ISSN:2790-1688 DOI: 10.56028/aetr.4.1.404.2023

Monitoring and Numerical Simulation of Differential Settlement of Widened Roads

Qihua Shen [1, a], Jianhan Hu [1, b], and Xiaochun Zhang [1, c]

[1]School of ITS, Southeast University, Nanjing, China;

[a] sqh13841832590@163.com, [b] hujianhan1997@126.com, [c] zxc01@263.net

Abstract. As the modulus difference exists, road widening is often susceptible to longitudinal cracks at the intersection of the old and new roads, affecting the life of the road and the safety of traffic. For monitoring the differential settlement of the widened road and the creep process of the lower soft soil, a monitoring program is designed and a finite element model is established to figure out the changes in the settlement and earth pressure. Based on the monitoring and numerical simulation, it can be obtained that the settlement difference is comparatively small under 12m mixing pile treatment and the lower soft soil has obvious creep law, which provides a specific case for the usage state of widening road and creep law of soft soil.

Keywords: Road widening; differential settlement; monitoring; numerical simulation.

1. Introduction

The uncoordinated deformation of old and new foundations in widened roads is the primary reason for problems in the road [1]. Most scholars [2,3,4,5] have studied differential settlement of widened roads and proposed several methods for actual projects. Zhu Shaoxun and Yang [6,7] established finite element models of widened road foundations to observe the effects of different treatments. It is found that the enhanced mat structures can reduce lateral uneven settlement effectively [8]. In addition, the total settlement can be reduced by setting PHC pipe piles in soft foundation [9]. There are also many scholars [1,10,11] who use the friction reinforcement effect of geogrid to reduce the uncoordinated deformation of old and new foundations. Although there are many schemes to improve the differential settlement, and differential settlement cannot be eliminated. So it is necessary to monitor the widened road in real real-time

2. Project introduction and monitoring program

2.1 Project Profile

With the acceleration of urbanization and the improvement of the country's economic level, the traffic volume has increased dramatically, and the roads mentioned in the project cannot meet the demand for traffic growth. Moreover, the original road was completed and commissioned during the "8th Five-Year Plan" period, with low design standards, causing the current poor traffic conditions. In this context, the old road needs to be widened to increase the road capacity. However, there is a modulus difference between the old and new subgrade after widening the road. After years of compaction, uneven settlement occurs on the road, which reduces the service life and driving comfort of the road.

Because the project is located in the southern Yangtze River Delta, this inhomogeneous settlement will be more serious. Therefore, the monitoring scheme is designed to ensure the operation status and service life of the road.

2.2 Geological Overview

This project is located in Guangdong Province, with a dense water network and abundant rainfall along the route. The area is mainly distributed with clay, silt, fine sand, and so on. After several

ISSN:2790-1688 DOI: 10.56028/aetr.4.1.404.2023

borehole sampling, the distribution of typical soil layers in this part can be obtained as shown in Table 1. below:

Table 1. Distribution table of typical soil layers.

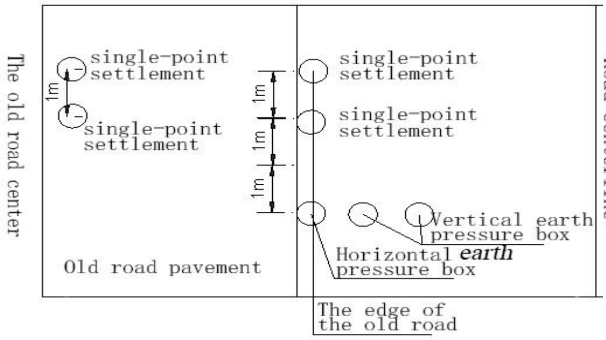
Layer	types	properties	Thickness
surface	Mainly fine sand	with humus	3m
Upper layer	sludge	flow plasticity, with shells	30m
Lower layer	grit	Saturated, dense, with pebbles	10m
bottom	weathered muddy sandstone	Low strength and fragile	

It can be obtained from table 1 that the lower part of the road has a thick layer of soft soil. And the soil has rheological properties, which is prone to produce large settlement under the action of upper load.

2.3 Monitoring scheme

With the thicker soft foundation in the lower part of the project, as well as the relatively large modulus of the old road, uneven settlement will occur at the intersection of the old and new roads. To ensure the operation status of the widened road, a long-term monitoring scheme is designed. The settlement values of -12m and -18m at the center of the old road and at the junction of the road were obtained by using single-point settlement meters. For monitoring the earth pressure, lateral soil pressure boxes and vertical soil pressure boxes are installed as shown in Fig. 2.

The plan layout of the monitoring points is shown in Fig. 1. and the cross-sectional layout is shown in Fig. 2.



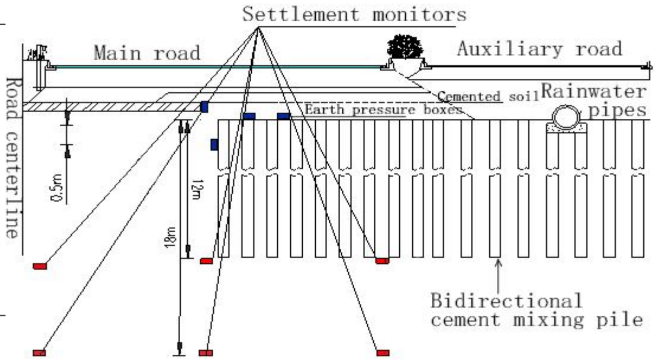


Fig. 1. The plan layout Fig. 2. The cross-sectional layout

3. Monitoring results

3.1 Subsidence monitoring

Based on the above monitoring program, the soft soil settlement values within the lower 12m and 18m can be obtained from the long-term monitoring since the widened road started operation. As the depth is deeper, the soil deformation is smaller, so the measurement data of 18m depth single point sedimentation meter can be approximated as the absolute settlement of soil. Therefore, the differential settlement can be observed visually according to the absolute settlement values of soil. The absolute lateral settlement difference of the widened road is illustrated in Figure 3; The compression amount of deep soft soil can be obtained by subtracting the settlement values of 12m depth from the settlement values of 18m depth, as shown in Figure 4.

As can be seen from Fig. 3., the settlement difference accumulated rapidly within about 120 days of monitoring, accounting for 48% of the total settlement difference. Subsequently, with the growth of time, the settlement difference increases at a smaller rate and the settlement curve stabilized.

It is known from Fig. 4. that the settlement of deep soft soil in the center of the old road and in the edge of the previous road gradually increases with time. However, the growth rate of both curves decreases and flattens out. Comparing the two curves above, it can be seen that the deeper

ISSN:2790-1688 DOI: 10.56028/aetr.4.1.404.2023

soft soils at the edge of the old road had greater settlement early in the monitoring period, but as monitoring days progressed, the compression was much less than in the center of the old road. The settlement rate at the center of the old road is significantly larger than the edge of the old road as time grows, which means the soil properties in the lower part of the old road center are poor.

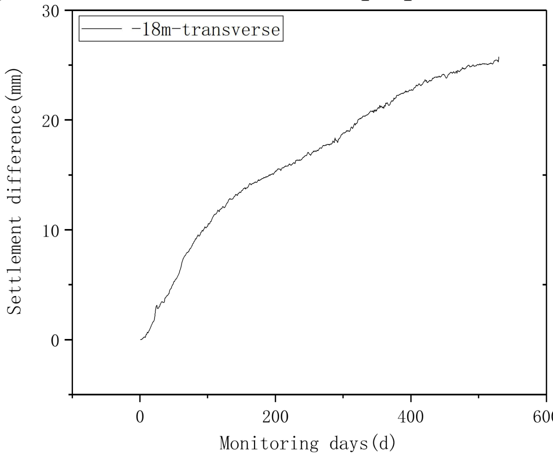


Fig. 3 Transverse absolute settlement difference

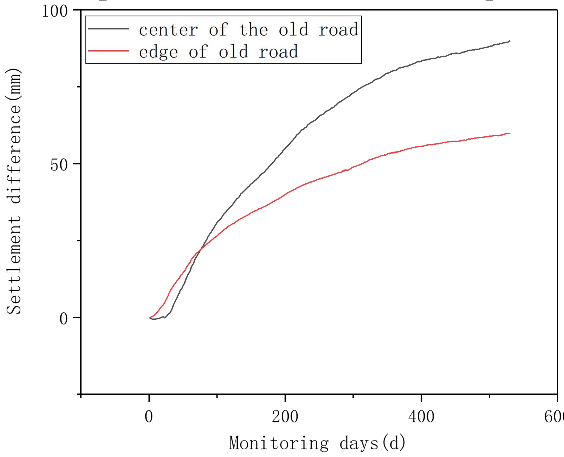


Fig. 4. Deep soft soil compression curve

A histogram was made by intercepting the monitoring data with 170、 340、 and 510 days of monitoring, as shown in Fig. 5. Based on this histogram, it can have a clear understanding of the variation of compression amount with time.

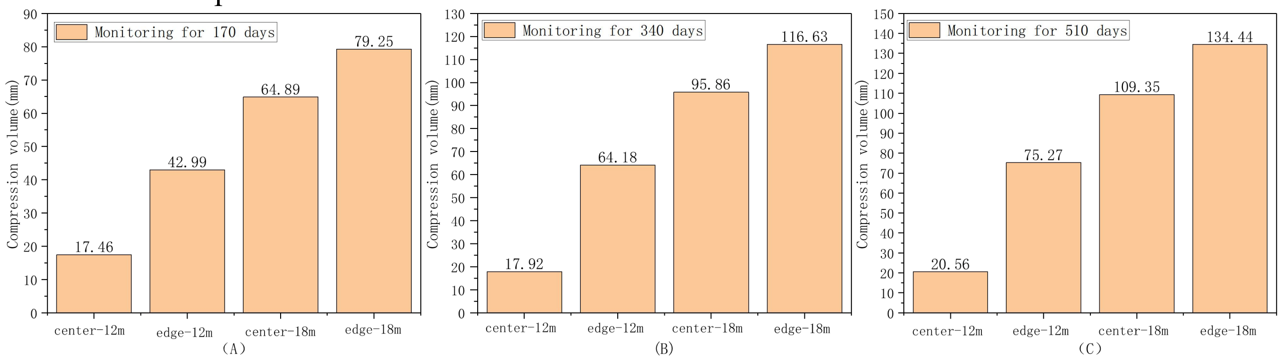


Fig. 5 Cumulative compression volume histogram

According to Fig. 5 (A), it can be seen that after 170 days of monitoring, the edge of the old road has a bigger compression volume than the center of the old road at the same depth. The compression of the deep soft soil at the center of the old road is 47.43mm, which is larger than that of the deep soft soil at the edge of the old road by 36.26mm. In Fig. 5 (B), the compression increased at all four locations, and the compression volume of the deep soft soil at the center of the old road is 77.94mm, while the deep soft soil at the edge of the old road is 52.45mm. Fig. 5 (C) has the same trend as Fig. 5 (A) and Fig. 5 (B). After 510 days of monitoring, compression volume gradually increases. The minimum compression at -12m of the old road center is 20.56mm, and the maximum compression value at -18m of the edge of the old road is 134.4mm.

A lateral comparison of Fig. 5 (A)(B)(C) shows that the absolute settlement becomes smaller with increasing monitoring time for both the center and the edge of the old road, indicating that the settlement tends to be stable.

3.2 Pressure Monitoring

The soil pressure boxes were arranged as shown in Fig. 2 above. And the specific earth pressure is shown in Fig. 6 below.

Fig. 6 contains the lateral soil pressure at the intersection of the old and new roads, the lateral soil pressure on the pile side 0.5m from the top of the stirred pile, the vertical soil pressure on the top of the pile, and the vertical soil pressure between the stirred piles. From this figure, it can be

ISSN:2790-1688 DOI: 10.56028/aetr.4.1.404.2023
seen that the lateral earth pressure increases first, reaches a peak between 120 and 150 days of monitoring, and then decreases at a smaller rate. The vertical earth pressure at the top of the mixed pile roughly follows a decreasing trend, which is below 0.01 MPa. The vertical soil pressure between the stirred piles is much greater than the vertical soil pressure on the pile, indicating that the soil between the stirred piles has a large bearing capacity and the pile foundation plays a favorable reinforcement role.

Fig. 7 presents a histogram of the lateral earth pressures monitored for 0, 50, 100, 150, and 200 days. As shown in Fig. 7, the lateral soil pressure on the pile side is significantly higher. There is a maximum lateral earth pressure at about four to five months of monitoring. After that, the lateral earth pressure decreases at a small rate.

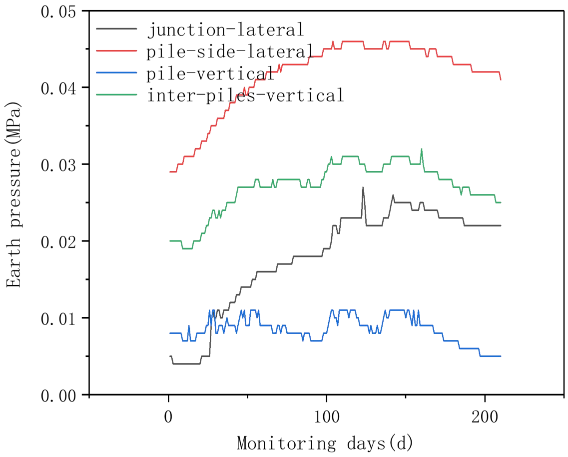


Fig. 6 Vertical and lateral earth pressure.

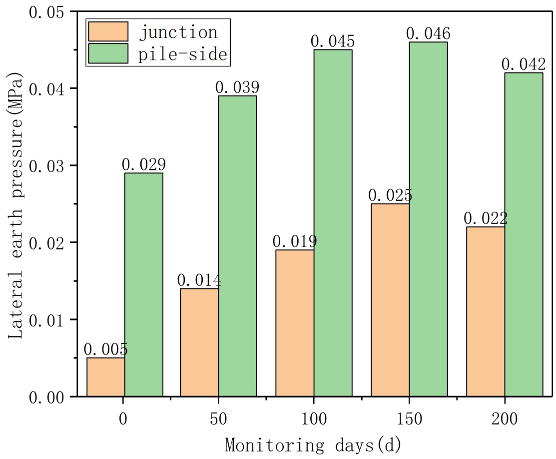


Fig. 7 Lateral earth pressure histogram.

4. Numerical Simulations

4.1 Computational modeling

Field samples were taken from the project area and corresponding tests were conducted to obtain the required parameters for the model. To simplify the model, the modulus of elasticity of the two-dimensional sheet pile is obtained for subsequent calculations using the principle of equivalent stiffness in material mechanics.

$$S = mn\frac{AE}{H} \tag{1}$$

The above equation is the total stiffness of the three-dimensional pile. “m” is the number of rows of transverse piles; “n” means the number of longitudinal piles; “A” means the cross-sectional area of a pile (m2); “E” denotes the elastic modulus of the pile (MPa); “H” is the length of the pile.

$$S^{'} = m\frac{DL}{H}E^{'} \tag{2}$$

The above equation represents the total stiffness of the sheet piles. “D”—the thickness of the plate (m); “L”—the length of the plate; “E'”—the modulus of elasticity of the sheet pile.

The modulus of elasticity E' of the sheet pile can be obtained by making the stiffness before and after conversion equal.

$$E^{'} = E\frac{nA}{DL} \tag{3}$$

From the principle of equivalent stiffness, the parameters of the agitated pile can be obtained. The model material parameters are shown in Table 2. and Table 3. below.

ISSN:2790-1688 DOI: 10.56028/aetr.4.1.404.2023

Table 2. Model material parameter

Structural layer	Thickness (m)	E (MPa)	μ	γ_d (KN/M^3)
Surface	0.18	1400	0.35	24.20
Base	0.54	1000	0.35	23.60
Sub-base	0.24	1500	0.25	23.50
Roadbed fill	0.8	40	0.4	18.50
Pile	—	300	0.3	22.00

Table 3. Drucker-Prager Model Parameter

Material Type	γ_d (KN/M^3)	C (KPa)	φ (°)	E (KPa)	μ	B (°)	k	ψ (°)
Old embankment	18.30	29.30	36.5	50000	0.4	28.7	1.0	28.7
Old earth foundation	18.00	18.30	28.0	22000	0.3	32.0	1.0	32.0
New earth base	17.60	8.00	24.0	10000	0.35	35.3	1.0	35.3

The model is constructed with the actual project 1:1, and it can be considered as a half-width model due to the symmetry of the road. The depth and width of the foundation are 40m to eliminate the effect of boundary conditions. The depth of the old roadbed is 3m, under which is the old soil foundation. The upper part of the old roadbed is covered with 0.8m of compacted fill, followed by 0.24m thick roadbed, 0.54m thick base, and the 0.18m thick surface layer above. In this model, the slope of the embankment is 1:1.5. The specific model dimensions are shown in Fig. 8.

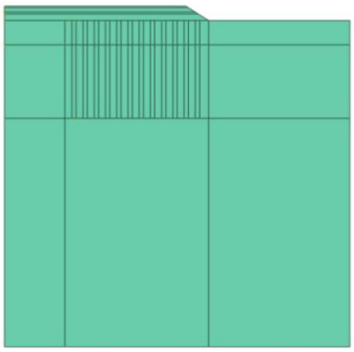


Fig. 8 Model dimension

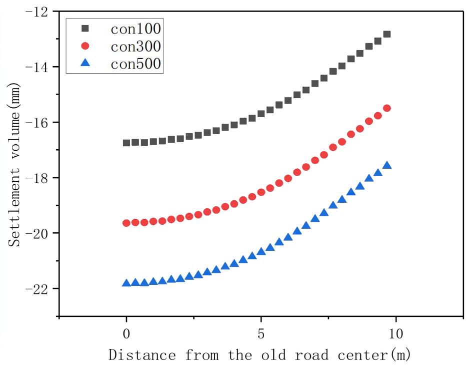


Fig. 9 Road surface settlement curve

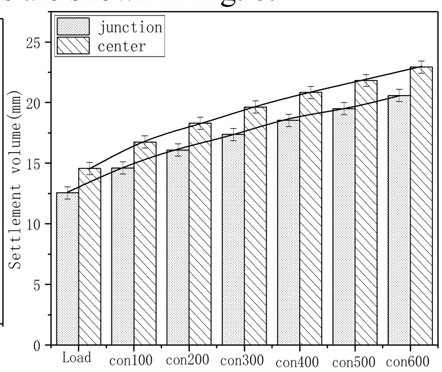


Fig.10 Settlement volume.

The transverse displacement constraint and bending moment constraint are set on the left and right sides of the model, and the bottom is fixed. The lower area of the embankment was balanced for ground stress and then filled and consolidated in layers. After the road is widened, a road traffic load of 13KPa is applied. The soil foundation deforms under the action of superstructure and vehicle loads.

4.2 Simulation results

According to the proposed model, the settlement values and earth pressure values with time can be obtained. Figure 9. presents the settlement value of each point of the pavement. Figure 10. shows settlement histograms at the center of the old road and at the intersection of the old and new roads for different consolidation days. The compression variation of the deep soft soil in the model is shown in Fig. 11. As shown in Fig. 12, The compression of 18m is compared horizontally which gives the difference in absolute settlement between the center of the old road and the edge of the old road. The scatter diagram of soil pressure on the pile side and the old road edge is shown in Fig. 13.

As can be seen from Fig. 9, after a period of consolidation of the widened road, the settlement in the center of the old road is larger than that in the widened area, indicating that the pile foundation plays a controlling role in settlement. Moreover, with the increase of consolidation days, the

ISSN:2790-1688 DOI: 10.56028/aetr.4.1.404.2023
difference in settlement at the intersection of the old and new roads decreases significantly, and the differential settlement is gradually stabilized.

As shown in Fig. 10, the compression volume at the center of the old road and at the edge of the old road increases with time, but the growth rate tends to be flat.

The compression variation curve of the deep soft soil obtained by numerical simulation is shown in Fig. 11. From the figure, it can be seen that the compression of the deep soft soil at the edge of the old road is greater than that of the deep soft soil at the center of the old road. With the increase of consolidation days, the compression volume increase, and the compression rate slows down. Compared with the deep soft soil compression monitoring curve, the deep soft soil compression in the center of the old road in Fig. 11 is smaller than the edge of the old road, but the compression trend is the same, which reflects the creep process of soft soil.

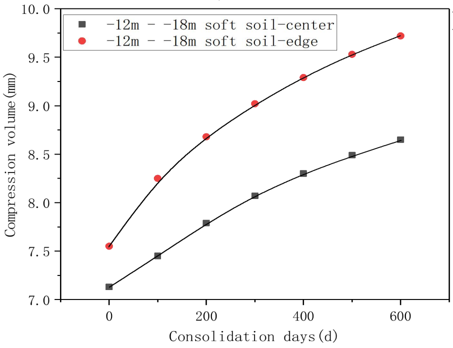


Fig. 11 compression curve

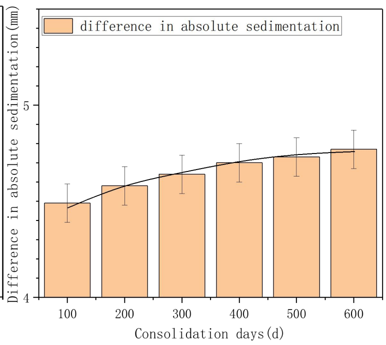


Fig. 12 settlement difference

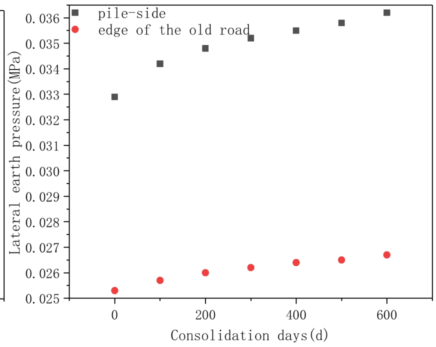


Fig.13. Lateral soil pressure

According to Fig. 12. above, the absolute settlement difference increases as the consolidation days increase, but the rate decreases and the absolute settlement difference is leveling off. Compared with Fig. 3, the monitored settlement difference is 25 mm at maximum, the simulated settlement difference does not exceed 5 mm, and the settlement difference curves have the same trend, indicating that the model has a high degree of credibility.

Fig. 13 shows the lateral soil pressure curve of the lower 0.5m of the mixing pile at the edge of the old road. As shown in Figure 13, the pile-side soil pressure is significantly greater than the lateral soil pressure at the edge of the old road. With the increment of consolidation days, the lateral earth pressure at the edge of the old road gradually increases and does not exceed 0.027 MPa after 600 days of consolidation. The lateral soil pressure on the pile side also increases with the increase of consolidation time, while the rate of increase decreases slowly, and the maximum lateral soil pressure is about 0.036 MPa after 600 d of settlement consolidation. The maximum difference between the simulated and monitored consolidated lateral soil pressure is 0.007 MPa in 200 days, which is about 16.67% of the monitored lateral soil pressure.

5. Results and Analysis

From the monitoring results, it is known that after the road widening is completed and opened to traffic, the lower soft soil has a larger compression volume by the upper load, and the pile side experiences a larger lateral soil pressure. However, the compression volume rate decreases with time and the settling stabilizes. Based on the monitoring results, it can be seen that the absolute settlement difference between the old and new junction and the old road center is less than 30mm, and the road operation condition is better. The change of lateral soil pressure reflects the creeping trend of soft soil laterally. The deformation and the lateral soil pressure of the pile increase at the beginning of monitoring, and after about 4-5 months the soft soil creep stabilizes and the lateral soil pressure decreases.

Equally, a similar pattern of variation can be obtained from the simulation. The amount of settlement becomes smaller as time progresses, with minimal differential settlement in the center of the old road and at the edge of the old road. Deep soft soils also show higher compression in the first four months, while the compression curve is flatter afterwards. The lateral soil pressure on the

ISSN:2790-1688 DOI: 10.56028/aetr.4.1.404.2023

pile side is simultaneously greater than the lateral soil pressure on the old road edge, and with the same magnitude of simulation results and monitoring results, the numerical simulation has high reliability.

6. Conclusion

As the existence of differential settlement of the widened road, the settlement and earth pressure monitoring of the piled widened road was applied to obtain the creep pattern of soft soil and the state of differential settlement of the road. ABAQUS finite element software was used to simulate the widened pavement and obtain the variation of the lower soft soil with consolidation days. The following conclusions can be drawn from monitoring and numerical simulations:

The use of 12m piles in the widened area of the region can effectively enhance the strength of the widened area and reduce the amount of differential settlement between the old and new roads.

The compression of the deep soft soil creep is higher in the early stage but decreases after 4 ~ 5 months and levels off at the end.

According to the monitoring results, the soil pressure on the side of the pile is significantly greater than several other soil pressures, and the piles act as a resistance to the rheological properties of the soft ground.

References

[1] HUANG Qinlong, LING Jianming, TANG Boming, et al. Experimental Research on Incoordinate Deformation Between Existing Subgrade and the Widening One [J]. Journal of Highway and Transportation Research and Development, 2004, (12): 18-21.

[2] CHEN Liangg, TANG Chengyao, LIU Junyong. Common Highway Embankment Hazards and Construction Techniques of Transition Zone between Existing and New Embankments [J]. Soil Engineering and Foundation, 2015, 29(03): 62-5.

[3] GUAN Chencheng. Research and practice of urban road widening and reconstruction [D]; Zhejiang University of Technology, 2017.

[4] WANG Gang, ZHANG Peng. Municipal roads old road widening new and old roadbed deformation coordination comprehensive treatment measures [J]. Communications Science and Technology Heilongjiang, 2020, 43(05): 15-6.

[5] JIANG Chao. Trial analysis of the widening of the road after work differential settlement control standards [J]. China Standardization, 2017, (06): 221.

[6] ZHU Shaoxun. Analysis of Differential Settlement of Widened Road Base under Soft Soil Conditions [J]. Engineering and Technological Research, 2021, 6(06): 90-1.

[7] YANG Zhiwei, YANG Dongxing, JIANG Zhenhua, et al. A new treatment method for differential settlement of widened roads [J]. Shanxi Architecture, 2022, 48(12): 119-22+31.

[8] JIANG Zhenhua, YANG Dongxing, YANG Zhiwei, et al. Analysis on the Control Effect of Enhanced Cushion on the Difference Settlement of New and Old Subgrade in Soft Foundation Area; proceedings of the 8th Annual International Conference on Material Science and Environmental Engineering, MSEE 2020, November 20, 2020 - November 21, 2020, Chengdu, Sichuan, Virtual, China, F, 2021 [C]. IOP Publishing Ltd.

[9] JIANG Rongze, CHEN Xiaoqi, XU Weijia. Technical analysis of PHC pipe pile for soft foundation treatment of road widening project [J]. Shanghai Highways, 2010, (03): 13-7+2.

[10] ZHANG Xiao. Application of geogrid reinforcement in urban road widening project [J]. Engineering Technology and Application, 2017, (03): 86+100.

[11] LU Hongqiang, ZHOU Minghui, ZOU Shuguo. The Application Research of Construction Grille-Bar Used in Road-Widening Engineering [J]. Journal of Shandong Jiaotong Unversity, 2010, 18(03): 62-5+77.