Journal of Ferdowsi Civil Engineering, Vol.27, No.1, 2016.

Fire Risk Assessment of Gas Infrastructure for Different Urban Land Use after Earthquakes (Case Study: District No. 20 of Tehran Metropolitan)

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1. Introduction

An analysis of the consequences of previous earthquakes shows that the most important issue following an earthquake is fire and explosion caused by gas network leaks, and, consequently natural gas networks have a high importance among the various different lifelines. Because of the old age of gas pipelines in district No. 20 of Tehran, and, in some cases, the passage of gas pipes across existing faults or in close proximity to them. T, these municipal districts have a high risk potential at times of probable incidents such as earthquakes and subsequent fires. Therefore, in this research an analytical method for calculating the probability of ignition due to problems in gas pipelines and the adjacent power distribution network following an earthquake and its consequences on different forms of land-use in district No. 20 of Tehran are presented.

2. Methodology

This research process includes five stages: 1-The analysis of seismic hazards, 2- The estimation of failure vulnerability against an earthquake, 3- The hazard analysis of fire following an earthquake, 4- The analysis of gas network flows, 5- The analysis of ignition and its consequence following an earthquake.

Ihe first stage for analysis of seismic hazard, electricity and gas network components characteristics of the study area, and existing land uses were identified. Moreover, the relevant information in segregated information layers were entered into the geographic information system using "ARC GIS" software. Then three probable earthquake scenarios (North of Ray fault, South of Ray fault, and North of Tehran fault) for the study area were considered. Then, after choosing appropriate attenuation relationships, the seismic parameters (Peak Ground acceleration and Velocity) for each of the segments of gas pipelines were calculated, which had previously been done in GIS.

In the second stage, the following were calculated for each of the three earthquake scenarios for estimating earthquake vulnerability, repair rate, probability of damage following an earthquake on the basis of Peak Ground velocity, its repair rate, and the probability of damage from Permanent Ground deformation (by using HAZUS methodology) in the center of each considered segment . In this stage, the damage probability of the considered segment in each repetition of the Monte Carlo simulation was compared with a random number in order to determine the kind of damage in the segment that was broken or had leaked,. Then the damage probability of the aerial power distribution lines in different damage states in the district was calculated.

In the third stage, for estimation of the ignition probability of each of the gas pipeline segments, the Fault Tree method was used. In this stage, in the considered fault tree method, two integral factors for fire following an earthquake – the source of spark, and the damage of the gas network – were considered. For this aim, the probability of existence of a flammable fuel was considered to be equal to the probability of the failure or leak of a gas pipeline. The probability of existence of the source of spark was assumed to be equal to the probability of a spark from the power distribution network due to damage. Finally, with the combination of ignition probability from leaking and failure in different damage states of the power distribution network, the ignition probability for each of the segments was obtained. In this stage, in order to determine whether or not the considered segment would be ignited, the ignition probability of the considered segment in each repetition of the Monte Carlo simulation was compared with a random number, and a decision was made accordingly.

In the fourth stage, with the specified break and leak points in the pipelines, the output gas rate from the damaged places was calculated using flow analysis. To this end, the times of an earthquake for two periods being morning and night were considered for a given consumption scenario. Then, flow analysis was done, and the gas pressure and volume inside the pipe segments and the leak rate for completion of the necessary information for ignition and explosion analysis were calculated using the Panhandle B equation.

In the fifth stage an analysis of ignition and its consequences after an earthquake was done. To this end, the necessary information for calculation of the fire radius of the ignited segments was collected using PHAST software and the radius of seven types of fire of different intensities was calculated (Witlox and Holt 2007). In this regard, the residential, industrial, educational and governmental sectors were chosen for analysis due to their proximity to pipelines and high exposure. Then, seven kinds of fire analysis were performed using GIS software in an oval shape on the ignited segments of the gas pipelines and the following cases were calculated:

1) The land-use areas affected by fire following an earthquake.

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2) The total area affected by fire following an earthquake.
3) The total population affected by fire following an earthquake.

In this research, the mentioned procedure (from stage 2 to the end) were repeated for each earthquake scenario using the Monte Carlo model for simulation of probabilities with a large number of iterations. In this way, the uncertainties about a break or leak and ignition for each segment for each earthquake scenario were modeled. Finally, the output results for the considered scenarios were analyzed statistically, and the probability distribution function of the output variables and their uncertainty were determined.

3. Results and discussion

Based on the results of this research in the extreme state which is related to the second scenario (South of Ray fault), on the average, the occurrence of four leaks, one break, and two ignitions due to damage of the 20- and 30-inch pipelines, the total area affected by the four mentioned occupancies was 25233 m^2, the affected number of people was 146 and the area of the affected district was 41210 m^2 due to a fire with a heat intensity of 4 kw/m^2 for the period of 18:00-23:00 hours. By applying the solution based on the replacement of the brittle pipes with flexible pipes, the mentioned results in the leak state were reduced by 75%, in the break state they were reduced by 100%, and in the ignition state they were reduced by 100%, the total area affected by the four mentioned occupancies was reduced by 82%, the affected population was reduced by 83%, and the area of the affected district was reduced by 83%.

4. Conclusion

The proposed model including different modules of system identification, seismic hazard analysis, vulnerability assessment of gas and power networks, probability analysis of fire following earthquake of the damaged gas network, flow analysis of the damaged natural gas pipelines, ignition and consequence analysis including Monte Carlo simulations may be used as powerful tools in fire risk analysis of urban areas after earthquakes.