liquefaction is significantly affected by earthquake magnitude, M, and ground water depth, so the probability of liquefaction can be determined as written in Equation [3]:

$$P[Liquifaction] = \frac{P[Liquifaction|PGA = pga]}{K_M.K_W} P_{ml} \qquad [3]$$

$$K_M = 0.0027M^3 - 0.0267M^2 - 0.2055M + 2.9188$$

$$K_W = 0.022d_w + 0.93$$

***K_M & K_W:** The moment magnitude and ground water depth correction factors respectively.*

***d_w:** depth to the ground water in feet.*

***P_{ml}:** a correction factor equal by 0.10 for moderately susceptible soils.*

The liquefaction susceptibility map is provided by the International Institute of Earthquake Engineering and Seismology (IIEES) by Komakpanah et al. (1995) as seen in Figure 3. According to this map, none of the compressor stations are located in the liquefiable zones but some parts of the pipeline are placed in the moderately susceptible zones. Further details about calculating expected PGD are available in the HAZUS Technical Manual.

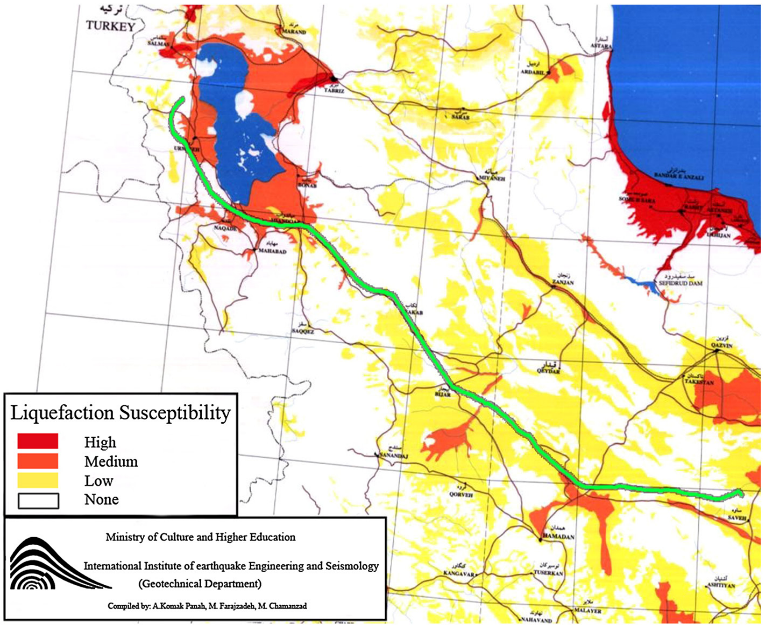

Figure 3: Liquefaction susceptibility map (Komakpanah et al. 1995)

The ground water depth conservatively assumed to be five feet in the susceptible regions and the moment magnitude was taken from Tavakoli and Ghafory Ashtiany model's maximum magnitude. By performing the aforementioned procedure in the GIS platform, the expected value of PGD conditioned to the liquefaction occurrence is in hand to calculate the repair rates of the pipeline in different hazard levels i.e. 475 or 2500 years return periods.

Discussion and analyses related to gas network and its components.

Definition of natural gas transmition network

Typically a natural gas transmition network consists of two components: pipelines and compressor stations. Pipelines may be built above ground (exposed) or underground (buried). Pipelines are typically made of mild steel with arc welded joints, although older pipelines may have gas-welded joints. These old pipelines are categorized as "brittle" and the other type is known as "mild". All of these types are vulnerable against probable earthquake. These are used for the transportation of natural gas over long distances. Many industries and residents could be severely affected if disruption of the natural gas supplies occurs. The 3rd Azerbaijan gas pipeline is made of mild steel with arc-welded joints.

Compressor stations serve to maintain the flow of gas in cross-country pipelines. Typically compressor stations are using gas turbine powered centrifugal compressor. Compressor stations are categorized as having either anchored or unanchored subcomponents. Compressor stations with unanchored subcomponents are more vulnerable to the earthquake comparing compared with the anchored ones. Compressor stations are divided into four main subcomponents.

1- Electric backup power,
2- Compressor,
3- Building,
4- Mechanical/Electrical equipment.

Based on the HAZUS technical manual, damages implied to a natural gas system shall be calculated respectively in pipelines and compressor stations. Pipelines are vulnerable to PGV and also PGD only in the case of liquefiable or landslide threats. On the other hand, compressor stations are mostly vulnerable to PGA and also PGD if located in a liquefiable or landslide zones.

As an important limitation of the roughly proposed fragility curves in HAZUS, the active fault crossing effects on the gas pipeline are not included. Therefore, the accuracy of the resulted loss should be suspected in the specified situations. The step-like permanent ground deformation, induced by the active crossing faults to the pipeline, has been reported as a significant factor of rupture (i.e. Stewart 2001). Hence, numerous studies have been focused on the numerical and experimental analysis of this issue (i.e. Karamitros et al. 2007; Takada et al. 2001; Trifonov and Cherniy 2010; Vazouras et al.

2012; Xie et al. 2013). Fortunately, as shows in Figure 1, the 3rd Azerbaijan gas pipeline is not crossed by any fault and therefore, the HAZUS rough fragility curves seem to be satisfactory.

According to liquefaction susceptibility map in Iran (Figure 3), in the current study, the compressor stations are not located in liquefiable grounds. Hence, there is no need to study PGD damage algorithm for the stations and only PGA is applicable for these compressor stations. As mentioned in the previous section, the PSHA analysis and the applied attenuation relationships make it possible to obtain PGA for these four compressor stations.

Damages and losses to pipelines

As mentioned before, the 3rd Azerbaijan gas pipeline is of the ductile pipeline type. The required inputs to estimate the damage to the given Natural Gas pipeline are: Geographic location of the pipe links, PGV, PGD and pipeline classification (Brittle or Ductile). The considered pipeline may encounter two damage states which are leak and break. Generally when a pipe is damaged due to the ground failure, the type of damage is likely to be break whereas the type of damage is likely to be a leak when the pipe is damaged due to seismic wave propagation. In the loss methodology, it is assumed that the damage due to seismic waves consists of 80% leaks and 20% breaks, while damage due to ground failure consists of 20% leaks and 80% breaks.

Pipeline Repair Rate due to wave propagation (PGV Algorithm)

Based on the post empirical studies by O'Rourke and Ayala (1993), the damage functions for ductile pipelines due to ground shaking were established as written in Equation [4].

$$\text{RepairRate}[\text{Repair}/Km] \cong 0.3 * 0.0001 * PGV^{2.25} \qquad \textbf{[4]}$$

PGV: Peak Ground Velocity (cm/sec).

By applying Equation [4], the repair rates is calculated for the pipeline in two hazard levels i.e. 475 and 2500 years return periods. Table 3 shows the total calculated numbers of Leaks and Breaks in the whole pipeline. Finally the pipeline is classified into five vulnerable classes as shown in Figure 4.

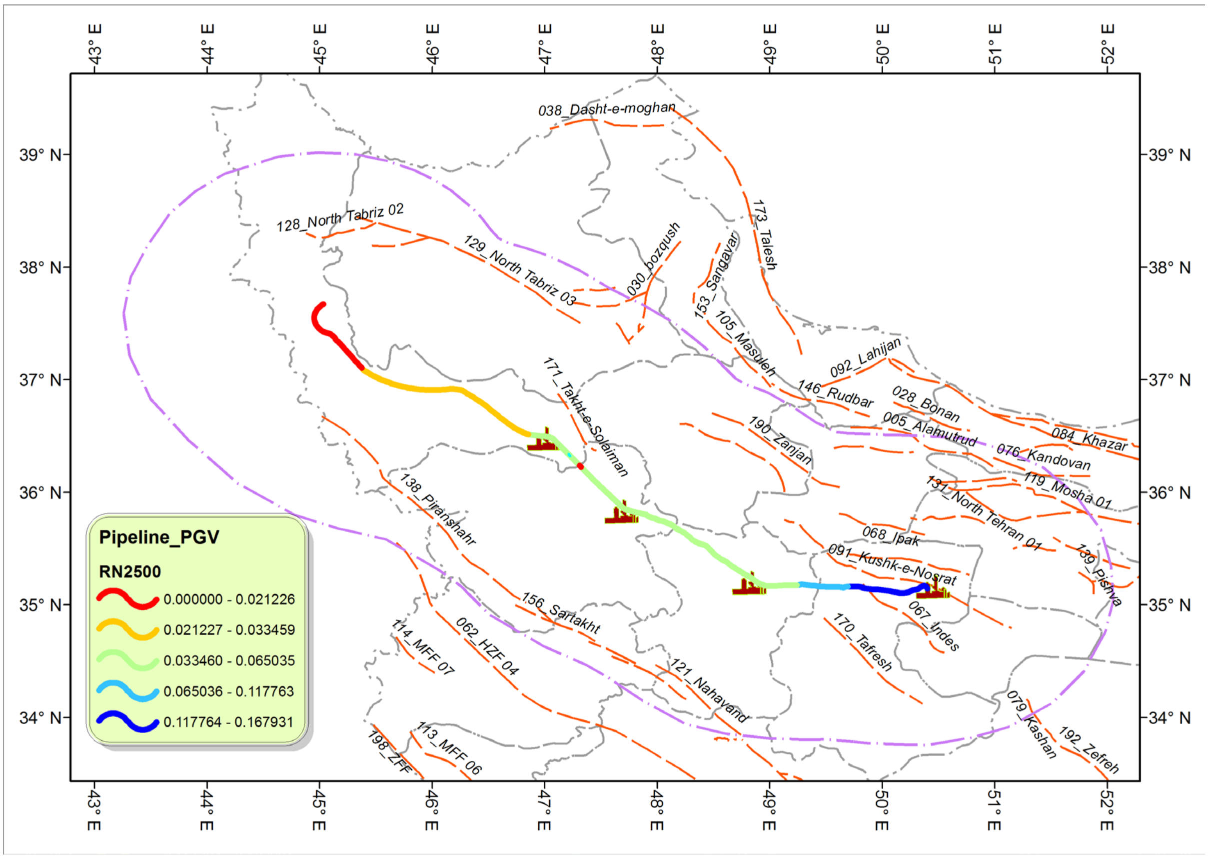

Figure 4: Repair number caused by PGV for 2475 years return period.

Pipeline Repair Rate due to ground failure (PGD Algorithm)

The damage algorithm for buried pipelines due to ground failure is based on research conducted by Honegger and Eguchi (1992) for the San Diego County Water Authority (SDCWA). Equation [5] shows the best-fit function to the fragility curve for the pipeline subjected to PGD.

$$\text{RepairRate}[\text{Repair}/\text{Km}] \cong 0.3 * \text{Probability}[\text{Liquefaction}] * PGD^{0.56} \quad [5]$$

PGD: Permanent Ground Deformation (Inch).

$$RepairRate\left(\frac{Repair}{Km}\right) \cong Probability[Liquefaction] \times PGD^{(0.56)}$$

The repair rate, due to ground failure, is calculated using Equation [5]. To estimate probable damages to pipeline, PGD values along the pipeline segments are calculated. The total amount of these parameters is shown in Table 3. Based on the HAZUS methodology, damages caused by PGD consist of 80% breaks and 20% of leaks.

Table 3: The total repair numbers, leaks and breaks along pipeline in 475 and 2500 years return periods.

Parameter Name	Total Repair number along whole pipeline (caused by PGV)	Total Repair number along whole pipeline (caused by PGD)
Repair Number 475 years	4.063306	4.082
Break number 475 years	0.812652	3.265
Leak number 475 years	3.250671	0.817
Repair Number 2500 years	10.088101	5.844
Break number 2500 years	2.017629	4.675
Leak number 2500 years	8.070484	1.169
Pipeline Length (Kilometres)	618	618

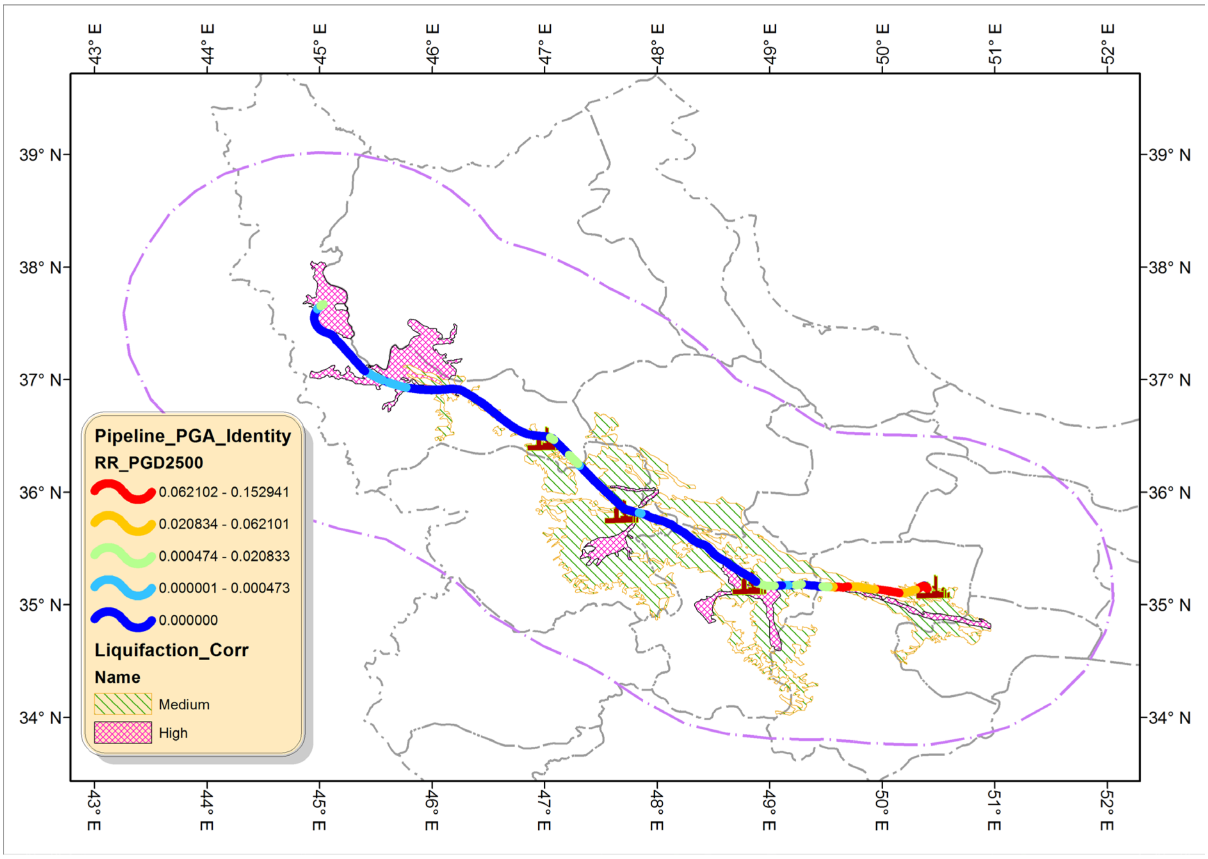

Figure 5: Repair number caused by Ground Failure for 2475 years return period.

Monetary loss for pipeline

The monetary direct losses are calculated based on the Iranian practice and local conditions. In this case, losses are calculated by means of expert opinions in NIGC. The direct loss for the gas pipeline consists of two major parts: (1) the vented gas cost, and (2) the repair cost.

The vented Gas Cost

Prior repairing the damaged section of gas pipeline, usually it is necessary to completely vent the 20 kilometres length sections, which are between each two Line Break Valves (LBV). These valves automatically and immediately close when pipeline breaks at the upstream or downstream. In the case of line break or line leak, the closest two LBVs to the damaged section isolate the pipe section and only the containing gas of this part is vented. By assuming the average working pressure of pipeline as 55 bars, and the natural gas as an ideal gas, the vented volume of gas is calculated:

$$\text{Gas Volume}\left(\text{m}^3\right) = \frac{\pi D^2}{4} * L * P_{ave} \qquad [6]$$

D: pipeline diameter(m)

L: pipeline section length(m)

P_{ave}: average working pressure(bar)

In the case of current study, the wasted gas volume is 1,284,000 cubic meter. Each cubic meter is about 35.315 cubic feet and one thousand cubic feet of natural gas costs approximately 3.1 U.S. dollars. Therefore, the vented gas cost/repair is approximately 140,500 U.S. dollars.

The Pipeline Repair Cost

The pipeline repair cost, as a consequence of the mobilization costs, machinery transfer for each repair and lack of time, is approximately 5 to 7 times more than the construction procedure. As a reasonable rough estimation, an amount of 5000 U.S. dollars is needed in order to repair a meter of 48 inch gas pipeline. The pipeline repair procedure (and consequently the corresponding cost) differs for the leak and break.

In the case of leak, the containing gas is vented. The repair procedure can be either based on pipe section replacement or using sleeves. The normal sleeve width for 48 inch diameter pipeline is about 70 cm. In the case of extensive leaks, the pipe section needs to be replaced. The repair cost for a common leak is approximately 3500 U.S. dollars.

In the case of break, the pipeline immediately explodes because of high working pressure. In some cases, neighbour welded joints were extremely affected and needed to be repaired. For the break damage state, at least a 12 meters length pipe needs to be replaced. Therefore, the repair cost for each pipeline repair is approximately 60,000 U.S. dollars.

Table 4: Damage to Pipeline and Loss for 475 Years Return Period.

Damage to Pipeline and Loss for 475 Years Return Period					
	Number of leak	Number of break	Vented gas cost	Pipe repair cost	**Total loss**
PGV Algorithm	3.2	0.8	562,000	59,200	**621,200**
PGD Algorithm	0.8	3.2	562,000	194,800	**756,800**

Table 5: Damage to Pipeline and Loss for 2500 Years Return Period.

Damage to Pipeline and Loss for 2500 Years Return Period					
	Number of leak	Number of break	Vented gas cost	Pipe repair cost	**Total loss**
PGV Algorithm	8	2	1,405,000	148,000	**1,553,000**
PGD Algorithm	1.2	4.7	829,000	286,200	**1,115,200**

Compressor Station damages and monetary losses

Damages to compressor stations

All of the compressor stations, along the pipeline, have anchored subcomponents. Therefore, the required parameters, in order to calculate the probability of exceeding a certain damage state, are derived from fragility curves which are shown in Figure 6. Five damage states are considered for the compressor stations: (1) None, (2) Minor/Slight, (3) Moderate, (4) Extensive and (5) Complete. PGA is the main important parameter for the compressor stations damage ratio. For the four compressor stations in the two considered hazard levels (i.e. 475 and 2500 years return period) the probability of each damage state is calculated and presented in Table 6.

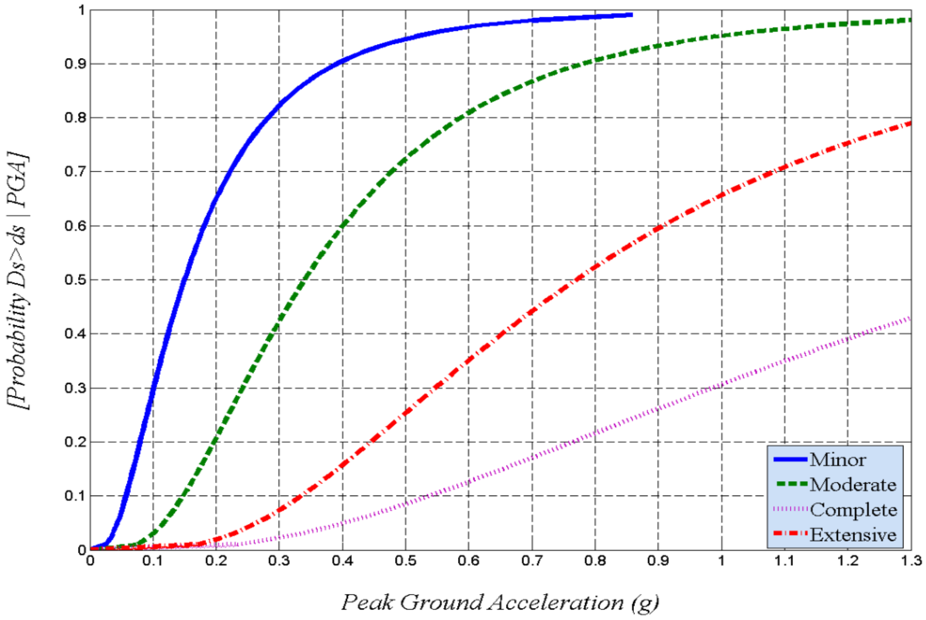

Figure 6: Fragility curve for compressor stations.

Table 6: Damage states probability for compressor stations.

Station Name	PGA 475 years (g)	No Damage	Minor	Moderate	Extensive	Complete
Station 1	0.24	27%	47 %	22 %	3 %	1 %
Station 2	0.11	77 %	21 %	2 %	0 %	0 %
Station 3	0.09	78 %	20 %	2 %	0 %	0 %
Station 4	0.12	60 %	35 %	4 %	1 %	0 %

Station Name	PGA 2500 years (g)	No Damage	Minor	Moderate	Extensive	Complete
Station 1	0.46	13 %	24 %	43 %	13 %	7 %
Station 2	0.18	42 %	43 %	14 %	1 %	0 %
Station 3	0.15	45 %	34 %	21 %	0 %	0 %
Station 4	0.25	22 %	55 %	19 %	3 %	1 %

Monetary Loss for the Compressor Stations

The HAZUS methodology divides a compressor station into four subcomponents: (1) Electric Backup power, (2) Pump, (3) Building and (4) Electrical/Mechanical Equipment with their respective fraction of total compressor station value. A common compressor station for the 3rd Azerbaijan Gas Pipeline with all its subcomponents costs approximately 40 million U.S. dollars.

The damage ratio for the subcomponents of each compressor station was calculated by using the probability of being in a certain damage state as seen in Table 7 and Table 8. It is worth noting that the damage ratio, for each subcomponent, is calculated based on its own fragility function. Additionally, the total damage ratio, for each compressor station in the two intensity levels (i.e. 475 and 2500 years return period), was calculated as written in the last row of each table. Finally, the corresponding monetary loss, caused by PGA for 475 and 2500 years return period, was calculated.

Table 7: Calculation results for Compressor Stations Monetary Losses (475 Years ReturnPeriod).

Subcomponents	*Fraction of Total Component Value*	*Damage Ratio for 475 years return period*			
		Station 1	Station 2	Station 3	Station 4
Electric Backup Power	30%	0.1186	0.0069	0.0042	0.0214
Pump	20%	0.0006	0. 000112	0.000092	0.0001226
Building	20%	0.179	0.0538	0.036842	0.0626
Electrical/Mechanical Equipment	30%	0.0054	0.00042	0.000345	0.0004596
Total	**100%**	**7.312%**	**1.29784%**	**0.87503%**	**1.91024%**
Compressor Station Monetary Loss		**$2,924,800**	**$519,136**	**$350,012**	**$764,096**
Total Monetary Loss for Compressor Stations		**$4,558,044**			

Table 8: Calculation results for Compressor Stations Monetary Losses (2500 Years Return Period).

Subcomponents	*Fraction of Total Component Value*	*Damage Ratio for 2500 years return period*			
		Station 1	Station 2	Station 3	Station 4
Electric Backup Power	30%	0.0184	0.0011	0.00055	0.0013
Pump	20%	0.0096	0.0002	0.000152	0.000736
Building	20%	0.4637	0.12	0.0906	0.1892
Electrical/Mechanical Equipment	30%	0.0588	0.0012	0.0006	0.006264
Total	**100%**	**11.782%**	**2.473%**	**1.84954%**	**4.02564%**
Compressor Station Monetary Loss		**$4,712,800**	**$989,200**	**$739,816**	**$1,610,256**
Total Monetary Loss for Compressor Stations			**$8,052,072**		

Results

Total monetary loss for Gas System

As previously discussed, the monetary losses for the two hazard levels of 475 and 2500 years were calculated as followings:

Total loss for 475 years return period:	**Pipeline:**	**1,378,000 $**
	Compressor Station:	**4,558,044 $**
Total loss for 2500 years return period:	**Pipeline:**	**2,668,200 $**
	Compressor Station:	**8,052,072 $**

Conclusions

The main aim in this study is to estimate the corresponding loss during and after a probable future earthquake in the region of the 3rd Azerbaijan gas pipeline in Iran. All of analyses were performed with spatial coordinates and on the GIS basis. In addition to the PSHA procedure along the pipeline, the HAZUS methodology was also implemented as the main skeleton for the loss estimation purpose. Due to incompatibility of the HAZUS approach with the domestic practices for the pipeline repairing cost analysis, a different methodology was proposed for more accurate monetary loss estimation. Including the vent gas cost in the total loss model can be accounted as one unique aspect of the proposed methodology. The final results reveal that the financial loss, corresponding to the 475 and 2475 years return period earthquakes, respectively, exceeds 5.9 and 10.7 million dollars which highlight the necessity for reasonable risk mitigation plan.

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