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RESEARCH AND DEVELOPMENT ON FRAGILITY OF COMPONENTS FOR THE GAS DISTRIBUTION SYSTEM IN GREATER TEHRAN, IRAN

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SUMMARY

As part of the project to estimate reliability of the gas system in Tehran against earthquake, research to set fragility curves for components of the system was executed. In order to apply methods used in the Japanese specification to estimate fragility of high pressure welded steel pipe against liquefaction, analyses were done for the pipe used in Iran and the applicability was confirmed. Regarding with the low pressure facilities, it was expected the part of house/service pipe was most vulnerable, but damage data due to past earthquakes in Tehran was not available. Therefore, fragilities of the housing/building structures were supposed and used as the index to estimate fragilities of low pressure facilities from the experience due to 1995 Kobe Earthquake.

INTRODUCTION

The gas network system in Greater Tehran area is always threatened by many active faults which historically caused severe earthquakes. The project to estimate reliability of the gas system in Tehran against earthquake had started in 2002. In order to carry out this estimation in a probabilistic manner, it is necessary to set fragility curves for all components of the system in a same manner. After several site investigations, it was assumed that vulnerability of pipeline facilities from 250psi to 60psi and facilities around customer such as riser pipe or house regulator has a significant impact on the result of this project. But the performance data of such facilities during past earthquakes in the local area was not enough for making up their fragility curve. Purpose of this study is to suppose fragility curves for the some damage modes by analytical measures and experiments for the whole project.

OUTLINE OF THE PROJECT AND MODE OF DAMAGES CONSIDERED

Fig. 1 shows the total flow for estimation in the project. In this flow, damage modes shown in Table 1 were considered.

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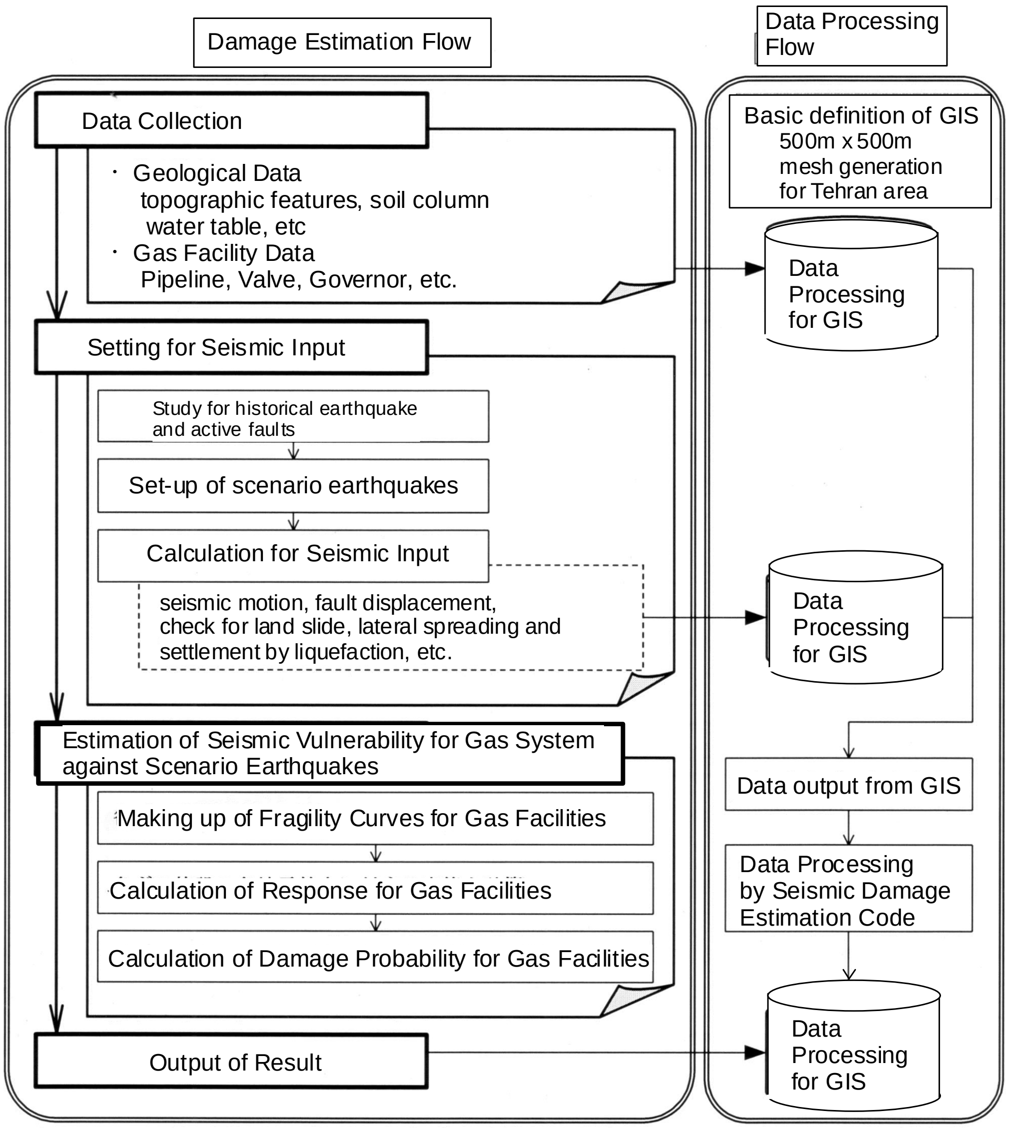


Fig. 1 Total flow of the project

Table1 Damage mode considered for the project

250psi, 100psi network	60psi network
Wave effect for straight pipe Wave effect for bend pipe Lateral spreading for straight pipe Lateral spreading for bend pipe Settlement for straight pipe Fault crossing Landslide for straight pipe Governor house failure Valve failure	Wave effect for straight pipe Wave effect for bend pipe Lateral spreading for straight pipe Lateral spreading for bend pipe Settlement for straight pipe Fault crossing Landslide for straight pipe Governor house failure Riser failure by house/building Curb valve failure

Fragility (vulnerability function) of pipeline due to wave propagation was set by the methodology of Japanese gas pipeline specification [1]. Fragility against fault displacement and land slide were set by the series of 3D shell FEM analyses done for this project. As for the fragility of pipeline suffered from displacement due to liquefaction was set by the methodology of Japanese gas pipeline specification [2], after the applicability confirmation process shown in next chapter. Regarding with the facilities of low pressure network, riser pipe, curb valve or meter/regulator with screw joint are pointed out that they are critical for the system function. But as there was no data about their damages, their fragility were assumed by analogy with fragilities of housing structures and results of laboratory experiment for them.

FRAGILITY OF PIPELINE AGAINST LATERAL SPREADING DUE TO LIQUEFACTION

In Japan, design specification for the high pressure pipeline undergoing permanent displacement due to liquefaction such as lateral spreading and settlement was established in 2001[2]. As bases of this specification, many cases of 3D FEM analyses and various experiments with actual pipes were done. Then simplified design formula to calculate deformation or bending angle and their allowable value were prepared for practical design work. As this is the only one specification prepared for gas pipeline against displacement due to liquefaction, it was applied for gas pipeline used in Iran to set their fragility curve. Fig. 2 shows the classification of pipeline network and their inner pressure in Iran and Japan. Regarding with inner pressure, it is found that this specification prepared for high pressure line in Japan can be applied to middle pressure line in Iran. But diameter and thickness of gas pipes used in Iran is not identical to that used in Japan, so the comparison between the result of simplified formulae in above specification and the result of FEM analyses against pipes used in Iran were done to confirm that this specification can be applicable for pipes in Iran.

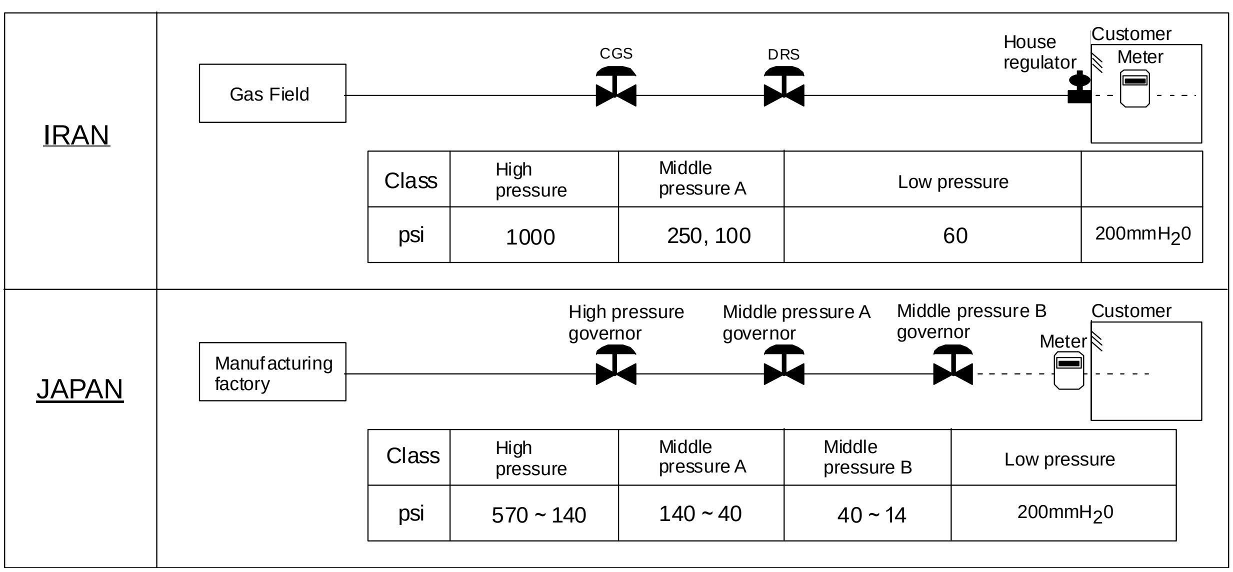


Fig.2 Classification of pipeline due to inner pressure in Iran and Japan

In this specification, simplified formulae were prepared for damage modes which are bending/compression for straight pipe and closing/opening deformation for bend pipe. It is supposed situation that the pipe is located at slope or along quay wall and is supported uniformly by ground. In this study, the modes of closing/opening deformation for bend pipe at slope ground were checked for their applicability. Table 2 shows the condition to which simplified equations can be applied. Table 3 shows pipes used in Iran. Bold figure means the value outside of the range specified in Table 2. In Fig.3, hatched area shows dimensions of diameter and thickness certified by specification [2]. Triangular mark in the figure shows that of pipe used in Iran.

Table2 Applicable scope of simplified formulae

	Formula for deformation	Formula for limit deformation
Material	—	X42・46・52・60・65 STPG370・410 STPT370・410・480 STPY400
Design factor	—	Up to 0.4
Nominal diameter	150A to 750A	100A to 750A
D/t	23 to 60	15 to 60
Initial bend angle	11.25 to 90 degree	0 degree and above
Curvature radius	1.5D and above	1.5D and above

Table 3 Specifications of pipes used in Iran

No.	Nominal Diameter		Type of steel pipe	Yield Stress	Thickness		D/t
	(inch)	(mm)		(PSI)	(inch)	(mm)	
1	**48**	**1219.2**	API-5L-X42	42000	0.438	11.1	**109.6**
2	**36**	**914.4**	API-5L-X42	42000	0.375	9.5	**96.0**
3	30	762.0	API-5L-X60	60000	0.375	9.5	**80.0**
4	30	762.0	API-5L-GRB	35000	0.312	7.9	**96.2**
5	24	609.6	API-5L-X42	42000	0.312	7.9	**76.9**
6	24	609.6	API-5L-GRB	35000	0.312	7.9	**76.9**
7	22	558.8	API-5L-X42	42000	0.312	7.9	**70.5**
8	20	508.0	API-5L-X42	42000	0.250	6.4	**80.0**
9	18	457.2	API-5L-X42	42000	0.250	6.4	**72.0**
10	16	406.4	API-5L-GRB	35000	0.250	6.4	**64.0**
11	16	406.4	API-5L-X52	52000	0.203	5.2	**78.8**
S-1	12	304.8	API-5L-GRB	35000	0.250	6.4	48.0
S-2	10	254.0	API-5L-GRB	35000	0.219	5.6	45.7
S-3	8	203.2	API-5L-GRB	35000	0.188	4.8	42.6
S-4	6	152.4	API-5L-GRB	35000	0.172	4.4	34.9
S-5	**4**	**101.6**	API-5L-GRB	35000	0.172	4.4	23.3
S-6	**2**	**50.8**	API-5L-GRB	35000	0.141	3.6	**14.2**

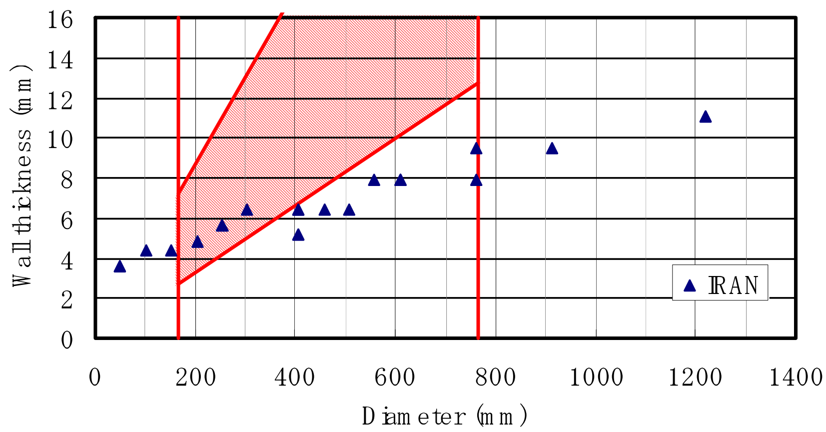
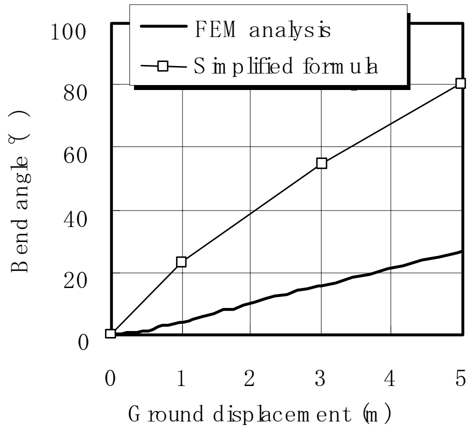


Fig. 3 Dimension of pipe used in Iran

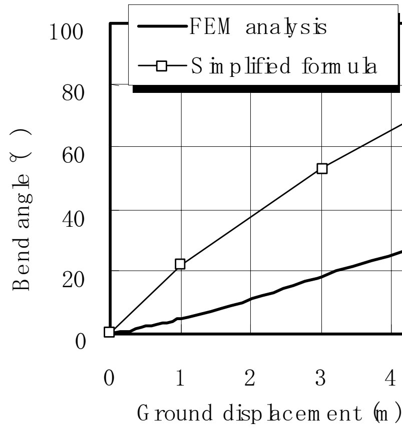
From Table 3, 6 types of pipe were selected and analyses were done for 10 cases shown in Table 4. The route of 250psi line in Tehran is very congested and there are many bend pipes in the route. So damage mode for bend pipe was investigated. Fig. 4 shows comparison of results between FEM analysis and simplified formula for 6 cases from cases in Table 4. (1) to (4) and (5) to (6) in Fig. 4 show closing and opening deformation mode respectively. In case of 06, bend angle due to simplified formula is below against the angle due to FEM analysis for ground displacement over 2.4 m. It is found that the gap between results becomes larger as ground displacement increases. In the meanwhile, the magnitude of ground displacement due to liquefaction shown was calculated [3]. Procedures to calculate displacements followed the methods of aforementioned specification for liquefaction. As the result, it was cleared that maximum ground displacement due to lateral spreading in this project was under 10cm because of flat ground surface of liquefied area.. So it was found that bend angle due to simplified formula has never fallen below that due to FEM analysis and the gap between them is not so large for the range of supposed ground displacement. Then, it was judged that simplified formulae could be applied for the calculation for pipes used in Iran.

Table4 Case of confirmation

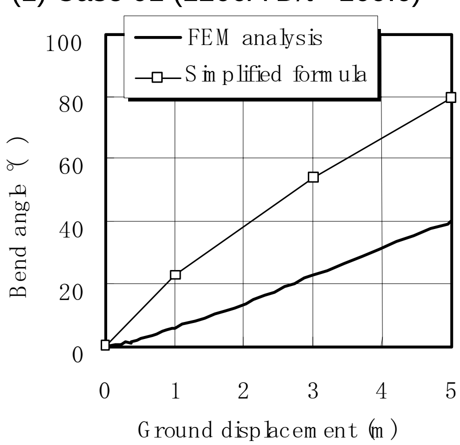
Case No.	Diameter (mm)	Thickness (mm)	D/t	Pipe material	Bend angle (deg)	Deformation mode
Case 01	1219.2	11.1	109.6	API-5L-X42	45	closing
Case 02	609.6	7.9	76.9	API-5L-GRB	45	closing
Case 03	406.4	6.4	64.0	API-5L-GRB	45	closing
Case 04	406.4	5.2	78.8	API-5L-X52	45	closing
Case 05	254.0	5.6	45.7	API-5L-GRB	45	closing
Case 06	50.8	3.6	14.2	API-5L-GRB	45	closing
Case 07	1219.2	11.1	109.6	API-5L-X42	90	opening
Case 08	609.6	7.9	76.9	API-5L-GRB	90	opening
Case 09	406.4	6.4	64.0	API-5L-GRB	90	opening
Case 10	406.4	5.2	78.8	API-5L-X52	90	opening



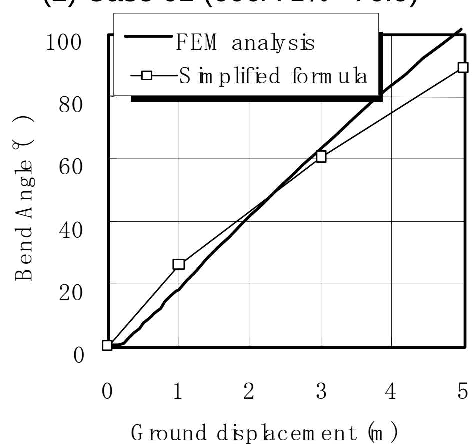
(1) Case 01 (1200A D/t =109.6)



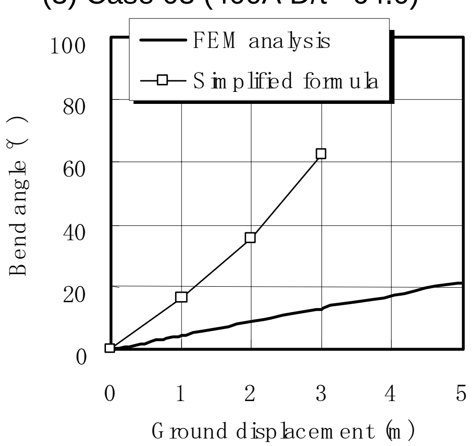
(2) Case 02 (600A D/t =76.9)



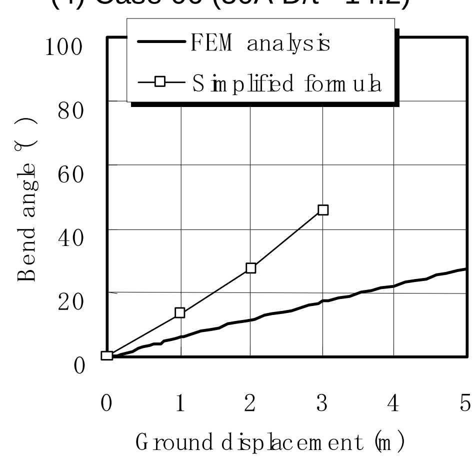
(3) Case 03 (400A D/t =64.0)



(4) Case 06 (50A D/t =14.2)



(5)Case 07 (1200A D/t =109.6)



(6) Case 08 (600A D/t =76.9)

Fig. 4 Results of comparison

FRAGILITY OF LOW PRESSURE GAS FACILITIES

In the gas supply system in Tehran, welded steel pipe and polyethylene (PE) pipe are used for low pressure network. Therefore, pipeline was considered as quakeproof. Fig.5 shows typical configuration of gas facilities around housing structures. As shown in Fig.6, Many screw joints and mechanical joints are used there. So it was supposed that this part can be a weak point of network because of the leakage from screw joint or mechanical joint.

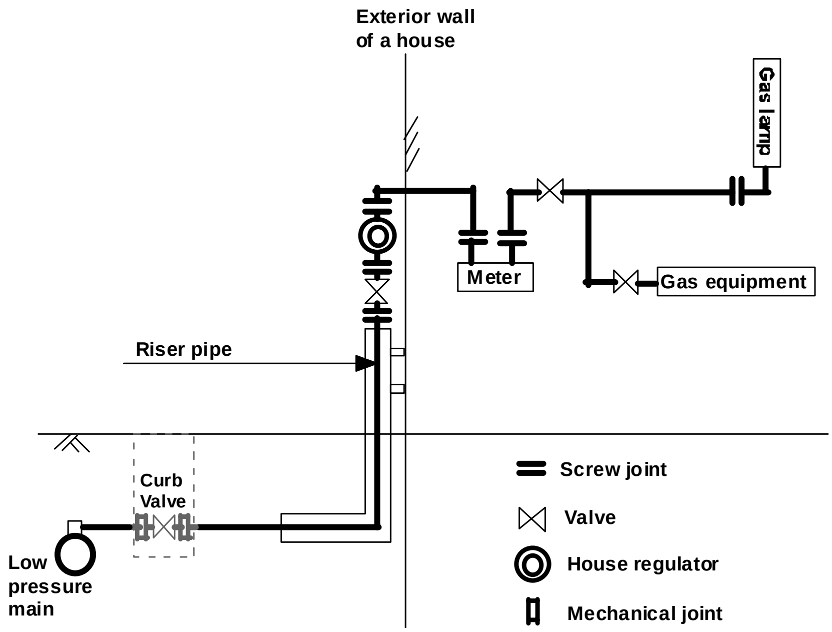


Fig.5 Gas facilities around housing structure

In the Kobe earthquake out of all of the 26,000 cases of gas pipe damages, 24,000 cases were from screw joints of customer's facilities. So, it is supposed that these screw joints may suffer damage when the house is completely destroyed or even half-way destroyed. Especially in Iran, these house regulators, gas meters and riser pipe are affixed directly to the walls of housing structures. And screw joints are used for the house regulator joint, the stop valve joint and gas meter joint on the risers. In the event of earthquake, not only will the screw joints come apart due to inertia force but the riser itself will be destroyed from the collapse or inclination of the housing structure. Even during the Kobe earthquake, there were a number of cases where the risers were damaged along with the full or half destruction of the house, although risers are not affixed to the house wall in Japan. It should be noted that at screw joints of both side of the stop valve and at the upstream side of the house regulator, the gas pressure is 60psi. This amount of pressure is classified as middle pressure in Japan. Even if the damage to the screw joints of both sides of the regulator is equal, the affects of the leakage from upstream of the regulator would be worse than the downstream. So the damage for these facilities around customer's dwelling may cause serious secondary disaster and they have to be included as important components in the project. In Iran, damage data of these gas facilities affixed to the wall or inside of house were not available, therefore, the fragility of the house and building was considered as substitute of their fragility. Table 5 shows the supposed correlation between damage state of housing structure and that of gas facilities. In Iran, riser pipe is made of steel or polyethylene (PE). For the type with steel riser pipe, curb valve is installed in hand hole between low pressure main and a riser pipe. Currently the gas leaks in the greater Tehran areas are 85% above ground, and 15% below ground (leakage from buried systems). In addition, of the underground gas leaks, about

75% are curb valve leaks. It is assumed that most of leakages occurred at the mechanical joints installed on both side of curb valve. They are affected mainly by the ground displacement not by house damage. So fragility of curb valve is estimated by bending/tensile tests aside from above mentioned facilities with screw joints.

Table 5 The correlation of damages between house and gas facilities

Classification	Structural Damage	Definition of damage state of gas facilities in the project
Major	complete collapse/ demolished	Occurrence of leakage or rupture
Moderate	partially destroyed/ deformed	Fear to fall into the major damage/ Possibly to maintain in the damage free state by improving the present situations
Minor or None	Slightly damaged/ sound	Immediately possible to continue or restart the operation

FRAGILITY OF RESIDENTIAL STRUCTURES

In case of estimation for residential structure, which means detached dwelling house or apartment building, its fragility curve is defined as the correlation between a level of seismic load (acceleration) and the probability to come at certain damage state shown in Table 5. The research to estimate vulnerability of buildings in Tehran was done by JICA project (2000) [4] in the past. In JICA project, the buildings were classified into 9 categories based on the data of housing census (1996). Fragility curves used in JICA project were based on the damage data of buildings in villages located near the epicenter of Manjil earthquake (1990). Fragility curve due to this data was defined as that for steel and brick type structure. As for other 8 types of structures, their fragility curves were settled by defining the difference of damage ratio of 50% from that of Steel and brick type in MMI scale. Data of US [5] and Kocaeri earthquake in Turkey (1999) were referred for setting differences by types. Shapes of all curves are identical in MMI scale. Fig.7 shows these fragility curves in acceleration scale used in JICA project. Probability distribution function of curve is supposed to be normal distribution. Some of these curves in Fig. 7 are used as prototypes for major damage state in this project. But it is assumed that JICA setting for mean value is reasonable but distribution for RC and steel is too wide by comparing with the curves due to Kobe earthquake and other papers. Therefore, curves shown in Fig.6 were modified as those shown in Fig.7. Probability distribution function was changed from normal distribution to log-normal distribution for modification.

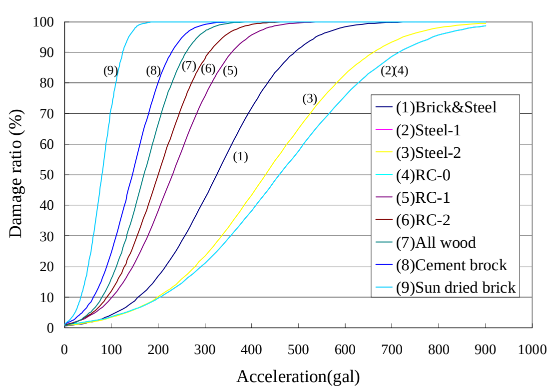


Fig.6 Fragility curves used as prototype

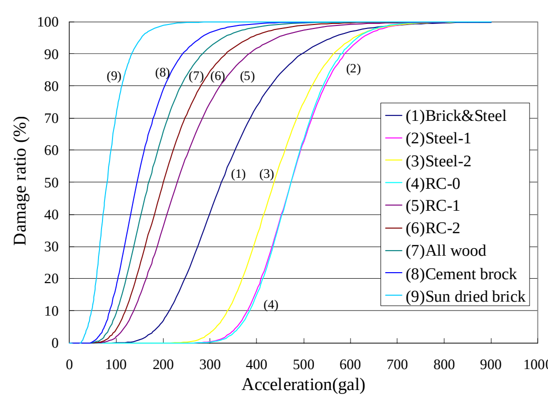
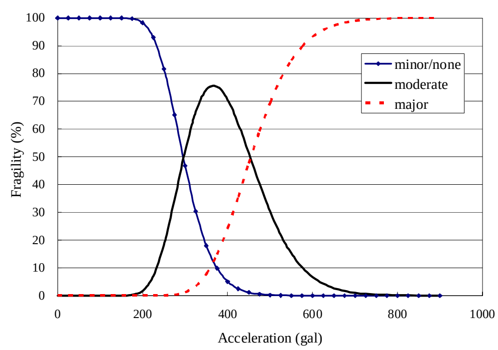


Fig.7 Fragility curves modified

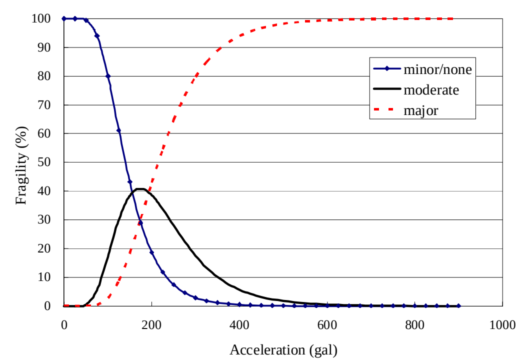
In this project, structures are classified into 4 types which were apartment building (housing complex) and single-family house (detached house) of higher and lower quake-proof strength. Table 6 shows parameters of curves. Fragility of rigid/stiff apartment was set as the mean of steel-1 and steel-2 in Fig.7. Fragile/weak apartment was set as the mean of RC-1 and RC-2 in Fig.7. To stand on the safe side, RC-0 was omitted. Fragility of fragile/weak detached house is equal to cement block in Fig.7. This category in JICA report contains wood & brick, wood & stone, all brick and brick & stone other than cement block. As for moderate damage state, mean values are determined as 65% of major state, whereas the standard deviations are same as major state. Fig.8 shows the fragility curves for each major state of structures used in the project.

Table 6 Structural types and their parameters for fragility curve

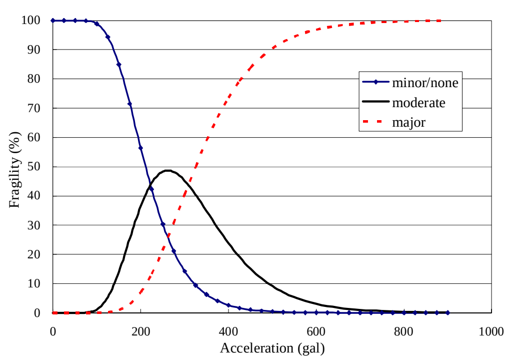
Structural type	definition	Mean / Standard deviation	Major damage	Moderate damage
Steel	Apartment (rigid/stiff)	μ(gal)	455	296
		σ(gal)	185	185
RC	Apartment (fragile/weak)	μ(gal)	215	140
		σ(gal)	400	400
Steel & brick	Detached house (rigid/stiff)	μ(gal)	325	211
		σ(gal)	330	330
Cement block and others	Detached house (fragile/weak)	μ(gal)	145	94
		σ(gal)	400	400



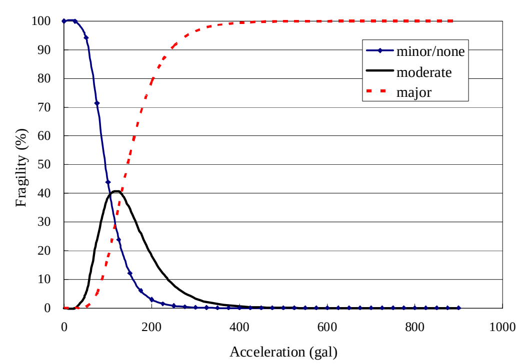
(a) Apartment (rigid/stiff)



(b) Apartment (fragile/weak)



(c) Detached house (rigid/stiff)



(d) Detached house(fragile/weak)

Fig.8 Fragility curve used in the project

CONCLUSIONS

Fragilities of gas facilities set by the procedures shown in this paper were applied to the project to estimate the vulnerability of gas supply system in Tehran, Iran. As for the welded steel pipe subjected to ground displacement due to liquefaction, it was confirmed that specification in Japan was applicable to pipes used in Iran. The method to substitute the fragility of buildings with that of low pressure gas facilities was supposed. After applying these procedures, reasonable result was acquired. To increase the accuracy of fragility set by the process shown in this paper, accumulation of damage data for gas facilities due to local earthquake is still required.

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