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STUDY OF WATER PIPE AND SOIL INTERACTION DURING PASSAGE OF STRIKE-SLIP FAULT

Yousef Kor[1], Omid Alipour Tomaj[2], Hamid Reza Rostamani[3], Mohammad Reza Borna[4] , mehrdad Purghaz[5], Mehrdad Farrokhi[*6]

1. *MSc of Environmental Engineering, Environmental Engineering Research center,Golestan University of Medical Sciences, Gorgan, Iran*
2. *Phd Candidate,Department of Agriculture and Natural Resources, Environmental Engineering Research center Gorgan Branch, Islamic Azad University,Gorgan-Iran*
3. *Phd Candidate of ITM , Environmental Engineering Research center, Golestan University of Medical Sciences, Gorgan, Iran*
4. *Phd Candidate of civil Engineering,Science and Research Branch, Islamic Azad University of Tehran, MSc of Golestan Province Gas Co, Gorgan, Iran*
5. *MSc of IT, Assistant of Torkman central Education Office,Bandar torkman, Iran*
6. *Professor, Department of Health in Disaster and Emergencies ,University of Social Welfare and Rehabilitation, Tehran, Iran*

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ABSTRACT

Pipelines may be ruptured due to large deformation caused by faults, liquefaction or instability of slopes. Safe and effective designing pipelines when crossing fault is one of major challenges facing pipelines' designers.The thesis studies reaction of a metal pipeline to the motion of a strike-slip fault. Soil and pipe interaction investigated by considering two types of soil: very sticky and weak granular soil under fault displacement. There has been used steel API5L grade.x65 for the pipelines.Since tension and strain are more near the fault, elements have been considered smaller near the fault and larger in other points. There has been modeled a fault by taking a fixed block and displacing to movable block and interaction of soil-pipe by entering mechanical properties of soil and pipe to software.

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Introduction

Faults are shaped because of compression, tension and shear movements of tectonic plates that sometimes, cause a few meters shifts. The shifts can be very destructive for underground facilities such as tunnels and pipelines. It is very common to use the buried metal pipes with welded connections to transfer water, oil and gas over long distances. The pipelines may pass from different geographical regions and sometimes through active faults. Since pipeline rupture may cause financial, environmental and safety damages, designing pipeline to tolerate fault relocation is very important. In many cases, destruction of pipelines has been recorded in earthquakes that occurred recently. For example, there was occurred an earthquake in Chlangpo fault;1991, Chichi Region, Taiwan. It was a reverse fault and moved up to 10 meters. Field

Corresponding Author: Mehrdad Farrokhi

observations indicate that strong earthquakes such as San Fernando ;1971, Managua ;1972, Hi Chang ;1975, Tangshan ;1976, Miyagi Ken ;1978, Manjil ;1990, Norsrij ;1994, Kobe ;1995 and Quja Eli ;1999 caused severe damage to the buried pipelines.[1]

Therefore, it is essential that pipelines will be designed, as which it passes fault safely and with the least risk of rupture. Response of the buried pipeline greatly influenced by direction of fault movement and direction of placing the pipeline in fault. Typically, a metal pipeline influenced by strain of straight stretch can safely tolerate against deformation, than when influenced by strain of direct pressure. For pipelines located on ground or the slippery or flexible support, fault movement is depreciated by the support and reduced tolerably for the pipe and does not have risk. However, when pipeline is burned because of security, aesthetic and ecological reasons, it is surrounded by a hard soil. During the displacement caused by fault motion, all displacement will transferred to pipelines with minimal reduction in amount of pipe displacement..[2]

As pipe is surrounded by a mass of hard soil, it will be deformed and fractured. Studies and field observations have shown the more hard the surrounded soil, the more rupture in pipeline, and it can experience more great strains higher than their capacity. Continuous displacements caused by fault movement of the permanent tensile strain caused by fault movement and create a lot of pressure in the pipeline. Ruptures include the localized buckling and great deformations in the pipe section. It is true that earthquake has a dynamic nature, but as there is studied relative movement between both plates during studying shifts, and it is applied to the motion section gradually and step by step, we can analyze it as pseudo-static..[3]

MaterialsAnd Methods

In the modeling, diameter and wall thickness of the pipeline are 914.4 mm (36 inches) and 12.7 mm (0.5 inches) respectively. Steel strain curve has been considered as elastic-plastic fully. Steel rupture tension of the pipe, its modulus of elasticity, Poisson'sratio and the internal pressure are 450 mpa, 210 Gp, 0.3 and 50 bar of 50 bar respectively (Figure 1).

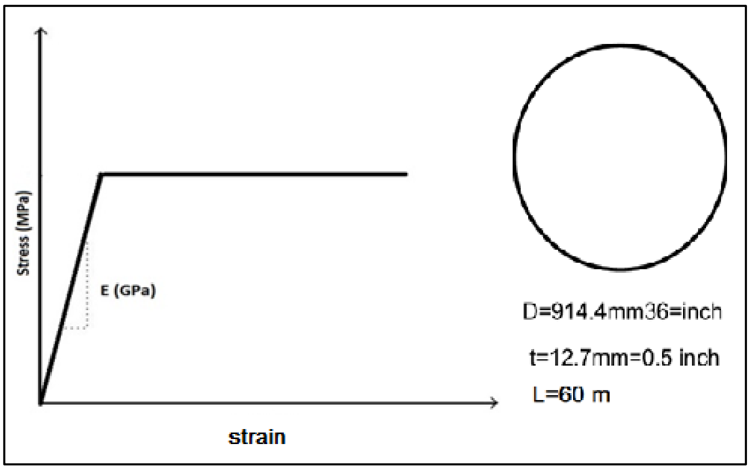

Fig. 1.: Stress-strain curve of steel

The considered soil is a granular soil with the following specifications:

Special weight: $\gamma = 17.5\frac{kn}{m^3}$;

Adhesion of clay: $C = 5kpa$;

Modulus of elasticity: $E = 25mp$;

Angle of internal friction: $\varphi = 30$;

Soil dilation angle: $\psi = 0.7$;

Poisson's ratio: $\vartheta = 0.30$

Finite Elements Modeling

Stimulation of pipeline and boundary conditions

Pipeline was firstly stimulated by simple method. It was completed by developing sciences and modelling software. Stimulation of pipeline Includes: 1) pipe stimulation; 2) its final sections. In beginning, welded steel line was considered as a cable and its end was controlled in earth. In this method, all incoming forces to the pipeline were considered as tensional (friction around the pipeline causes traction on the pipe). Considering high length (approx.1km) is one of specifications of the method. This method was error because of lack of considering buckle hardness of the pipeline, lack of applying internal pressure and lack of correct modeling surround soil reaction. In next researches, the pipeline was considered as a reactionary bed. This method has stimulated buckle difficulty of the pipeline and bed reaction by using springs equivalent soil hardness.

By developing the method, there was not stimulated bed soil, but surrounded soil by equivalent springs. These springs were connected to pipe in different points that are called discrete soil spring. Hardness of the springs is equivalent with hardness of the surrounded soil on different axial directions, transverse, upright and down right. In this method, length line is high and its two ends are completely fractured. The method, as the common method to analyze the passed pipeline from fault, has the following disadvantages:

Since the pipeline is considered as bar and there is used bar element B31 in ABAQUS software for modeling, this element has no ability for internal pressure and it cannot stimulate local buckle.[4]

High length of the modeled pipeline causes increasing analysis time considerably.

Soil is connected as discrete springs and it is not possible to modeling soil as integrated.

In efforts to solve the defects of the method and by developing modeling software, there were stimulated the pipeline and soil with plate and brick elements respectively. By doing the two corrections, there was possible to model soil integrated, applying internal pressure and stimulating local buckling. However, problem of high length was remained in the pipeline. Therefore, there was used method of equivalent boundaries in the next researches. In this method, there has been calculated stiffness of any desired length of pipeline by theoretical relationship and manual computations, and then the length is deducted from theory length. Then equivalent stiffness of to the pipeline length, which should be eliminated, will be applied to remains of the pipeline as boundary conditions. Using this method not reduced the analysis time intensely, but provided lack of need to computers with powerful processors. Another way that is used to consider the required length for analysis is based on the matter that considers that section of the pipeline with the most movement from the fault and the greatest possible participation response; it neglects the rest of theoretical length that its elimination has a negligible impact on the results. In this research, for software modeling, there was considered 60 m and 250 cm for length of metal pipeline and depth respectively. It has been selected based on researches and experiences of previous researchers. There has been considered 0.3 for friction between the soil and out surface of the pipeline for clay and surface contact between the pipe and the software is intended to be friction. There have been considered 914.4 mm (36 inches) and 12.7 mm (0.5 inches) for pipe diameter and wall thickness. The used steel in the pipe is API 5L grades X65. The considered element for modeling the pipeline is S4R. The letter S shows kind of element. Here, number 4 in shell elements shows four-node element and the letter R means solving integrals through the reduced integral method. There were considered 54 elements as number of the intended elements for the pipe environment and length of each element along the pipeline equals 1/26 D outer diameter of the pipe. Total elements of the pipeline are 10252 (Fig. 2).

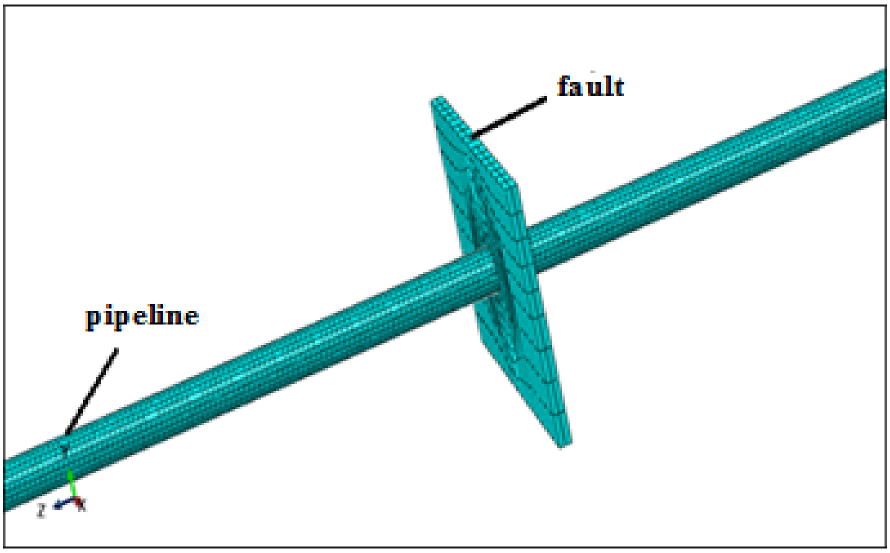

Fig. 2, Modeling pipeline and fault

Simulating fault, soil and boundary conditions

Simulating fault is one of important stages. Researchers conduct it similarly. However, the recent methods have changed it slightly. The soil surrounding the pipe is considered as a hexagonal prism (block) that the fault line divides it into two equal parts. The right and left blocks are footwall (fixed part) hanging wall (moving parts) blocks respectively. In this research, the last method has been used that is described below. In general, fault contains hanging wall and footwall. In modeling, the footwall moving in all directions is identified and only the upper surface of the soil is considered as free surface, and it can move vertically (possible of swelling the soil). For modeling the hanging wall, there has been identified moving lower surface and that side of the prism surface that surrounds end of the pipeline vertically (roller bearing) and it moves horizontally only. Shifting is applies in the fault toward both lateral sides of soil prism and to the pipe end node simultaneously. Maximum moving of the fault has been considered 1 m. Block dimensions in directions X, Y and Z are 10, 60 and 5 meters respectively. The total number of elements in the soil for modeling software is 14544 (Fig. 3). For modeling soil, there were used brick elements C3D8R. the letter R means solving through the reduced integral method. Number 8 represents an eight-node element, 3D means three-dimensional characters and letter C represents elements of Continum type.

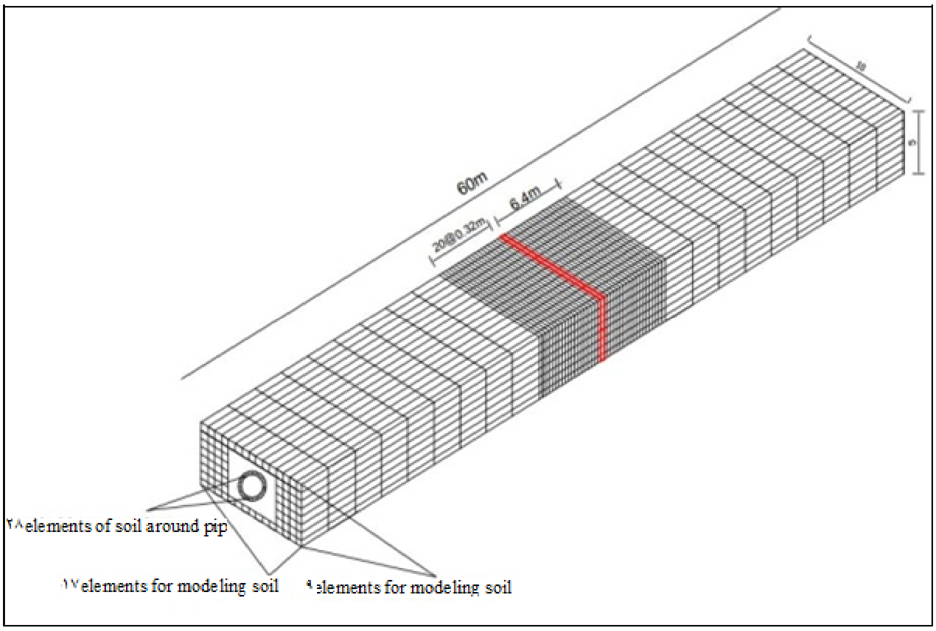

Fig. 3. The model geometric specifications

Pipe-Soil Interaction

Contact between soil and pipe has been considered as surface to surface type. Modeling was performed according to the above descriptions. There was analyzed amount and location of maximum stress and strain. There were applied gravity loading and then fault displacement. After some analysis, the displacement time was selected based on the matter that amount of kinetic energy is reduced compared with internal energy to decrease dynamic effects at an acceptable level

The maximum applied displacement by the fault on pipeline is 1 m (Fig. 4). As seen in Figure 5, the maximum displacement is occurred in the pipeline at a distance of 11.36 m from the pipeline and equals with displacement of the fault (1 m), not near the fault. This is because of using granular soil instead of local soil or compacted cohesive soil around the pipe. Granular soil allows the pipeline to move freely to comply with the requirements. The maximum stress in the pipeline caused by changing location of the fault is 518.8 MPa and at a distance of 7.12 m from the fault in down cell (Fig. 6). It should be noted that numbers of the software are as meters and kg..[5]

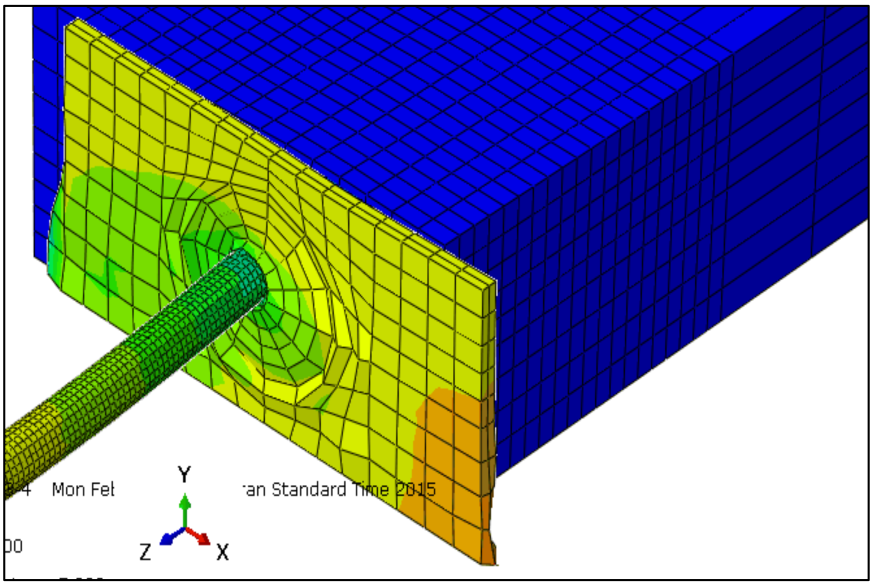

Fig. 4. Applying displacement from the fault to the pipe

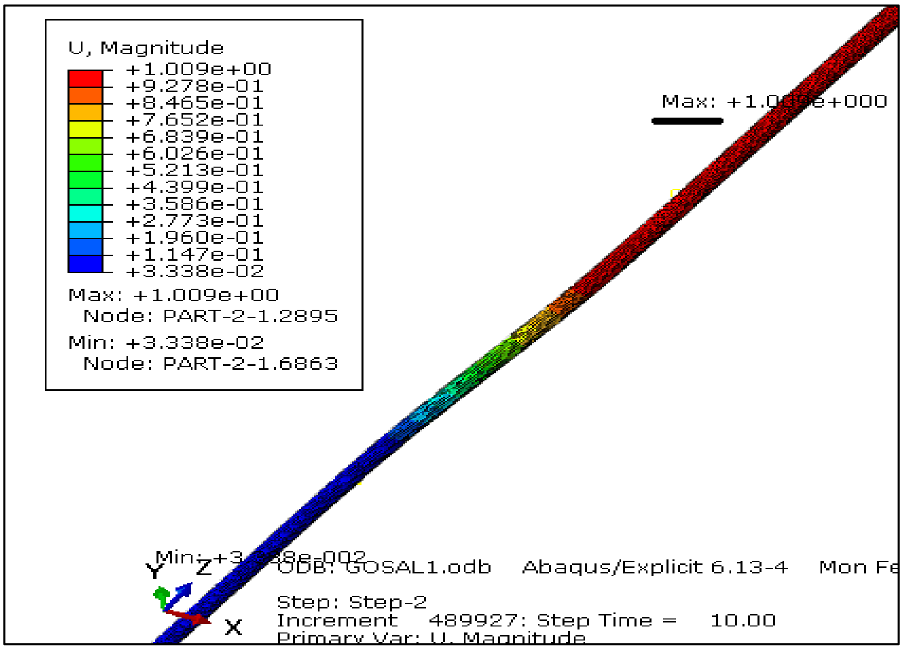

Fig. 5. The maximum displacement of the distance away from the fault line

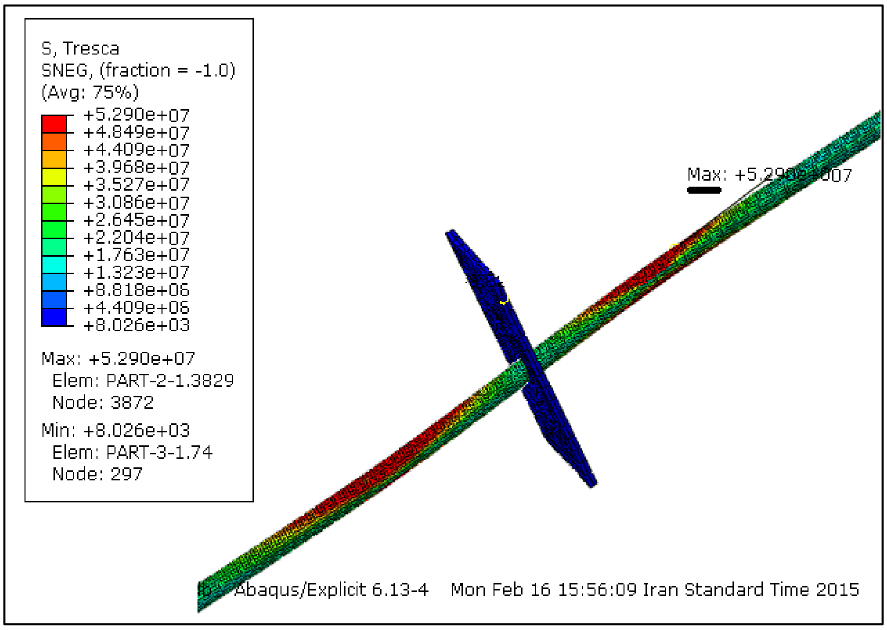

Fig. 6. The maximum stress occurs at distance away from the fault line

Conclusion

There was used finite element modeling to study the interaction of soil and pipe when crossing fault. Due to the tensions, there were used smaller and larger elements in the region near the fault and in other parts respectively. It was found that tensions are in the lowest level in the point of intersection of the fault and pipeline, and critical stresses and strains occurred away from the fault. The tension in the pipeline can be controlled by increasing and decreasing the width of the trenches. In every particular fault, it can be identified the maximum displacement of the fault by the statistical and field study. In the event, we can decrease the tensions in the pipelines to the least level.

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