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Seismic response of buried pipes to microtunnelling method under earthquake loads

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ABSTRACT

Microtunnelling is a of trenchless method excavation that had great growth in recent years and it has been used to install water, sewage, oil and gas pipelines using powerful hydraulic jacks for pushing special pipes. In this study, regards to the importance of microtunnelling resistance against earthquake, it is attended to the seismic dynamic analysis under the earthquake force. Failure and destruction in microtunnelling pipes, cause it's lack of efficiency in the aftermath of the earthquake and may even cause a fire and irreversible events and regards that microtunnelling pipes are vital arteries, immune and resistance against earthquake is inevitable. In this study changes of the diameter, thickness, depth, length and material of the microtunnelling pipes and the type of their surrounding soil and changes in the underground water level under the earthquake load by modeling in FLAC 3D software are investigated. The results of this study show that increasing the diameter of microtunnelling pipes increases its displacements of the soil around by 0.59% and decrease it's resistance against seismic waves. Increasing the thickness of microtunnelling pipes reduces the displacements of its surrounding soil to 0.33%. By increasing the stiffness of microtunneling pipes, the displacements of its soil around will reduce by 2.5%. Based on the results obtained, by increasing length of the microtunnelling pipe under the earthquake load, displacements in the soil around the pipe increase by 18% and may cause damage to the pipe. Also the joint area of buried pipes is more damageable than their sidewall during the earthquake. By increasing depth of the pipes the displacements reduces by 27.5%. In this study by reducing the groundwater level the displacements of the soil around the pipes reduce to 7% and recommended to use methods such as digging drainage wells to reduce buried pipe floats. By increasing the soil parameters such as the bulk and shear modulus, friction angle, and cohesion in the microtunnelling surrounding soil, the displacements will decrease to 41%. It is concluded that the depth of the pipes and the type of their surrounding soil have the greatest effect on increasing of the pipes resistance and reducing its vulnerability against the earthquake.

1. Introduction

Today the underground constructions such as tunnels and underground utilities such as sewage pipelines, water, gas, electric and telecommunication play a main role in the development of the countries. Underground structures are safe to earthquake, but this does not reduce a bit of their design importance to deal with the earthquake energy. These structures must be designed in such a way that they are resistance to internal or external dynamic loads or seismic waves. Dynamic loads are the loads that are a function of time. Static loads are a special state of dynamic loads that are defined by constant function.[1] Tunnel behavior under earthquake loading is affected by many factors such as shape, depth and stiffness of the tunnel lining and the nature of the input motion. [2] Diagonal tunnels with small dimensions, which also called as micro-tunnel, refer to tunnels that their size is so small that only one person can passes through it; and in the England refer to the tunnels with an inner diameter of less than 0.9 m. [3]

Implementation methods of projects of the urban utilities network are divided into two sections of open trench and without trench.[4] The term of without trench refer to some methods of coding or network reconstruction in which the extent of damage to the Earth's surface and surface of streets and passages are minimized. Pipe jacking operations, microtunnelling (piping) technology and machine drilling technologies are among the without trench methods; in the method the pipe course is created using machine drilling technology. The comparison of trench excavation and microtunnelling that was carried out in this analysis shows that, if indirect construction costs and social and environmental costs are considered with appropriate weights, microtunnelling is

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preferable to traditional trench excavation. [5] In Japan when urban infrastructures need to be constructed, the difficulty of utilizing the ground or shallow strata will necessarily lead to the more frequent use of the deep strata. a new pipe jacking method has been established that can be adapted to 20 m below the ground or more. Using the method, the driving machine and the jacking pipe continue to move an underground until the completion of the driving. [6] The pilot tube microtunnelling method while relatively new to North America, has seen an increase in utilization between 2006 and 2010, while more traditional methods of trenchless installation have seen a minor decrease in utilization over the same time. This technology is ideal for the installation of pipe on tight line and grade for installation lengths generally utilized between manholes in a municipal setting. As the need to replace buried pipe infrastructure in urban areas increase, it is expected that pilot tube microtunnelling will see an increase in utilization due to its low impact and small footprint of operation. [7] As a result of Aftabur Rahman and Hisashi Taniyama the 3D discrete element method (DEM) analysis was carried out to examine the response of buried pipeline owing to fault movement and it discusses the force–displacement relation between pipes and particles in the axial and vertical directions for fault movement. Relative displacement near the fault crossing point indicates the momentous effect of particles on pipes. Particles near the crossing point reach the yield value earlier than particles far from the fault. The force between pipes and particles reveals the effects of particles on the pipeline during rupture. The force response increases gradually with distance from the rupture point, confirming the critical points near the fault line. [8] Uckan and Partners had studied in a simplified numerical model for buried steel pipes crossing strike-slip faults and oriented perpendicular to the fault. Two pipes with different diameter to thickness (D/t) ratios and steel grades are used. It is recommended that Fragility expressions for buried pipelines at fault crossings should be developed by simplified methods and also the effects of stiffness of the steel pipes and the surrounding soil on the seismic response should be studied through a parametric study. [9] Vazouras et al. reported with increasing pipeline length, the force–displacement relationship reduces to the corresponding relationship for an infinite length. [10]

This study pursues three general objectives: to introduce the microtunnelling to familiar with its procedure; to obtain the proper acceleration for dynamic analysis of microtunnelling using SeismoSignal software; to model microtunnelling using FLAC software [11] and its dynamic analysis due to the earthquake vibrations for different models of microtunnelling, which includes changes of the diameter, thickness,depth,length and material of the microtunnelling pipes and the type of their surrounding soil and changes in the underground water level.

2. Microtunnelling operations

Microtunnelling is a trenchless method for installing pipes underground with different soil conditions, and uses a remotely controlled microtunnel boring machine (MTBM) combined with the pipe jack-and-bore method with precise tolerance of the direction. Also processes of microtunnelling and insertion of the pipes is simultaneous. For the microtunnelling drilling of two shafts is required: drive shaft and the receiving shaft. So that at the beginning of the pipeline, a well called as the drive shaft will be drilled with dimension in accordance with the soil type, utilization type and pipe size. After shaft be prepared and concreted, the MTBM drilling machine and hydraulic jacks are located at the bottom/end of the well. The receiving shaft will be prepared at the end of the course, up to 100–200 m from the drive shaft (according to conditions) for the removal of the drilling machine. After the preparation of the drive well, the microtunnelling operations will be started by means of the drilling machine, so that the drilling machine directed into the course at first and followed by the pipes and hydraulic jacks.[12] This method results in the construction of a flexible, impermeable and structurally resistant pipeline. [13]

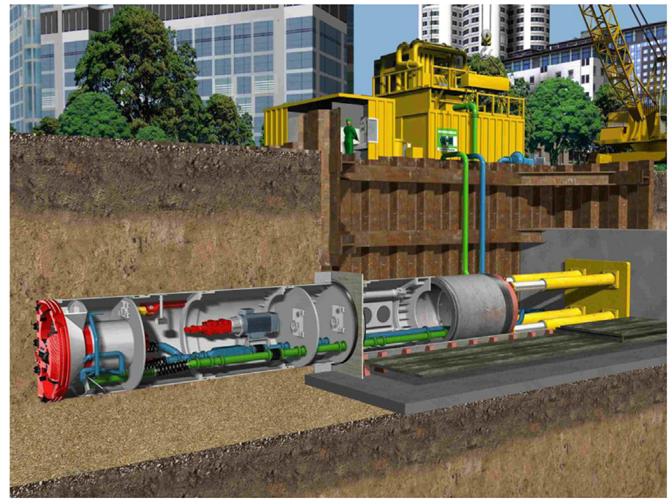

Fig. 1. General view of the microtunnelling drilling system using MTBM [17].

Microtunnelling, as a kind of trenchless method, is an alternative of horizontal directional drilling method for pipeline trenchless construction. Compared to HDD(horizontal directional drilling), Microtunnelling can be used in hard rock and soils with gravel and cobbles.[14] At some point there is a tradeoff between the benefits and drawbacks of using increasingly long drives; as such, drive lengths should be optimized based on many factors such as proposed sewer structures, necessary connections, maintenance requirements, surface disruptions, environmental factors, ground conditions, obstructions, shaft installation, alignment considerations, alternatives, pipe requirements, navigation techniques, experience level, productivity, equipment limitations, necessary training, access to pipeline and face, modifications to utility and muck systems, safety concerns, costs, and schedule.[15] Several problems have been encountered during the construction process including face instability, shaft failure and groundwater related issues.[16] Fig. 1 shows a general view of the microtunnelling drilling system.

3. Theory

Microtanning is an excavation method for the construction of urban infrastructures such as water, sewage and gas pipelines. Due to the extensive expansion of the urban infrastructures pipes and its vulnerability due to the propagation of earthquake waves is high, this will intensify the need for research in this area. Failure and destruction in urban infrastructures make it impossible for them to be exploited during the post-earthquake period and may even cause fires and irreparable events. In this study, a part of microtanning segmented pipes under the Japan's Kobe earthquake has been investigated, and various factors such as pipes and its surrounding soil features that influence the resistance of the pipes during the earthquake are studied. The pipes are of polymeric concrete material and for the dynamic analysis; the FLAC ^{3D} numerical software has been used.

4. Research range

Dynamic analysis of the earthquake vibration effects is done by software FLAC^{3D}, version five.

To dynamic analysis the accelerograms X, Y components of the Kobe earthquake, Japan with maximum acceleration of 0.483 g and 0.464 g are used.

Diameters of the used microtunnelling pipes are in the range of 0.61–1.52 m.

Thicknesses of the used microtunnelling pipes are in the range of 0.1–0.2 m