Journal of Theoretical and Applied Information Technology
30th November 2012. Vol. 45 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

THREE-DIMENSIONAL NUMERICAL ANALYSIS ON EXCAVATION AND SUPPORT OF DEEP PIT NEAR THE SUBWAY TUNNEL BY COMPUTER SIMULATION TECHNIQUE

[1, 2]DAPENG ZHU, [1]YUNDIAN LIN, [3]ECHUAN YAN

[1]School of Civil Engineering and Architecture, Southwest Petroleum University, Chengdu 610500, Sichuan, China

[2]Key Laboratory of Road & Bridge and Underground Engineering of Gansu Province, Lanzhou Jiaotong University, Lanzhou 730070, Gansu, China

[3]Faculty of Engineering, China University of Geosciences (Wuhan), Wuhan 430074, Hubei, China

ABSTRACT

Computer simulation technique was an effective method to analyze the influence of pit excavation on the stress-strain of soil around pit. Based on ANSYS and FLAC simulation software, in order to ensure the safety of building and subway tunnel nearby the pit excavation, the processes of excavation and support of deep foundation pit were simulated by the finite difference method, this paper obtained stress and deformation characteristics of the soil around pit and underground structures such as subway tunnel. The results showed that the method reflected interaction effects of retaining structure and soil in excavation process, and it could predict stress-strain and stability accurately when the pit was excavated to the designed depth. The study provided a scientific basis for pit design and safety assessment of pit excavation near the subway tunnel.

Keywords: *Excavation, 3-D Simulation Analysis, Subway, Pit Deformation, Support Structure*

1. INTRODUCTION

With the rapid development of urbanization, some high-rise buildings and underground space were developed and utilized, so foundation pit had become one of the main geotechnical engineering in city [1, 3]. Due to the site limitations, the foundation pit with the support system had become more and more popular, deformation even failure of buildings surrounding the pit was one of the multiple engineering accidents in recent years [4, 5].

Rock and soil could be seen as a half-space infinite mass with complex stress-strain relationship [6, 8]. Before the pit excavation, the rock mass kept a relative equilibrium states, and the existed equilibrium was broken because of excavation, and stress field will be changed within a certain range of soil until it reached a new equilibrium state [9, 11].

In the two changed equilibrium processes， a slip deformation and stress variation occurred on the soil， so it affected the near building, and especially for underground structures (such as subway tunnel). However, now the studies that how pit excavation effects the nearby subway tunnel is fewer.

In order to ensure the safety of the deep foundation pit excavation, the building and its nearby subway tunnel during pit excavation, the processes of excavation and support were simulated by ANSYS and FLAC software, stress and deformation characteristics of the soil around pit and underground structures such as subway tunnel were obtained, it provided a strong basis optimization for designing and safety assessment of the subway tunnel near the pit.

2. OVERVIEW ON DEEP PIT PROJECT

The deep foundation pit is in the south of the Tianfu Square and the north of the mosque in Chengdu, the total construction area is 64161 m^2 which includes ground floor area of 38239 m^2 and underground construction area of 25921 m^2. Stories of building over and in the ground are 5 and 4 floors respectively.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The local part of a building over the ground is the large span cantilever, and the local part in the ground is at the top of the subway. The average depth of excavation pit is -25.4m, and the base of the structure is an isolation system.

The total supporting structure of foundation pit is the pile-anchor composite structure, and west side of the slope supporting system is double pile with diameter 1m and space of 2m×4m，and other sides of supporting system is single pile with diameter 1m and space of 2m (see Figure 1). Anchor cable support system is located between the piles and anchoring force passed to pile by steel beams.

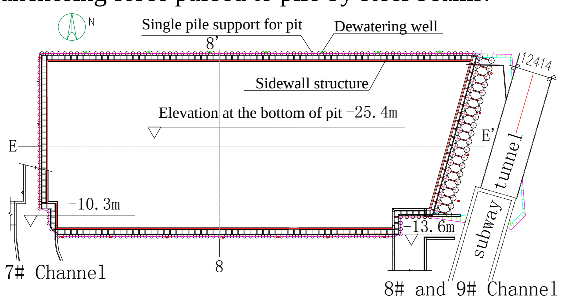

Figure 1: Floor Plan Of Supporting Structure Of Foundation Pit

The engineering has the following characteristics.

(1)The condition of on-site construction is relatively poor. The construction site is located in the core area of Chengdu and near Tianfu Square, three sides of the pit are the main city's thoroughfares and the other side is close to dense buildings of the Xiaohe Street.

(2)The environment surrounding the deep foundation is complex and the subway passed near deep pit. The distance between the excavation location and the nearest tunnel is only 12m, and the supporting piles margin and the nearest subway tunnel is 5m.

(3)The supporting structure of the deep pit engineering is different from the ordinary temporary support structure, but as part of the building maintenance infrastructure, so it is permanent structure.

3. COMPUTER SIMULATION TECHNIQUE

3.1 Introduction Of Ansys And Flac

ANSYS is a general finite element modeling package for numerically solving a wide variety of mechanical problems. The software allows researchers to construct models of structures, stratum medium, and it apply operating loads and study physical responses, such as stress, pressure, etc. It permits an evaluation of a design without having to build and destroy multiple prototypes in testing.

FLAC is a general-purpose code that can simulate a full range of nonlinear static and dynamic mechanical problems, with coupled fluid flow, heat flow and structural interaction. Any geometry can be represented, and the boundary conditions are quite general. FLAC simulates the behavior of nonlinear continua by the generalized finite difference method.

Computer simulation technique on deep pit includes two steps. Firstly, based on the ANSYS platform and geotechnical distribution characteristics of site, finite element model containing geological interface was established, and the model was mainly composed by tetrahedral element. Second, ANSYS model was imported the FLAC software.

3.2 Calculation Model

X-axis and Z-axis were toward the east and south direction, and Z-axis was upward vertically, stratum medium is the layer of miscellaneous fill and loose gravel, slightly dense gravel layer, medium dense gravel layer, dense gravel layer and the weathered mud rock layer from top to bottom. The length of model along X-axis, Z-axis and Y-axis is 500m, 300m and 75.4m respectively. The computational model includes he south mosque and Xiaohe Street dense buildings.

Taking into account the calculation accuracy, grid of the excavation and the subway tunnel (radius 6m) area is encrypted, the grid outside excavation area is relatively coarse, and the ANSYS model was composed of 39659 nodes, 194 grids.

21392 structural units including piles, beams and cables were joined when ANSYS model was imported into the FLAC software, and at last the simulation analysis of excavation and supporting realized. Grids of computing model were shown in Figure 2.

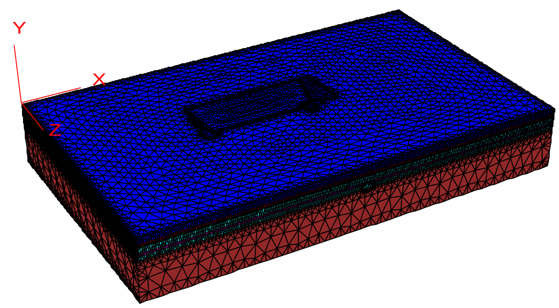

Figure 2: Grid Mesh Chart

Journal of Theoretical and Applied Information Technology
30th November 2012. Vol. 45 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

3.3 Boundary Conditions

The ground was set to be free boundary, the deformation in all directions was allowed. Displacement in X-direction was constrained on the boundary of X=0m and x=500m, and also displacement in Z-direction was constrained on the boundary of Z=0m and Z=300m, the bottom (Y=-75.4m) of the model was the fixed constraint boundary in all directions, so the displacement was zero. For shallow soil, the initial stress field could be considered by the gravity stress, the influence of tectonic stress was ignored.

3.4 Selection On Calculation Parameters

Computational model included the zone units and structural units, and geotechnical materials were considered to be the Mohr-Coulomb material. Model consists of the six kinds materials. Geotechnical material parameters were shown in table 1, the calculation parameters about concrete and rebar, channel were selected based on the specifications.

（1）Remove the non-soil units, and impose the displacement boundary conditions and gravity loads, and calculate the initial stress field.

（2）Remove the soil unit within the scope of the subway tunnel excavation, and implementation the equivalent supporting structure of the subway tunnel, and solve the model to reach equilibrium

（3）Impose pile ahead, and implement the first excavation, remove the soil units within first excavation.

（4）Add the first layer of surface units and the anchor cable unit, and solve the model to reach equilibrium.

（5）Repeat the above step 3 and step 4 until a maximum excavation depth reaches -25.4m.

Table I: Geotechnical Material Parameters

Order	1	2	3	4	5	6
Stratum	Miscellaneous fill	loose gravel	slightly dense gravel	medium dense gravel	dense gravel	weathered mud rock
Density ρ ($10^3 kg/m^3$)	1.75	2.00	2.10	2.15	2.20	2.30
Deformation modulus E_0 (MPa)	30	40	50	60	70	500
Poisson's ratio μ	0.35	0.30	0.28	0.25	0.22	0.30
internal friction Angle φ (°)	9.0	32.0	38.0	43.0	45.0	35.0
internal friction force c (MPa)	0.01	0	0.0	0.0	0.0	0.3
Tensile strength σ_t (MPa)	0	0	0	0	0	0.1

Because foundation pit has been precipitation before excavation and it didn’t taken into account the effect of groundwater. In order to save paper space, only the stress and deformation characteristics of a maximum depth were analyzed.

4. RESULTS ANALYSIS

4.1 Deformation Of Soil Around Pit And Tunnel

Figure 3 showed the three-dimensional total displacement after pit was excavated to -25.4m.the displacement increased because of unloading excavation. Bomb deformation mainly occurred inner the pit, and uplift phenomenon at the bottom of the pit was about 3.844cm.

Surface morphology of displacement can be regarded as a series of the same minor axes oval. Compared to the previous excavation step, the range of deformation parallel to the long axis outside pit expands further. The range of deformation which was more than 1 cm (green narrow bands) at the central part of long axis increases further.

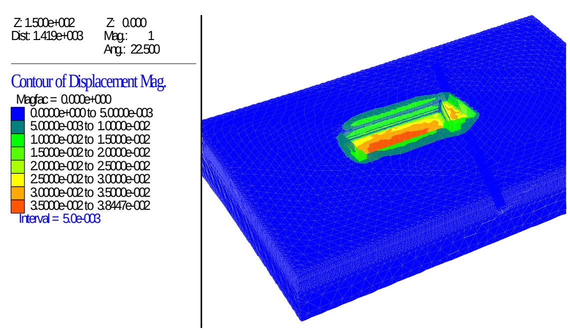

Figure 3: Three-Dimensional Displacement Graph Of Pit (Unit: M)

Figure 4 and Figure 5 showed the displacement graph of the main 8-8' cross section perpendicular to the long axis and E-E longitudinal section perpendicular to the short axis. Deformation contour was half-closed oval extending to the top of

Journal of Theoretical and Applied Information Technology
30th November 2012. Vol. 45 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

the pit, and the axis of oval was short side or long side. The displacement in the middle foundation pit was more than in two both sides (footings). Displacement decreased gradually from the bottom down.

Figure 6 showed total three-dimensional displacement of spray layer. The displacement in east spray was more than other sides, due to the obvious constraint role of cross-angle in each direction, so the displacement at southwest and northwest corner was smaller than at the middle part. The Z displacement of the south and north sprayed layer was greater than of the eastern and western, the X displacement of the eastern and western sprayed layer was greater than of the south and north.

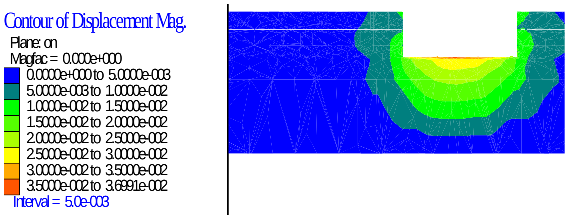

Figure 4: Displacement Graph Of 8-8' Cross Section (Unit: M)

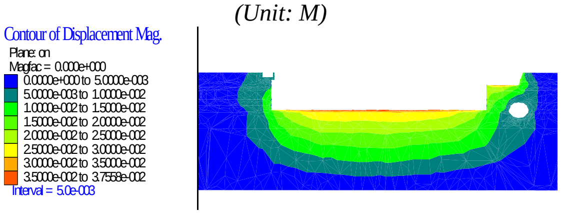

Figure 5: Displacement Of E-E' Longitudinal Section (Unit: M)

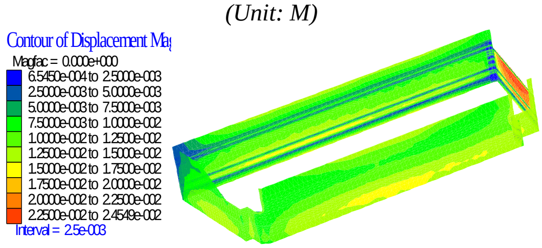

Figure 6:Three-Dimensional Displacement Of Spray Layer (Unit:M)

Figure 7 showed total displacement graph of subway tunnel when pit was excavated to -25.4m.

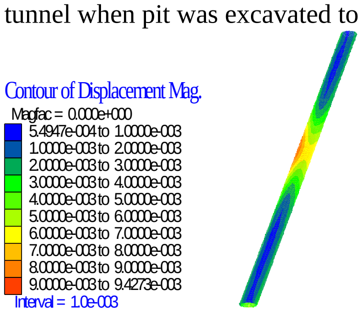

Figure 7: Total Displacement Graph Of Subway Tunnel (Unit: M)

The top deformation of tunnel support structure was about 0.5mm by tunnel itself excavation, but it is about 9mm and approximately 0.07% in the span of 12.5m by pit excavation. Thus, pit excavation affected the deformation of subway tunnel significantly, so we should pay more attention to the pit excavation near subway tunnel.

4.2 Stress Analyses On Soil Around Pit And Tunnel

Figure 8～9 and Figure 10～11 showed the maximum and minimum principal stress distribution of the main 8-8' cross section and E-E longitudinal section, where the positive stress value indicated tension and negative stress value indicated compression.

The main stress of strata was compressive, surface and sidewall of pit appeared tensile stress, so the range gradually expanded with the excavation depths.

The stress concentration was very obvious at the foot of the slope and around tunnel.

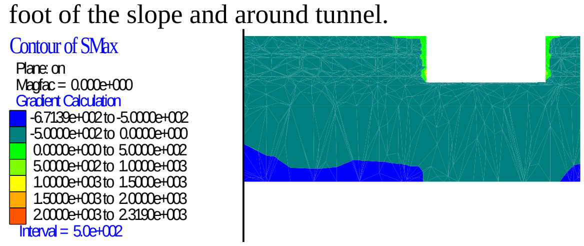

Figure 8:Maximum Principal Stress Of 8-8' Cross Section

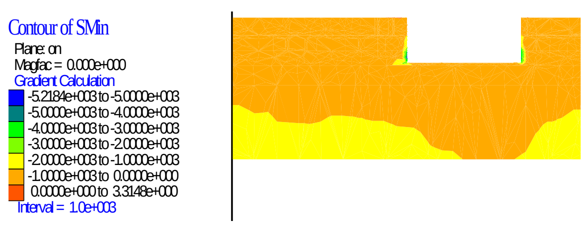

Figure 9:Minimum Principal Stress Of 8-8' Cross Section

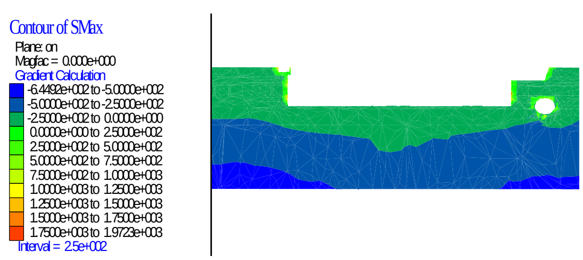

Figure 10: Maximum Principal Stress Of E-E' Longitudinal Section

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

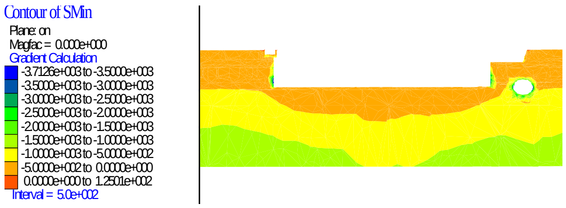

Figure 11: Minimum Principal Stress Of E-E' Longitudinal Section

Figure 12 and Figure 13 showed the maximum and minimum principal stress distribution of subway tunnel. The maximum principal stress was tensile and located at the bottom and top of the tunnel, the maximum tensile stress was $4.1e^3$ kPa, two lateral walls of the tunnel were compressive, and the maximum was $2.5e^3$kPa, and the minimum principal stress was also compressive.

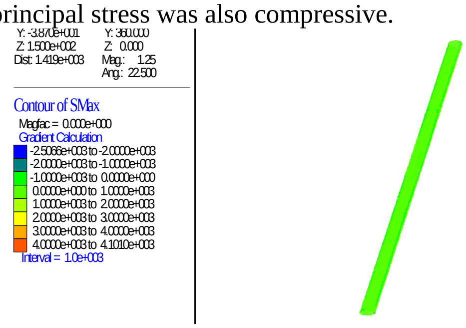

Figure 12: Maximum Principal Stress Of Tunnel Support Structure

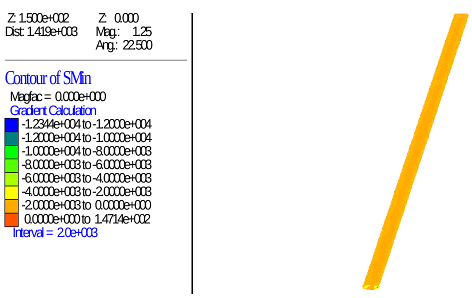

Figure 13: Minimum Principal Stress Of Tunnel Support Structure

4.3 Analyses On Failure Mode

Figure 14 showed the 3D plastic zone distribution, and Figure 15 showed the 3D shear strain increment.

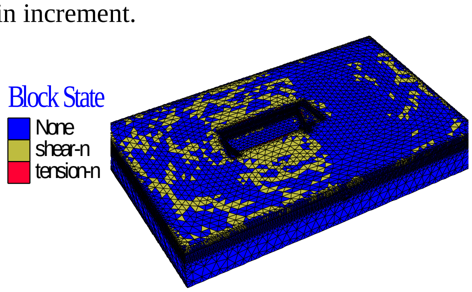

Figure 14: 3D Plastic Zone Distribution Of Pit

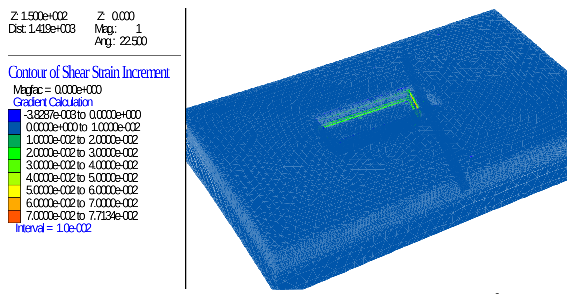

Figure 15: 3D Shear Strain Increment Of Pit

The shear and tension yield deformation appeared around the pit outside. Compared to the previous step excavation depth of 21m, the shear yield zone increased at the eastern side and tensional yield zone of ground outside pit significantly.

Shear strain increment of E-E ' longitudinal profile is greater than 8-8' cross section (Figure 16 and Figure 17). Compared to the previous step excavation, the shear strain increment increased significantly on foot of slope and at the central parts of lateral wall, and it appeared three rectangular strips with the same symmetry axis.

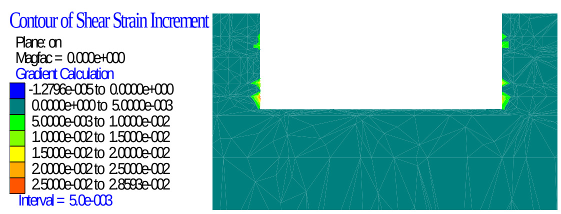

Figure 16: Shear Strain Increment Of 8-8' Cross Section

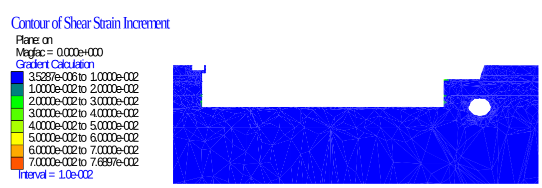

Figure 17: Shear Strain Increment Of E-E' Longitudinal Section

5. CONCLUSION

(1)Based on ANSYS and FLAC software, the three-dimensional finite difference model of foundation pit was established, and the model could truly reflect the excavation process of retaining structure and soil interaction effects, and it also could predict stress-strain characteristics accurately when the pit was excavated to the designed depth.

(2)Three-dimensional numerical calculation could reflect the changes in stability of foundation pit accurately. Soil outside the pit occurred shear yielding and the tension yield deformation mainly in shallow. Three rectangular strips appeared on foot of the slope and the central parts of the lateral wall from the three-dimensional shear strain diagram. The plastic zone and the shear strain didn't yet fully pass through, so the stability of foundation pit was good.

(3)Three-dimensional numerical calculation could reflect deformation variation of foundation accurately. When pit was excavated to the designed elevation, the maximum uplift displacement was about 4cm in the bottom of the pit, and maximum displacement outside the pit was about 1.5cm, and displacement of sprayed layer was about 2.5cm, so the above displacements met the specification requirements. The displacement at the top of support structure was approximately 9mm, and it was relatively small. Displacement of pit outside the north and south side was significantly greater than the east side, so pit construction had influence on the south side of building, and construction should pay close attention to the trend of the deformation of buildings nearby the south side. In addition, pit excavation affected the deformation of subway tunnel significantly, so we should pay more attention to the pit excavation near subway tunnel.

(4) Three-dimensional numerical calculation obtained stress-strain characteristics of the pit and the supporting structure accurately. It was changed the stress state of soil surrounding by pit excavation, when pit was excavated to the designed elevation, the maximum compressive stress of the maximum principal stress on the typical cross section remained unchanged, but the maximum tensile stress increased significantly. The maximum compressive stress of the minimum principal stress on the typical cross section increased significantly, but the maximum tensile stress remained unchanged. Pit excavation increased the maximum tensile and compressive stress of the maximum principal stress of the subway tunnel support structure, and reduced the maximum tensile and compressive stress of the minimum principal stress.

ACKNOWLEDGEMENTS

This work was supported by Open Fund of Key Laboratory of Road & Bridge and Underground Engineering of Gansu Province (Kfjj-11-01), science and technology projects from Ministry of Housing and Urban-rural Development (2012-K3-14) and A Project Supported by Scientific Research Fund of Sichuan Provincial Education Department (10ZA074，12ZA197).

REFRENCES:

[1] W.D. Wang, H.H. Zhu, "Geotechnical engineering and new technology", Chinese Journal of Underground Space and Engineering, Vol. 7, No. z1, 2011, pp. 1274-1291.

[2] Q.H. Pan, Y.M. Yin, "Cause of collapse and treatment for a deep foundation excavation shoring pile", Construction Technology, Vol. 40, No. z1, 2011, pp. 117-119.

[3] S.H. Kim, N. Li, "Interaction behaviours between parallel tunnels in soft ground", Tunneling and Underground Space Technology, Vol. 44, No. 19, 2004, pp. 448-450.

[4] Y. Wang, "The cause and countermeasures for accident at shallow and big foundation pit in Shanghai", Chinese Journal of Underground Space and Engineering,, Vol. 7, No. 3, 2011, pp. 599-603.

[5] T. Li, S.B. Shi, "Constitutive model for unsaturated cohesive soils with a unified yield surface", Journal of Beijing University of Technology, Vol. 37, No. 11, 2011, pp. 1684-1691.

[6] J.W. Zhou, Z.Y. Li, "A new damage model for structured soils", Building Science, Vol. 27, No. 11, 2011, pp. 28-32.

[7] Z.M. Chen, K.M. Ouyang, "Analysis of the Impact of the metro station excavation on the adjacent building", Journal of Lanzhou Jiaotong University, Vol. 28, No. 4, 2009, pp. 25-29.

[8] X. Han, N. Li, "Study on characteristics of structural deformation caused by urban excavation", China Civil Engineering Journal, Vol. 44, No. S1, 2011, pp. 135-142.

[9] W.H. Huang, "Application of wireless adhoc network in monitoring of steel support stress: case study on construction of deep foundation pit of Guangxi University metro station", Tunnel Construction, Vol. 32, No. 4, 2012, pp. 561-565.

[10] Z.C. Cheng, J.P. Miao, "Research on displacement and stresses of soldier pile structure in foundation pit of metro station in Chengdu", Tunnel Construction, Vol. 32, No. 3, 2012, pp. 309-314.

[11] V.M. Ulitskii, S.I. Alekseev, "Preservation of buildings during the installation of foundation pits and the laying of utilities in saint Petersburg", Soil Mechanics and Foundation Engineering, Vol. 39, No. 4, 2002, pp. 133-138.