Scientific Journal of Impact Factor (SJIF): 5.71
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406
International Journal of Advance Engineering and Research Development
Volume 7, Issue 10, October -2020

Micro-Tunneling Challenges inRocky LandsContains HugeBoulders

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ABSTRACT - *Wastewater collection network is one of the most important urban infrastructures, which its development is very critical due to its location in the urban area and in the vicinity of municipal utilities and traffic constraints. Trenchless mechanized Excavation methods are one of the most effective methods to implement the wastewater collection network of Tehran, which has been rapidly developed due to its low cost, high quality and also its low impact on municipal furniture and utilities and traffic issues. The micro-tunneling project in east of Tehran is one of the samples for implementing Tehran's wastewater collection network. This project with the 1400, 1600 and 1800 mm polymer concrete pipes has been completed on Mirdamad, Shariati, Mojtabaie and Khajeh Abdullah Ansari Streets with the length of 3900 m using micro-tunneling machine manufactured by German Herrenknecht Company and is currently in operation.Since the project route is adjacent to the foothills and northern rivers of Tehran, it has special characteristics in the term of geographical location. The geological situation of project site is also so that the density and size of boulders are increased with increase in depth of earth. Therefore, it was very difficult to design and implement the micro-tunneling operations of this project in the vicinity of numerous stones and boulders and interaction between pipes and boulders caused many challenges such as cracking and failure of polymer concrete pipes as well as deviations in the project route in addition to many problems encountered during Excavating operations due to the proximity of micro-tunneling path to many boulders around the project route.The purpose of present article was to investigate the interaction between micro-tunneling path and boulders around the pipeline path as well as the raised challenges and obstacles through experiences obtained from micro-tunneling project of east of Tehran as well as the conducted as well as numerical studies and to provide solutions for each of the above mentioned problems.*

Key words- *Micro-Tunneling, Rocky Land, Angular Deviation, Pipe Fracture, Boulder.*

I. INTRODUCTION

Micro-tunneling technology is one of the trenchless excavation methods to install prefabricated pipes in the ground. Polymer concrete pipes are a type of prefabricated pipes utilized in micro-tunneling method, which their usage has been expanded due to their various advantages. Some advantages of polymer concrete pipes are as follow:

1. High compressive, tensile and bending strengths and High elastic modulus.
2. Very high chemical resistanceand high wear resistance and impact strength.
3. Water impermeability of polymer concrete structure.
4. High durability of polymer concrete products
5. Consisting of echo-friendly material compatible with the environment

Despite these advantages of polymer concrete pipes, they have very low flexibility compared to other pipes such as GRP pipes, which makes the polymer concrete pipes fragile. In fact, polymer concrete pipes are cracked easily in the case of unbalanced distribution of stress inside the pipe and formation of stress concentration. The specific geological conditions of Tehran and existence of heterogeneous layers along with many boulders in the site of micro-tunneling project in east of Tehran have led to an interaction between polymer concrete pipes and existing boulders in the ground and this has caused challenges in performing micro-tunneling operation in this type of geological condition.

II. Specifications of micro-tunneling project of east of Tehran

2-1- Project Overview

The infrastructures of Tehran metropolis should be developed in proportion to its increasing expansion and growth. Implementing the main lines of Tehran wastewater collection network is only possible through micro-tunneling technology due to traffic constraints and numerous municipal utilities. The micro-tunneling project of east of Tehran with internal diameter of 1400, 1600 and 1800 mm located in KhajehAbdollah Ansari, Mojtabaee, Shariati and Mirdamad Streets has been implemented by KAYSON Company in a total length of 3900 m and is currently in operation.

2-2- Geological conditions of the project

In the geological term, the route of this project is in dense alluvial layers. These alluvial layers include small boulders to massive boulders in a range from surface of the earth to depths of the earth. In addition, Tehran City is covered by quaternary alluvial sediments and consists of sedimentation of large rivers, which results in massive boulders in the heterogeneous alluvial layers.

In the process of designing micro-tunneling projects, it is very important to accurately identify the geological layers and the project route, drilling equipment and other prerequisites should be selected based on geological conditions.

Figure 1: micro-tunneling project in east of Tehran

In the micro-tunneling project of Tehran, 32 borings were dug to determine the geological identification of project site. The geological conditions of project site and project overview have been presented in Table 1 and Figure 1, respectively.

Table 2: the results obtained from boring of project identification

Line	Bulk Density ton/m^3	Cohesion Kg/cm^2	Friction Angle	E-Gpa	Rock Compressive Strength(Mpa)	Rock Tensile Strength(Mpa)
A-B	1.95-2.12	0.15	39	100-120	200	19.2
	1.89-2.06	0.25	36	50-75	200	19.2
B-C	1.97-2.13	0.21	38	100-120	200	19.2
C-D	1.94-2.11	0.23	37	100-120	200	19.2
E-D	1.92-2.09	0.2	37	35-50	200	19.2
G-F	1.85-1.95	0.1	45	100-120	200	19.2

As it was indicated in geotechnical investigations of the project route, the number and volume of rocks and boulders are increased with increase in depth of the earth. Considering the location of project route in this type of geological layer, a number of polymer concrete pipes were cracked during implementation of project route due to the interaction between project route and boulders and the load-bearing strength of pipes was significantly decreased and ultimately caused the fracture of pipes. The fracture of polymer concrete pipes not only exposed the project implementation process to safety hazards and other dangerous events, but also significantly increased the time and cost of project implementation. In the micro-tunneling project of Tehran, two main fracture mechanisms of polymer concrete pipes were considered as challenges of performing micro-tunneling operations in this type of geotechnical conditions:

I. Pipe fractures due to interactions between pipes and boulders (Figure 2).
II. Pipe fractures due to angular deviation of the pipeline (Figure 3).

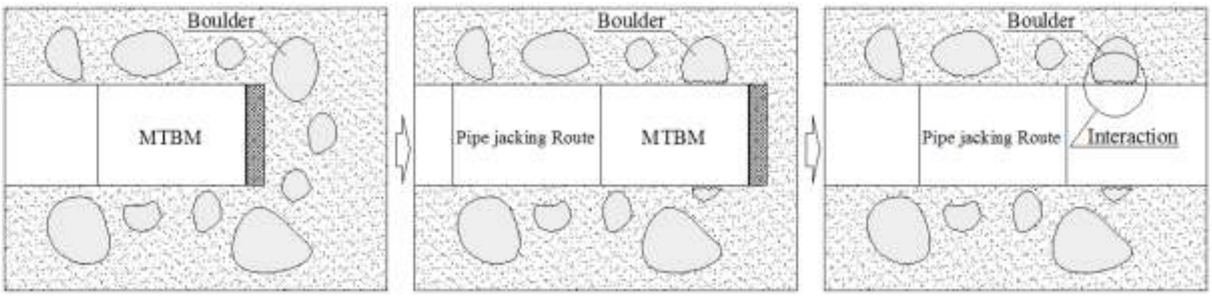

Figure 2: the interaction between pipes and boulders

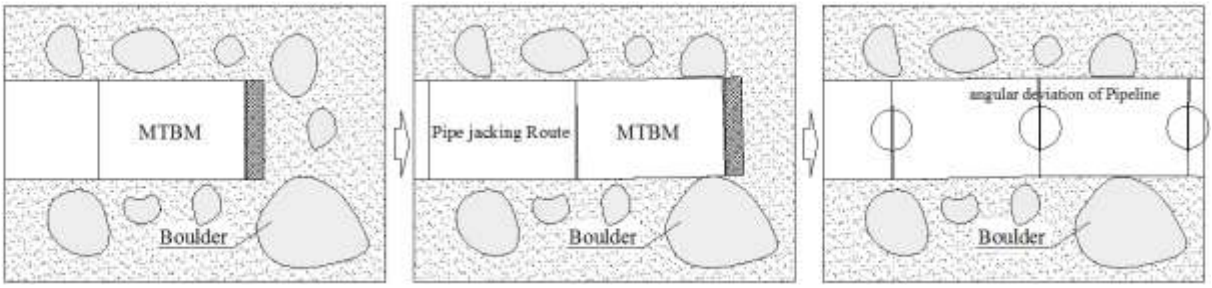

Figure 3: angular deviation of the pipeline

The finite element analysis of different types of pipe fracture mechanisms was conducted in the vicinity of boulders to accurate identification of pipe fracture mechanism and to adopt prevention, control and correction solutions.Three-dimensional analysis was also carried out using ANSYS software to three-dimensional modeling of polymer concrete pipes as well as modeling their interaction with boulders. It was also very necessary to perform calibration before modeling and problem analysis to accurately identify the behavior and properties of polymer concrete materials and ensure modeling accuracy.

2-3- Calibration

It was necessary to perform calibration for modeling of polymer concrete materials to ensure the accuracy of results obtained from numerical studies. For this purpose, the test samples were obtained from fractured pipes along the project route (Figures 4, 5 and 6) through concrete core drilling and subjected to compressive strength test in the laboratory. The three-dimensional modeling of samples was also carried out using ANSYS Software (Figure 7).

Figure 4: lab test

Figure 5: samples in the lab

Figure 6: core drilled samples

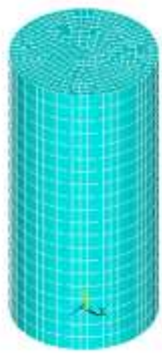

Figure 7: the sample modeled using ANSYS Software

The results obtained from compressive strength test have been presented in Figure 8. This sample was placed in a compressive strength test device. The data obtained from output of device has been presented in the diagram of Figure 9.

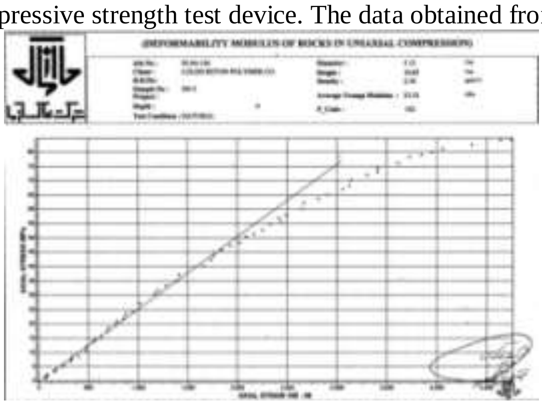

Figure 8: the results of compressive strength test from sample in the lab

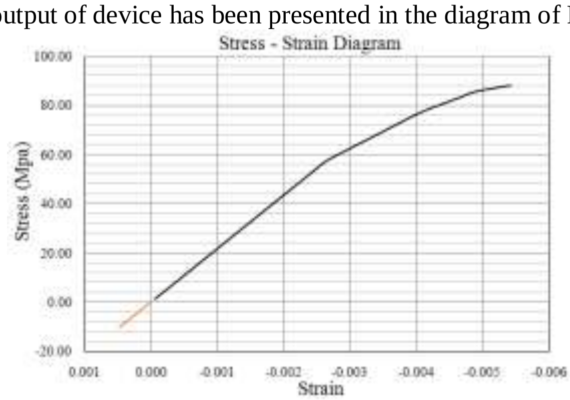

Figure 9: the stress-strain-diagram of polymer concrete materials

Also, the laboratory sample was modeled with all the dimensions and material specifications through ANSYS Software and analyzed under the effect of load-bearing strength. The results of numerical modeling from ANSYS software presented in Figure 9 and the laboratory results of compressive test presented in Figure8 are nearly identical and validate data obtained from numerical modeling analysis in ANSYS Software. The highest value of compressive strength was equal to 88 MPa in both analyzes.

2-4- Numerical modeling

The ANSYS Software was used for numerical modeling of samples. The following items should be observed to obtain accurate modeling of analyzed samples with maximum compliance with actual conditions (Figure 10):

1. Modeling of polymer concrete pipes
2. Loading conditions
3. Support conditions
4. Modeling of pipes fitting and GRP
5. Modeling of interaction between pipe and boulders

2-4-1- Modeling of polymer concrete pipes

SOLID65 element was used to model polymer concrete pipes in ANSYS software. In Software, the behavior of pipes was treated as nonlinear behavior using polymer concrete properties (laboratory results and model calibration).

2-4-2- Loading conditions

In micro-tunneling technology, force is transmitted by the main jack in Driving shaft, then applied to the first pipe inside the shaft using pushing ring, passed to the excavation machine through pipes one after the other and finally to the ground opposite the excavation machine. In the numerical modeling, the force was similarly applied to the first pipe (which has been shown in Figure 9 using blue color) by the push ring (which has been shown in the right side of figure 9 by purple color) and finally transmitted to excavation machine (which has been shown in the left side of figure 9 by purple color) by the pipes in order to simulate real-life modeling. Also, the force was applied at a linear increase rate to the ultimate value tolerated by actual model.

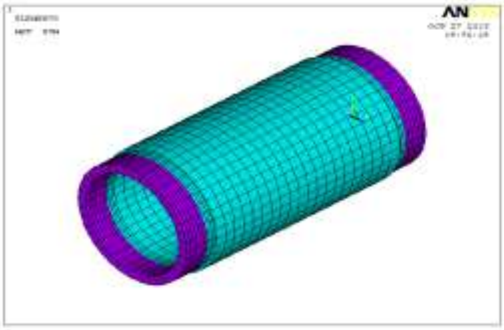

Figure 9:modeling of polymer concrete pipe in ANSYS Software

2-4-3- Support Conditions

The micro-tunneling route was in direct contact with the ground around it. Therefore, the pipes were in direct contact with the ground and could not be moved perpendicular to the micro-tunneling route. Since only a limited number of pipes were modeled and it was avoided to model whole of the route, the effect of force created by the friction between pipes and the ground was neglected and only the interaction between pipes and boulders has been considered. Therefore, the micro-tunneling route only moved along the direction of pipeline by applying the force of main jack and there was no change in the direction perpendicular to micro-tunneling route. The modeling was carried out by considering above mentioned conditions.

2-4-4-Modeling of pipes fitting and GRP

As it can be seen from Figure10, the fitting of pipes in joints is so that the GRP thick loop has enclose at fitting point of joints and caused that the pipes have no off-track displacement in relation to each other along the micro-tunneling route and the displacement of pipes in relation to each other is only possible along the pipeline route. Therefore, the GRP element has made the displacement at the pipe joints along the pipeline and prevented displacements perpendicular to the pipe. In addition, CONTACT elements have been used to transfer forces from pipes to each other.

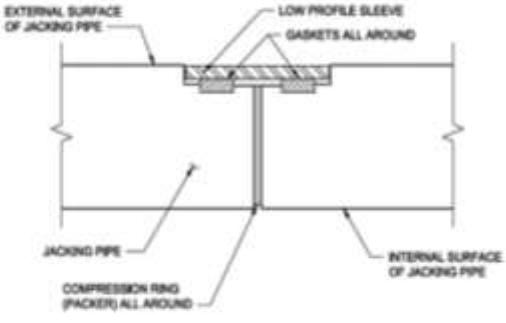

Figure 10: fitting of pipes to each other using GRP loop

2-4-5-Modeling of interaction between pipe and boulder

The SOLID65 and SOLID185 elements have been used to model polymer concrete pipes and boulders, respectively. The TARGE170 element has been also used to model the interaction between pipes and boulders. The displacement of boulders was fixed without any change of location.

2-4-6- Pipe fractures due to interactions between pipes and boulders

Implementing the wastewater project in east of Tehran was only possible through micro-tunneling method due to the specific conditions of project route, existence of numerous surface and subsurface utilities and infrastructures, passing under the rivers and excavating undergroundwater level. The complex geology of e project route has caused it to be adjacent to alluvial soil with numerous boulders and this has led to many challenges in the process of implementing project route. Boulders located in front of micro-tunneling excavation machine's drill-bit have been carved by cutting tools and cutter discs and it is possible for massive boulders that only a part them in the drilling path has been carved and rest of them remained adjacent to the micro-tunneling path. Vibrations in the micro-tunneling path have caused a number of boulders to be loosening and as a result, the boulders in the upper half of pipeline have been placed on the polymer concrete pipes due to their weight. GRP materials are the most vulnerable part of the pipe at the pipe and GRP joint when faced with boulders due to the lower rigidity of GRP aggregates compared to polymer concrete pipes as well as the lower diameter of GRP components compared to the diameter of pipes, which is in accordance with ASCE standard design and construction guideline for micro-tunneling. As it can be seen from Figures 11, 12 and 13, the interaction of boulders at the joints of pipes has caused stress concentration in the pipes and ultimately led to pipe fracture.

Figure 11: upper fracture of pipe

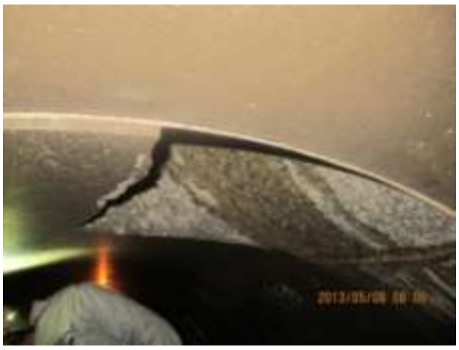

Figure 12: Pipe fracture at the joints

Figure 13: Interaction of pipe and boulder alongside the pipe

As it can be seen from Figure 14, the data obtained from output of micro-tunneling machine indicated that fracture of pipes caused by interaction with boulders does not require much force and the pipes are cracked and fractured with little force.

One of the pipes' fracture in project route stopped micro-tunneling operation and the restart of operation required crushing and removing of damaged pipe from the project route and re-fitting of pipes to each other.

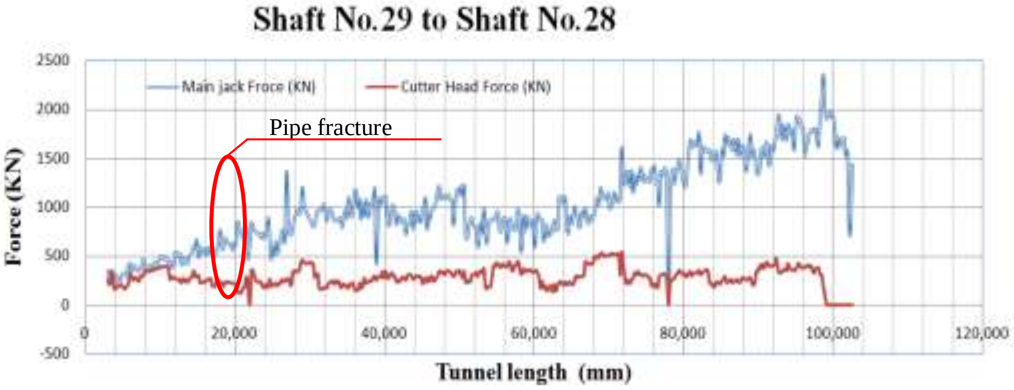

Figure 14: the data obtained from output of micro-tunneling machine

As it has been shown in Figure 16, the numerical modeling of this type of fracture mechanism caused by interaction between pipe and boulder was carried out to investigate and evaluate the fracture mechanism and prevent its repetition.

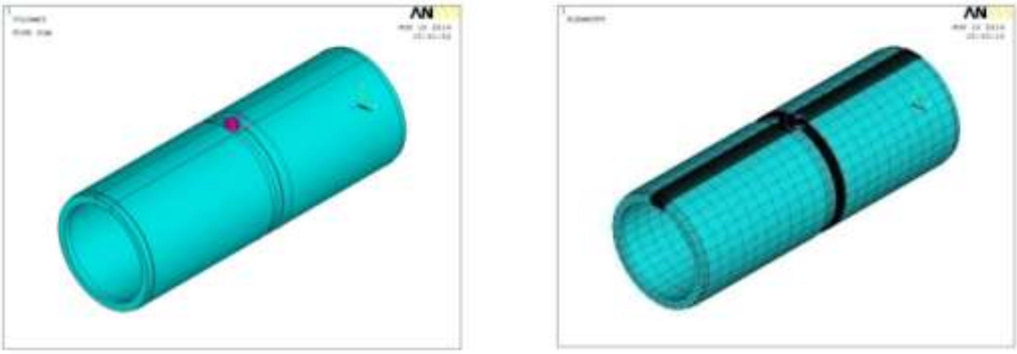

Figure 16: the pipe-boulder interaction in upper part of pipe and at the joint

Figure 17 represents the results of stress flow obtained from sample analysis in the interaction between pipe and boulder. According to the results obtained from this analysis, the pipe has been fractured with 10tons axial force, while the permissible force applied to pipes is more than 1000 tons. Therefore, this type of fracture mechanism caused by interaction between pipe and boulder has significantly decreased the capacity of pipe due to the stress concentration in the position of pipe contact with boulder.

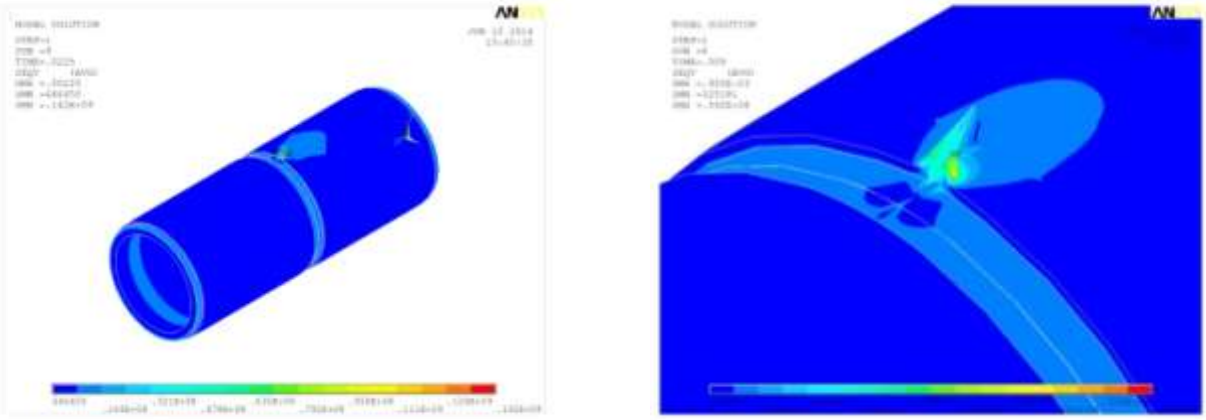

Figure 17: the stress results obtained from sample analysis using ANSYS Software

The stress concentration formed at the joint of the pipes and boulder caused the pipes to be cracked and eventually fractured. During implementation of the project route, three cases of pipe fracture occurred with the same mechanism. Considering significant number of pipes fractures caused by this fracture mechanism, the problem was solved by increasing the thickness of GRP, decreasing the difference between outside diameters (OD) of pipe and GRP and eliminating the edges the most sensitive part of pipes during occurrence of pipe fracture phenomenon.

2-4-7- Pipe fractures due to angular deviation of the pipeline

The vertical and horizontal deviation of pipeline is one of the most important parameters in controlling the quality of implemented micro-tunneling paths. In addition to the guidelines for permissible value for any deviations within the desired range, the project route becomes out of direct state in lack of controlling the deviations and this can cause non-alignment position of pipes. Failure to align the pipes causes stress concentration and ultimately leads to crack and fracture of pipes. However, the project route was diverted upward in one of the implemented lines of micro-tunneling project in east of Tehran due to the collision of a part of machine with rock layers. After passing the machine through rock layer by means of guided jack bores, the mentioned route was modified (Figure 18). Modifying the created deviation caused the pipeline to be cracked with applying a little force.

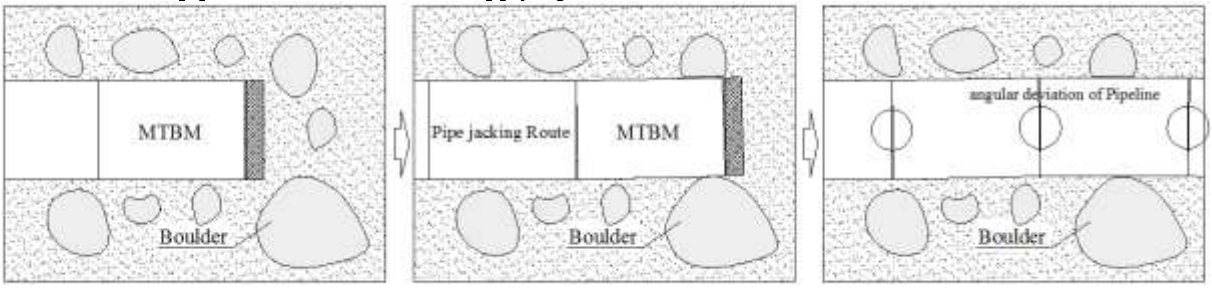

Figure 18: the angular deviation of pipeline

Numerical analysis was performed for five consecutive pipes (Figure 19) using ANSYS software. The deviation of pipes was taken into account in this modeling and the pipe fittings were also considered on the basis of accurate data.

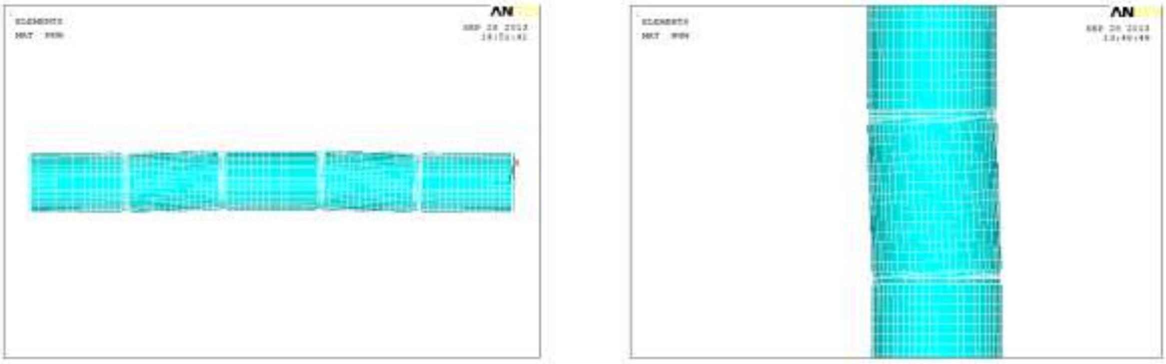

Figure 19: modeling of angular deviation using ANSYS software

Analyzing the sample in ANSYS software indicated that the maximum stress has occurred in the contact surface between two pipes and all jack forces have been transferred from one pipe to another only through a narrow area of pipes due to the angular deviation of piped and opening of a part of fitting in joint between pipes. Therefore, stresses at the contact site have been increased by decrease in contact surface and has led to fracture of pipes (Figure 20). As it can be seen in the stress distribution obtained from sample analysis in ANSYS software, the maximum load-bearing strength of pipe is approximately 150 tons, which is much less than the load-bearing strength of polymer concrete pipes (1000 tons) (Figure 21).

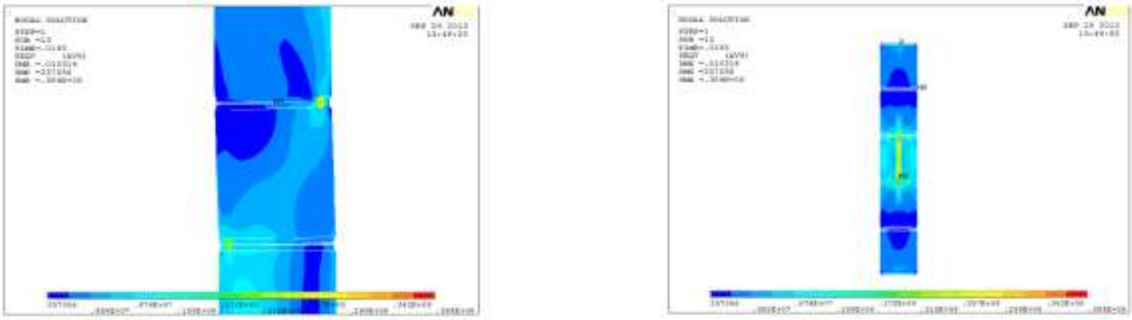

Figure 20: the results obtained from analysis using ANSYS Software

According to the results of this analysis, the angular deviation caused fracture of polymer concrete pipes in the deflection range (Figure 21) and hence, continuing the implementation of micro-tunneling operation required crushing and removing of damaged pipe from the project route, destruction of rocky layer, fixing angular deviation and ultimately re-fitting of pipes to each other.

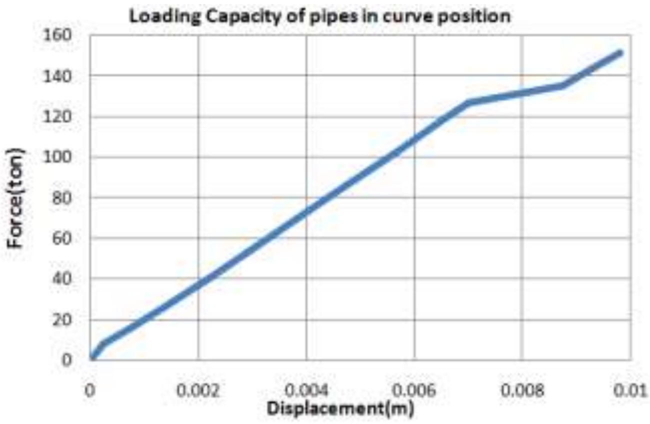

Figure 21: final load-bearing strength in angular deviation mode

III. CONCLUSION

The angular deviation is very important in soils with large boulders and the route should be modified or the compress of pipeline should not exceed from a certain value in the case of angular deviation occurrence.
The investigations indicated significant effect of interaction between pipes and boulder on decreased load-bearing strength of pipes and their fracture. Therefore, the following solutions are recommended:

1. The depth of project route should be located on relatively homogeneous soil without boulder in the step of designing project route as much as possible. This requires a thorough understanding of geological layers. It is better to utilize from non-destructive methods in identifying soil texture and boulder volumes due to lack of detection of boulder volumes in the identification borings.
2. Aligning the outside diameters of GRP with outside diameters of pipe, eliminating the sensitive edges in polymer concrete pipes and continuous bentonite injection are among the effective factors in decreasing the impact of interaction between pipes and boulders.

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