Original Research Article

Study on characteristics of ground connecting wall and surface deformation during excavation of subway foundation pit in soft soil area

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Abstract: In order to deeply explore the deformation mechanism and response mechanism of the retaining structure and the surrounding soil during the excavation process of the subway in the soft soil area of Suzhou, the construction project of the foundation pit of 8 metro stations in the area was selected, the foundation pit construction projects of 8 metro stations in the area was selected, and the evolution of underground continuous wall displacement and surface settlement was researched during excavation by arranging monitoring points. The results show that, the horizontal displacement curve in the depth direction of diaphragm wall is similar to the "bow" type during excavation, and the trend of "bow" type increases with the increase of excavation depth. The maximum horizontal displacement of the whole foundation pit is located at the midpoint of the long side, and it slowly moves down during excavation, and finally tends to be stable. The maximum horizontal displacement is about 0.6-0.8 of the excavation depth, and the maximum horizontal displacement is 0.1%-0.3% H. During the excavation of foundation pit, the surface settlement increases, and the overall deformation is "concave", with the maximum value of 0.014%~0.326% of the excavation depth. The maximum horizontal wall displacement and maximum surface settlement are linearly distributed with the excavation depth of the foundation pit, and the maximum surface settlement is also positively correlated with the maximum horizontal wall displacement. The maximum horizontal displacement of the wall is 0.54~1.14 times of the maximum surface settlement. The influence of the horizontal wall insertion on the horizontal displacement of the maximum wall is significant, and the influence on the maximum surface settlement is not strong.

Keywords: Soft soil area; Diaphragm wall; Excavation of foundation pit; Surface settlement; Deformation characteristics

1. Introduction

Subway excavation projects invariably rely on diaphragm walls as crucial support structures to maintain the stability of the excavation site. However, the deformation of these diaphragm walls is subject to a multitude of influencing factors, which pose a significant challenge to accurate prediction and control. Current computational theories, despite their advancements, are still unable to fully incorporate and account for all these complex and diverse factors. As a result, there are often notable discrepancies between the deformation values calculated using theoretical models and the actual deformations observed during the construction process. In contrast, experimental data obtained through on-site monitoring offer a more reliable and accurate means of reflecting the real mechanisms by which various factors interact and affect excavation deformation.

Consequently, it is of utmost importance to conduct comprehensive analyses of deformation patterns derived from multiple excavation projects within a specific region. By closely examining the effects of diaphragm wall penetration ratios and excavation depth on both the retaining structures and the surrounding surface deformations, a more profound understanding of the underlying processes can be achieved. This approach not only aids in enhancing the accuracy of deformation prediction but also provides valuable insights for optimizing the design and construction procedures.

In recent years, the research community, both domestically and internationally, has been actively engaged in extensive investigations into excavation deformation patterns, yielding remarkable and significant results. Scholars such as Wang Wei[3], OU[4], LEUNG[5], Xu Zhonghua[6], and MASUDA[7] have dedicated their efforts to studying the factors that influence excavation deformation and their corresponding mechanisms in various regions, including Xi'an, Taipei, Hong Kong, Singapore, and Japan. Their research has shed light on the unique characteristics and challenges associated with different geological and construction environments.

Li Shu[8] focused on analyzing the deformation of excavations and the changes in surface settlement during subway station construction in Beijing, providing valuable data and insights specific to the local context. PECK[9] explored the relationship between excavation depth and surface settlement in loess regions, contributing to the understanding of deformation behavior in such geological formations.

Despite the extensive research efforts of many scholars in the fields of diaphragm wall deformation and surrounding surface settlement, it is essential to recognize that subway station excavation deformation characteristics are highly influenced by a vast array of factors. The engineering geological conditions, in particular, play a pivotal role in determining the construction safety and can lead to significant variations in deformation characteristics from one region to another.

This paper undertakes a statistical analysis of the deformation monitoring data of diaphragm walls and surrounding surfaces from eight subway stations in a specific area. By quantitatively studying the evolution of wall displacement and surface settlement, it aims to provide robust and reliable data support for the design and construction of similar projects in the region. This data-driven approach not only fills the gap between theoretical models and real-world applications but also serves as a valuable resource for engineers and practitioners to make informed decisions and implement effective measures to ensure the safety and stability of subway excavation projects.

2. Geological conditions and project overview of subway stations

2.1. Regional geological conditions

The civil construction project of a particular metro line is situated within the soft soil area of a city. The foundation soils within a depth of 60 meters are part of the Quaternary fluvial, estuarine-bay, littoral, estuarine-delta, and alluvial deposits. These soils predominantly comprise clay, silt, and sand, which are distributed in a horizontal manner.

Taking into account the characteristics, genesis, age, and physical-mechanical properties of the foundation soils, and by referring to the "Local Metro Exploration Standard Layers," the site stratigraphy has been divided into seven principal layers. **Table 1** presents a detailed list of the specific soil layer names and their corresponding physical-mechanical indices. This information is of utmost importance as it provides a comprehensive understanding of the soil conditions at the construction site. The different soil types and their properties will significantly influence the design and construction processes of the metro line. For instance, the clay content and its plasticity index can affect the stability of the excavations and the choice of foundation types. The silt and sand fractions, along with their permeability and shear strength, will determine the drainage requirements and the potential for soil liquefaction. Knowledge of these soil characteristics allows engineers to make informed decisions regarding the appropriate construction techniques, such as the use of diaphragm walls for retaining soil and groundwater control, and to calculate the expected deformations and settlements during and after construction. Overall, the detailed soil information presented in **Table 1** serves as a crucial foundation for the successful implementation of the metro line project in this soft soil area.

Table 1. Soil layer names and physical mechanics.

Soil Layer Name	Natural Unit Weight /($kN \cdot m^{-3}$)	C /($KN \cdot m^{-3}$)	ϕ /(°)	E_S /MPa	Depth /m
Fill Soil	18	0	15	6.9	2
Silty Clay	18.6	32	15.5	5	2.2
Silty Sand	18.7	5	20	4	2.3
Silty Sand	18.7	15	26.5	19	7.3
Silty Clay	18.9	18	21	5.1	7.4
Silty Clay with Silt	18.9	27	20.5	5.3	5.2
Sandy Silt	19.0	24	18.2	26	3.9

2.2. Engineering overview statistics

In order to minimize the interference of special and potentially confounding factors on the deformation characteristics under study, this research deliberately focuses on a specific type of subway stations, namely rectangular ones. These stations possess a relatively consistent geometry, each being approximately 200 meters in length and 20 meters in width. The excavation depths for these stations vary within the range of 15.6 to 27.3 meters, which represents a significant span and thus necessitates a detailed examination of the associated deformation patterns.

The eight stations selected for this study are all constructed employing the cut-and-cover method. This construction technique involves excavating an open trench and then covering it with a structural deck or roof after the construction of the underground components is completed. The retaining structures play a crucial role in maintaining the stability of the excavation during the construction process. In this case, they are composed of diaphragm walls, which are integrated with reinforced concrete and steel supports. This combination provides the necessary strength and rigidity to resist the lateral earth pressures exerted by the surrounding soil.

Moreover, the diaphragm walls and the internal structures are designed to form composite walls, which serve as permanent structures. This design choice not only ensures the long-term stability of the underground facility but also has implications for the overall deformation behavior. The composite nature of the walls allows for a more efficient transfer of loads and stresses, thereby influencing the distribution of deformations.

The engineering overview statistics for these eight selected stations are presented in Table 2. This table likely contains detailed information such as the specific dimensions of each station, the exact excavation depths, the properties of the diaphragm walls (such as thickness and material strength), the configuration and spacing of the supports, and other relevant parameters. By compiling and analyzing these data, a more comprehensive understanding of the engineering characteristics and the factors contributing to the deformation can be achieved. This, in turn, will assist in developing more accurate predictive models and engineering solutions to optimize the design and construction of similar rectangular stations in the future, ensuring both the safety and functionality of the subway infrastructure while minimizing potential deformations and associated risks.

Table 2. Statistical information of station project overview.

Station Number	Foundation Pit Excavation Size			Retaining Method	Diaphragm Wall Embedded Depth /m
	L/m	W/m	D/m		
1	145.1	20.6	27.3	Diaphragm Wall + Concrete Support + Steel Support	9.2
2	153.2	21.6	24.5		10.6
3	204.6	20.5	17.6		8.2
4	146.6	20.4	21.6		10.9
5	190	22	18		6.9
6	186	19.6	17.8		5.4
7	215	20.7	15.6		5.5
8	193.5	19.8	16.24		7.0

3. Analysis of excavation deformation characteristics

The comprehensive and detailed study meticulously analyzed the extensive data collected from a significant number of 90 surface settlement monitoring points as well as 263 inclinometer monitoring points specifically located on the diaphragm walls. Through careful examination and precise measurement, it was interestingly discovered that the surface settlement values fluctuated within a particular range, stretching from -3 mm, which notably indicates an upward movement or uplift of the surface, to 30 mm, signifying a downward displacement or settlement. Meanwhile, the lateral displacement of the diaphragm walls also showed a specific pattern, varying from -3 mm, suggesting a certain outward deformation, to 18.6 mm, representing an inward deformation towards the excavation area. When considering these findings as a whole, the collected data strongly suggest that both the excavation pit and the surrounding ground experience relatively minor deformations. This observation, in an indirect manner, effectively showcases the remarkable effectiveness of employing diaphragm wall support systems in the challenging conditions of soft soil areas, highlighting the importance and value of such construction techniques in ensuring the stability and safety of the overall structure.

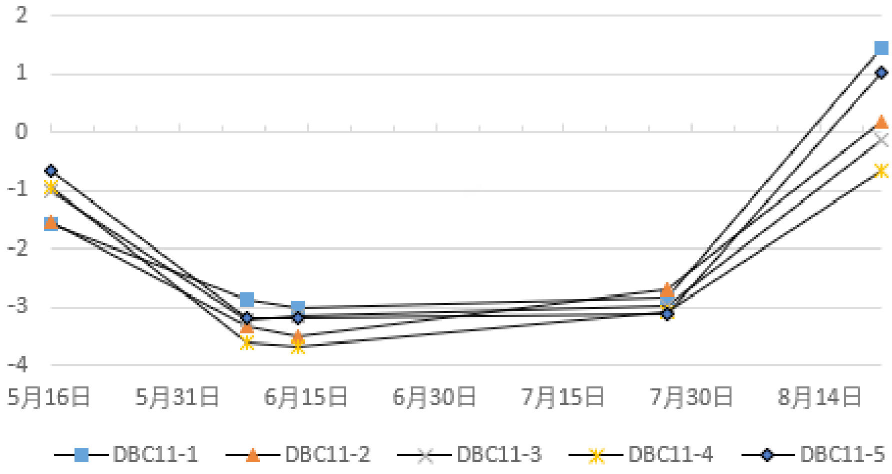
3.1. Range of deformation magnitude

The in-depth and systematic study carried out a meticulous analysis of the data which was sourced from as many as 90 surface settlement monitoring points and an extensive 263 inclinometer monitoring points strategically positioned on the diaphragm walls. Upon close inspection and detailed calculation, it was ascertained that the surface settlement manifested a variation within the range of -3 mm to 30 mm. Here, it is crucial to note that the negative values within this range are indicative of an upward movement or uplift of the surface, whereas the positive values signify a downward shift or settlement. In parallel, the lateral displacement of the diaphragm walls was observed to span from -3 mm to 18.6 mm. It should be emphasized that the positive values in this context denote an inward deformation directed towards the excavation area. When considering all the data in its entirety, it becomes evident that both the excavation pit and the surrounding ground display relatively diminutive deformations. This overall observation serves as an indirect yet powerful testament to the high level of effectiveness associated with the utilization of diaphragm wall support in the rather challenging and complex soft soil areas. This not only validates the engineering approach but also underlines its significance in maintaining the structural integrity and stability of the construction site.

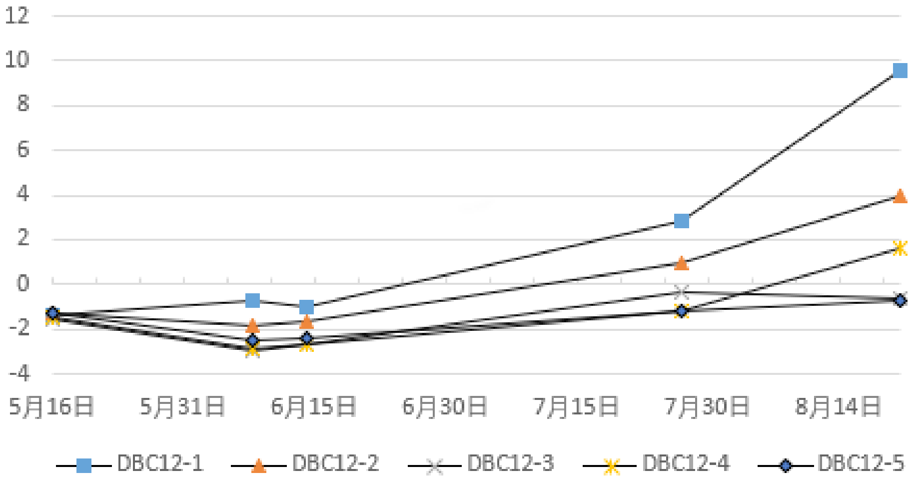
3.2. Deformation of individual diaphragm wall and surface settlement

(1) Diaphragm Wall Deformation Analysis

In order to conduct a highly detailed and specific analysis of the deformation behavior exhibited by a particular monitoring point on the diaphragm wall during the process of excavation, the inclinometer data from two highly representative points situated at the midpoint of the long side of the excavation were deliberately selected. These two points were aptly defined as Point 1 and Point 2, and their positions are clearly illustrated as shown in Figure 1.



(a) Measuring Point 1



(b) Measuring Point 2

Figure 2. Time-history curve of the settlement deformation of the surrounding ground at a distance of (1 - 5) m from the two measuring points.

Upon careful examination of Figure 1, it becomes apparent that throughout the five distinct excavation stages, the maximum horizontal displacement recorded at Point 1 was precisely 17 mm, and this occurred at a specific depth of 12 m. In the case of Point 2, the maximum horizontal displacement was measured to be 18.6 mm, which was observed at a depth of 14 m. When considering the overall situation, the horizontal displacement pattern of the diaphragm wall reveals a characteristic where the deformation is relatively larger in the middle section and notably smaller at the ends. This displacement curve bears a resemblance to a distinct “bow” shape. Interestingly, this “bow” shape becomes even more prominent and pronounced as the excavation depth progressively increases.

As the excavation operation delves deeper, the overall horizontal displacement in the depth direction of the excavation also experiences an increase. Concurrently, the maximum displacement point gradually shifts downward, and it is approximately located at a range of 0.6 to 0.8 times the excavation depth. After the completion of the final excavation stage, it was determined that the maximum lateral displacement at Point 1 was approximately 0.103% of the excavation depth, while at Point 2, it was around 0.124%. In general terms, the maximum horizontal displacement values were found to fluctuate within the range of 0.1% to 0.3%. This detailed analysis provides crucial insights into the deformation characteristics of the diaphragm wall during excavation, which can be of great significance for future engineering design and construction operations, allowing for more accurate predictions and appropriate preventive measures to be implemented to ensure the stability and safety of the overall structure..

(2) Surface Settlement Analysis

Figure 2 presents the time-history variation curves of the surface settlement monitoring points that are positioned within a range of 1 to 5 meters from the previously analyzed Points 1 and 2. Upon scrutinizing Figure 2, it can be clearly discerned that the overall deformation pattern of the surrounding ground surface exhibits a roughly “concave” distribution. In the initial stage, a slight uplift deformation is noticeable. However, as the excavation depth steadily augments, the surface gradually undergoes settlement, and this settlement magnitude is substantially greater than that of the initial uplift. The occurrence of the initial uplift can be primarily attributed to the vibrations generated by the construction machinery and the loading effect of the equipment and materials placed in the vicinity of the excavation area. As the excavation operation advances further, the release of the internal soil stress becomes more prominent, consequently leading to the observed settlement. This settlement phenomenon intensifies with the increasing excavation depth, and the trend becomes increasingly conspicuous.

The surface deformation data at the monitoring points located 1 to 5 meters away from the excavation face reveals that as the distance from the excavation face expands, the surface deformation correspondingly decreases. This implies that the impact exerted by the excavation activity on the surrounding soil layers diminishes as the distance from the source of disturbance (i.e., the excavation face) increases. At a distance of 5 meters from the excavation face, the surface deformation is found to be minimal, falling within the range of 1 to 2 mm. In general, the maximum surface deformation is calculated to be between 0.014% and 0.326% of the excavation depth.

3.3. Excavation depth on deformation of diaphragm wall and surrounding surface

The eight stations that have been meticulously selected possess excavation depths that span from 15.6 meters all the way to 27.3 meters. When calculated, the average depth among these stations is determined to be 19.83 meters. The influence curves, which vividly depict the relationship between the excavation depth and both the horizontal displacement of the diaphragm wall as well as the settlement deformation of the surrounding surface, are presented in Figures 3 and 4.

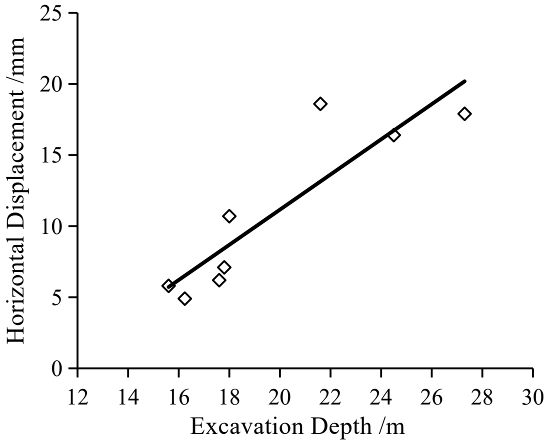


Figure 3. Relationship between the maximum horizontal displacement of the diaphragm wall and the excavation depth.

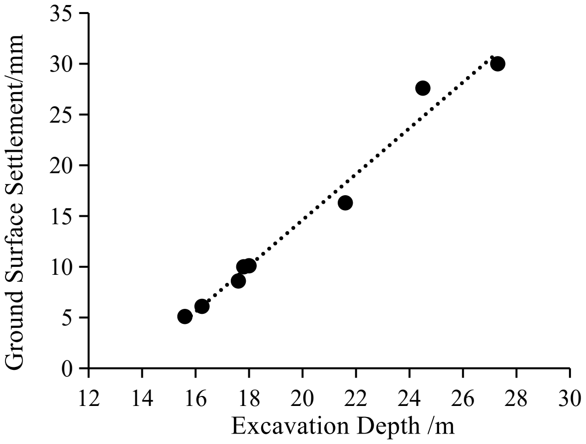


Figure 4. Relationship between the maximum ground surface settlement and the excavation depth.

By closely examining Figures 3 and 4, it becomes evidently clear that there is a distinct pattern. The maximum horizontal displacement exhibited by the diaphragm wall and the maximum settlement displacement occurring on the surrounding surface tend to increase in an approximately linear fashion in direct correlation with the increase in the excavation depth. The degree of fit between the observed data and the linear trend is remarkably good. This excellent fit serves as a strong indication that the excavation depth wields a highly significant impact on the lateral deformation characteristics of the retaining structure and also plays a crucial role in determining the maximum settlement magnitude of the surrounding surface. Such findings are of utmost importance in the field of engineering, as they provide valuable insights for predicting and controlling the deformations associated with excavation activities, thereby enabling more precise design and construction strategies to be implemented to ensure the stability and safety of the overall project.

This particular study has arrived at conclusions that deviate from those presented in reference[8]. The stations under investigation in this study are situated within the soft soil area of a specific city. The soil in this region is characterized by a notably high water content and a relatively low shear strength. During the process of excavation, this combination of soil properties leads to a pronounced impact on the internal stress state of the soil. The high water content causes the soil to be more susceptible to deformation, and the low shear strength offers less resistance, thereby resulting in significant alterations to the stress equilibrium within the soil mass.

In contrast, the research described in reference[8] pertains to loess geological conditions where the water table is lower. Loess, under such circumstances, exhibits a higher shear strength when its water content is low.

This inherent property of loess implies that during excavation, the influence on the internal stress distribution of the surrounding soil is comparatively weaker. The soil is more stable and less prone to experiencing drastic changes in its stress state.

Consequently, in the study referred to in[8], the relationship between the excavation depth and the deformation of the pit and the surface lacks the regularity that might be expected. This disparity can be attributed to the fundamental differences in the soil types and their associated properties, which in turn lead to varying responses to the excavation process. Understanding these distinctions is crucial for accurately predicting and managing the deformation effects in different geological settings, highlighting the importance of considering soil characteristics when conducting excavation projects.

3.4. Influence of diaphragm wall embedment ratio on deformation of the wall and surrounding surface

The excavation depths of the eight carefully chosen stations span from 15.6 meters to 27.3 meters. Upon calculation, it is determined that the average depth among these stations is 19.83 meters. The embedment depths of the diaphragm walls, on the other hand, vary from 5.4 to 10.9 meters. This results in an embedment ratio that falls within the range of 0.303 to 0.505. The influence exerted by the diaphragm wall embedment ratio on both the horizontal displacement of the wall and the settlement deformation of the surrounding surface is graphically illustrated in Figures 5 and 6.

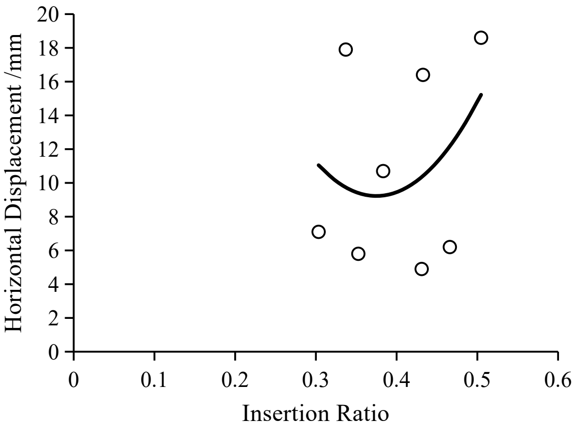


Figure 5. Relationship between the maximum horizontal displacement of the diaphragm wall and its insertion ratio.

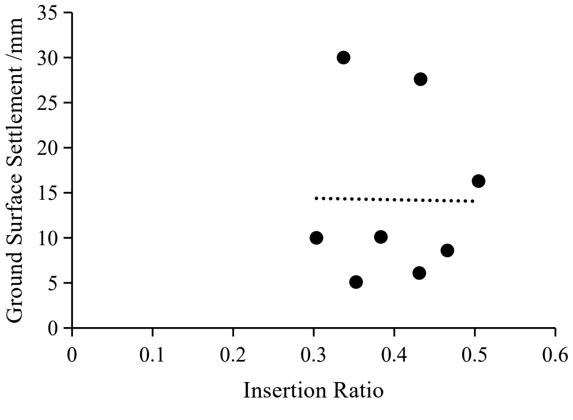


Figure 6. Relationship between the maximum ground surface settlement and the insertion ratio of the diaphragm wall.

When observing Figure 5, it becomes evident that there exists an approximate quadratic polynomial relationship between the maximum horizontal displacement of the diaphragm wall and the embedment ratio. As the embedment ratio changes within the range of 0.303 to 0.505, initially, the maximum horizontal displacement shows a decreasing trend as the embedment ratio increases. This can be attributed to the fact that a greater embedment depth provides enhanced stability and resistance to lateral movement, thereby reducing the horizontal displacement. However, an interesting phenomenon occurs when the embedment ratio exceeds 0.35. At this point, the maximum horizontal displacement begins to increase exponentially, and this trend becomes increasingly prominent. This might be due to various factors such as changes in soil-structure interaction, the redistribution of soil stresses, or the onset of different deformation mechanisms at higher embedment ratios.

Figure 6 reveals that the influence of the diaphragm wall embedment ratio on the maximum surface settlement is not as straightforward and lacks a strong, discernible regularity. Instead, as the embedment ratio is incremented, the maximum surface settlement displays a wavelike pattern. This could potentially be a result of the complex interplay between multiple factors, including the variable soil properties at different depths, the combined effects of the diaphragm wall's behavior and the surrounding soil's response, and the influence of other construction-related factors that are not easily quantifiable or predicted. Understanding these complex relationships is essential for optimizing the design and performance of diaphragm wall systems in different engineering projects, as it allows for more accurate predictions and better control of deformations to ensure the overall stability and safety of the excavation and its surrounding environment.

3.5. Relationship between maximum horizontal displacement of diaphragm wall and maximum surface settlement

During the actual on-site construction process, a multitude of diverse factors concurrently exert their influences on both the horizontal displacement of the diaphragm wall and the settlement of the surrounding surface. Owing to the inherent and significant correlation that exists between these two aspects, this particular study undertakes a detailed analysis of the relationship between the maximum horizontal displacement of the diaphragm wall and the maximum surface settlement for the eight selected stations. **Figure 7** serves to vividly depict the relationship between the maximum surface settlement and the maximum horizontal displacement of the diaphragm wall.

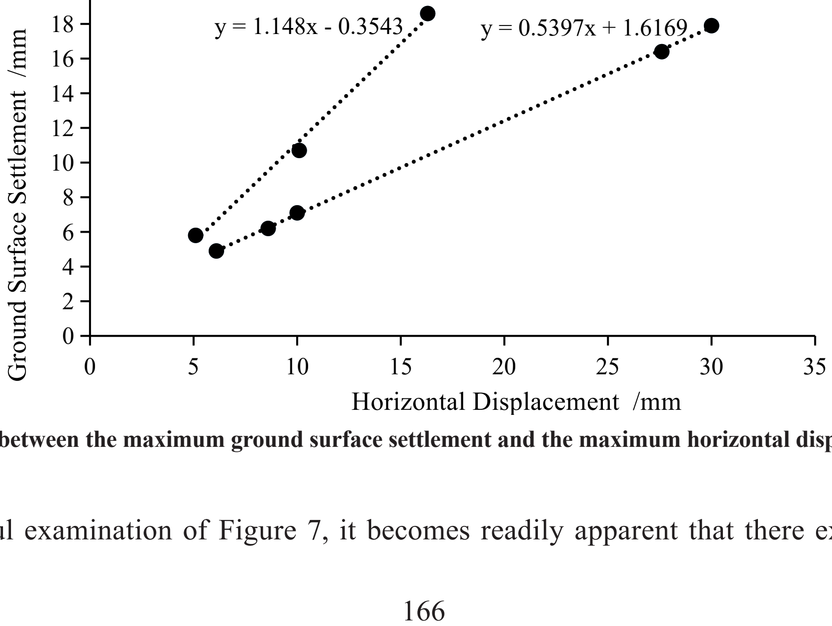


Figure 7. Relationship between the maximum ground surface settlement and the maximum horizontal displacement of the diaphragm wall.

Upon a careful examination of Figure 7, it becomes readily apparent that there exists an approximate positive correlation between the maximum surface settlement and the maximum horizontal displacement of the diaphragm wall. Specifically, the maximum horizontal displacement falls within a range that is 0.54 to 1.14 times the magnitude of the maximum surface settlement. The in-depth analysis conducted herein suggests that as the excavation depth progressively increases, it inevitably disturbs the original stress state within the soil layers. This disturbance effectively leads to an unloading phenomenon within the soil mass. As a direct consequence of this, the diaphragm wall experiences a horizontal displacement towards the inside of the excavation pit. Subsequently, the wall exerts what is known as active earth pressure on the soil situated behind it. This action then causes the surrounding soil to also undergo displacement in the direction towards the excavation side, which is inevitably accompanied by the occurrence of surface settlement. This complex chain of events highlights the intricate nature of the interactions between the diaphragm wall and the surrounding soil during the construction process, and emphasizes the importance of closely monitoring and understanding these relationships in order to ensure the overall stability and safety of the excavation and its adjacent areas.

4. Discussion

The present study on the excavation of eight subway stations in a soft soil area has provided valuable insights into the deformation behaviors of diaphragm walls and surrounding ground surfaces. The findings have significant implications for understanding the complex interactions between excavation activities and the geotechnical environment.

The observed “bow” shape deformation of the diaphragm wall in the depth direction and its relationship with excavation depth is a crucial aspect. As the excavation deepens, the increase in maximum horizontal deformation and the downward shift of the maximum deformation point can be attributed to the redistribution of soil stresses. The soil behind the diaphragm wall experiences unloading, leading to lateral movement towards the excavation pit. This behavior is not only affected by the excavation depth but also by the soil properties characteristic of soft soil areas, such as high compressibility and low shear strength. Understanding this deformation pattern is essential for designing appropriate support systems to limit excessive displacements and ensure the stability of the retaining structure.

The transition from initial heave to settlement of the surrounding ground surface as excavation progresses is another important observation. The heave in the initial stages can be related to the vibrations and surcharge from construction activities, while the subsequent settlement is mainly due to the release of soil stresses and the deformation of soil layers. The decrease in surface deformation with increasing distance from the excavation face is expected, but the quantification of this effect, such as the minimal deformation at 5 m distance, provides practical guidelines for assessing the extent of the affected zone. This knowledge can help in planning the layout of adjacent structures and utilities, minimizing the potential damage caused by ground movements.

The linear relationship between excavation depth and the maximum horizontal displacement of the diaphragm wall as well as the maximum ground settlement highlights the dominant role of excavation depth in soft soil areas. This is in contrast to other geological regions where the influence of excavation depth may be less pronounced. The positive correlation between the maximum ground settlement and the maximum horizontal displacement of the diaphragm wall further emphasizes the interconnection between the retaining structure and the surrounding soil. Engineers can utilize these relationships to predict the likely deformations based on the planned excavation depth, enabling them to implement preemptive measures to control and mitigate potential risks.

The significant impact of the diaphragm wall insertion ratio on the maximum horizontal displacement, especially the exponential increase when the ratio exceeds 0.35, is a critical finding. This suggests that there is an optimal range of insertion ratios for minimizing wall displacements. However, the lack of a strong regularity in its influence on the maximum ground settlement indicates the complexity of the soil-wall interaction. Future research could focus on further elucidating the underlying mechanisms and exploring ways to optimize the insertion ratio to balance the stability of the wall and the surrounding ground.

In conclusion, this study has enhanced our understanding of the deformation mechanisms in soft soil subway excavations. The results can be used to improve the design and construction practices, leading to more efficient and safer excavation projects. However, it should be noted that the study is based on specific field conditions, and further investigations in different geological settings and with varying construction parameters are warranted to generalize the findings and develop more comprehensive design guidelines. Additionally, the long-term behavior of the excavated sites and the potential for secondary deformations should also be considered in future studies to ensure the durability and functionality of the subway infrastructure. Overall, the insights gained from this research contribute to the continuous improvement of geotechnical engineering practices in subway construction and related fields.

5. Conclusion

This comprehensive study, which is firmly grounded in the practical excavation projects of eight subway stations located within the soft soil area of a specific city, undertakes an in-depth investigation into the impact mechanisms of various factors, such as the excavation depth and the diaphragm wall insertion ratio, on the deformation patterns of both the diaphragm walls and the surrounding ground surfaces. This is achieved through meticulously designed field monitoring experiments. The principal conclusions drawn from this research are as follows:

During the course of the excavation process, the deformation of the diaphragm wall in the depth direction manifests a characteristic “bow” shape. This particular shape becomes increasingly prominent as the excavation depth continues to augment. Concurrently, the maximum horizontal deformation of the diaphragm wall also experiences an upward trend with the increase in excavation depth. Notably, the location of the maximum deformation gradually migrates downward. The position of this maximum deformation is approximately within the range of 0.4 to 0.6 times the excavation depth. In terms of magnitude, the maximum horizontal displacement values span from 0.1% to 0.3% of the excavation depth.

As the excavation progresses and the depth increases, the deformation of the surrounding ground surface undergoes a transition from an initial state of heave to one of settlement. It is observed that the farther the distance from the excavation face, the lesser the impact on the ground surface deformation. For instance, at a distance of 5 m from the excavation face, the deformation is measured to be only within the range of (1 to 2) mm. A comprehensive analysis of the data reveals that the maximum ground surface deformation lies between 0.014% and 0.326% of the excavation depth.

The influence of the excavation depth on both the maximum horizontal displacement of the diaphragm wall and the maximum ground settlement exhibits a linear distribution. This finding strongly indicates that within soft soil areas, the impact of the excavation depth is far more pronounced compared to other geological regions. In this particular area, there exists an approximately positive correlation between the maximum ground settlement and the maximum horizontal displacement of the diaphragm wall. Specifically, the latter is found to be within the range of 0.54 to 1.14 times the former.

The insertion ratio of the diaphragm wall plays a significant role in influencing the maximum horizontal displacement of the wall. Notably, when the insertion ratio exceeds 0.35, the maximum horizontal displacement experiences an exponential increase. However, in contrast, the influence of the insertion ratio on the maximum surrounding ground settlement does not display a strongly discernible regularity.

These conclusions not only enhance our understanding of the complex deformation behaviors in soft soil subway excavations but also provide valuable insights and practical guidance for future similar projects. They can assist engineers in better predicting and controlling deformations, thereby ensuring the safety and stability of subway construction and the surrounding environment.

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