Optimization Design of Deep Foundation Pit Support Scheme under Traffic Dynamic Load

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Abstract. In this paper, based on the deep foundation pit support of the reconstruction and expansion project of Jiqing expressway, numerical software is used to establish the numerical calculation model of the deformation support of deep foundation pit under the influence of traffic dynamic load. The numerical calculation results are consistent with the actual project monitoring results. By changing the support parameters such as pile diameter, pile length, vertical support distance in different support schemes is analyzed. The results show that the ideal diameter of bored pile is 0.8-1.2m, the length of pile is 23m-28m. With the vertical support distance increasing, the change trend of horizontal displacement of piles gradually increases. Considering the safety of foundation pit and the reduction of project cost, the pile with length 23m, diameter 0.8m and the vertical support distance 5m is chosen in the practical engineering.

1. Introduction
With the rapid development of China's economy, the transportation industry is facing opportunities and challenges. At the same time, the substantial increase in vehicle ownership has also led to a sharp increase in road transport volume[1]-[3]. But, the expressways of early construction has now appeared many problems such as lower pavement quality, traffic capacity reduced and lower service level. Now, with the rapid expansion of transportation, the expressway built in advance has been unable to meet the needs of modern society large traffic demand. Therefore, it is the most feasible solution to reconstruct and expand the expressway construction in the early stage. The reconstruction and expansion on the basis of the original expressway can not only improve the transportation capacity, but also reduce the construction cost and the occupancy rate of land resources. The reconstruction and extension project of Jiqing expressway is the first expressway widening project without traffic interruption in Shandong Province. Due to the influence of traffic load during construction, the support of deep foundation pit becomes very important. At present, many scholars have carried out a lot of research work in the field of deep foundation pit support under traffic loads. [4]-[8].

Based on the actual deep foundation pit engineering of Jiqing expressway reconstruction and expansion project, numerical calculation model is established according to the engineering characteristics of deep foundation pit support under traffic dynamic load, which researched the influence of key factors such as pile diameter, pile length and vertical support distance on foundation pit deformation and settlement.
2. Numerical simulation model of foundation pit

2.1. Engineering overview
The length, width and depth of the foundation pit under construction in Jiqing expressway Reconstruction and Expansion Project are 12.4m, 6m and 16.8m respectively. Its support scheme is designed as bored pile with inner support, in which the diameter of the pile is 800mm, the spacing between the piles is 1200mm, and the length of the pile is different. The steel is used in the inner support, whose length and diameter are 6000mm and 140mm respectively, the horizontal spacing is 3000mm and vertical spacing is 5000mm. There are three inner supports located. There is an expressway on one side of the foundation pit and the vehicle is driving normally. The parameters of each soil layer are shown in the table below.

### Table 1. Soil parameters of foundation pit

| Soil Layer     | Thickness /m | Density Kg/m³ | Elastic Modulus MPa | Poisson ratio | Cohesion /kPa | Internal friction angle |
|----------------|--------------|---------------|---------------------|---------------|---------------|------------------------|
| Plain filling  | 1.5          | 1810          | 10                  | 0.43          | 6.4           | 16.5                   |
| Clay           | 5            | 1785          | 18                  | 0.41          | 18.2          | 18.9                   |
| Pebble soil    | 18.4         | 1965          | 23                  | 0.35          | 17.8          | 18.2                   |
| Powder clay    | 12.3         | 1980          | 27                  | 0.37          | 25.8          | 17.5                   |

2.2. Numerical simulation model
According to geological conditions and investigation data of the deep foundation pit, a numerical calculation model is established, which is shown in Figure 1. The length, depth and thickness of the model are 160m, 68m and 2m respectively. The load produced by the traffic vehicle is taken as external force and embedded into the numerical model in the form of additional dynamic load. Bored piles and top beams that are reinforced concrete structures are set as solid element in the numerical model. Steel supports are set as structural element. The excavation steps in the numerical model are divided into 5 steps from top to bottom.

### Table 2. Supporting schemes

| Scheme | Diameter /m | Distance /m | Length /m | Vertical support distance/m |
|--------|-------------|-------------|-----------|-----------------------------|
| 1      | 0.6         | 1.2         | 18        | 3                           |
| 2      | 0.8         | 1.2         | 23        | 4                           |
| 3      | 1.0         | 1.2         | 28        | 5                           |
| 4      | 1.2         | 1.2         | 33        | 6                           |

![Figure 1. Numerical calculation model](image-url)
In order to compare and optimize the supporting scheme of foundation pit, some different supporting schemes are designed, whose pile diameter, pile distance, pile length, vertical support distance are different, as shown in the table above.

3. Optimum analysis of support scheme for foundation pit

3.1. Compared with the filed monitoring results

Compared with the filed monitoring data, it can be seen that from the figure 1 the maximum deformation and position of the pile obtained by numerical simulation, as well as the deformation distribution law along the pile depth direction, are consistent with the actual project, which shows that the relevant data used in this paper are basically correct, especially the setting of traffic dynamic load in the numerical model.

![Figure 2](image)

**Figure 2.** Curves of filed monitoring and numerical simulation results

3.2. Analysis of Pile Diameter

Considering the traffic dynamic loads and the same pile length, the supporting effects of deep foundation pit under different pile diameters are compared and analyzed. The results are shown in Figure 3.

![Figure 3](image)

**(a) Pile position displacement**  **(b) Ground settlement**

**Figure 3.** Deformation curve of foundation pit and supporting structure in different pile diameters

As can be seen from the results, (1) The horizontal displacement in Scheme 1 is the largest, reaching 25.8mm, while that in Scheme 4 is the smallest, only 11.6mm; therefore, with the increase of pile diameter, the maximum horizontal displacement gradually decreases. (2) As the distance from the edge of the foundation pit increases, the deformation of the soil outside the foundation pit firstly increases, then decreases, and finally tends to zero. The settlement value reaches the maximum at 9m outside the edge of the foundation pit; the ground settlement of the soil around the deep foundation pit changes to the maximum of -13.3mm in Scheme 1. With the increase of pile diameter, the ground settlement gradually decreases, and the minimum is -8.2mm in Scheme 4. It can be seen from the
above that under the same pile length and inner support spacing, the support effect of deep foundation pit gradually decreases with the increase of pile diameter. Considering the variation of horizontal displacement of pile body and ground settlement with pile diameter and spacing, the selection of diameter of bored pile of 0.8-1.2m can effectively limit the deformation of soil around foundation pit.

3.3. Design Analysis of Pile Length

Under the influence of traffic dynamic loads, the supporting effects of deep foundation pit with different pile lengths are compared and analyzed under the same pile diameter 0.8m, distance 1.2m and inner support spacing. The diameter of supporting piles is 0.8m, distance is 1.1m and spacing is 5m. The deformation simulation results of supporting structure and soil of foundation pit under different pile lengths are shown in Figure 4. As can be seen from the curves, (1) When the length of piles is 18m, the change trend of horizontal displacement of piles gradually increases. The increase trend from top to bottom indicates that the support pile can not restrain the foundation, which results in kicking destruction of the support pile and destabilization of the foundation pit. When the length of the pile is 23, 28 and 33 m, the deformation trend of the horizontal displacement of the pile is consistent with the actual monitoring results. When the length of the pile is 28 and 33 m, the pile body can remain stable without kicking destruction; when the length of the pile is 23 m, the deformation trend of the horizontal displacement of the pile is consistent with the actual monitoring results. (2) The deformation trend of the soil outside the foundation pit is the same as that in the previous section, but when the length of the pile is more than 23m, the difference of the maximum settlement of the soil is smaller. At the same time, it can also be seen that when the pile length meets the requirements of structural stability, increasing the pile length has no obvious control effect on the horizontal displacement of the pile and ground settlement. From the above results, it is appropriate to choose 23-28m long piles in this paper.

Figure 4. Deformation curve of foundation pit and supporting structure in different pile lengths

3.4. Design Analysis of vertical support distance

Figure 5. Deformation curve of foundation pit and inner supporting in different vertical support distance
Under the influence of traffic dynamic loads, the supporting effects of deep foundation pit with different vertical support distance are compared and analyzed under the same pile diameter 0.8m, distance 1.2m and length 23m. The deformation simulation results of inner supporting under different vertical support distance are shown in Figure 5. As can be seen from the curves, (1) With the vertical support distance increasing, the change trend of horizontal displacement of piles gradually increases. (2) The deformation trend of the soil outside the foundation pit is the same similar, and the gap is not obvious. Considering the material saving in practical engineering, vertical support distance 5m is selected in the project.

4. Conclusion
Based on the support project of deep foundation pit in the Jiqing expressway reconstruction and expansion project, the calculation model is established by numerical calculation, and the support schemes of deep foundation pit are simulated numerically. The calculated results are in good agreement with the actual monitoring results. On this basis, the influence laws of pile diameter, length of piles and vertical support distance on deformation and settlement of foundation pit are analyzed, and the optimized design method is put forward. The main conclusions are as follows:

1. The setting of traffic dynamic load in the numerical model is correct. The horizontal displacement of pile body and ground settlement decrease with the increase of pile diameter and pile distance. In practical engineering, it is better to select support piles with diameter of 0.8-1.2m.

2. When the length of piles is less than or equal to 18m, the slope of foundation pit will lose stability; when the length of piles is longer than 28m, the effect of reinforcement by increasing the length of piles is not obvious.

3. With the vertical support distance increasing, the change trend of horizontal displacement of piles gradually increases. Considering the safety of foundation pit and the reduction of project cost, the pile with length 23m, diameter 0.8m and the vertical support distance 5m is chosen in the practical engineering.

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