Seismic Analysis of Urban Water Supply Systems (Case Study: Qazvin City, Iran)

Mahdi Shadab Far, Zhang Qingping, Reza Rasti, and Seyed J. Faraji

***Abstract*—**Today, most people have settled in a habitat named city, a place with a distinct structure and function from its surroundings, which has created a new mean of civilization and human identity. Undoubtedly one of the most vital lifelines in modern societies is the water pipelines and its governing system. In this regard, there should be a policy for purposive conveyance of water and providing the basic needs for citizens to manage the disorders and surmount the possible problems. What is responsible for this task is the water supply system and networks which should improve the life in societies. Meanwhile, the knowledge of urban managers out of water systems status also seems a very vital issue because acquiring this knowledge they can take necessary action against unexpected disasters such as earthquakes. So, in this article, after doing several full dynamic finite element analyses on Qazvin distribution water pipelines, it has been tried to present the vulnerability maps of pipelines in the various hazard levels in the form of GIS maps to reach a general understanding of Qazvin water network status which located in a seismically active area and help the relevant authorities to take appropriate action on this issue.

***Keywords*—**Water transmission systems, urban management, earthquake, incremental dynamic analysis, GIS maps

I. Introduction

Over several human historic periods, secured access to water has been considered as the primary and basic condition for social and economic sustainable development and served as important factor in culture and civilization. According to hydrologists, water no longer serves as ample and economic valueless goods, but it is a commodity without substitute with high economic value in all production and consumption fields [3].

A systematic outlook of urban management toward the current urban system and its peerless importance in the present human's life has provided the ground for addressing to any risk and threat, which may create problem in this regard. Among of them, the subject of earthquake and the underlying dangers and problems is one of the important issues that may overshadow water transmission grid system. Inter alia, Iran has special and noticeable position in this sense for which Iran's seismic status is in such a way that unfortunately over 90% of its total area as well as approximately 95% of Iranian cities are situated on seismic faults and or their adjacent regions.

Earthquake is the most frightening natural weapon which can cause ground surface changes and consequently human civilization destruction. Meanwhile, urban water supply system is undoubtedly one of the most vulnerable lifelines in which a slight disturb can be led to a serious challenge [11, 14].

Qazvin city, which serves as center of Qazvin Province and one of the great cities in central Iran, has not been so far from this cycle and it is located on Iranian seismic belt. As it is explained in the following at this article, due to its location on the joint neck point among northern and western provinces of Iran, proximity to Tehran, and having several industrial areas as well as enjoying several important scientific centers including Qazvin Imam Khomeini International University, Qazvin University of Medical Sciences, and Qazvin Islamic Azad University, Qazvin possesses very important and crucial stand in this region [22]. Therefore, we will explain about the position of water transmission systems in urban administration areas in Qazvin City against the possible risks caused by earthquake and way of resistant construction of these systems against such risks.

II. A Review on Technical Literature

Action and communication are the foundations of the human society and this principle highlights its place more and more in today's world. In a world where communication has an important role, undoubtedly there are ways to make these connections. Apparently, the human societies are based on the urban framework and its systematic systems while the dominant communication lines form the highways of each city. Those lines start from the highways and introduce the narrow streets to the human community.

To the extent that history shows the first hydrologic experiences were dated from Sumerian and Egyptians in the Middle East at ancient time so that date of dam- construction on Nile River is referred to 4000BC. At this time, similar activities had been done in Chinese Ancient Civilization as well and afterward in 1500BC for the first time water transfer pipelines have been used in Crete, Greece [15]. Then in 700 BC in Iran, some people dug aqueducts to transfer water to

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other regions [9].

Since the beginning of historic period to about 1400BC, systematic management and ever- increasing notice to this matter has made several philosophers and scholars to be preoccupied regarding hydrology cycle including Homer, Thales of Miletus, Plato, Aristotle, and Polyaenus of Lampsacus etc and it has prepared the ground for substitution of hydrologic philosophical concepts by scientific observations. These are some observations that include urban administration macro system as well as systematic notice to water transmission grids and required paying growing attention to this issue.

Of some remarkable essays in this regard, one may refer to an article under title of “Earthquake damage scenario simulation of water supply system in Taipei” by Ji-Hao Lin & Walter W. Chen, which it has been published within SPIE essays collection as volume no 7143. In this article, earthquake effects on water supply pipelines has been noticed in Taiwan and role of urban management in addressing the problems caused by that matter was examined. Then the possible damages caused by earthquake on water transmission grid in Taipei city has been simulated by means of the existing software and the resultant losses was estimated [7].

Among other studies in this field, one may imply an essay called as “Seismic analysis of water supply systems by earthquake scenario simulation” written by Gee-Yu LIU et al, which this study has been presented by National Taiwan Earthquake Engineering Researches Center and in this article, simulation of a scenario has been analyzed seismically in water supply systems in order to thereby improve efficiency and readiness of public and private sectors in the case of occurrence of disaster on the one hand and to extract some empirical simplified formulae for calculation of damages caused by earthquake, pipelines repair rate, and hydraulic analyses on water grid system in under- pressure water pipelines etc on the other hand [8].

The other essay to which one could refer was presented by Professor Masakatsu Miyajima in essays collection within Symposium of the Learned Lessons from Great Earthquake 2011 in Eastern Asia, which has been published in 2012. This article studied on the inflicted losses to water transfer facilities at eastern Japan, particularly Sendai City caused by earthquake 2011 and analysis on sudden reduction and increasing water pressure by conduction a field study [13].

Of other papers, which is related to research subject to some extent is an essay written by Hiroyuki Kameda under title of “Engineering management of lifeline under earthquake risk” that the given article has been publish in international congress on engineering education in 2012 and in which some certain specifications of engineering of earthquake vital arteries and vital elements have been reviewed within earthquake engineering practices and in particular it has referred to two issues i.e. seismic safety in interaction to the outline and an analytic method and finally it has noticed the orientation toward seismic engineering future and training of third generation in this field of knowledge [6].

Among other articles, which particularly related to subject of the present research, is a paper presented by Seyed Mehdi Zahraei under title of “The investigation into seismic vulnerability of constructions in Qazvin City”, this essay was published in 2005 and it had a transient glance at subject of seismic nature of Qazvin City and its resultant damages and eventually it has evaluated seismic and qualitative vulnerability of buildings in Qazvin City and general strategies to improve the status quo [23].

Of the other researches in this context, an article entitled as “Hydrodynamic Analysis of Aircraft Water Supply” by M. Toppel et al. can be pointed out in which the solution of unsteady flow in pipe networks and high pressure fluid reservoir are investigated in order to simulate the airplanes water consumption and calculate the wave pressure in tall buildings, factories and water supply networks [20].

One of the other interesting studies in this field is an article entitled "Research on the Steady Motion in Water Distribution Looped Pipe Networks". In this paper, using a physical model, Madalina et al. presented an automatic computation program for modeling the steady water flow in water distribution networks which usually used in water supply systems and irrigation installation [10].

As we observe here, in most of these essays, authors have tried to remove weak points and defects by pathological analysis on the existing situation and finding these points and eventually to purpose useful strategy in this regard. Also in this paper, we have dealt with particularly to exploring the position of water supply transmission systems in urban administration areas against earthquake and their vulnerability versus this risk and it has been tried to approximate the status quo after quake by using the acquired results from numerical analyses for water supply grid in Qazvin city as a case study and to describe way of resistant construction of the related structures and systems.

III. Importance of Water Transmission Grids

Following the expansion and spreading human communities and formation of societies within multi thousand and multi hundred thousand communities, which have been organized in physical matrix and structure of cities, ever- increasing necessity and notice to water has revealed its position as the foremost vital artery within human communities in the governing system on urban areas. The necessity of this matter becomes doubled when we notice that the least gap and defect in this trend even within a very short time interval will be followed by enormous and irrecoverable losses and costs whether financially or in terms of life risk.

Among them, with a sensitive position in terms of geographic, natural, and political situation for Iran, Qazvin has a very noticeable stand in this region for which it is situated near Iranian capital i.e. Tehran on the one hand; and it is adjacent to an active fault on the other hand [12, 23]. With about 55km² of area this city is located on some part of Iranian plateau at the southern piedmont of Alborz Range and within the route among Tehran and Rasht, Zanjan, and Hamedan (Fig.1). What it causes to draw ever- increasing attention to Qazvin is extensive growth in urban population in this city in such a way that its population exceeded from 380000 [17].

Fig. 1 Schematic map of Qazvin City and its suburb area

There is no dispute for anyone that population is mainly required more systematic administration system and more ordered services system among of which water transmission network plays noticeable and decisive role as one of the most crucial vital arteries in any ecosystem.

Something that highlights the necessity of considering the earthquake induced damages is the seismically active area of Iran and its geographical position on seismic belts. This matter caused Iran to be divided to four seismically active zones including Alborz, Central Iran, Zagros and Kape Dagh [16]. Qazvin city is located in a seismically active state in the Alborz zone and it usually experiences a severe earthquake every few years.

Occurrence of earthquake and thus its consequent defect in water transmission grid will be directly followed by noticeable human casualties and financial losses since by failure and interruption in each pipeline the possibility for water population and incidence of epidemic diseases, further destruction of buildings, water rationing, lack water transmission to firefighting centers and hospitals etc will increased and as a result administrative crisis will become extensive and more equivocal in urban area. Thus, it has been tried in this study to review and analysis on status of Qazvin city water transmission network upon occurrence of earthquake by a systematic view and to purpose the results within GIS maps framework.

IV. QAZVIN WATER TRANSFER NETWORK

Qazvin water transmission network comprises of several systems with longer to medium exploitation use life and whereas no comprehensive plan had been prepared at the beginning of construction of this project so very little documented information has been available concerning these systems and no plan of construction about these systems exist in practice. For this reason, pipeline route map and their geotechnical properties were prepared by conducting geophysical and geotechnical studies in this field.

According to the given results from these studies, Qazvin water pipelines were classified into 38 pipelines based on Fig 2 and Table 1 [21]. As it will be explained in next parts, in this article all these 38 pipelines will be analyzed by means of Finite Element Method (FEM) at 3 hazard levels including operation level, hazard level 1 and hazard level 2 in order to make needed efforts by urban directors to acquire comprehensive knowledge regarding their position in the course of their organizing and improvement.

In the following, we will examine the quality of soil status and rate of its affection by seismic vibrations by the aid of the necessary modeling works so that to find situation of urban water transmission by means of more comprehensive knowledge.

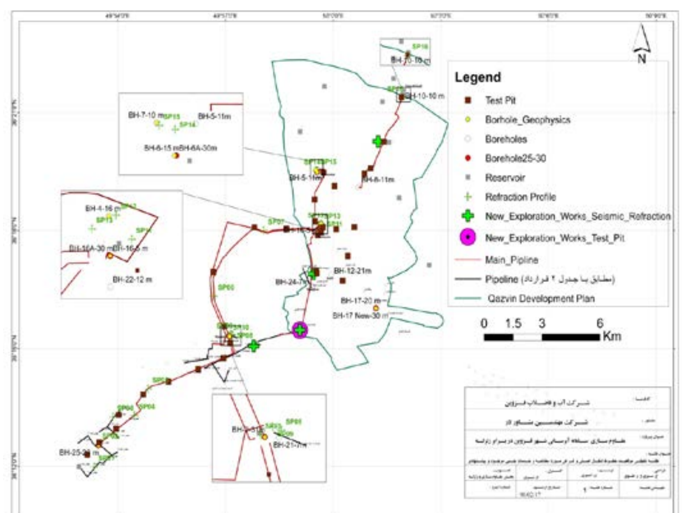

Fig. 2 Qazvin City water pipelines map

Table 1 Route, material, diameter, and length of pipelines [21]

Route No	First- End	Material*	Diameter (mm)	Length (m)
1	Collector no 6 Mahdi Abad - Well no 8 Mahdi Abad	DCI	600	900

2	Well no 8 Mahdi Abad - Well no 15 Mahdi Abad	DCI	880	800
3	Well no 15 Mahdi Abad - Mahdi Abad collector wells towards Kosar tank	DCI	780	800
4	Rest of Mahdi Abad collector wells towards Kosar tank – Dam road	DCI	5640	900
5	Rest of Mahdi Abad collector wells from Dam road - Kosar tank	DCI	1005	600
6	Kosar tank – Zamzam tank	DCI	1000	700
7	Kosar tank – Zamzam tank	DCI	10500	700
8	Well no 4 of new Choobindar – Kosar tank area	DCI	1040	600
9	Hamedan crossroad – Etefaghat building area	DCI	3060	600
10	Etefaghat building area - 30,000 cubic meters tank of Zamzam	DCI	2082	500
11	Joint of Choobindar tank transmission line - Line no 900 near the old Choobindar well no 2	DCI	50	900
12	old Choobindar well no 2- 10.000 cubic meter Kosar tank	DCI	700	600
13	30,000 cubic meter Zamzam tank - Minoodar tank	DCI	4050	600
14	30,000 cubic meter tank of Kosar town - 1500 cubic meters Ismail Abad tank	DCI	5150	150
15	Mahdi Abad Well no 1 - Mahdi Abad Well no 2	DCI	680	200
16	Mahdi Abad Well no 2 - Mahdi Abad Well no 3	DCI	600	300
17	Mahdi Abad Well no 3 - Mahdi Abad Well no 4	DCI	895	300
18	Mahdi Abad Well no 4 – Collectors of Mahdi Abad wells no 1 to 5	DCI	300	400
19	Mahdi Abad Well no 5 – Collectors of Mahdi Abad wells no 1 to 5	DCI	380	250
20	Collectors of Mahdi Abad wells no 1 to 5 – Connection to line no 600	DCI	780	500
21	Mahdi Abad well no 14 - Mahdi Abad well no 13	DCI	480	200
22	Mahdi Abad well no 13 - Mahdi Abad well no 6	DCI	700	300
23	Mahdi Abad well no 6 - Location of Mahdi Abad collectors	DCI	200	60
24	Mahdi Abad well no 7 - Mahdi Abad well no 8	DCI	380	200
25	Mahdi Abad well no 9 - Mahdi Abad well no 10	DCI	460	250
26	Mahdi Abad well no 12 - Mahdi Abad well no 11	DCI	410	250
27	Mahdi Abad well no 11 - Mahdi Abad well no 10	DCI	600	300
28	Mahdi Abad well no 10 - Mahdi Abad well no 8	DCI	480	350
29	New Choodindar well no 1- New Choobindar well no 2	DCI	430	250
30	New Choobindar well no 2- New Choobindar well no 3	DCI	525	400
31	New Choodindar well no 3- New Choobindar well no 4	DCI	940	500
32	New Choobindar well no 5- Location of Kosar tank	DCI	240	250
33	Old Choobindar well no 4 - Old Choobindar well no 3	DCI	1005	350
34	Old Choobindar well no 3 - Old Choobindar well no 1	DCI	1300	600
35	Location of old Choobindar well no 1 - Location of Hamedan crossroad	DCI	500	200
36	Kheirabad City Well – Underground 1500 cubic meters Choobindar tank	Asbestos	500	200
37	Underground 1500 cubic meters Choobindar tank - 900 mm pipeline	Asbestos	1020	200
38	New road Nasrabad wells – Etefaghat Building	Asbestos	1000	250

* DCI: Ductile Cast Iron

V. THE USED SOIL PROFILES

According to the report relating to geotechnical studies on Qazvin City, soil of this region has been classified into eight profiles along with water pipelines route with the followings specifications (Fig 3 & Table 2) [21].

VI. EQUIVALENT SOIL SPRING

Since we will deal with modeling of pipelines in the given software and conducting Finite Element Analysis (FEM) so rather than pipeline, it necessitates considering surrounding soil and interaction between pipeline and soil as well [18, 19]. Thus, Equivalent Soil Spring method was adapted for soil modeling. So instead of soil surrounding pipeline, some springs are modeled in horizontal and vertical axes (Figs 4 &5).

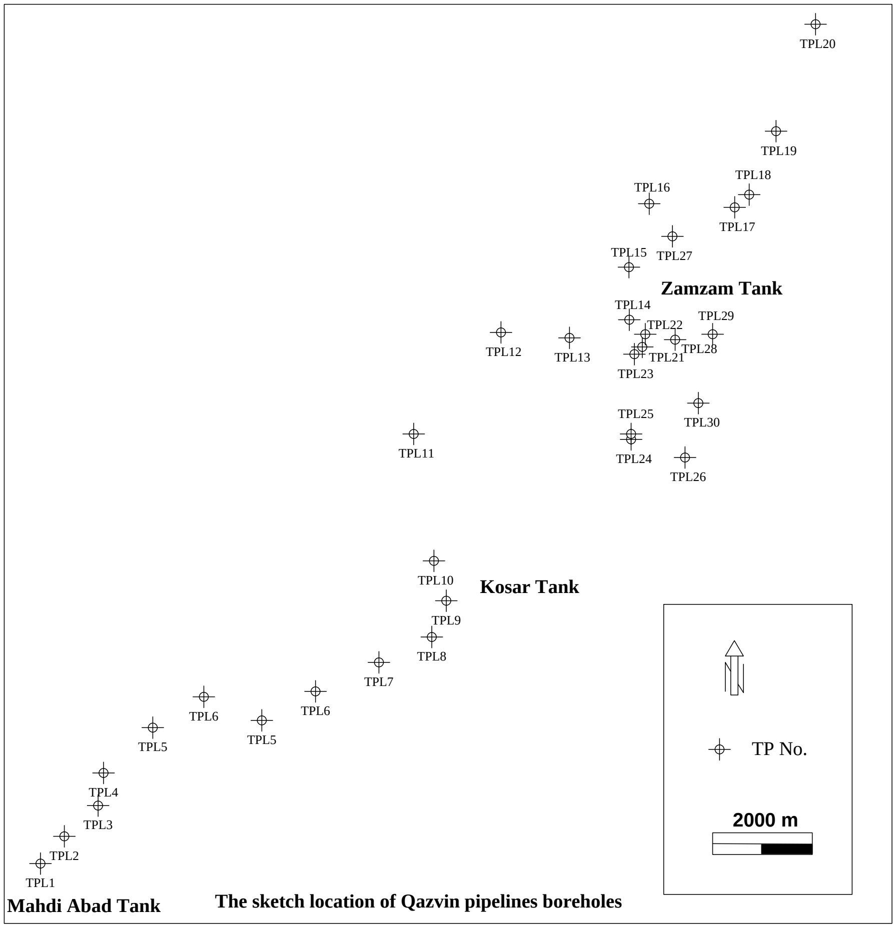

Fig. 3 Title and situation of the drilled boreholes in geotechnical studies [21]

Table 2 The specifications of different soil profiles in the region

Soil profile	C (kg/cm^2)	Φ	N_{spt}	Γ (gr/cm^3)	E (kg/cm^2)	Eq. Type	Wells
Prof. 1	0.3	22	25	1.6	110	III	TPL 4, 5, 12
Prof. 2	0.1	30	35	1.6	250	III	TPL 3, 8, 14, 21, 23
Prof. 3	0.1	24	30	1.7	220	III	TPL 6, 7, 9, 10, 11, 13, 22, 24, 26, 28, 29, 30
Prof. 4	0.3	15	30	1.6	150	III	TPL15, 20
Prof. 5	0	30	50	1.8	500	II	The wells between *Kosar* tank and *Niloo* town
Prof. 6	0.85	0	25	2	150	III	The wells between *Zamzam* tank and *Kosar* Tank
Prof. 7	0.08	35	20	1.95	400	II	The wells near the water and waste water headquarter building
Prof. 8	0.4	20	11	1.95	100	IV	The wells near the *Etefaghat* building

Different regulations and articles have introduced different methods for estimating the stiffness coefficients of these springs. One of the most famous sources among them is American Lifeline Alliance code (ALA 2005) [6]. In the ALA (2005), as will be explained in the following, the spring coefficients are calculated using a series of simple formulas and proposed graphs as the force per unit length.

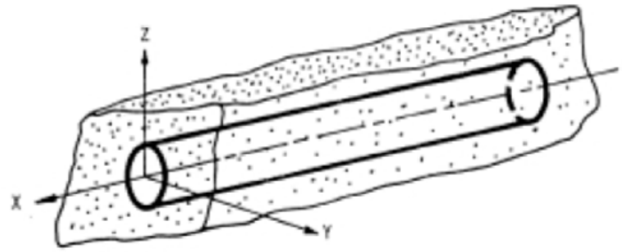

Fig. 4 Real model of pipeline and surrounding soil [2]

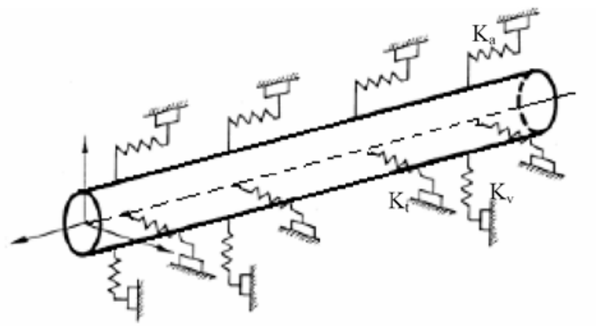

Fig. 5 Modeling of pipeline and surrounding soil by means of spring equivalent elements [2]

A. Lateral equivalent soil spring coefficient

Lateral equivalent soil spring coefficients depend on loading transfer capacity of soil. Thus, in order to calculate soil spring coefficient, we should calculate soil lateral loading capacity. For this purpose, we use the present formulas by American Lifeline Alliance (ALA 2005) codes as follows [2].

$$p_u = \begin{cases} S_u N_{ch} D & \text{for clay} \\ \bar{\gamma} H N_{qh} D & \text{for sand} \end{cases} \quad (1)$$

Where,

S_u = Shear strength of undrained soil

N_{ch} and N_{qh} = the needed coefficients that are derived from diagrams in Figure 6

D = Pipe external diameter

$\bar{\gamma}$ = Weight per unit of soil effective volume

H = Pipe buried depth (from pipe X- axis to soil level)

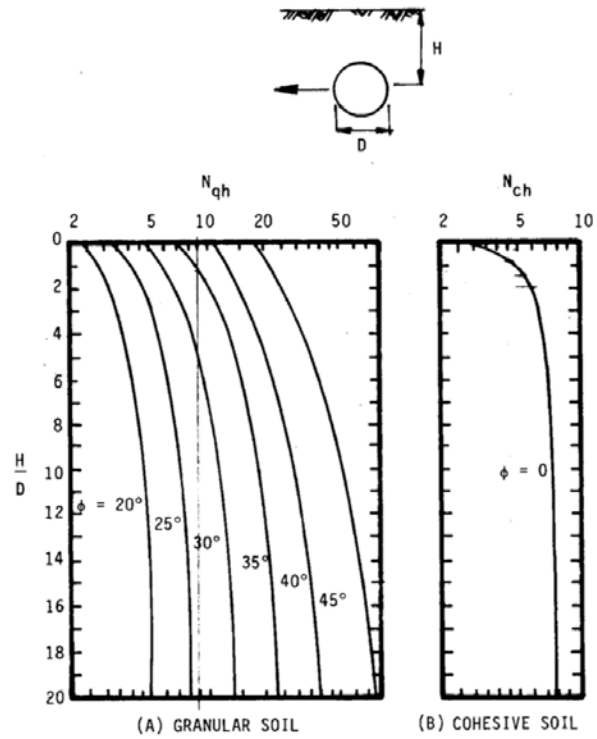

Fig. 6 Soil lateral loading coefficient for sandy and clay soils versus pipe height to diameter ratio

According to Indian Institute of Technology Kanpur – Gujarat State Disaster Management Authority (IITK-GSDMA) Codes, if the given soil is not of sandy type or fully clay so sum of two above formula may be used to compute soil residual loading capacity [5]. Namely:

$$p_u = S_u N_{ch} D + \bar{\gamma} H N_{qh} D \quad (2)$$

But, doing it may cause soil stiffness and it is not secured. For this reason, in the cases when soil internal friction angle is not adequately high we may adapt the given formula for sandy soil. In the following, we should compute soil residual displacement at its maximum residual strength. For this purpose, we also use the given formula by American Lifeline Alliance Codes [2].

$$y_n = \begin{cases} 0.07 \text{ to } 0.1(H + D/2) & \text{for loose sand} \\ 0.03 \text{ to } 0.05(H + D/2) & \text{for medium sand} \\ 0.02 \text{ to } 0.03(H + D/2) & \text{for dense sand} \\ 0.03 \text{ to } 0.05(H + D/2) & \text{for stiff to soft clay} \end{cases} \quad (3)$$

Now, we consider slope of joint line between Pu and yn points as lateral equivalent soil spring coefficient (Fig 7).

$$K_h = \tan\alpha \quad (4)$$

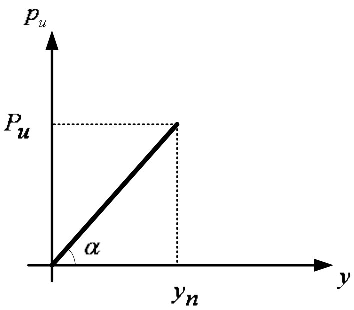

Fig. 7 Lateral equivalent soil spring coefficient

B. Vertical equivalent soil spring coefficient

In this part, we also calculate soil loading capacity in vertical direction by means of the formula purposed by American Lifeline Alliance Codes [2].

$$q_u = \begin{cases} S_u N_c D \quad for\ \ clay \\ \bar{\gamma} H N_q D + \frac{1}{2}\gamma\, D^2 N_\gamma \quad for\, sand \end{cases} \tag{5}$$

Where,
S_u = Soil undrained shear strength
N_c , N_q and N_γ = The needed coefficients that are derived from charts in Figure 8.
D = Pipe external diameter
$\overline{\gamma}$ = Weight per unit of soil effective volume
H = Pipe buried depth (from pipe X- axis to soil level)

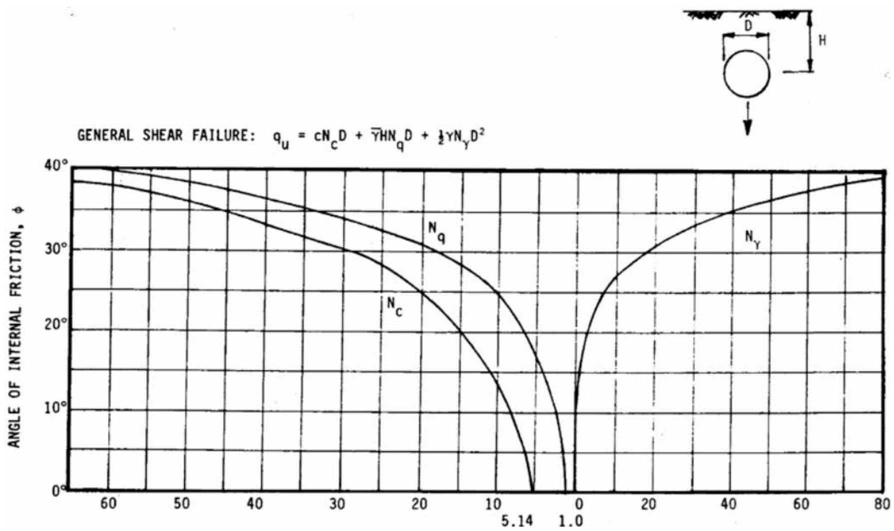

Fig. 8 Soil vertical loading coefficients for sandy and clay soils versus soil internal friction angle

In the following, we calculate soil displacement at its maximum vertical strength. For this purpose, as also use the present formula in American Lifeline Alliance [2].

$$z_u = 0.1D\ to\ 0.15D \quad for\, both\, sand\, and\, clay \tag{6}$$

At present, we consider slope of the joint line between P_u and y_n points as vertical equivalent soil spring coefficient (Fig 9).

$$K_v = \tan\beta \tag{7}$$

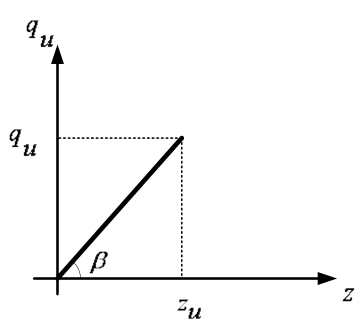

Fig. 9 Vertical equivalent soil spring coefficient

For instance, route no 2 (according to Table 1), namely from Mahdi Abad Well no 8 to Well no 15 has the soil corresponding to profile no 2, which is given in Table 3.

Table 3 Calculation of spring coefficients for route no 2

Input		Output	
H (m)	2	H/D	2.5
D (m)	0.8	DL (N/m)	25600
γ_{soil} (N/m^3)	16000	γ^{-} (N/m^3)	6000
γ_w (N/m^3)	10000	p_u (N/m)	67200
C (kg/cm^2)	0.1	y (m)	0.072
Φ	30	tanα	933333.3
X_1 (m)	0.6	k_h (N/m)	560000
X_2 (m)	0.6	q_u (N/m)	264960
N_{qh}	7	z (m)	0.08
N_{qv}	18	tanβ	3312000
N_γ	18	k_v (N/m)	1987200

VII. Earthquake Accelerogram

To conduct dynamic analysis, appropriate accelerograms should be adapted and scaled with respect to seismic properties of the region. Therefore, risk assessment studies were carried on this region for this purpose and three acceleration time histories were extracted from each of them at three hazard levels. The main characteristics of these given acceleration time histories for various hazard levels are as follows (Tables 4-6).

Table 4 The selected earthquakes for hazard level with 75 year return period (operation hazard level)

Area	Name of Earthquake	PGA (g)	PGV (cm/s)
Between well no 6 & Cosar	Avaj-l	0.195	32.259
	Avaj-t	0.238	32.456
	Cape Mendocino, 021	0.225	36.708
	Cape Mendocino, 291	0.225	36.708
	Qaen, L	0.213	20.606
	Qaen, T	0.216	45.077
Between Zamzam & Cosar	Northridge, 095	0.262	38.464
	Northridge, 185	0.297	55.995
	Qaen, L	0.293	54.799
	Qaen, T	0.288	41.907
	San Fernando, 291	0.279	38.028
	San Fernando, 021	0.281	39.515
Between Zamzam & Minoodar	Northridge, 095	0.224	27.85
	Northridge, 185	0.255	36.164
	Qaen, L	0.339	36.241
	Qaen, T	0.291	47.579
	San Fernando, 021	0.239	36.717
	San Fernando, 291	0.285	45.541

Table 5 The selected earthquakes for hazard level with 475 year return period (hazard level 1)

Area	Name of Earthquake	PGA (g)	PGV (cm/s)
Between well no 6 & Cosar	Imperial Valley, 045	0.329	45.024
	Imperial Valley, 135	0.372	64.362
	Cape Mendocino, 270	0.332	46.529
	Cape Mendocino, 360	0.361	64.266
	Northridge, 060	0.306	71.764
	Northridge, 330	0.363	64.071
Between Zamzam & Cosar	Northridge, 330	0.47	97.561
	Loma Prieta, 000	0.415	77.925
	Imperial Valley, 045	0.36	58.289
	Northridge, 104	0.305	38.653
	Cape Mendocino, 000	0.436	70.966
	Northridge, 060	0.344	40.94
Between Zamzam & Minoodar	Cape Mendocino, 000	0.428	49.423
	Cape Mendocino, 090	0.425	49.403
	Northridge, 104	0.424	61.469
	Northridge, 194	0.422	58.526

Table 6 The selected earthquakes for hazard level with 2475 year return period (hazard level 2)

Area	Name of Earthquake	PGA (g)	PGV (cm/s)
Between well no 6 & Cosar	Loma Prieta, 067	0.691	131.121
	Loma Prieta, 337	0.615	121.66
	Landers, LN	0.5	81.549
	Landers, TR	0.411	61.871
	Tabas, L	0.541	101.151
	Tabas, T	0.558	125.087
Between Zamzam & Cosar	Landers, LN	0.605	762.61
	Landers, TR	0.687	455.829
	Loma Prieta, 067	0.824	140.999
	Loma Prieta, 337	0.653	136.196
	Manjil, T	0.614	122.978
	Tabas, L	0.575	109.76
Between Zamzam & Minoodar	Landers, 000	0.618	320.822
	Landers, 275	0.76	310.808
	Manjil, L	0.697	85.804
	Manjil, T	0.602	86.328
	Tabas, L	0.6415	84.181
	Tabas, T	0.61	114.493

VIII. PIPE MODELING

Each of pipelines should be connected as separate pieces together by some springs and modeled by them [4]. These springs should have the needed axial, residual, and rotational stiffness in order to tolerate the longitudinal and lateral vibration exerted on pipe.

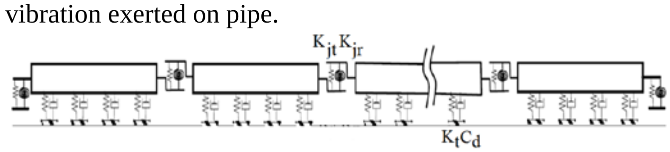

Fig. 10 Modeling of the piece pipeline

The noticeable point in these pipe joints is that the joint under stress should have stiffness relatively the same as stiffness of the given pipe; namely, joint stiffness under stress should be approximately as EA/L. But this joint does not need high stiffness in tension for this joint in order to be able to move freely. Thus, as it also shown in Figure 11, we initially use LINK element that contains 6 rates of stiffness in X-, Y-, Z- axis, and θx, θy, and θz in this essay. In the related part of axial stiffness, we enter tensile axial stiffness value that is a small number close to 1000N/m. if we only use this element the stressed joint only adapts 1000N/m stiffness as well. For this reason, we take help from GAP element and produce the given stress stiffness by this link (Fig 11). As a result, our given joint behavior (Fig 12) is modeled.

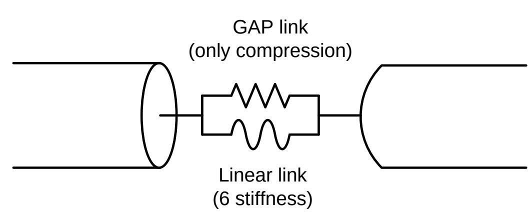

Fig. 11 Details of the piece pipe joints

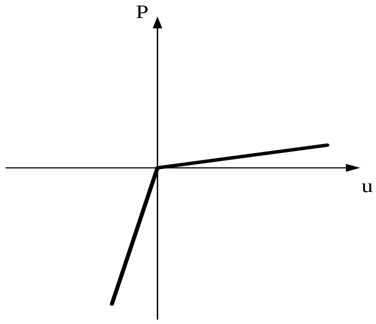

Fig. 12 Axial behavior of joint that is defined by GPA and LINK elements parallel composites

At the next step, we complete modeling problem by defining the specifications of soil equivalent springs in both vertical and horizontal axes (Fig 13).

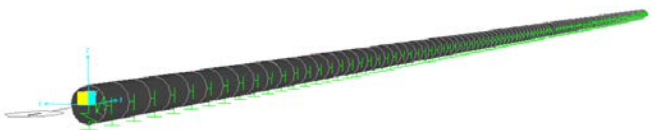

Fig. 13 The perfect model of pipeline and soil equivalent horizontal and vertical springs

At next phase, we will define the acceleration time histories relating to operation hazard level, hazard levels 1 and hazard level 2 as the exerted load on pipe for the software and in the following we introduce conducted analysis for all load- cases in fully dynamic modes by means of direct integration method.

IX. The Given Results from Analysis

After model; analysis for all accelerometer graphs at all hazard levels, envelope of the results was examined and the maximum moment, stress, and strain were derived for pipelines. The maximum derived strain should be compared with the maximum allowed strain value at all hazard levels in order to make decision that whether pipe status needs to adjustment and reclamation or not.

A. Final results in water transmission system

We may divide the final results derived from analysis on water pipelines system in Qazvin city into four classes as follows:

Class 1) good mode- The existing strain in pipe is very smaller than strain maximum level (Green).

Class 2) medium mode- The existing strain in pipe is smaller than strain maximum level but safety interval is low (Yellow).

Class 3) bad mode- The existing strain in pipe is the same as strain maximum level (Orange).

Class 4) extremely bad mode- The existing strain in pipe is greater than strain maximum level (Red).

Final results for all routes of pipelines are summarized in Table 7 with respect to the above classification.

Table 7 The final results from analysis on Qazvin City water pipelines system

Route No	First- end	Operation SHL*	SHL 1	SHL 2
1	Collector no 6 Mahdi Abad - Well no 8 Mahdi Abad	1	1	1
2	Well no 8 Mahdi Abad - Well no 15 Mahdi Abad	1	1	1
3	Well no 15 Mahdi Abad - Mahdi Abad collector wells towards Kosar tank	1	1	1
4	Rest of Mahdi Abad collector wells towards Kosar tank - Dam road	1	1	1
5	Rest of Mahdi Abad collector wells from Dam road-Kosar tank	1	1	1
6	Kosar tank - Zamzam tank	1	1	1
7	Kosar tank - Zamzam tank	1	1	1
8	Well no 4 of new Choobindar - Kosar tank area	1	2	3
9	Hamedan crossroad - Etefaghat building area	1	1	2
10	Etefaghat building area - 30,000 cubic meters tank of Zamzam	1	1	1
11	Joint of Choobindar tank transmission line - Line no 900 near the old Choobindar well no 2	1	1	2
12	old Choobindar well no 2 - 10.000 cubic meter Kosar tank	1	1	3
13	30,000 cubic meter Zamzam tank - Minoodar tank	1	1	1
14	30,000 cubic meter tank of Kosar town - 1500 cubic meters Ismail Abad tank	1	1	3
15	Mahdi Abad Well no 1 - Mahdi Abad Well no 2	1	2	4
16	Mahdi Abad Well no 2 - Mahdi Abad Well no 3	1	1	2
17	Mahdi Abad Well no 3 - Mahdi Abad Well no 4	1	1	2
18	Mahdi Abad Well no 4 - Collectors of Mahdi Abad wells no 1 to 5	1	1	1
19	Mahdi Abad Well no 5 - Collectors of Mahdi Abad wells no 1 to 5	1	1	3
20	Collectors of Mahdi Abad wells no 1 to 5 – Connection to line no 600	1	1	1
21	Mahdi Abad well no 14 - Mahdi Abad well no 13	1	1	3

22	Mahdi Abad well no 13 - Mahdi Abad well no 6	1	1	1
23	Mahdi Abad well no 6 - Location of Mahdi Abad collectors	1	2	4
24	Mahdi Abad well no 7 - Mahdi Abad well no 8	1	2	4
25	Mahdi Abad well no 9 - Mahdi Abad well no 10	1	1	3
26	Mahdi Abad well no 12 - Mahdi Abad well no 11	1	1	3
27	Mahdi Abad well no 11 - Mahdi Abad well no 10	1	1	2
28	Mahdi Abad well no 10 - Mahdi Abad well no 8	1	1	2
29	New Choodindar well no 1-New Choobindar well no 2	1	2	3
30	New Choobindar well no 2-New Choobindar well no 3	1	2	3
31	New Choodindar well no 3-New Choobindar well no 4	1	2	3
32	New Choobindar well no 5 - Location of Kosar tank	1	2	4
33	Old Choobindar well no 4 - Old Choobindar well no 3	1	2	4
34	Old Choobindar well no 3 - Old Choobindar well no 1	1	2	3
35	Location of old Choobindar well no 1 - Location of Hamedan crossroad	1	2	3
36	Kheirabad City Well - Underground 1500 cubic meters Choobindar tank	2	4	4
37	underground 1500 cubic meters Choobindar tank - 900 mm pipeline	2	4	4
38	New road Nasrabad wells - Etefaghat Building	2	4	4

SHL: Seismic Hazard Level

GIS maps for these results are also as follows:

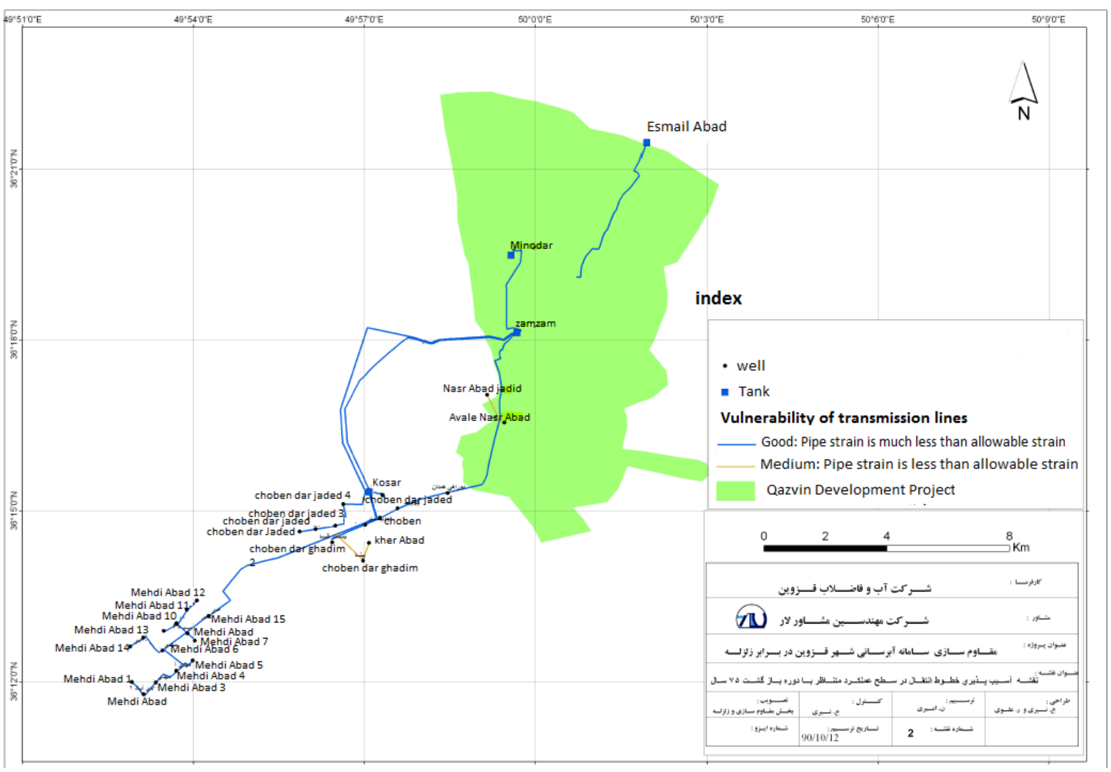

Fig. 14 Vulnerability map of water transmission lines in the performance level corresponding to the return period of 75 years

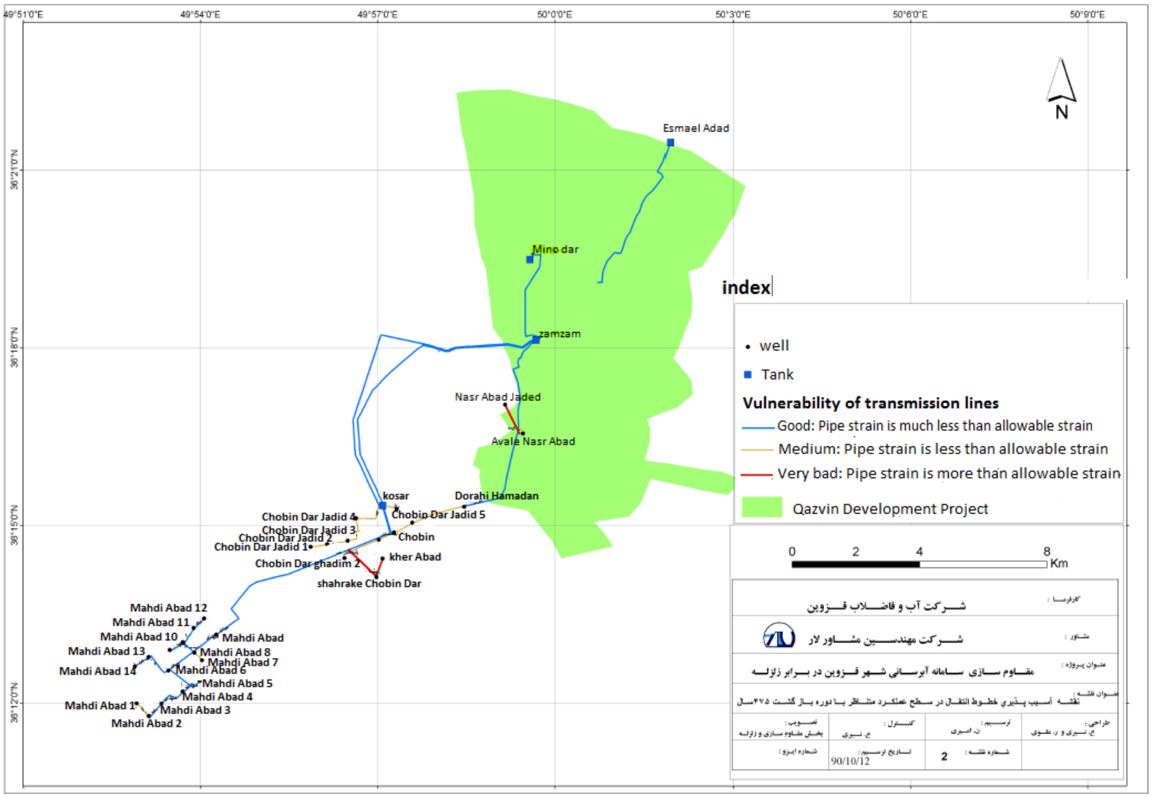

Fig. 15 Vulnerability map of water transmission lines in the performance level corresponding to the return period of 475 years

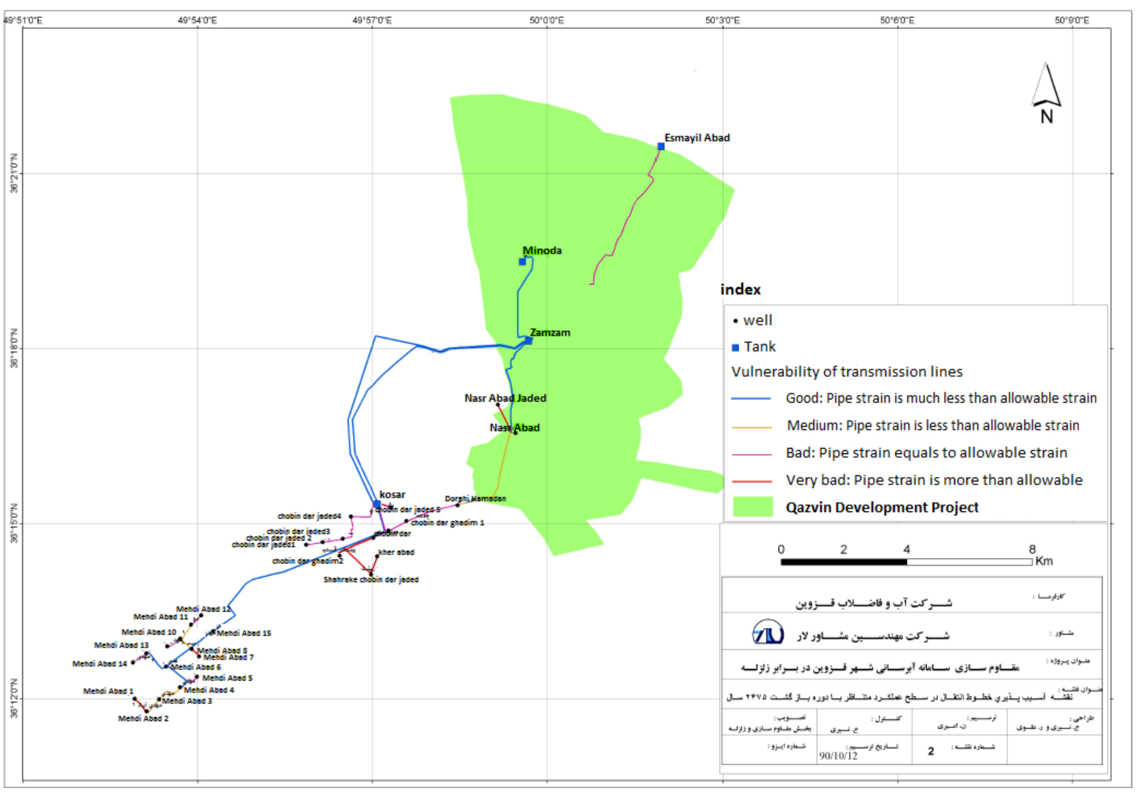

Fig. 16 Vulnerability map of water transmission lines in the performance level corresponding to the return period of 2475 years

X. Conclusion

In the present essay, it was tried to notice purposefully analysis, review, and organizing water transmission grid in Qazvin City by the aid of an analytic outlook so that in this course to make effort concerning to one of the paramount vital arteries in urban area by means of intellectual management.

In this sense, Finite Element Method (FEM) has been adapted to analyze Qazvin water transmission pipeline. In this technique, with respect to the identified routes as well as calculated stiffness of springs, pipelines were modeled. Then by considering the given studies, risk analysis was conducted and three classes of acceleration time history graphs were selected separately at three different levels so that they were utilized for dynamic analysis on pipeline.

At the stage of extraction the given results from this analysis, the maximum moment, stress, and strain caused by the above-said loadings were extracted for seismic risk at any level. The above extracted values were compared with the allowed quantities at all hazard levels in order to determine the status of pipelines under dynamic loading caused by earthquake.

A review on the result of analysis may characterize some points that it seems important to mention them:

- Asbestos pipelines only can tolerate seismic vibration at operation hazard level and they cannot bear earthquake input energy at hazard levels 1 and 2. Fragility of these pipes and lack tolerability for the exerted displacements and strains on them are the main cause for weak behavior of these pipes under vibration.

- Although due to lower stiffness, pipelines with smaller diameter may tolerate lower force as well alternately they have less capacity. Thus, in many cases their capacity is smaller than seismic needed potential for earthquake and consequently they will need to reclamation.

- Pipelines with older age can tolerate seismic tremors less than pipelines at younger age. This is due to Aging effect in mechanical and physical properties of their materials. For this reason, it is observed that under some conditions the more aged pipelines are subjected to losses more than younger lines.

According to results of analysis, since rather than asbestos pipelines other remained pipelines are not exposed to any certain damage at operation hazard level and hazard level 1 so it seems pipelines are at appropriate mode. It sounds that earthquake is like a loop, which its consequences depend on performance method of three groups (policymakers, experts, and executives). Therefore, if these three groups act appropriately and do their tasks at best and in accordance with practical criteria then earthquake risks is reduced to the great extent; otherwise, earthquake will be followed by a lot of losses and disasters in the countries so this issue is further perceived that urban directors notice this point, particularly in Qazvin City, which has been especially considered for this purpose.

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