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Impact of Wind Loads on the Mechanical Behaviors of Prefabricated Partition Walls in Underground Stations

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Abstract. Considering the factor of wind load, this study explores the engineering application of prefabricated assembled partition walls in underground stations. Using the finite element analysis software ANSYS, we simulate the displacement deformation and mechanical behavior of the assembled partition wall in the station under the action of wind load. At the same time, the mechanical characteristics of the assembled partition wall under the consideration of only self-weight factors are also used as a comparison to further analyze the main cause of partition deformation. We also extract the displacement data of the assembled partition wall in actual engineering and compare it with the numerical values obtained from the simulation software, providing theoretical support for actual engineering, and verifying the feasibility of ANSYS in engineering applications. The following conclusions are drawn self-weight is the main cause of partition deformation; the position and size of the holes directly affect the structural performance of the wall; the prefabricated assembled wall can meet the actual engineering needs of the subway.

Keywords. Wind load, prefabricated partition wall, underground station, finite element analysis, self-weight

1. Introduction

Over the past decades, China's construction industry has heavily relied on the input of resource factors and massive investments to drive its growth. However, it faces significant challenges such as low levels of industrialization and informatization, inefficient production methods, low labor productivity, substantial energy and resource consumption, and inadequate technological innovation capabilities. As a result, there is an urgent need to transform and upgrade the development model of the construction sector. In this context, prefabricated construction has emerged as a highly efficient and versatile solution in the field of engineering, offering numerous benefits in terms of construction speed, cost-effectiveness, and design flexibility. This approach has gained significant popularity across various engineering projects, ranging from commercial buildings to residential complexes and industrial facilities [1-8].

Within the realm of prefabricated construction, prefabricated partition walls have gained significant traction as an efficient and versatile solution for dividing interior spaces. These walls, manufactured off-site and assembled on-site, offer a range of

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benefits in terms of time savings, cost-effectiveness, sustainability, and design flexibility. Prefabricated partition walls are constructed in controlled factory environments, where they are manufactured with precision and quality control measures. This off-site manufacturing process enables simultaneous work on various construction components, reducing project timelines significantly. By the time the building site is prepared, these walls are ready for installation, minimizing on-site construction activities and streamlining the overall building process.

Despite the widespread application [9-16] of Prefabricated Partition Walls in various sectors such as Commercial Buildings, Residential Projects, Industrial Facilities, and Transportation Infrastructures, there is a notable scarcity of research examining the mechanical characteristics and the corresponding influencing factors of these walls. For the Prefabricated Partition Walls, the rationality and economic feasibility of these new sub-structures need to be verified. Moreover, the impacts of their mechanical properties on the overall structures should not be overlooked. Considering the expensive nature of prototyping and on-site testing, it is highly viable to employ numerical methods (FEM, FDM) to analyze the mechanical behavior and deformation characteristics of Prefabricated Partition Walls under different working conditions.

This paper mainly uses the finite element software ANSYS to comprehensively analyze the mechanical characteristics of the assembled partition walls in subway stations under both dead loads and wind loading in different directions. By analyzing its stress and displacement cloud map, we further verify the feasibility of assembly technology in subway station design, to provide guidance for actual engineering.

2. Prefabricated Partition Walls

The application of prefabricated assembled partition walls [17-18] in the Suzhou Metro is considered a pilot project. Considering factors such as the actual progress of the overall construction, station design, pipeline openings, and operational safety, the research project for prefabricated assembled partition walls has selected a large open space in a future commercial development area of a specific station in Suzhou as the pilot area. This area is relatively enclosed, providing an ideal setting for the construction, testing, and experimentation of the partition walls. It allows for a thorough assessment of their performance, durability, and installation techniques without any disruption to train operations. The pilot project will serve as a valuable opportunity to evaluate the feasibility and benefits of implementing prefabricated assembled partition walls in the Suzhou Metro system, with the potential for future expansion to other stations. The gathered insights and lessons learned from this pilot initiative will contribute to optimizing construction processes, enhancing efficiency, and improving the overall quality and safety of the metro infrastructure.

As plotted in Figure 1, the commonly used prefabricated assembled partition walls are generally composed of four types. Walls I and III are both side walls, with Wall I having a bay window, while Wall III does not. Wall II is a partition wall; Wall IV is the back wall, including a main door. All prefabricated assembled partition walls are constructed by assembling modules of the same size. Therefore, conducting stress analysis and displacement analysis on each wall is an important basis for assessing their long-term performance.

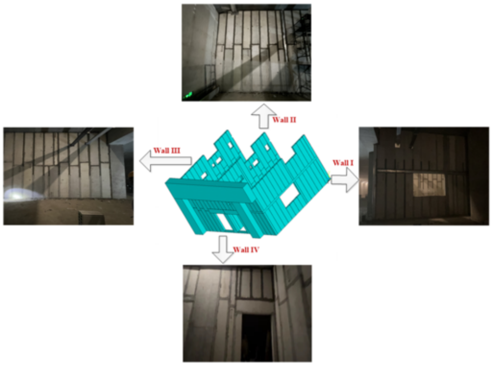


Figure 1. Schematic plot of four prefabricated partition walls in subway stations.

3. Finite Element Modeling

With the help of ANSYS finite element analysis software, the assembled partition walls (Wall I, II, III, and IV) are modeled and analyzed as a whole, and the wall thickness is 200mm. The main analysis process includes the following steps: establishing a geometric model, defining unit attributes and material properties, dividing grid units, applying boundary conditions and loads, and extracting corresponding data. The main materials are steel, special mortar, partition wall template, and beam-column (the parameters of special mortar and partition wall template are provided by the manufacturer), and the overall unit type uses solid 185 units (preprocessor/Add/Add/Solid/Brick 8 node 185). The steel material is divided into 0.1 m units, the mortar is divided into 0.05 m units, the partition wall template is divided into 0.2 m, and the beam-column unit is divided into 0.3 m. The specific grid division is also shown in Figure 1. Fixed constraints are applied to the upper and side parts of the down-turned beam, fixed constraints are applied to the bottom of the concrete column, three-way constraints are applied to the bottom and side of the partition wall, and three-way constraints are applied to the top and bottom of the steel column. Considering the self-weight of the wall, the wind load is selected as 2.1 KPa, and it is applied to the four partition walls in the form of uniform force, thereby studying the mechanical characteristics of different partition walls under the same wind load. The specific parameters of the material are selected as shown in Table 1.

Table 1. The selected values of model parameters.

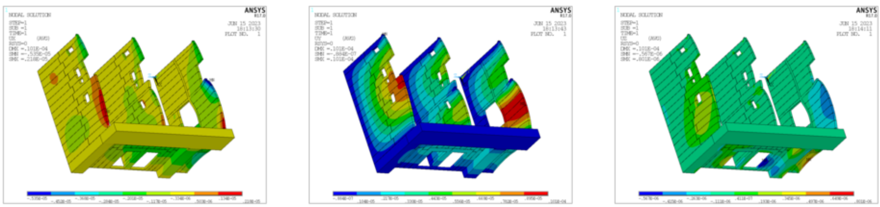
Materials	Young's Modulus/GPa	Poisson's ratio ν	Density/kg/m^3
Steel	206	0.29	7850
Mortar	1.64	0.3	1500
Partition formwork	16	0.3	1090
Beam and column	30	0.3	2500

Based on the mechanical characteristics of the assembled partition walls under the action of wind load, the study mainly focuses on five working conditions, namely, the case merely considering the self-weight of the wall, and the case considering that wind loads are applied to the four partition walls from different directions separately.

4. Results and Discussion

4.1. Displacement When Only Considering Self-Weight

In order to distinguish the internal force deformation of the assembled partition wall due to self-weight and the internal force deformation caused by the application of wind load, and to further analyze the main cause of the displacement deformation of the assembled partition wall, this study only considers the displacement deformation diagram of the assembled partition wall under the factor of self-weight. Analyzing the displacement cloud map (as shown in Figure 2) can be found: the maximum displacement in the x direction is 0.0053 mm, the main deformation area is at the top of wall one, near the steel column position, mainly because the top of the steel column has applied three-way constraints, and at the same time, stress concentration is caused by the existence of holes, so larger deformation occurs at the corresponding position; the maximum displacement in the y direction is 0.0101mm, the most unfavorable position is at the top of wall one, the main reason is that wall one has opened larger holes, easy to produce stress concentration, so the steel beam and steel column are used as support conditions at the corresponding position to ensure the safety of the partition wall; the maximum displacement in the z direction is 0.000801 mm, the main displacement occurs at the bottom of the steel column, the main reason is that it bears a part of the self-weight stress generated by the concrete beam, but the deformation is small to meet the actual engineering needs; the overall maximum displacement is 0.0101mm, meeting the design requirements.

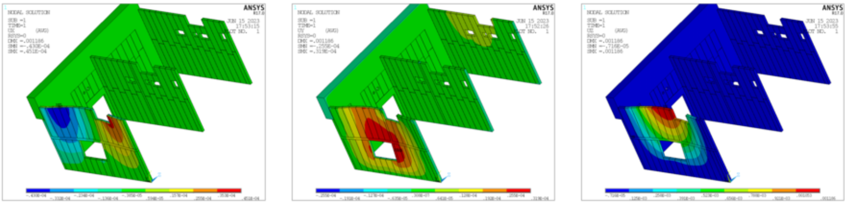


(a) (b) (c)

Figure 2. Displacement distribution considering only dead weight: (a) x-direction; (b) y-direction; (c) z-direction.

4.2. Displacement Distribution of Wall One under Wind Load

Analyzing the displacement cloud map (as shown in Figure 3) can be found: the maximum displacement in the x direction is 0.0451 mm, the main deformation area is at the top of wall one, mainly because the top of the partition wall has not applied constraints and wind load is applied, causing the interaction of wind load and self-weight, so a larger displacement occurs in the x direction; the maximum displacement in the y direction is 0.0319mm, the most unfavorable position is near the hole of wall one, the main reason is that wall one has opened a larger hole as an observation window, easy to produce stress concentration; the maximum displacement in the z direction is 1.186mm, the main displacement occurs at the top of wall one, the main reason is that the wind load directly acts on wall one in the z direction, the top of wall one has not applied constraints, the self-weight and wind load superimpose, so a larger displacement occurs, but the deformation is small to meet the actual engineering needs; the overall maximum displacement is 1.186mm, meeting the design requirements.

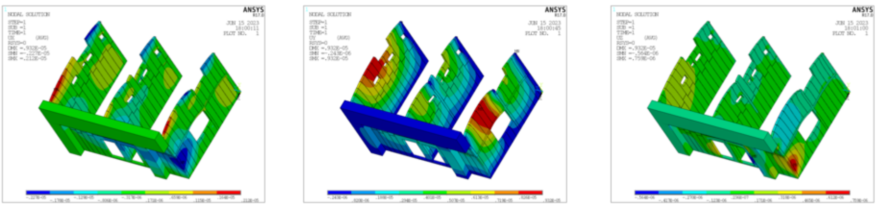


(a) (b) (c)

Figure 3. Displacement distribution of wall one under wind load: (a) x-direction; (b) y-direction; (c) z-direction.

4.3. Displacement Distribution of Wall Two under Wind Load

Analyzing the displacement cloud diagram (as shown in Figure 4), it can be observed that the maximum displacement in the x-direction is 0.00227 mm. The deformation primarily occurs at the location of the columns underneath the concrete beam, mostly due to the substantial displacement caused by the self-weight of the concrete beam. The maximum displacement in the y-direction is 0.00932 mm, occurring at the top of Wall One. This is primarily because Wall One has a large opening, and no constraint is applied at the top. The maximum displacement in the z-direction is 0.000759 mm, mainly occurring in the middle of the steel column. This is primarily due to it bearing part of the self-weight stress caused by the concrete beam. However, the deformation is small enough to meet the practical needs of the project. The overall maximum displacement is 0.00932 mm, meeting the requirements of the construction standards.

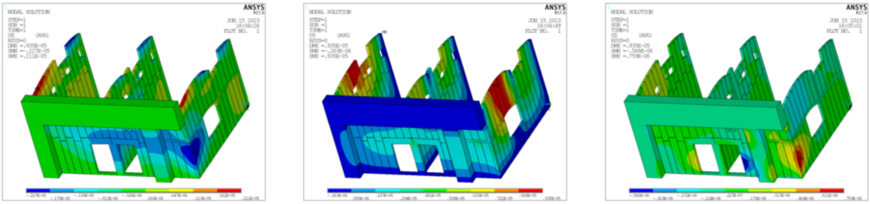


(a) (b) (c)

Figure 4. Displacement distribution of wall two under wind load: (a) x-direction; (b) y-direction; (c) z-direction.

4.4. Displacement Distribution of Wall Three under Wind Load

Analyzing the displacement cloud diagram (as shown in Figure 5), it can be observed that the maximum displacement in the x-direction is 0.00227 mm. The deformation mainly happens at the top of Wall Three, mainly because no constraint is applied to the top of the partition wall, and the wind load is also applied to this wall, which, together, result in larger displacement. The maximum displacement in the y-direction is 0.00935 mm, with the least favorable position at the top of Wall One. This is primarily due to the large opening in Wall One, coupled with the lack of constraint at the top. The maximum displacement in the z-direction is 0.000759 mm, occurring at the base of the steel column. This is mainly due to it bearing part of the self-weight stress from the concrete beam. However, the deformation is minor enough to satisfy the actual engineering requirements. The overall maximum displacement is 0.00935 mm, meeting the design requirements.

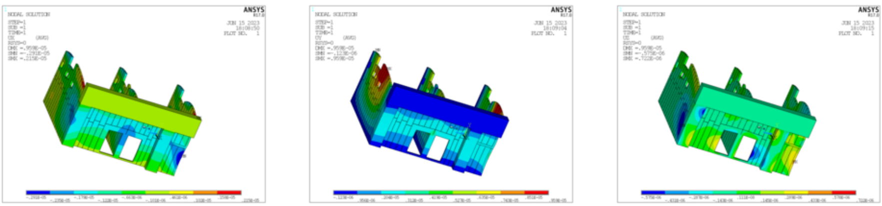


(a) (b) (c)

Figure 5. Displacement distribution of wall three under wind load: (a) x-direction; (b) y-direction; (c) z-direction.

4.5. Displacement Distribution of Wall Four under Wind Load

Analyzing the displacement cloud diagram (as shown in Figure 6), it can be found that: the maximum displacement in the x direction is 0.00291 mm, the main deformation area is at the top of wall one and the position of the grid column under the concrete beam, mainly due to the larger displacement caused by the lack of constraints at the top of the partition wall, and the existence of the self-weight of the concrete beam leading to larger displacement; the maximum displacement in the y direction is 0.00959mm, the most unfavorable position is at the top of wall three, the main reason is that wall three has opened larger holes, easy to produce stress concentration, and the lack of design of the grid column unable to bear the stress; the maximum displacement in the z direction is 0.000722 mm, the main displacement occurs at the bottom of the steel column, the main reason is that it bears a part of the self-weight stress generated by the concrete beam, but the deformation is small to meet the actual engineering needs; the overall maximum displacement is 0.00959mm, meeting the design requirements.



(a) (b) (c)

Figure 6. Displacement distribution of wall four under wind load: (a) x-direction; (b) y-direction; (c) z-direction.

5. Conclusion

With the help of finite element software ANSYS, five working conditions of the application of prefabricated partition walls in subway stations were analyzed, numerical simulation analysis was carried out from self-weight and wind load in four different directions, and displacement verification was carried out with the help of actual engineering, and the following conclusions were drawn:

The self-weight of the assembled partition wall is the main cause of displacement deformation, and the displacement deformation caused by wind load is small compared to self-weight.

The overall structure deformation of wall one is larger than other walls, which can be further optimized by applying steel columns or constraints at the top of the partition wall, and the hole position is prone to large stress concentration.

The structures of wall two and Wall three are similar, although wall two has applied steel columns to bear part of the stress, but the overall internal force deformation is similar. It can be proved that the position and size of the hole are the main factors affecting the deformation of the wall.

The prefabricated partition wall can meet the construction requirements, has been applied in actual engineering, and can prove that ANSYS has certain guiding significance in engineering application.

The major technical problem of the prefabricated partition wall in the subway is the vibration load when the subway passes, which is not considered here, and needs to be further studied in model analysis.

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