THE MORE FLEXIBLE THE NODES, THE LESS VULNERABLE THE NETWORKS

Saeid Bakhshandeh Abkenar

ABSTRACT

Water networks are included pipes and nodes. Usually against earthquake motions, design codes emphasis on the pipeline and try to develop solutions to strengthen the pipe body or make higher resistant joints in the pipelines. However, dynamic effects of earthquake on water networks show the most important parts of the pipelines in a distribution network are their junctions, which are the most vulnerable part of the network to the effects of earthquake left on the system. It means nodes or junctions play a vital role during earthquake. Originally, more events on the pipelines come from nodes rigidity and finding solutions for making flexible nodes can change pipelines behavior against ground motions. Rigid nodes are formed in water networks because of the nature of components installed in the nodes. Function of valves force their ports connect to the other components by rigid connectors. Making flexible connectors between valves and the other components cause flexible nodes and increase their degree of freedom. Consequently, it is expected the vulnerability of junctions highly decreases.

KEYWORDS

Earthquake, Water Pipeline, Node, Expansion Joint, Flexible Joint

1 INTRODUCTION

Pressurized water pipelines including distribution and transmission are often subjected to damage by ground motions during earthquakes. Therefore, it is necessary to take effective arrangements into consideration, in the design of the water networks. Using allowable body stress and joint deflection and improving resistance of pipe joints make a strong pipeline but it is evident and deniable that this is more labor-intensive and time consuming or briefly is an expensive pipeline. More precise understanding for finding new arrangements, in addition to seismology and ground displacements and technical specifications of pipes, requires to take the other components of pipeline systems into account. Valves and fittings are the other important components which play a critical role during ground motion. Their function often cause special shape and parts that can affect the network behavior in seismic motions. Hence, it seems the most important parts of the pipeline in distribution network to improve its seismic behavior are their junctions, which are the most vulnerable parts of the network to the effects of earthquake left on the system. However, it seems to some extent, importance of nodes are ignored and usually engineers focus on the pipeline and related structures. The main object of this paper is to open a discussion by which making more flexible network become possible and consequently decreasing damages and events in water networks during seismic motions will be hopefully achievable.

To achieve this aim, water engineers need to be familiar or revise the basic principles of earthquake and ground motions and effects of these motions on water networks. Then, based on the capabilities and predictable behavior of different components of network during earthquake make an effort to find best solution and arrangements.

Presented discussions in this paper are qualitative based on the author's idea about making more flexible network to damp earthquake waves. Focus on the equations are conceptual just for better understanding the effective items in each discussion. This is due to median nature of this idea which is neither an exclusive hydraulic engineering discussion nor an earthquake engineering issue. It comes from details of water engineering and need to be developed by earthquake engineering. Hence, some basic concepts about earthquake and different components of water network are presented to make a useful discussion for both water and earthquake engineers.

2 EARTHQUAKE AND WATER NETWORK PIPELINES

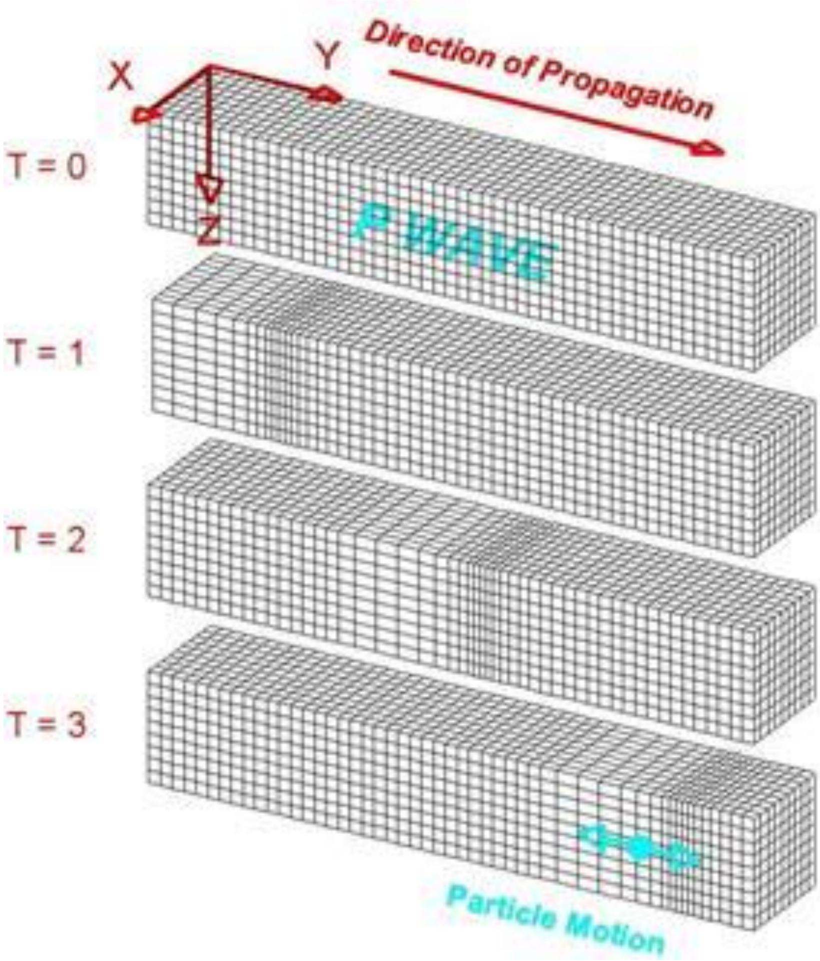
2.1 SEISMIC WAVES

As Prof. Lawrence W. Braile (2006) simplified; because of the elastic properties of Earth materials (rocks) and the presence of the Earth's surface, four main types of seismic waves propagate within the Earth. Compressional (P) and Shear (S) waves propagate through the Earth’s interior and are known as body waves. Love and Rayleigh waves propagate primarily at and near the Earth's surface and are called surface waves. Wave propagation and particle motion characteristics for the P, S, Rayleigh and Love waves are illustrated in Figures 1-4.

P-wave is a longitudinal wave. P motion travels fastest in materials, so the P-wave is the first-arriving energy on a seismogram. Generally smaller and higher frequency than the S and Surface-waves. P waves in a liquid or gas are pressure waves, including sound waves.

In the Figure 1, the directions X and Y are parallel to the Earth's surface and the Z direction is depth. T = 0 through T = 3 indicate successive times. The disturbance that is propagated is a compression (grid lines are closer together) followed by a dilatation or extension (grid lines are farther apart). The particle motion is in the direction of propagation. The material returns to its original shape after the wave has passed.

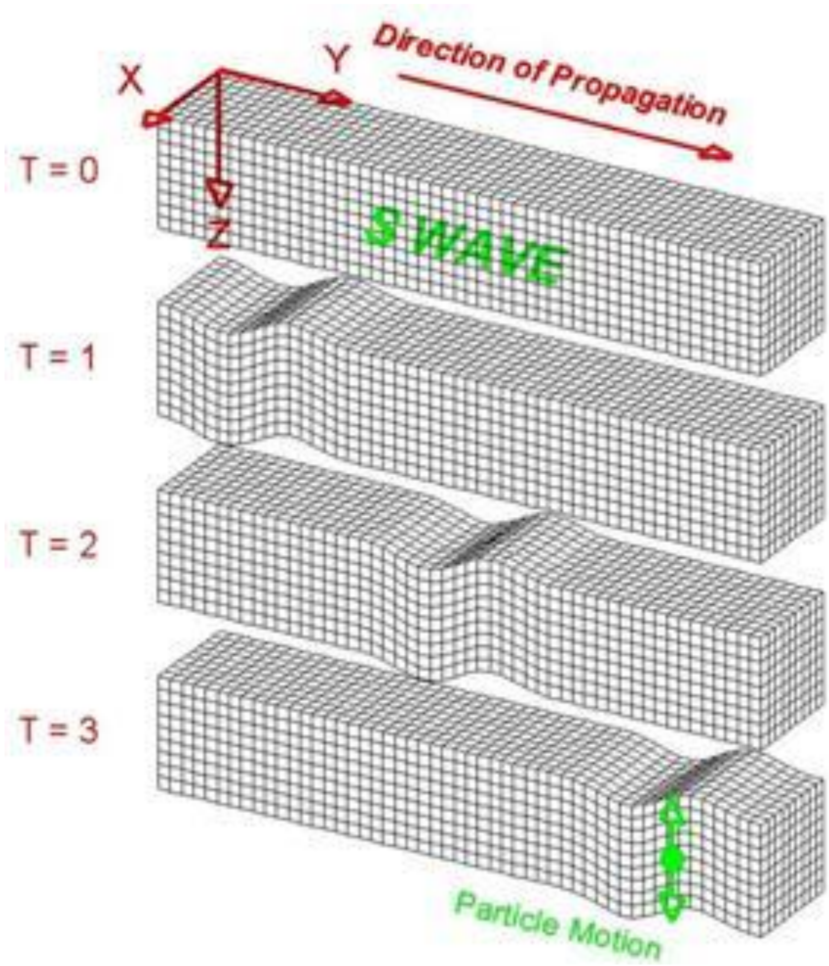
Figure 1: Perspective view of elastic P-wave propagation through a grid representing a volume of material



S-waves do not travel through fluids, so do not exist in Earth's outer core (inferred to be primarily liquid iron) or in air or water or molten rock (magma). S waves travel slower than P waves in a solid and, therefore, arrive after the P wave. S-wave as a Transverse ware is known to other names such as Shear Wave and Secondary Wave.

As illustrated in the Figure 2, the disturbance that is propagated is an up motion followed by a down motion (the shear motion could also be directed horizontally or any direction that is perpendicular to the direction of propagation). The particle motion is perpendicular to the direction of propagation. The material returns to its original shape after the wave has passed.

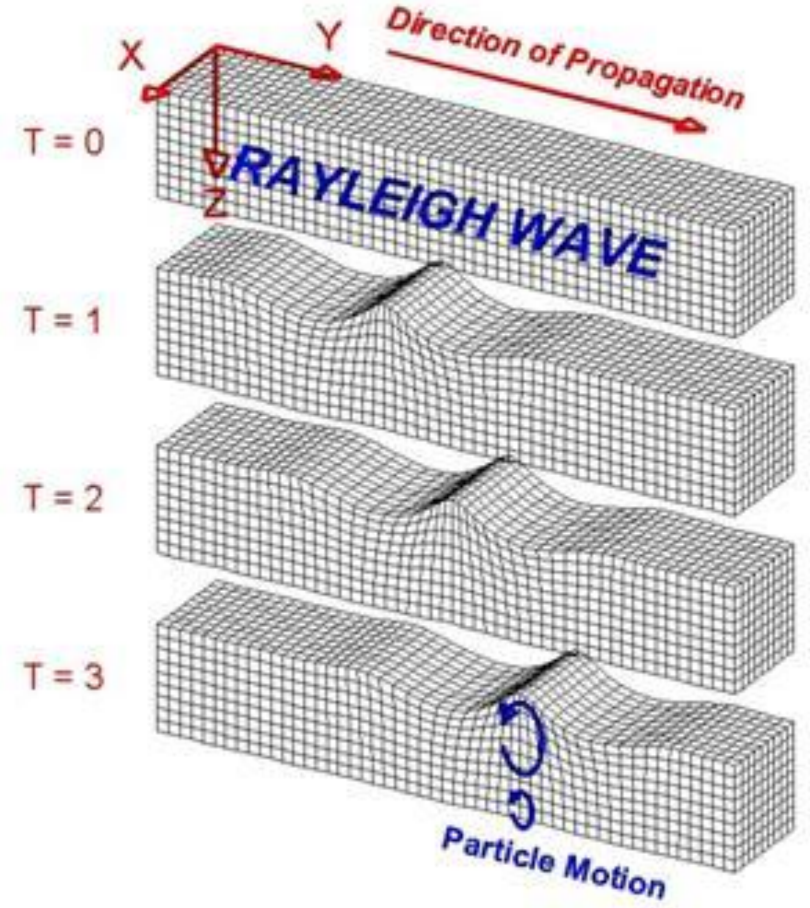
Figure 2. Perspective view of S-wave propagation through a grid representing a volume of elastic material.



Rayleigh waves are also dispersive and the amplitudes generally decrease with depth in the Earth. Appearance and particle motion are similar to water waves. Depth of penetration of the Rayleigh waves is also dependent on frequency, with lower frequencies penetrating to greater depth. Generally, Rayleigh waves travel slightly slower than Love waves.

Mean while Rayleigh waves are considered surface waves. As illustrated in the figure 3, the disturbance that is propagated is, in general, an elliptical motion which consists of both vertical (shear; perpendicular to the direction of propagation but in the plane of the raypath) and horizontal (compression; in the direction of propagation) particle motion. The amplitudes of the Rayleigh wave motion decrease with distance away from the surface. The material returns to its original shape after the wave has passed.

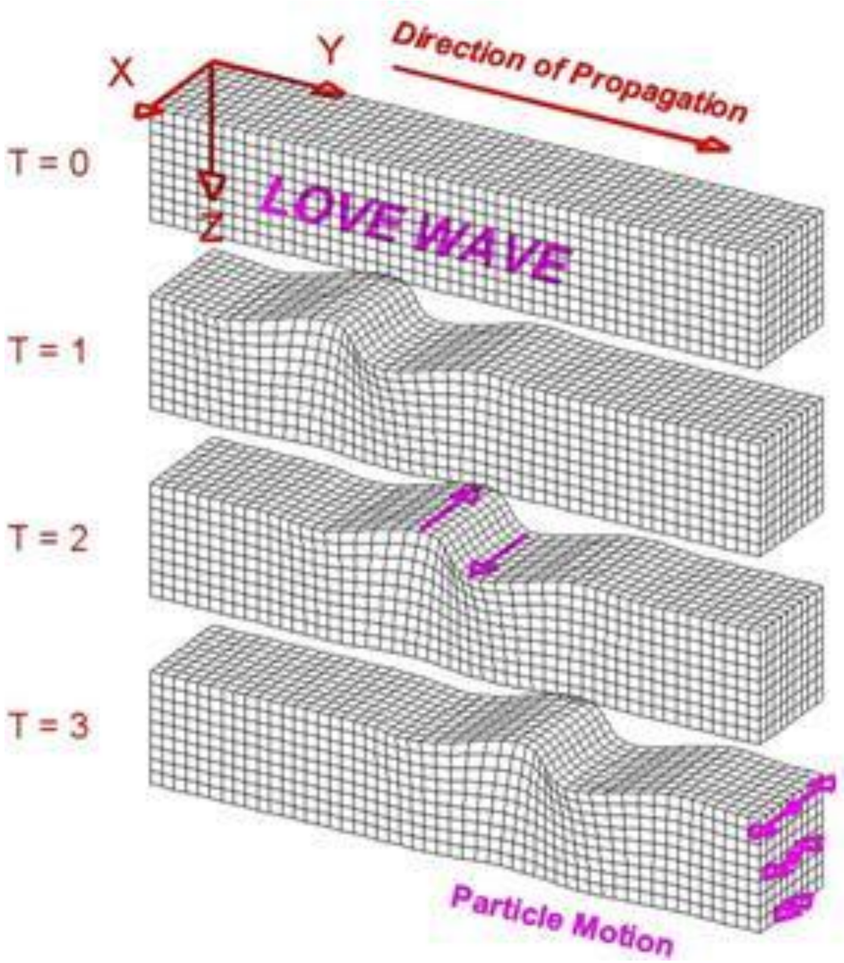
Figure 3. Perspective view of Rayleigh-wave propagation through a grid representing a volume of elastic material



Love waves exist because of the Earth's surface. They are largest at the surface and decrease in amplitude with depth. Love waves are dispersive, that is, the wave velocity is dependent on frequency, generally with low frequencies propagating at higher velocity. Depth of penetration of the Love waves is also dependent on frequency, with lower frequencies penetrating to greater depth.

Love waves are considered surface waves. As illustrated in figure 4, the disturbance that is propagated is horizontal and perpendicular to the direction of propagation. The material returns to its original shape after the wave has passed.

Figure 4. Perspective view of Love-wave propagation through a grid representing a volume of elastic material



2.2 EFFECTS OF EARTHQUAKE ON WATER SUPPLY EQUIPMENTS

The effects of earthquake on water supply system equipments can be classified into the following two types and the seismic loading for each type is calculated separately:

1.Dynamic effects of earthquake caused by ground vibrations (propagation of seismic waves in soil), calculation of which results in the following three responses:

- Acceleration (in above-ground and stationary structures results in inertia force)

- Velocity (in buried structures, especially in transmission and distribution pipelines, is more effective than acceleration)

- Displacement (seriously damages all types of structures, especially transmission pipelines buried in the ground)

According to previous description, due to dilated characteristics of longitudinal wave (P-wave), axial stress mainly made by this wave and bending stress is caused by the S-wave due to transverse movement of shear wave. However, in usual calculations specially in the Japan code, velocity of shear wave propagating is used to estimate the axial and bending stresses of pipes.

2.Static effects or geotechnical hazards, which cause permanent ground displacements that are of the following types:

- Liquefaction (and lateral spreading, especially in the banks of seas and rivers)

- Landslide (in foothills with steep slopes).

- Faulting (in station structures located on faults or buried lines crossing beneath them)

Generally, design of pipeline against the above factors are expensive and non-economic and should be tried to change pipeline pathway to avoid the aforementioned displacements, if possible. However, it sometimes is inevitable and to the possible extent should be lowered the vulnerability of pipeline systems by using specific studies. Discussion about permanent ground displacement and its effect on the water pipelines is very important but is not an objective for this paper.

2.3 SEISMIC HAZARDS TO BURIED PIPELINES[ISO-16134]

In general, there are several main causes of seismic hazards to buried pipelines:

a) ground displacement and ground strain caused by seismic ground shaking;

b) ground deformation such as a ground surface crack, ground subsidence and lateral spread induced by liquefaction;

c) relative displacement at the connecting part with the structure, etc.;

d) ground displacement and rupture along a fault zone.

2.4 MANNER IN WHICH THE EFFECTS OF EARTHQUAKE ARE APPLIED TO BURIED PIPELINES

a) To calculate the effects of the force resulting from ground displacements on buried structures, “Response Displacement Method” is used. In this method after calculating ground displacement in the specific areas and determining the spring constant of the soil surrounding the structure, the applied force is calculated. In this method velocity spectrum is used.

b) In the response displacement method, by calculating the strain of the surrounding soil regarding the viscosity between the buried structure and its surrounding soil, the strain of a buried structure can be calculated.

2.5 DETERMINING THE SEISMIC FORCE APPLIED TO THE BURIED PIPELINES

Response displacement method is developed based on *beam on elastic foundation theory*. In this method by using the earthquake velocity response spectrum and by assuming the first mode of soil shearing vibration the extent of displacement is calculated and based on the elasticity of the soil is transformed into the effective force acting on the structure.
According to this method, there are many approximate and exact methods for analytical purposes. Exact methods are applied in the computational calculations by using numerical methods such as finite element. And it is evident that approximate methods are solved by simplifying assumption and do not need numerical methods. They are easier than exact methods and accuracy of their results are not exact.
In the past researches, effects of earthquake waves has been dealt with on the pipeline located in different directions. As Shakib and Bayat (2004) reported according to the methods of Hindy and Novak (1979) and Atkinson, et al (1982), angle of strike of earthquake wave has been taken into consideration as below:

- For P-wave:

$$\varepsilon_p = \frac{V}{c_P} \sin^2\gamma \cos\gamma \qquad (1)$$

$$k_p = \frac{a}{c_P} \sin^2\gamma \cos\gamma \qquad (2)$$

- For S-wave

$$\varepsilon_p = \frac{V}{c_s^2} \sin\gamma \cos\gamma \qquad (3)$$

$$k_p = \frac{a}{c_s^2 \sin^2\gamma} \qquad (4)$$

where:

ε_p: is axial strain of pipe
k_p: is curvature of pipe
a: is the acceleration on the ground surface
V: is the velocity of ground displacement
c_p: velocity of P-wave propagation
c_s: velocity of S-wave propagation
γ: incident angle of earthquake wave with the pipeline

Same direction of ground motion and pipe axis for buried pipeline is the most critical condition for axial strain. On the other hand perpendicular direction of ground motion and buried pipeline is the most critical condition for bending strain.
Curvature of pipe can be used to determine the bending strain:

$$\varepsilon_b = k_p\, D/2 \qquad (5)$$

where:

ε_b: is bending strain
D: is pipe diameter

According to the above equations, axial and bending stresses are known as below:

$$\sigma_a = E_P.\varepsilon_a \qquad (6)$$
$$\sigma_b = E_P.\varepsilon_b \qquad (7)$$

where:

E_P: is elasticity modulus of pipe

To estimate the stresses induced to Rayleigh wave should be replaced the R-wave (velocity of Rayleigh wave propagation) instead of propagation velocity of P-wave or S-wave in the above equations [371-Pg50].
In addition to the above equations Hindy and Novak(1980) and Atkinson, et al(1982), developed them by applying correction factors for pipeline with expansion-flexible joint to determine axial and bending stresses. This correction due to taking into consideration the flexible joints causes a considerable reduction in axial and bending stress. It means, in addition to contact angle between pipe and earthquake wave, flexibility in pipe joints are important too.
Mean while, for design purpose and calculation of seismic analysis and design of buried pipelines can use the methods presented in the Iranian Guideline for Seismic Design of Water supply systems (2012) issued according to the valid code of Japan. In this manner most critical condition take into consideration.

2.6 HORIZONTAL DISPLACEMENT AMPLITUDE OF GROUND

The horizontal displacement amplitude of the ground is calculated using Equation (8):

$$U_h(x) = \left(\frac{T_G}{2\pi}\right)^2 \cdot a \cdot \cos\frac{\pi \cdot x}{2H} \qquad (8)$$

where

$U_h(x)$ is the horizontal displacement amplitude of the ground x m deep from the ground surface to the centre line of the pipe, in meter (m)

x is the depth from the ground surface, in meter (m)

T_G is the predominant period of the subsurface layer, in seconds (s)

a is the acceleration on the ground surface for design, in meter per second squared (m/s2)

H is the thickness of the subsurface layer, in meter (m)

2.7 PIPE BODY STRESS

Pipe body stress is calculated using Equations (9), (10) and (11).

Axial stress:

$$\sigma_L = \xi_1 \cdot \alpha_1 \cdot \frac{\pi \cdot U_h(x)}{L} \cdot E \tag{9}$$

where:

α_1: is the transfer coefficient of ground displacement in the pipe axis direction

Bending stress:

$$\sigma_B = \xi_2 \cdot \alpha_2 \cdot \frac{2\pi^2 \cdot D \cdot U_h(x)}{L^2} \cdot E \tag{10}$$

where:

α_2: is the transfer coefficient of ground displacement in the pipe perpendicular direction

and combination of the axial and bending stresses as combined stress:

$$\sigma_x = \sqrt{3{,}12 \cdot {\sigma_L}^2 + {\sigma_B}^2} \tag{11}$$

since U_h is horizontal displacement amplitude, the axial stress (σ_L), bending stress (σ_B), and combined stress (σ_x) are the maximum amount of their stresses regardless of the earthquake wave angle.

2.8 GROUND STRAIN IN PIPE AXIS DIRECTION, ε_G

This is calculated using Equation (12)

$$\varepsilon_G = \frac{\pi . U_h(x)}{L} \tag{12}$$

2.9 Real amount of ground displacement obtained in a case study

In order to better understanding about the real displacement of ground during eartquake, a case study for the city of Tehran is cited. This was studied by Jooyabnou Consulting Enginners Co. (2009). According to this report, by using of the method of " **generating artificial wave of strong ground motions** ", acceleration in the bedrock was calculated and the ground surface acceleration was determined by using the local magnification factor.

The **SHAKE** (as a computer program for earthquake response analysis of horizontally layered sites, by: Schnabel, Per B.; Lysmer, John; Seed, H. Bolton, University of California, Berkeley) used to calculate the maximum acceleration, velocity and displacement of the ground in the city of Tehran, and data prepared by **INTERNATIOAN INSTITUE of EARTHQUAKE ENGINEERING and SEISMOLOGY** (IIEES).

Based on the above studies, calculations of surface acceleration, velocity and displacement caused by ground motion associated with the most important faults in Tehran and around including, Mosha, North of Tehran, North of Ray and South of Ray faults has been done.

To familiarize with these faults their lengths have been given as below:

- Length of Mosha fault: 400 km
- Length of North of Tehran fault: 95 km
- Length of North of Ray fault: 16.5 km
- Length of South of Ray fault: 18.5 km

Amount of displacement of the above faults, is illustrated in figures 5-8:

Figure 5 Ground displacement induced movement of MOSHA FAULT around the city of TEHRAN-IRAN

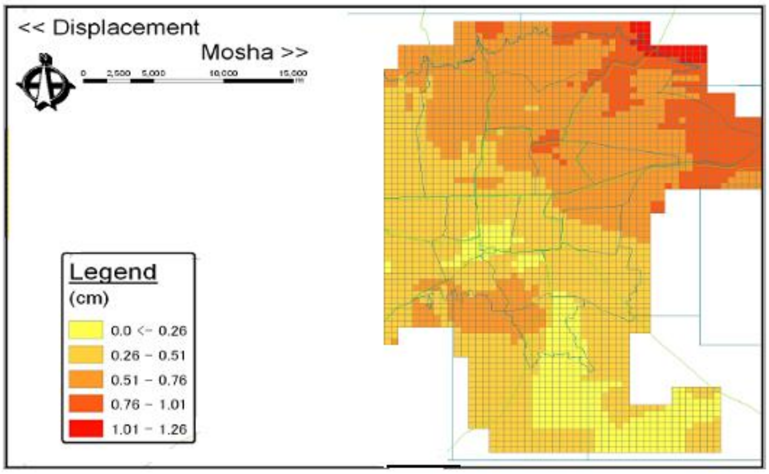


Figure 6 Ground displacement induced movement of NORTH of TEHRAN FAULT in the city of TEHRAN-IRAN

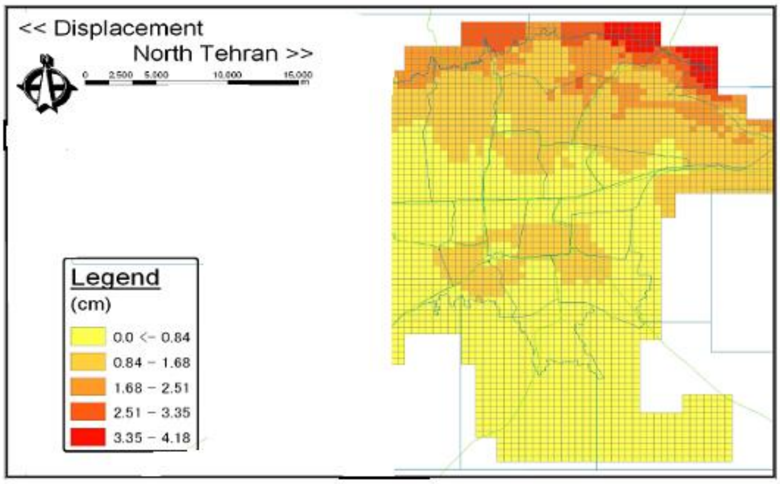


Figure 7 Ground displacement induced movement of NORTH of RAY FAULT in the city of TEHRAN-IRAN

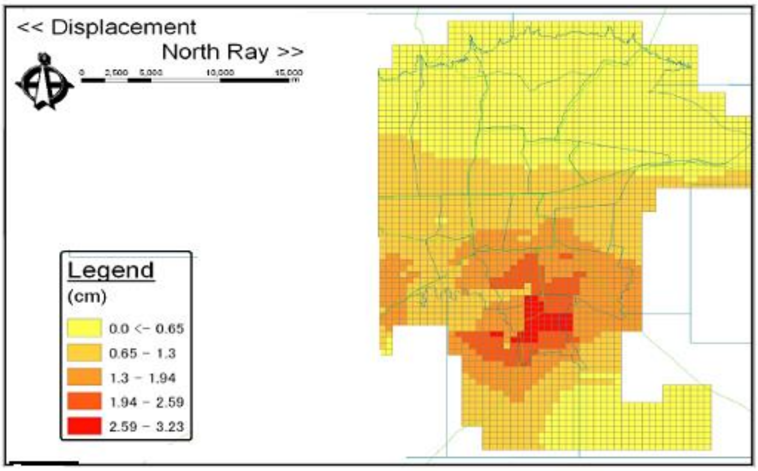
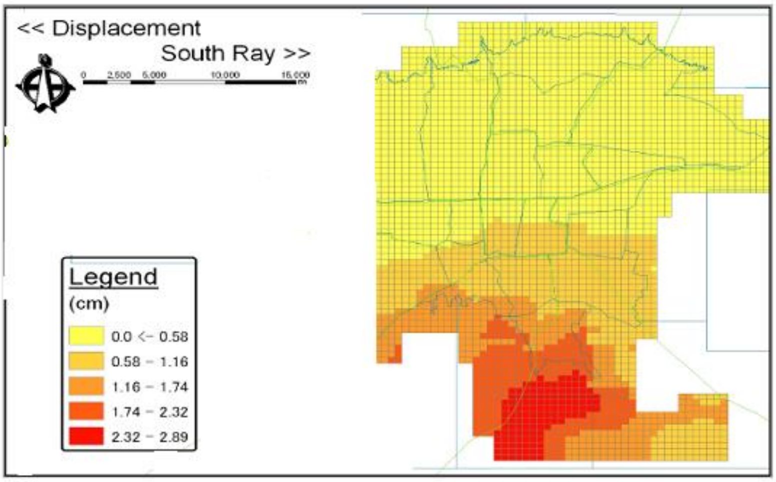


Figure 8 Ground displacement induced movement of SOUTH of RAY FAULT in the city of TEHRAN-IRAN



As illustrated in the above figures, the ground displacement values at worst, is associated with North Tehran fault where its highest will be from 3.35 to 4.18 cm. Therefore, the amplitude of ground displacement caused by the most effective fault should be considered for less than 5 cm. Mean while, it has to be repeated that the above

displacements are not considered permanent ground displacements and material returns to its original shape after the wave has passed.
It means the water supply pipelines in the city of Tehran are subject the above displacements during earthquakes induced the introduced faults. If the pipeline system can absorb the ground movement, it will secure the safety against ground motion. In practice, acceptable safety will be secured according to rational risk on the basis of economic conditions and the nature of earthquake hazard and vulnerability of water supply systems.
Regardless of minimum pipe body strength against such displacements, water networks need enough absorption capacity for expansion or contraction against the axial forces and deflection against bending stresses.
Observance of these items cause probability of serious damage in the water pipeline systems decrease considerably. To achieve these aims, engineers need to be more familiar with the pipeline components and their behavior during earthquake.

2.10 WATER DISTRIBUTION NETWORK AND TRANSMISSION

In a general, water supply systems in the distribution and transmission parts are included pipe and nodes.

2.10.1 WATER PIPELINE

Distribution or transmission water pipelines are long pressurized pipes, typically underground, for conveying and distributing water. Depending on the purpose, there are different criteria for classification of pipeline that mostly are mentioned as below:

- Buried/Above ground pipelines
- Pipelines with flexible/rigid joints
- Ductile/Brittle pipeline
- Pressurized/By gravity pipeline

In this paper water transmission and distribution network as pressurized pipelines are considered. Generally, these pipelines are buried and this is why only buried pipelines are focused in this paper. Burying is defined "placing of pipes underground in a condition where they touch the soil directly". Burying is for safety and in addition does not cause traffic restrictions. The buried pipelines are more protected against environmental events. Another advantage of burying is to minimize the effects of climate changes on pipeline and its contents.

Buried pipelines are of two types:

- disjoint pipelines

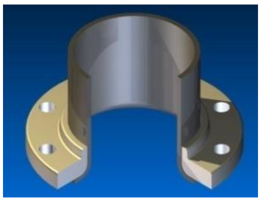
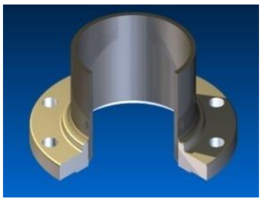
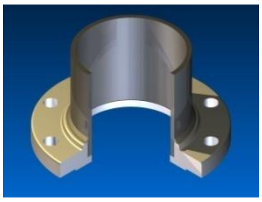
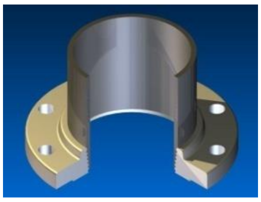
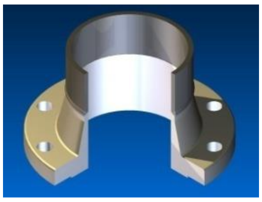
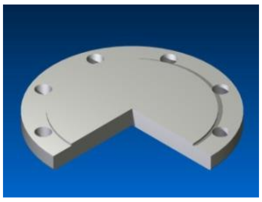
- unbroken pipelines.

Buried unbroken pipelines are mostly constructed of welded steel or poly ethylene. Disjoint pipes are usually 6 to 12 meter segments and there are different materials such as ductile iron, GRP, Asbestos cement pipes that are produced as disjoint pipes.

2.10.2 NODES

Nodes or junctions are points at where pipelines connect to each other. In practice, pipeline connection need to the several components. Hence nodes are points including fittings and valves and their accessories. Usually, valves connect to the fittings or pipes through flanges. In the pipeline systems, a pipe flange is a disc, collar or ring that attaches to pipe with the purpose of providing increased support for strength, blocking off a pipeline or implementing the attachment of more items. Pipe flanges are usually welded or screwed to the pipe end and are connected with bolts. A gasket is inserted between the two mating flanges to provide a tighter seal. There are 6 basic types of pipe flanges in figure 9

Figure 9 Six basic types of pipe flanges

 *Lap Joint Pipe Flange*	 *Slip-On Pipe Flange*	 *Socket Weld Pipe Flange*
 *Threaded Flange Pipe*	 *Weld Neck Pipe Flange*	 *Blind Flange*

"The most important parts of the pipelines in a distribution network are their junctions, which are the most vulnerable part of the network to the effects of earthquake left on the system". For what reason, the junctions are the most vulnerable parts of a water supply during an earthquake? and what arrangements need to decrease the vulnerability of the nodes?

As previously mentioned, ground displacement create axial and bending stresses in pipes. In more detail, same direction of ground motion and pipe axis for buried pipeline is the most critical condition for axial strain and perpendicular direction of ground motion and buried pipeline is the most critical condition for bending strain.

Imagine pipelines located in different directions are not connected to each other. Even though, in such cases each pipeline has its axial and bending strain but since they are not considered as connected network the differences of the axial and bending strain do not affect to their seismic behavior. Unbroken pipelines do not break and disjoint pipelines are not disconnected because of the independent behavior of the pipelines.

Obviously, restriction of movement of some points in pipelines or reducing the degrees of freedom in some nodes will cause stress concentration at those points due to different strain induced earthquake waves. If this stress concentration is greater than the allowable stress of pipeline, the applied forces cause breakage or disconnection in the pipelines body or joints.

According to the basic discussions in Strength of Materials, with increasing rigidity of joints, relative motion is decreased and axial and bending stresses are increased. Flanged nodes which connect different pipelines by using flanged components are considered rigid connection and changes the network to a moment-resisting frame. In other words, in the flanged nodes, the axial and bending strains in different pipelines affect behavior of the other pipelines during earthquake and definitely increase the potential of pipeline failure by breaking or disconnecting the pipeline joints. It means the flanged nodes as rigid connections play a role similar to the junctions between the pipelines and the structures, which are the points of stress concentration and sudden deformations.
Obviously, by increasing the degree of freedom in the connection points can provide a flexible network to damp different stresses in the nodes due to different strain in the connected pipelines. Increasing the degree of freedom in the nodes not only are included those specific points connecting the pipelines to the structures such as reservoirs, pump stations, bridges, valve chambers etc. but the points connecting pipelines in different directions as well.

Degree of freedom will be properly available in the network nodes if flanged or constrained nodes change to the flexible nodes by adding the expansion or flexible segments between the flanged joints.

Therefore expansion and flexible joints can be used to reduce or prevent damages. If a ground is in such a condition, the pipeline should be able to bear all the deformations. Figure 9 shows effect of the employment of the highly earthquake resistant materials and joints in Japan during Kobe earthquake in 1995 (Fokuda).

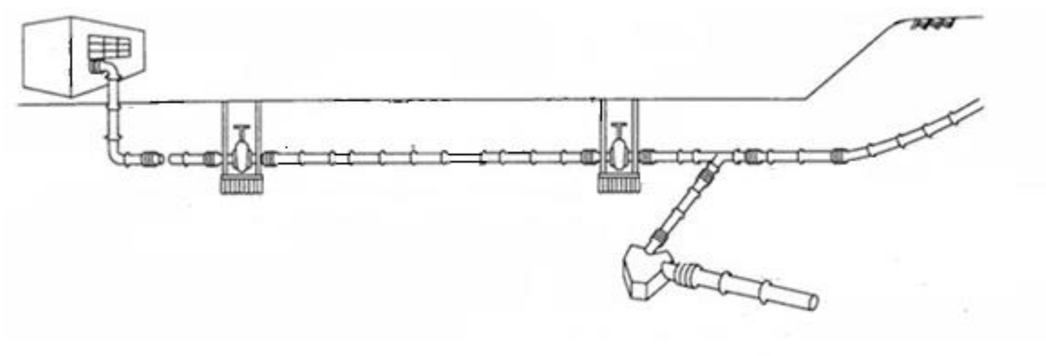
Figure 10 Deformed flexible pipe (Kobe-Japan)

The picture shows role of a deformed flexible pipe (covered expansion joint) in the Kobe water supply system during earthquake. Definitely if flexible pipe was not installed, a large damage had suffered in this pipeline. Use of expansion joint is crucial for such places in which two parts of a system subject to different displacements

Expansion and flexible joints are produced in different types for axial movement, lateral movement, angular rotation. In addition single or double expansion joint with or without hinge can provide different degree of freedom for the connections.

Expansion and unbreakable joints should be employed to prevent displacement and rupture of straight pipelines. In sections subject to bending forces highly flexible expansion clamping joints has to be used.

Figure 11 Schematic of typical usage of expansion joint in a disjoint pipeline system



Use of the expansion and flexible joint against ground motion need to enough studies to prevent any damage during earthquake. For example in the 2011 Great East Japan Earthquake, the largest water leakage flows occurred at failed expansion joints in 2400mm and 1200mm diameter water pipelines in Miyagi Prefecture. The damage mechanism of buried expansion joints was investigated by site damage inspections and seismic response analyses, which suggested that the expansion joints had absorbed certain settlement before the earthquake, and as a result, the seismic shaking triggered expansion joint failure (Higashide et al., 2012).

3 GENERAL CHARACTERISTICS OF PIPELINES

At the end of this article, a diverse list of general characteristics of buried pipeline gained from previous earthquakes, laboratory results and parametric studies has been given to use for design purposes, Shakib and Bayat,(2004):

- The pipe deformation is mostly as same as motion of the surrounding soil.
- Axial strain in buried pipes is greater than the bending strain.
- Because of phase difference, the maximum strain and ground acceleration do not occur at the same time.
- If the pipeline is more ductile, it has less potential of vulnerability
- Probability of pipeline damage in loose ground (low N in SPT) is more than rigid ground
- Increased rigidity of the soil surrounding the pipe will increase the velocity of wave propagation and therefore decrease the strain.
- With the increasing rigidity of fittings the relative motion of the components is reduced and consequently the maximum axial and bending stress increase.
- The probability of pipeline damage connecting to the structures is high. Therefore, the junctions between the pipes and the structures should have the required deformation absorption capacity.
- With increasing the pipeline length, the amount of stresses are added. Increased amount in the axial stress compared to the bending stress is significant. If pipeline length becomes longer than 150 times of the pipeline diameter, this effect will be negligible.

4 SUMMARY

As mentioned in the above discussions, in water network, pipelines are generally buried. On the other hand, due to the network structure, pipelines are connected to each other in different directions. Nodes are points at where non-aligned pipelines connect to each other. In practice, connection of pipelines in the nodes are made by using components such as valves and fittings. Valves are devices that play an operational role in water network to regulate, direct or control the water flow by opening, closing, or partially obstructing various passageways. Valve are always connected at their ports to pipes or other components. In large scale, valves are often connected to other components by flanges. Of course, the other methods such as threading, compression fittings, welding, etc. are possible as well. Regardless of connection type in the nodes, valves connection functionally causes rigid nodes which their degree of freedom is zero. On the other hand, earthquake waves cause different axial and bending strain in different directions. Therefore, combination of the both issues, rigid connections and various strain, cause extra stresses in the nodes connecting non-aligned pipelines. Originally, reason for existence of the added stresses in each pipeline are applied strain from the other pipelines. These stresses can be damped by increasing degree of freedom in the junctions and specifically by changing rigid nodes to flexible nodes. Making flexibility in the rigid junctions are achievable by adding expansion joints between connections of valves and fittings. Mean while, since function of valves need the fixed position, it is recommended to seat and fix on concrete foundations.

REFERENCES

- Braileã L.W. (2006) 'Seismic Waves and the Slinky' Purdue University, 1-3
- Higashide T., Yabuguchi T., Imai T. and Koike T. (2012), 'Seismic performance assessment of expansion joints for water lifelines', 1
- Iranian '*Guideline for Seismic Design of Water supply systems*' (2012)
- Jooyabnou Consulting Engineers Co. (2009), ' Report of Master plan of Tehran Multi-Utility Tunnels ', Vol. 3
- Fouda I.H. (2002), 'Damages in the Kobe Earthquake and Japanese seismic design guidelines of drinking water supply facilities', III Curso Internacional sobre Microzonificación y su aplicación en la Mitigación de Desastres, 63
- Shakib H., Bayat H. (2004), *'Seismic Analysis and Design of Buried Pipelines'* , Building and Housing Research Center, R-371,48