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ANALYSIS OF THE EARTHQUAKE IMPACT ON URBAN TUNNELS USING MODELING IN PHASE 2 SOFTWARE

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Abstract: This article presents a comprehensive survey of the seismic impact experienced by urban tunnels, with a specific focus on the Line 7 of the Tehran Metro. Employing finite element software during Phase 2 of modeling, the study investigates the potential effects of seismic activity on tunnel stability. The research involves a meticulous examination of concurrent factors, primarily alterations in earthquake acceleration values and adjustments to the depth of the tunnel. The findings reveal that effective maintenance practices within the underground Metro Stations play a crucial role in minimizing the seismic impact on tunnel stability. The study underscores that the key mitigation strategy involves enhancing the structural integrity and reinforcing the conditions under which the tunnel is maintained. By doing so, the article suggests that urban planners and engineers can contribute significantly to the overall resilience and safety of underground metro systems in seismic-prone regions, such as Tehran.

Keywords: *Earthquake, Urban tunnels, Tehran Metro Line 7, Modeling, Phase 2, Seismics*

1. INTRODUCTION

Nowadays, human activities (e.g., towers and buildings constructions, tunneling and underground excavations, traffic) have been increasing due to the need for development (Tavanaei et al., 2020). The extraction and transportation of rock, particularly in mining and tunneling operations, are perceived as potential triggers for seismic activity, potentially leading to slip along fault lines (Kocharyan et al., 2022). The study on the vulnerability of tunnels under seismic loading has been of great interest among researchers under various geological conditions (Srivastav and Satyam, 2020). The construction of earthquake-resistant underground structures requires an understanding of how the propagating seismic waves, as caused by earthquakes. in this case, interact with an underground system such as tunnels. For most underground structures, the underlying rock's inertia is large relative to the structural inertia and hence the tunnel's seismic reaction is determined by the surrounding soil or rock mass response. However, a surface structure's seismic reaction is governed by its inertial effects (Forcellini, 2017; Forcellini, 2018; Forcellini, 2019). Previous natural disasters, including earthquakes, had a significant impact on transport networks with severe consequences for the users and supply chain. The resilience assessment of critical assets such as tunnels is of paramount importance for increasing safety and maintaining their functionality in seismic-prone areas (Huang et al., 2022). The study has been conducted using Rocscience's Phase 2 software which has been used frequently to understand various case scenarios related to the seismic response of tunnels (Sun and Dias, 2019). We seek to provide valuable insights into the dynamic interactions between seismic forces and tunnel structures. Furthermore, our objective is to identify and emphasize the critical role of effective maintenance practices within the underground Metro Stations in mitigating the seismic impact on tunnel stability.

2. MATERIALS AND METHODS

The Phase 2 software, specifically in its 8.1 version, necessitates specific data inputs to facilitate the modeling process. Phase 2 offers robust tools for simulating dynamic loads and seismic events. Its ability to model the complex interactions between seismic waves and geological materials is crucial for accurate seismic analysis, these models ensure realistic simulation of ground response during an earthquake. Therefore, for this situation of the project, our best choice was Phase 2.

The required data encompasses various parameters and specifications essential for accurately representing the conditions and characteristics within the system being analyzed. This inclusive data set serves as the foundational information that the software utilizes to generate a comprehensive and detailed model, enabling a thorough exploration and evaluation of the targeted subject matter. For numerical modeling, we need to collect the following data and apply them in the right order in the software:

- The "Define Material" stage: Specific Gravity of Soil, Poisson's Ratio, Friction Angle, Cohesion, Young's Modulus, Shear Strength.
- The "Define Liner" stage: Liner Type, Young's Modulus, Tensile Strength, Specific Gravity, Compressive Strength, Liner Thickness, Poisson's Ratio.
- The "Define Joint" stage: Normal Hardness, Shear Hardness.
- The "Define Bolt" stage: Bolt Diameter, Young's Modulus, Tensile Strength, Bolt Spacing.

The required data were obtained from the engineering geology unit specifications (ET) differentiated in soil layers along the tunnel route. To assess the earthquake impact, a station from Tehran Metro Line 7 was selected. In this station, a tunnel with a diameter of 9.2 m is located at a depth of 19.6 m. In each stage, the earthquake acceleration is increased by 0.1 g, and the induced changes in the vicinity of the tunnel are examined. The tunnel, excavated in ET-5 soil, is composed of silty and clayey materials with the addition of sand, characterized as follows:

- Effective Cohesion: $c = 31$ KPa
- Effective Internal Friction Angle: $\Phi = 28°$
- Poisson's Ratio: $\upsilon = 0.35$

To mitigate the boundary effects on the results, the side boundaries of the tunnel are considered to be 10 times the tunnel radius. It should be noted that the tunnel radius is 4.6 m.

3. FINDINGS AND RESULTS

Considering the given information, a geometric model of the tunnel was created using Phase 2 software, as depicted in *Figure 1*. Subsequently, the created model underwent analysis under various earthquake accelerations, and the obtained results were examined.

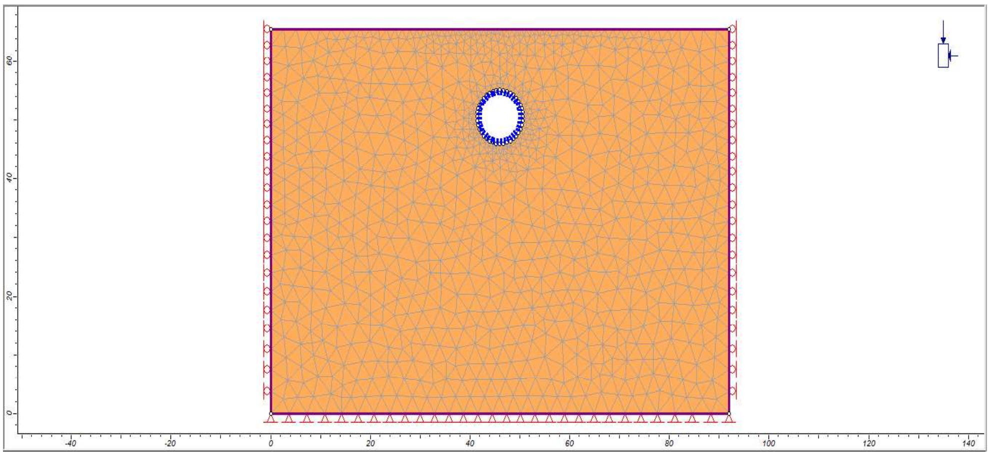

Figure 1

The model created by Phase 2 for the tunnel with a depth of 19.6 m was analyzed without the influence of an earthquake

In the subsequent stages, the earthquake acceleration is increased by 0.1 g, and the results are examined under accelerations 0.1 g, 0.2 g, 0.3 g, and 0.4 g. The results of the earthquake impact on the stability of the tunnel at a depth of 19.6 m are presented in *Table 1*.

Table 1

The results of the earthquake impact on the stability of the tunnel located at a depth of 19.6 m

The imposed acceleration	Minimum safety factor	Maximum displacement [cm]	Maximum share force [N]	Maximum bending moment [kNm]
without influence	0.95	0.89	91.078	202.44
0.1	0.95	0.97	106.33	239.43
0.2	0.63	1.33	107.59	241.05
0.3	0.63	0.489	109.68	245.2
0.4	0.63	0.63	114.01	256.45

To investigate whether the depth of the tunnel influences the earthquake's impact on tunnel stability, an example is considered for analysis at a depth of 15 m, based on the design of Tehran Metro Line 7 tunnel. The details of this analysis will be discussed further.

Analysis of the problem at a depth of 15 m: considering the provided information and utilizing the Phase 2 software, a geometric model of the tunnel was created as depicted in *Figure 2*. Subsequently, the created model underwent analysis under various earthquake accelerations, and the obtained results were examined.

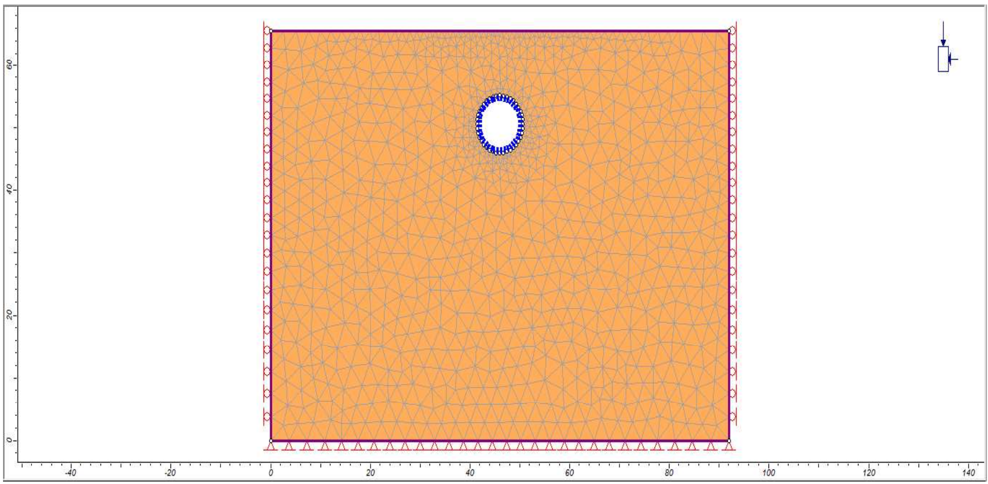

Figure 2

The model created by Phase 2 for the tunnel with a depth of 15 m and earthquake acceleration of 0.1 g

Similar to the analysis at a depth of 19.6 m, in the subsequent stages, the earthquake acceleration is increased by 0.1 g, and the results are examined under accelerations 0.1 g, 0.2 g, 0.3 g, and 0.4 g. The results of the earthquake impact on the stability of the tunnel at a depth of 19.6 m are presented in *Table 2*.

Table 2

The results of the earthquake impact on the stability of the tunnel placed at a depth of 15 m

The imposed acceleration	Minimum safety factor	Maximum displacement [cm]	Maximum share force [N]	Maximum bending moment [kNm]
without influence	0.95	0.73	80.941	183.95
0.1	0.95	0.899	81.968	185.22
0.2	0.95	1.28	83.101	186.46
0.3	0.95	0.49	85.871	191.42
0.4	0.95	0.63	89.368	200.77

For the assessment of tunnel stability under various seismic intensities, a circular tunnel with a diameter of 9.2 m at a depth of 15 m in the soil of Tehran was modeled using the finite element method in the Phase 2 software. Based on this, the variations in displacement, safety factor, shear force, and flexural moment (induced in the support system) were examined under different earthquake accelerations. It was observed that at a depth of 15 m, the earthquake intensity had no effect on the safety factor, and the safety factor remained constant. The maximum displacement occurred at an earthquake intensity of 0.2 g, and with increasing earthquake intensity, both the maximum shear force and the maximum flexural moment also increased. This assessment was also conducted for depths of 25 and 30 m, separately, and the results were nearly similar to those at a depth of 15 m, except for the maximum displacement, which occurred at an earthquake intensity of 0.1g for depths of 25 and 30 m.

4. DISCUSSION AND CONCLUSIONS

In summary, based on the obtained results, it seems that earthquake occurrences have not significantly affected the stability of tunnels, However, in urban tunnels, even minor displacements could potentially lead to considerable damage, especially at the surface. Therefore, it is highly advisable to employ modeling and predictive techniques to anticipate and mitigate potential displacements in these areas.

Considering the variations in shear forces and flexural moments imposed on the support system, it can be concluded that in seismically active areas, the tunnel maintenance system should be designed and implemented with greater strength and fundamentality. The complex interaction of geological forces in seismically active areas requires a careful investigation of the effects on tunnel structures. The need for a comprehensive approach to tunnel maintenance is highlighted by the fluctuations in flexural moments and shear stresses that the support system experiences during seismic events. Given that these forces have the potential to place significant strain on the infrastructure, it is necessary to improve the structural stability and fundamental strength of the tunnel maintenance system. This supports the tunnels' immediate stability and establishes a foundation for long-term resilience against the unpredictability of the forces released by seismic activity.

Additionally, the dynamic character of seismic forces should be considered in the design of the tunnel maintenance system, which calls for a forward-looking strategy. Infrastructure in seismically active regions must be able to endure both the immediate effects of seismic waves and any possible aftershocks. It becomes critical to put in place a stronger maintenance system since it acts as a preventative precaution against possible harm and guarantees the tunnel structures' long-term survival. Strong implementation and strategic planning are essential for protecting tunnel infrastructure from the intricate problems that seismicity presents. The study focused on a specific tunnel geometry, which may limit the applicability of the findings to other types of tunnels. Expanding the study to include a wider variety of tunnel designs could provide a more comprehensive understanding of tunnel behavior under diverse conditions.

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