Impact of Pit Excavation Proximity on Tunnel Integrity

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Abstract. This study meticulously investigates the influential dynamics exerted by pit excavation on structures of adjacent underground tunnels, with a specialized focus on the resultant deformation effects attributed to the varying proximities separating the excavation sites from tunnel constructs. Employing rigorous model analyses conducted at designated intervals ranging from 8 meters to 24 meters, the research successfully elucidates a definitive and consistent pattern; it is observed that augmenting the distance between the pit and the tunnel significantly diminishes the extent of tunnel deformation experienced both in horizontal and vertical perspectives. This critical relationship unearthed by the study underlines the paramount importance of adopting meticulously calculated engineering design and the implementation of robust monitoring systems as fundamental measures in mitigating the associated risks prevalent within the expanse of urban underground construction endeavors. Noteworthy within these discoveries is the revelation that horizontal tunnel displacements, in comparison to their vertical counterparts, are markedly more pronounced in their reaction to alterations in the spatial gap that lies between the pit and the tunnel. This distinct sensitivity accentuated in the horizontal displacements signals the imperative for the formulation and application of customized mitigation strategies, specifically honed to address the asymmetrical nature of deformation induced by pit excavation activities in close quarters to tunnel infrastructures. Hence, these insights provide a valuable impetus for stakeholders in the field of construction engineering to incorporate such nuanced understandings into their projects, thereby enhancing the overall stability and safety of subterranean constructions within densely developed urban territories.

1 Introduction

In this paper, we delve deeper into the complexities and implications of pit excavation, particularly in the context of its effects on nearby tunnel structures and operations. Pit excavation, a prevalent activity in urban construction and underground engineering, plays a pivotal role in meeting the developmental demands of modern cities. However, it also poses potential risks and challenges, especially to the structural integrity and operational efficiency of adjacent tunnels. These impacts can range from minor disturbances to significant damage, potentially leading to costly repairs and operational disruptions. Thus, understanding the various impact factors of pit excavation, such as the distance from tunnels, soil characteristics, excavation depth and technique, is crucial for effective planning and management of excavation projects. This study aims to provide comprehensive insights into these factors, offering guidelines and recommendations for mitigating risks and ensuring the safety and sustainability of tunnel operations during and after pit excavation. Through this research, we aim to contribute to the development of more resilient urban infrastructure and the advancement of safe construction practices in densely built environments.

2 Literature Review

2.1 Underground Engineering and Pit Excavation

Underground engineering plays an indispensable role in modern urban construction [1], including subways, tunnels, underground parking lots and other forms [2]. Meanwhile, pit excavation, as a precursor of underground engineering, is often a prerequisite for the implementation of underground engineering. Pit excavation usually involves earthmoving, construction of support structures, and utilization of underground space. However, pit excavation activities may have important impacts on the surrounding underground structures, especially on the neighboring tunneling works [3].

2.2 Challenges in underground engineering

Tunneling works are usually located underneath cities and are closely linked to geological elements such as groundwater [4], soil and rock formations. The structural stability and operational safety of these works are crucial for the sustainable development of cities. However, excavation activities in underground works may cause a series of problems, including surface settlement, elevated

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water table, and changes in subsurface stress, which may have direct or indirect impacts on tunneling [5].

2.3 Linkage between pit excavation and tunneling

Pit excavation, especially at greater depths, significantly alters subsurface stress distributions, impacting not only the excavation site but also neighboring structures like tunnels. The removal of earth during excavation changes the load distribution, leading to a shift in surrounding stresses. This can cause ground movements detrimental to the structural integrity of nearby tunnels. The redistribution of these stresses is particularly problematic for tunnels, as it can lead to surface settlement and structural deformation, such as cracks or bends in the tunnel lining, compromising both safety and functionality [6].

Furthermore, deep pit excavation often triggers a rise in groundwater levels, posing challenges like water surges that can exert additional hydrostatic pressure on tunnel linings, potentially leading to leakage or flooding. This change in hydrogeological conditions can result in unforeseen complications for tunnel stability. The vibrations from excavation equipment can also create seismic-like waves, adding stress to tunnels, especially those not designed for such forces. Thus, careful planning and thorough geological assessments are crucial in excavation projects to mitigate these risks and ensure the integrity and longevity of both the excavation site and adjacent tunnels..

2.4 Current status of domestic and international research

Studies at home and abroad have shown that the impact factors of pit excavation on neighboring tunnels are very complex [7], including geological conditions, excavation methods, tunnel structures, monitoring techniques and other aspects. In China, some studies have already deeply explored the interrelationship between pit excavation and tunneling and proposed a series of countermeasures. For example, some studies have suggested adopting suitable support structures to reduce the change of underground stress or implementing strict monitoring and real-time data analysis to detect problems and take measures in time [8]. However, there are still some issues that need to be further investigated, such as the differences in the impact of pit excavation on different types of tunnels, and the coping strategies under complex geological conditions [9].

3 Methodology and significance of the research

The significance of this research lies in its focused examination of how pit excavation impacts adjacent tunnel structures within an urban environment. As cities expand and the demand for underground spaces increases, construction activities like pit excavation become more prevalent. These activities are critical for developing underground parking, shopping areas, and transportation systems, but they also pose potential risks to the stability and safety of existing subterranean structures, particularly tunnels [10].

Urban development often necessitates these excavations to occur in close proximity to tunnels, where the interplay of soil stress, groundwater levels, and surface settlement can have deleterious effects on tunnel integrity. Understanding these impacts is vital for mitigating risks and ensuring the sustainability of both the excavation works and the tunnel operations.

This study utilizes a single variable control method, keeping the tunnel center depth constant at 13 meters while varying the distance from the pit to the tunnel center between 8 and 24 meters. The methodology involves recording the maximum horizontal and vertical displacements of the tunnel post-excavation, thereby assessing the relationship between the pit-to-tunnel distance and tunnel deformation.

Through a comparative analysis of displacement data, the study aims to discern patterns that could inform safer construction practices. For example, our preliminary findings indicate a clear trend: as the distance between the tunnel and excavation site increases, the horizontal displacement decreases significantly, suggesting that a greater buffer zone could enhance tunnel safety.

4 Effect of distance between pit and tunnel on tunnel deformation

In assessing the effect of the distance between a pit and a tunnel-on-tunnel deformation, it's crucial to maintain consistent conditions for accurate analysis. By fixing the tunnel center depth at 13 meters and keeping other parameters constant, the single control variable method becomes an effective approach for this study. Models are established with varying distances between the tunnel center and the edge of the foundation pit, specifically at intervals of 8m, 12m, 16m, 20m, and 24m. This systematic variation allows for a detailed examination of how increasing distances impact the extent and nature of tunnel deformation. By analyzing these models, we can gain insights into the threshold distance at which the impact of the pit excavation on the tunnel begins to diminish significantly. This analysis is pivotal for understanding and mitigating the risks associated with tunnel deformation due to nearby excavation activities, thus aiding in the development of safer construction practices and more resilient underground structures.

4.1 Horizontal displacement analysis

Record the maximum value of horizontal displacement of the tunnel at different center spacing when the excavation of the foundation pit is completed, and use it to draw a comparison figure 1. Comparison Figure 1 was made and Figure 2 was made to show the trend of horizontal displacement of tunnels with different center spacing. The trend of the horizontal displacement of the tunnel is shown in Figure 2 to show the trend of the horizontal displacement of the tunnel.

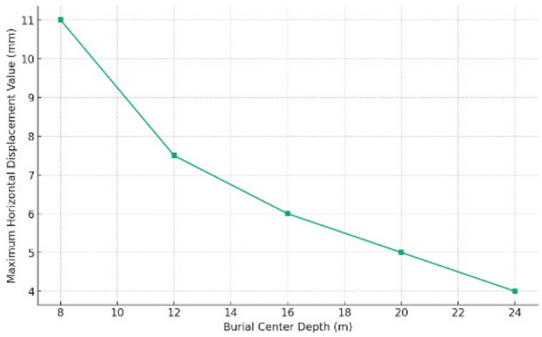

Figure 1 Comparison of the maximum value of horizontal displacement under different burial distances

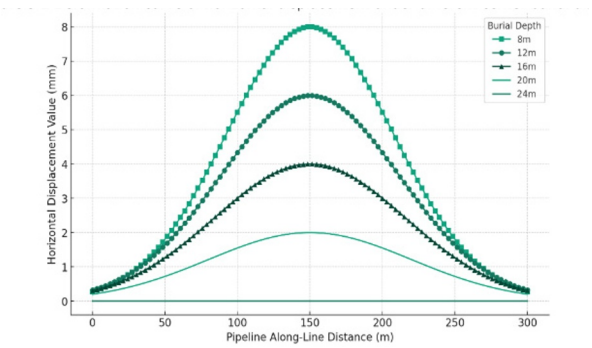

Figure 2 Deformation curve of horizontal displacement under different center burial distances

From Figure 1, it can be concluded that the horizontal displacement of the tunnel gradually decreases and the rate of change slows down as the distance between the tunnel and the foundation pit gradually increases. displacement maximum value decreases and the rate of change slows down. At 8m, 12m, 16m, 20m and 24m, respectively, the maximum horizontal displacement of the tunnel decreases and the rate of change slows down, At 8m, 12m, 16m, 20m and 24m, the maximum horizontal displacements of the tunnel are 10.24mm, 7.59mm, 5.84mm, 4.78mm and 4.05mm respectively, which means that the difference in displacements between two adjacent horizontal distances is 2.65mm, 1.75mm and 2.65mm respectively. 2.65mm, 1.75mm, 1.06mm and 0.73mm, and the difference ratios are 34.9%, 30.0%, 22.2% and 18.0%, respectively. and 18.0% respectively. When the horizontal distance of the tunnel increases from 8m to 24m, the maximum horizontal displacement of the tunnel gradually decreases from 10.24 mm to 4.05 mm, a decrease of 6.19 mm, or 60.5%. According to Fig. 2, it can be seen that the overall change rule of the horizontal displacement of the tunnel under different center burying distance is almost the same. are almost the same. The maximum displacements of the tunnels all occurred at the center position. When the horizontal distance between the foundation pit and the tunnel distance between the pit and the tunnel is within the excavation depth of the pit, the deformation of the tunnel is larger, but when the horizontal distance between the pit and the tunnel reaches the excavation depth of the pit, the deformation of the tunnel is larger. When the horizontal distance between the foundation pit and the tunnel reaches more than 1.5 times of the excavation depth of the foundation pit, the deformation degree of the tunnel is relatively small. In summary, the The magnitude of horizontal displacement depends largely on the horizontal distance between the tunnel and the foundation pit.

4.2 Vertical displacement impact analysis

Record the maximum vertical displacement of the tunnel with different center spacing at the completion of pit excavation, and use it to draw a comparison figure 3. Comparison Figure 3 is drawn to show the trend of vertical displacement of the tunnels with different center spacing. The trend of vertical displacement of the tunnel is shown in Figure 4.

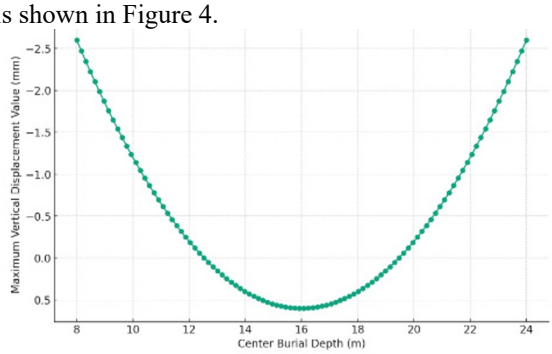

Figure 3 Comparison of the maximum vertical displacement for different center burial distances in the tunnel" at the top of the graph

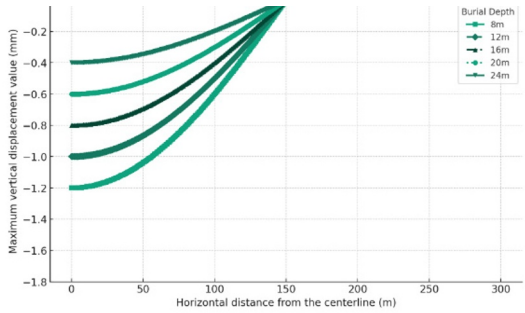

Figure 4 Deformation curve of vertical displacement under different center burial distances

Figure 3 shows that the maximum vertical displacement of the tunnel decreases as the distance between the tunnel and the pit increases, and the rate of change is slow. Correspondingly, the maximum vertical displacements of the tunnel at horizontal distances of 8m, 12m, 16m, 20m and 24m are 1.67mm, 1.28mm, 1.01mm, 0.82mm and 0.70mm, with the differences of 0.39mm, 0.27mm, 0.19mm and 0.12mm, respectively, and the difference ratios are 30.4%, 26.7%, 23.2% and 17.4%, 23.2% and 17.4% respectively. When the horizontal distance of the tunnel is increased from 8m to 24m, the maximum value of the vertical displacement increases from 1.67mm to 1.67mm. When the horizontal distance of the tunnel is increased from 8m to 24m, the maximum value of vertical displacement decreases from 1.67mm to 0.70mm, a decrease of 0.97mm, or 58.1%. According to the vertical displacement curves shown in Figure 4, it can be observed that the overall trend of the vertical displacement of the tunnel is more or less the same.

The overall change trend of the tunnels is more or less the same. In addition, the maximum displacements

occurred in the middle of the tunnel. By comparing the rate of change of horizontal and vertical tunnel displacements under different burial spacings, it can be found that that changing the burial distance has a more significant effect on the horizontal displacement of the tunnels. Therefore, it can be concluded that when changing the burial distance between the foundation pit and the tunnel, the horizontal displacement of the tunnel is more significant. tunnel, it can be concluded that when the burial distance between the pit and the tunnel is changed, the horizontal displacement of the tunnel is affected to a greater extent.

5 Conclusion

In conclusion, this study has systematically investigated the impact factors of pit excavation on neighboring tunnels, with a focus on the effects of horizontal and vertical displacements due to varying distances between the excavation site and the tunnels. The findings indicate that as the distance from the pit to the tunnel increases, both the horizontal and vertical displacements of the tunnel decrease, with the rate of change decelerating. Specifically, the horizontal displacement is more significantly affected by changes in the distance between the pit and the tunnel than the vertical displacement, suggesting that horizontal stability should be given priority in the construction management strategy. The maximum horizontal displacement showed a notable reduction from 10.24 mm to 4.05 mm as the center distance increased from 8 m to 24 m, which is a significant decrease of 60.5%. Similarly, the maximum vertical displacement diminished from 1.67 mm to 0.70 mm, a decrease of 58.1%. These results underscore the importance of careful planning and implementing appropriate engineering controls to mitigate the impacts of pit excavation on tunnel stability, especially in densely populated urban environments where space is constrained. Additionally, the study's insights into the difference in displacement change rates across varying distances provide critical data for urban developers and engineers to forecast potential impacts and devise countermeasures, enhancing the overall safety and sustainability of underground constructions.

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