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MECHANICAL RESPONSE ANALYSIS AND TREATMENT MEASURES OF PARTITION WALL OF METRO STATION

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ABSTRACT

In the process of metro station construction, the partition wall is usually used to prevent the displacement of the soil behind the wall to ensure the construction platform. This research aims to analyze the response of partition wall to keep the safety of the structure. The time-horizontal displacement and cracks of the partition wall are measured during the process of metro station construction. The finite element software FLAC 3D is used to simulate the response of partition wall, and the reasons of partition wall cracking and displacement are analyzed by finite element simulation and measurement data. The stiffness and self-stability of the partition wall in the station is powerful, the stress concentration appeared on the central area and caused cracks of the partition wall. Reducing the pressure exerted on the partition wall and shifting partial pressure exerted on the partition wall by the construction of the medium plate can solve the tress concentration problem. Through the data analysis of the strengthened partition wall, the reinforcement effect is good, ensuring the safety of the subsequent construction. The causes of partition wall cracking are found during process of metro station construction, and the solution proposed in this paper is effective. Engineers can refer to this paper to analyze the response of partition wall in the construction of similar structures, which can ensure construction safety and reduce construction cost.

KEYWORDS

Metro station, Partition wall, Force response analysis, FLAC 3D, Construction method

INTRODUCTION

Following unceasing economic development of world, the infrastructure facilities are being quickly built. In the process, metro has become the most important constituent of a city and the development mark, in addition, it has also become one of the important traffic tools for the resident. The construction of metro station often faces underground interleaved pipelines or pipe packs, for facilitating the construction of metro station, these pipelines or pipe packs need to be moved and restructured. However, a long move time will affect the construction period of metro station, therefore, for the avoidance of elongation of construction period, solution measures are necessary. The present usual measure is to divide one station into two parts for construction and two foundation pits are excavated for construction of main structure. In such case, partition facilities are necessary at the separation location for assuring the stability of foundation pit in the excavation process, therefore, it is quite necessary to carry out a force response analysis for the separation location of metro station.

On basis of the site environment of Chengdu metro station, XU utilized FLAC difference software to carry out a simulative calculation for the surrounding structure of station and the excavation of foundation pit, analyzed the reasonable insertion depth of the surrounding pile in the stratum of expansion soil and the changes of the increment of axial force of lateral bracing , the maximum pile movement and the displacement of pile end against expansion force, in addition, raised the measures for assuring the stability of surrounding structure [1]. ZHANG used FLAC 3D software to simulate the deformation of the surrounding structure of open-excavation metro station under force, carried out a comparison analysis for the calculation results and the site monitoring data and made the following conclusions: Following the increase of the diameter of the surrounding pile, the horizontal of pile body apparently reduces. However, overlarge diameter of surrounding pile is not apparently helpful for controlling the deformation of pile body [2]. For the special geological and geomorphic features in Nanning region, CHEN analyzed and investigated the deformation of various tiers of side slope and surrounding structure. The result shows that, if a bracing is used at pile top or not greatly affects the stability of pile, it is not suitable to apply cantilever pile as surrounding structure, due to the effect of the excavation of deep foundation pit, self-support structure, gravity stress and expansion properties of rock mass, horizontal deformation and vertical upheaval with different degrees appear on the top and face of various tiers of side slope [3]. A case study of interaction between a monitored deep excavation and existing buildings is presented by MOHAMED [4]. And the set of measurements obtained with different monitoring devices have been compared with the 3D numerical analysis using a finite difference code in which the dewatering is taken into account through an uncoupled flow-mechanical calculation. A good agreement is observed between the numerical results and the monitoring data. Short remarks regarding the prediction of the excavation behaviour by means of 2D compared to 3D numerical analysis results are briefly issued. An advanced finite element analysis model was developed to simulate the dynamic interactions among the soil, partition walls, and subway station by considering different connection modes for the diaphragm wall and sidewall and the effect of the initial static stress by ZHUANG [5]. The results show that the existence of diaphragm wall will strengthen the lateral stiffness and reduce the lateral deformation of underground subway station, however, in some cases, it is not entirely for preventing a seismic damage in the underground subway station. This paper presents a comparison between the diaphragm wall movements from FEM analysis predictions and field measurements for two projects by TEPARAKSA [6], the new Bank of Thailand head office and the Rosewood Hotel, which were constructed with different techniques. The predicted movement agreed well with the field measurements.

This paper took a three-floor metro station as the background and the surrounding structure of the station applied partition wall. The station passes electric power pipe rack, for avoiding the effect on construction period, the partition wall was built in the middle of station. In combination with actual engineering situations and monitoring data, the paper carried out a force response analysis for the partition wall in the construction. In addition, finite element software FLAC 3D [7,8] was used to simulate force response of partition wall. Then, the reasons of partition wall cracking and displacement are analyzed by finite element simulation and measurement data. Finally, the paper proposed corresponding solutions for the force status of the partition wall, which can provide a reference for the subsequent similar situations.

PROJECT DESCRIPTION

Main structure

The paper takes a three-floor station of a metro project as the background, the station was designed as three-story, one-island and one-side type, which can transfer train with the existing stations. The main structure of the station is 163.25m long, the standard segment is 31.35m wide, the island-type platform is 13m wide, the side-type platform is 4m wide, the standard segment is 26.85m deep and the end well is 29.39m deep. Furthermore, the partition wall is 31.35m long, 1m wide and 26.85m deep.

Enclosure structure

The enclosure structure of the station applied a system combining partition wall and internal bracing. Between the station and the existing stations, partition wall with 600 mm thick was applied, the enclosure structures in other segments applied partition wall with 1000 mm thick. I-steel connection with excellent watertight effect was used. The deformation of foundation pit and the environment protection level of the project were considered as level one. The total plane enclosure length of the partition walls was 395.874m, the standard length of wall segment was 6m (partially 5m), 69 segments were divided for constructed. The first and the fourth internal bracing applied reinforced concrete bracing, the second, the third, the fifth and the sixth internal bracing applied steel bracing.

Engineering background

Affected by the move & reconstruction construction period of electric power pipe rack, the partition wall used for the main foundation pit of the metro station was hard to be closed as scheduled, therefore, it was necessary to add underground continual partition wall at electric power pipe rack. The location of the partition wall is shown in the following Figure 1 and Figure 2. Concrete bracing and steel bracing were applied inside the station. In the east to the partition wall, partial structures had been done, only the first concrete bracing and the second steel bracing were left for construction in site. The first concrete bracing was 1.5m below ground, the second steel bracing was 6.5m below ground, the medium plate in the negative one floor was being constructed, the height was 9m below ground; due to electric power pipe rack, in the west to the partition wall, one segment of partition wall was respectively left for construction on the south and north side, therefore, the east and west side of the partition wall were constructed simultaneously. In the construction process of the partition wall west to the partition wall, channel-forming disturbance and running of large equipment brought large side pressure for the partition wall, caused such defects of the partition wall as cracking and deformation, which left large hidden safety hazards to the east structure.

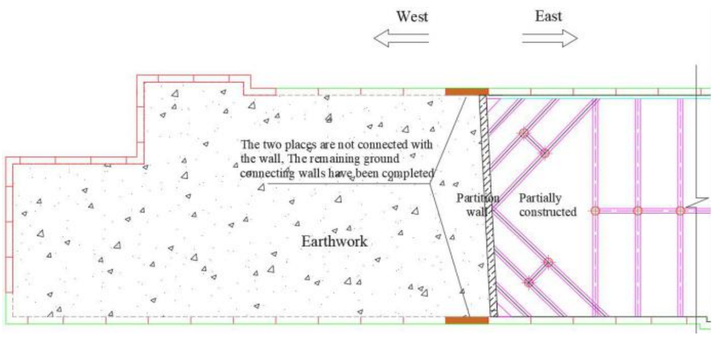

Fig. 1 - Position of underground continuous partition wall

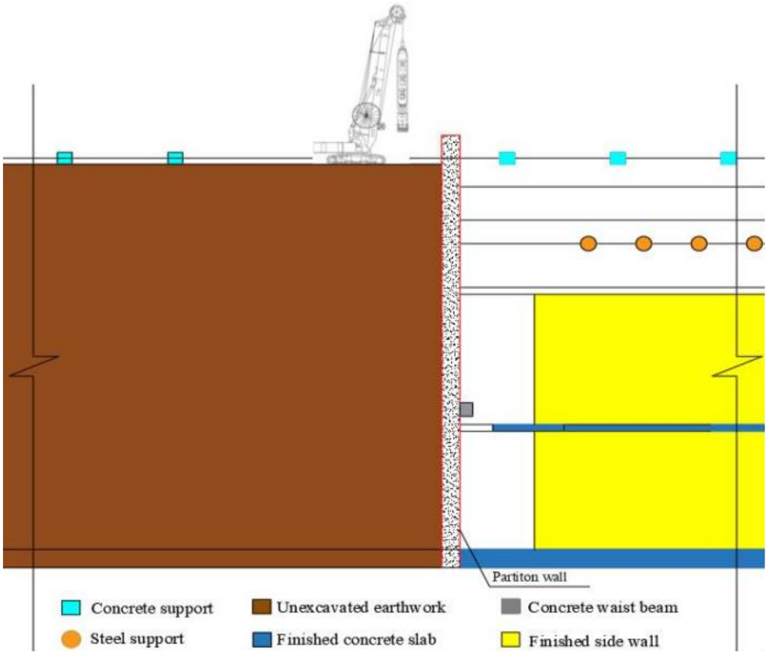

Fig. 2 - Longitudinal section of metro station

According to actual site progress, in the west to the underground continual partition wall, the remained partition wall was being constructed, the method of forming channel by hydraulic grab was applied. In the east to the underground continual partition wall, the reinforced bar used for the medium plate of negative one floor was being bound, within 10m below the first steel bracing, there was not a structure supporting to the partition wall. In the construction of the remained partition wall, apparent crack appeared in the partition wall, the sketch map on the location of crack is shown in Figure 3.

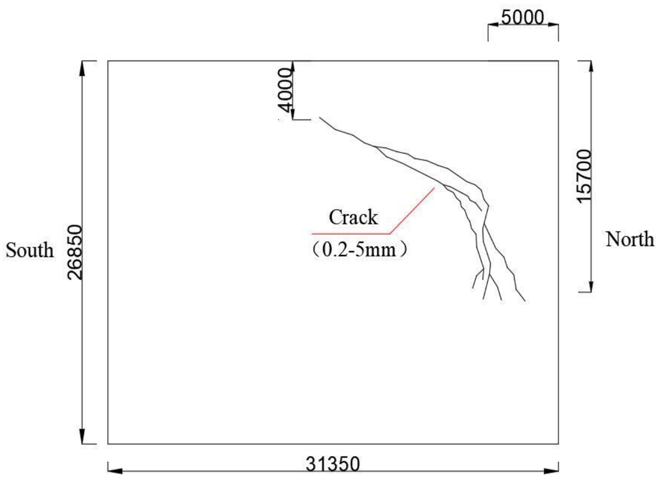

Fig. 3 - Position of crack on the partition wall

Figure 3 shows that the crack appeared at the location 5m to the north partition wall and 4~15.7m below ground. The following four main reasons were analyzed:

(1) In the west to the partition wall, partition wall was being built, hydraulic grab channel-forming method was used, the disturbance caused by the slurry inside channel and hydraulic grab generated a large side pressure on the partition wall;

(2) In the west to the partition wall, the secondary backfill of the old electric power pipe rack was not dense, slurry oozed and caused a large water pressure to the partition wall;

(3) The use of such large machineries as hydraulic grab in the construction of partition wall generated a large eccentric pressure on the partition wall;

(4) In the east to the partition wall and within the scope of 10m below the first steel bracing, there was not a structure, therefore, the lateral force at the partition wall was hard to effectively transmit to the main structure.

As mentioned above, the eccentric force undertaken by the partition wall within the scope exceeded the standard anti-crack value of wall, many cracks appeared [9,10]. Therefore, it is quite necessary to investigate the effect of the construction of the partition wall in the west to the partition wall on the partition wall.

PARTITION WALL MODEL

In order to further analyze the force at the partition wall, the paper utilized finite element software FLAC 3D for simulating the force at the partition wall, elastomer model was adopted. The concrete strength grade is C35, the volume modulus of material was 1.75×10^4MPa, the shear modulus was 1.3125×10^4MPa, the elasticity modulus was 3.15×10^4MPa, the poisson ratio was 0.2, the constitutive relation adopted multilinear intensification model; the elasticity modulus of load-bearing reinforced bar used 2.05×10^5MPa, the constitutive relation adopted bilinear isotropic intensification model. The model applied Kinematic Hardening Criterion and Mises Yield Criterion with isotropic intensification [11]. In the division of entity grid, hexahedron was applied. Between common reinforcement and concrete, node was used for coupling, the slippage between reinforcement and concrete was not considered. For the four corners at the bottom of the partition wall, XYZ direction was restrained; for the four corners at the top of the partition wall, XY direction was restrained. The division on model grid is shown in the following Figure 4.

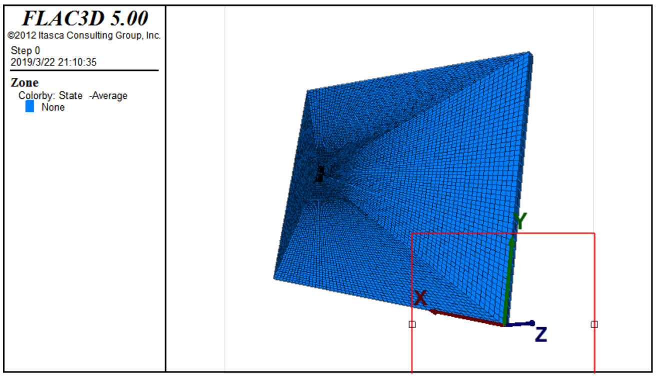

Fig. 4 - Partition wall model

ANALYSIS FOR MONITORING DATA AND MODEL

In case of a defect in construction site, it is quite important to seek for the reasons, effects and formulate the solutions. As mentioned previously, the cracking reasons of the partition wall in the metro station were introduced and a force model was established, in order to further analyze the effect of the crack on the station, the paper analyzed the monitoring data and the data calculated on basis of the model, defined the location with the largest force at the partition wall, analyzed its effect on the station, simultaneously, raised corresponding solutions for subsequent construction [12].

Analysis for monitoring data

Location of monitoring point

In consideration of risk, 14 monitoring points were arranged at the partition wall, the monitored data included horizontal displacement of wall(ZQT), surface settlement(DBC), groundwater level(DSW), supporting axial force(ZCL), vertical displacement of wall top(ZQC) and horizontal displacement of wall top(ZQS), etc. The locations of the monitoring points are shown in the following Figure 5.

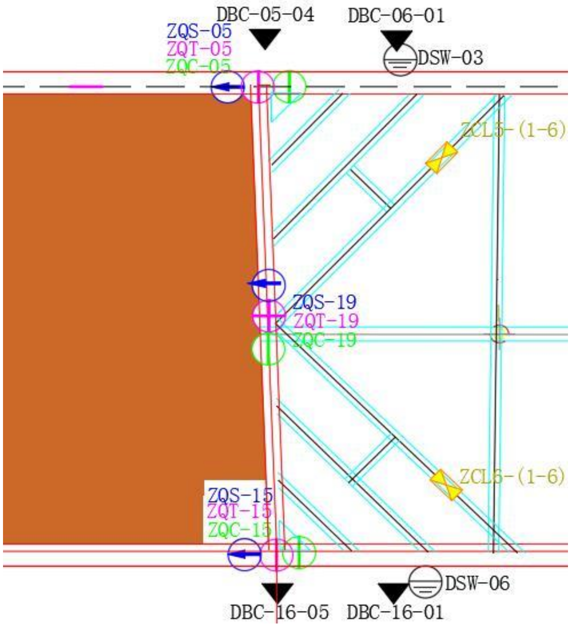

Fig. 5 - Position of monitoring points

Analysis for the data of the monitoring point

By analyzing, it is intuitively reflected that the data of all monitoring points are the horizontal displacement of the partition wall. Taking the monitoring point ZQT-19 as an example, these data were collected, the monitoring data half a month before and after a crack appeared in the partition wall were selected for drafting the curve of time-horizontal displacement on partition wall, as shown in Figure 6.

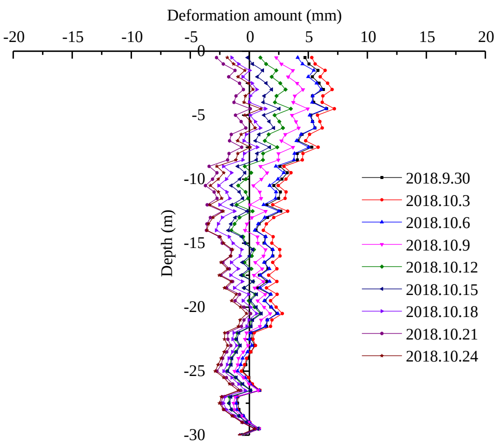

Fig. 6 - Curve of Time-Horizontal displacement on partition wall

By analyzing the curve of time-horizontal displacement on partition wall, the following conclusions may be made:

(1) Following the continual increase of the burial depth of the partition wall, the deformation of the partition wall generated by external force becomes more and more small, main reasons: the bottom plate had been built, the partition wall had been linked with the bottom and inlaid into earth mass, therefore, the lower deformation is small.

(2) The deformation of the underground continual partition wall is small, even at the time of cracking of the partition wall, the maximum deformation is only 5mm, this shows that the stiffness of the partition wall is large, the deformation caused by external force is small and the self-stability is powerful.

Model analysis

Through the above analysis on the monitored data, it is found that the stiffness of the underground continual partition wall is large and the self-stability is powerful. However, in the construction process of the adjacent partition wall west to the partition wall, crack appeared in the partition wall, this phenomenon shows that possible stress concentration occurred. Because the data could not be effectively monitored, finite element model was used to carry out a simulated force response analysis, seek for the most unfavourable force-bearing location, so as to raise corresponding solutions timely [13,14].

After a model was established, data analysis and calculation were carried out. After the displacement deformation attained by model calculation and the displacement deformation attained by monitoring were compared, as shown in Figure 7 and Table 1.

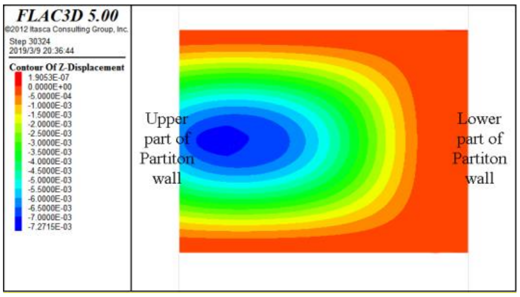

Fig. 7 - Cloud diagram of displacement deformation

Tab. 1 - Comparison between model data and monitoring data

Displacement deformation (mm)	Depth of foundation pit (m)						
	-1	-5	-10	-15	-20	-25	-30
monitoring data f_t	5.58	7.21	4.49	2.58	1.92	0.67	0.57
model data f	5.72	7.27	4.86	2.96	1.95	0.73	0.62
DR	2.51%	0.83%	8.24%	14.73%	1.56%	8.96%	8.77%

DR=difference ratio= $(f - f_t)/ f_t$

It is found that the error between both is smaller than 15%, the result shows that the model is correct. Subsequently, the model calculation results were used to output positive stress cloud picture in YY direction, as shown in Figure 8.

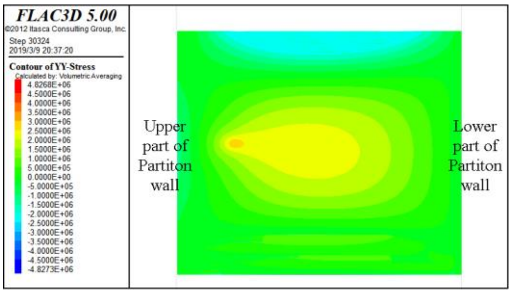

Fig. 8 - Cloud diagram of positive stress in YY direction

The following conclusions may be made after the cloud diagram of positive stress in YY direction is analyzed:

(1) At the orange yellow location of the above figure, the partition wall cracks, it shows that the stress in the area is large and reaches 1.81MPa in the stress cloud picture. According to ***Concrete Structure Design Specification GB 50010-2010***, the designed tensile strength of C35 concrete is 1.57MPa, the force borne by the concrete in the area is larger than the design strength, therefore, crack appeared on the surface of the partition wall.

(2) For the blue area in the stress cloud picture, i.e. the area linking the partition wall and the north partition wall, the force is large and reaches 2.03MPa, the data shows that such area has overlarge force, it is possible that a large crack occurred, therefore, it is necessary to take timely measures for consolidating the partition wall for assuring the safety of subsequent construction.

TREATMENT MEASURES AND RESULTS

Treatment measures

Through the above calculation analysis on the monitored data of the partition wall and the finite element model, it was found that the stiffness of the partition wall is large and the self-stability is powerful. However, stress concentration appeared inside and caused crack of the partition wall in the stress concentration area. For assuring the safety of subsequent construction, the following measures were proposed:

(1) When it was found that the partition wall cracked, the construction of the partition wall west to the partition wall was paused immediately, so as to avoid a larger impact force that might extend the cracks.

(2) Because the medium plate in the negative second floor east to the partition wall was not directly built to the partition wall, steel bracing would be increased between the medium plate in the negative second floor and the partition wall, the interval is 2m, so as to assure that the pressure was transferred by the partition wall to the main structure;

(3) Quickening the construction of the medium plate in the negative first floor until the partition wall, so as to bear partial pressure exerted to the partition wall.

Results

After the above treatment measures were taken to strengthen the partition wall. The model of partition wall was established again, and cloud diagram of positive stress was obtained, as shown in Figure 9.

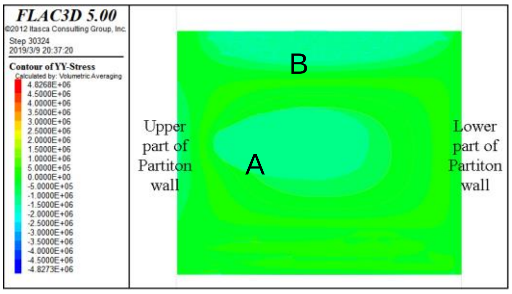

Fig. 9 - Cloud diagram of positive stress in YY direction after taking measures

The stress at the maximum stress point of the partition wall before and after reinforcement (i.e. A and B points in the figure above) were compared, and the data was shown in *Table* 2.

Tab.- 2 Stress comparison of A and B before and after reinforcement

Stress (MPa)	Before reinforcement	After reinforcement
A	1.81	0.56
B	2.03	0.69

The following conclusions can be obtained from the data analysis in the above table:

(1) The stress at point A reached 1.81MPa before reinforcement, and the design strength of concrete has been exceeded and cracks have been produced. After reinforcement, the stress in this area was reduced to 0.56MPa. This shows that the cracks in this area have been effectively controlled and will not continue to expand, so subsequent construction can be carried out.

(2) The stress at point B reached 2.03MPa before reinforcement, and it is connected by the ground connecting wall on the north side, so it cannot be observed directly. There may be large cracks in this area. After reinforcement, the stress in this area was reduced to 0.69MPa. This value is less than the design strength of concrete specified in the code, which indicates that the area has reached the safety index after reinforcement and can be used for subsequent construction tasks.

CONCLUSIONS

The paper took a three-floor station of a metro project as the background, in combination with the engineering practices that the partition wall to be used in the project cracked in the construction of other partition walls, analyzed the monitoring data on the partition wall, utilized the finite element software FLAC 3D for simulating the force at the partition wall, subsequently, proposed corresponding solutions on basis of the force borne by the partition wall, made the following conclusions:

(1) The stiffness and self-stability of the partition wall in the station is powerful, the stress concentration appeared on the central area and caused cracks of the partition wall;

(2) Reducing the pressure exerted on the partition wall and shifting partial pressure exerted on the partition wall by the construction of the medium plate can solve the stress concentration problem.

(3) Through the data analysis of the strengthened partition wall, the reinforcement effect is good, ensuring the safety of the subsequent construction, and guiding the relevant construction work.

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