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EARTHQUAKE BEHAVIOR OF UNDER-GROUND PIPELINE NETWORK

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Abstract : *In this study, a new method is proposed to evaluate the seismic behavior of buried jointed water pipeline networks subjected to wave propagation. First, using finite element method and solid elements, different kinds of currently used connections in the network are modeled, and their nonlinear behavior in all directions is obtained. Second, a 950-meter long network consisting of ductile iron pipes segments of 6-meter length and springs characterizing the connections, are modeled using beam elements. Three-component displacement record of the Tabas earthquake is applied to the network considering the time lag between support inputs, and the nonlinear soil- pipe interaction. The record is applied once in North-South direction and once in East-West direction with different wave propagation velocities. Results of interest such as stress values and rotations at various points of the network are then obtained, and critical points are introduced in each direction. Results show that the points other than the critical ones at the network intersections remain elastic.*

Keywords-Finite Element Method, Ductile Iron Connections, Three Component Displacement Records, Nonlinear Soil-Pipe Interaction.

Introduction

Water supply networks are one of the main components of urban infrastructures and their continuous and uninterrupted operation is of great importance in today’s life. These networks are vulnerable to seismic wave propagation, and adverse consequences followed directly or indirectly from damages, affect the citizens. Since the jointed pipe network constitutes a significant part of Tehran’s water supply system, investigating the network operation during the design earthquake and ensuring its functionality after the earthquake is necessary. For the first time in 1930, earthquake effects on water networks were considered. However, analytical and numerical studies have started since two decades ago . So far, seismic damage assessment on water distribution networks has been conducted by using various methods including theoretical methods such as artificial neural network . Due to difficulties in describing ground-motion intensity over a region and since the link between the ground-motion intensities and lifeline performance is usually not available in closed form, Jayaram and Baker proposed a simulation-based framework for developing a small but stochastically-representative catalog of earthquake ground-motion intensity maps that can be used for lifeline risk assessment. In references reports on the earthquake damage on jointed pipe networks are issued. Toprak *et al*. evaluated the performance of the water supply system in Denizli, Turkey. They compared the relative effects of transient ground deformations and permanent ground deformations based on maps of liquefiable soil and zones of pre-dicted lateral ground displacements.During the past earthquakes, most of the jointed pipe network failures have occurred at connections, where connection pull-out, cut and crushing (concrete pipe connections) have been reported . A large number of the studies have been conducted on continuous pipeline networks, and because of the complexities in jointed pipe networks compared to the continuous ones, fewer studies on jointed pipe networks considering connection be- havior have been made. Most of the studies on jointed pipe networks have been based on observations or esti- mations, and only in the past two decades, thanks to software and laboratory advances, research in this area has been expanded. Abdoun *et al*.conducted an experimental study on the behavior of buried continuous pipe- line subjected to ground faulting. Karamitros *et al*. presented a rigorous method to calculate the response of continuous pipes considering the axial and bending stiffness. Junhee Kim *et al* carried out the experimentation of a reinforced concrete segmented concrete pipeline. Accurate measures of pipeline displacements and strains were captured up to the compressive and flexural failure of the pipeline joints. The present study is carried out on a part of water supply network of Tehran metropolis in which ductile iron pipes of 6 meter length and connections of Tyton and Bolted gland types are used. Focusing on non-linear behavior of the connections, the present study tries to identify mechanically vulnerable points of the network. The analyses are performed using appropriate Finite Element (FE) software. Details of the study are presented in the following sections.

Tyton Connections-

In Tyton Connections, the gap between spigot and socket due to the manufacturing tolerances, and operational limits, has a significant impact on the results and by increasing the gap, the flexural behavior of the connection becomes softer. In the productions of the company, this manufacturing tolerance is equal to 1 mm and this value is used in modeling. In stress contours, deformation and nonlinear behavior of Tyton connections under compressive loading are shown. It should be mentioned that, the red color represents areas of the maximum stress, while the blue shows areas of the least stress. As there is a 4 mm distance (gap) between spigot and the socket in axial direction. The only resistant factor against spigot inward movement is its friction with the gasket that can be ignored. When the gap is finished, two cast iron segments (spigot and socket) start to contact each other, and from this stage on, the inward movement is accompanied by a high axial stiffness until the stress at the edge of the plain head (spigot) reaches the yield point. This yielding occurs in the entire pipe section, simultaneously. Finally, the stress reaches its ultimate value. Since the only resisting factor against spigot's movement in tension is its friction with the gasket, for Tyton connections, a small value is considered as the tensile stiffness, there is a distance between socket and spigot in shear as well as the axial direction that causes a very soft behavior at the beginning of the movement. With the socket and spigot colliding, the behavior is stiffened until the spigot yields in its contact point with the socket, because the thickness of the spigot is less than the socket head. Unlike the compressive mode, in shear mode, the yielding gradually spreads from the contact points of two pipes, and by increasing the contact surface of the two segments, yielding area expands. It is worth mentioning that Tyton connections of different diameters are modeled with different lengths, and the results show that the length parameter does affect the connection behavior. Thus, it can be deduced that the shear and flexural behaviors of Tyton connections cannot be compared based only on their diameters. For the flexural loading, the end of the socket is fixed, and by defining a constraint point at the end of the spigot, the whole section is restrained. Afterwards, by rotating the point, the section also rotates uniformly. To determine the effect of the gap between the socket and spigot, the flexural behavior of Tyton 150 for three dif- ferent gaps of 0, 1 and 3 mm is evaluated and the results of 1 mm gap are used in the network. However, by increasing the gap from 1 to 3 mm, a significant increase in the initial slackness and a decrease in the stiffness can be noticed. In addition, the ultimate strength is signifi- cantly reduced due to the drop in the effective cross section for bending which, leads to stress concentration.

Bolted Gland Connections

According to the Bolted gland connection (mono), stress concentration occurs near the 200 mm end, and in 300 mm end, stresses decrease due to the increase in the cross section.It can be stated that when the thickness of the 200 - 300 culvert with two socket heads (bolted gland double) is more than that of the two attached pipes, stress concentration in the two pipes and the culvert segment remains almost within the linear limits.Considering , one can note that since the culvert segment has been attached to the straight pipes at both ends, it can easily rotate. This makes the connection softer and reduces its ultimate shear resistance so that no high stress would be imposed to the culvert. In the connection of the pipes and the culvert, stress values in- crease in the pipes, while in the culvert segment, stress values remain in the elastic range due to its higher thick- ness value.

Bend Connections

In 200 mm bend connection, similar to 200 - 300 mm culvert with two spigots, the connected pipes are weak- er in shear direction compared to the bend segment, and stress in the bend remains in elastic range. In this connection, unlike the 200 mm bend, there is a significant stress in the body. In this case, the segment of the bend, in addition to the transmitted force from spigot, should over- come the induced moment. This moment causes plastic stress near the support (in the side with no pipe). In the support itself, because of its considerable thickness, stress remains in elastic range. The behavior of 300 mm bend is completely different from 200 mm bend and the capacities of these two bends are not comparable. By comparing the behavior of the connections graphs, it can be seen that Tyton connections gaps cause softer behavior in comparison to Bolted gland connections. For example, the maximum elastic strength of 200-300 Bolted gland connection with 1 spigot (mono) in shear is about 30% higher than the corresponding force of 200 mm Tyton. The main fault of the Tyton connections is in tension, as the only resistant factor is the friction be- tween the gasket and the spigot, which is very low and is actually negligible. Complementary information about the behavior of the current connections is presented in the main report of the work.

Modeling and Seismic Analysis of the Network

In this study, a part of Tehran water distribution pipeline network is considered with an overall length of 950 meters. It is constituted of a number of bends, culverts and straight pipes.

Soil-Pipe Interaction

This interaction has been taken into account based on which the behavior of soil is modeled by bilinear springs, whose specifications depend on the pipe diameter, soil type and density, its internal friction angle, and the burial depth of pipe. In the modeling, a burial depth of 1.5 meters and compacted sand are considered. Equivalent soil springs are defined with translational properties in three directions, while the equivalent springs of the connections between two pipe segments have three translational and three rotational components. It is necessary to note that equivalent soil springs are placed every 1 meter along the pipe, and at both ends of the connection. For modeling boundary conditions, after testing different scenarios, it is finally decided that the rotations being restrained at four boundary points (ends of the pipelines) in all three directions and the translations being free is the situation most consistent with the actuality, because, the least local stress is caused in the foregoing scenario.

The Minimum Effective Length

The minimum effective length in pipelines was defined by Tahamoli-Hosseini. They determined the term for the continuous pipelines (welded connections that can be supposed as continuous pipes) . In short, the minimum length for which the boundary conditions do not affect the response of the midpoint of the pipeline is called the minimum effective length. To determine this length for jointed pipelines, two pipelines with lengths of 30 and 60 meters and a diameter of 150 mm are considered. A sinusoidal wave with equation $y0 \sin(2\pi t/T)$, has been applied to the spring supports with a phase difference, which depends on the shear wave velocity in soil. T (period of the wave) equals 1 sec, and Vs (the shear velocity) equals 150 m/s.

It can be concluded that in jointed pipelines, the boundary conditions have almost no effect on the behavior of the pipelines, even in case of small total lengths as 30 m. It can be deduced that, the pipeline is much softer than the dense sand soil and bears almost the whole displacements, while displacements of soil springs are very small.

Network Analysis with Tabas Earthquake Record

Tabas earthquake record is applied to the spring support with a phase difference, which depends on shear wave velocity in soil. This record is applied once in North-South and once in East-West directions.

From the analysis, it is found that, for lines perpendicular to the wave direction, rotations and stresses are very small and lines parallel to the wave direction sustain the maximum damage. In addition, for the critical points of intersections of the branches that are parallel to the wave direction, a high damage is expected.

During the wave movement along North-South direction, the intersection of 150 mm Tyton Pipeline and 200 mm Tyton Pipeline is the critical point. That can be as a result of changes in displacement transmission so that the pipeline parallel to wave direction is suddenly cut and the new pipeline becomes perpendicular to the wave direction and the previous pipeline. The intersection of Tyton 150 pipelines (parallel to the wave direction) and Tyton 200 pipelines (perpendicular to the direction of wave propa- gation). Wave moves in the N-S direction along Tyton150. In the desired point, the N-S line is cut, and a per- pendicular new line is created. This leads to a disturbance in the imposed displacement transmission system, and stress and rotation rise locally. The connection is of Tyton type; therefore, orthogonal pipes can rotate freely around the connection and stress values rise along the pipe. It is observed from the deformation illustrated that when the network moves along the N-S di- rection, the resistant factor against the pipeline of the Tyton 150 is the axial friction of the soil. This factor against perpendicular line is the lateral horizontal component of the soil spring that is much larger than the axial component. It means that the pipeline of Tyton 150, in the axial direction, has a larger freedom of movement than Tyton 200 pipeline; therefore, the pipeline of Tyton 200 would be made to deform.Similarly, when the wave moves along the East-West direction and is parallel to Tyton 200, Tyton 300 and perpendicular to Tyton 150 pipelines, critical points are the connection points of the bends. Bend connections are of Bolted gland type that are much more resistant against deformation in comparison to Tyton connections. Despite the high level of stress values in Bolted gland connections, their rotations are less than those of Tyton connections.

LITERATURE REVIEW-

Vladmir Zivica (April 2003) studied the causes for corrosion on reinforcement are studied where the action carbonation and chloride attack are given preliminary importance.

Ted R. Mortan (December 1973) in this paper talks about fiber glass reinforced plastics used in many applications; from boats to missiles. The article is mainly concerned with the use of fiber glass reinforced plastics for corrosion resistant applications.

Anees U. Malik (March 2001) the paper deals with studies carried out on the corrosion and mechanical behaviour of fusion bonded epoxy (FBE) coating on steel in aqueous media which include product water, distilled water and saline water. The mechanical testing's on coating include adhesion, bending and Cathodic disbondment testing.

Conclusions

In general, when seismic waves propagate in the earth's surface, phase differences and frequency contents of an incoming wave are the factors contributing in the failure of buried pipe networks. According to the analysis conducted in the present study, the following results are obtained

1) In pipes of larger diameters, because of the higher flexural stiffness, less rotation occurs under the same relative displacement imposed from the soil. Considering the rotations of 200 and 300 pipelines, it can be seen that with 50% increase in the diameter of the pipe, rotations decline by almost 15%. This does not mean that pipes with larger diameters performed better because with increasing diameter, the maximum allowable rotation without leakage and damage is reduced.

2) For modeling boundary conditions, the best scenario, during which the least local stress is caused, is fixed rotations and free translations in all three directions at both ends of a pipeline.

3) Since relative displacement is the cause of damage, in pipes orthogonal to the wave direction no damage occurs, for there is no time lag and successively no relative displacement between different points.

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