Study on deformation prediction of cement-stabilized soil base

Yunfeng Peng*, Dongdong Si and Hailin Wu

College of Hydraulic & Environmental Engineering, China Three Gorges University, Yichang 443002, China
* Corresponding author’s e-mail: whpyf@qq.com

Abstract. The cement-stabilized soil base has the advantages of high strength, suitable stiffness, water resistance, frost resistance, etc. In this paper, the mechanical behavior and structural characteristics of cement stabilized soil foundation from construction to operation are analyzed by using three-dimensional elasto-plastic finite element method. The process of pavement filling and traffic load is simulated in the analysis. Based on the construction process, the structural characteristics and mechanical properties of cement stabilized soil foundation under asphalt concrete pavement condition are studied. The general rules of deformation and stress of soil-cement foundation under different conditions are discussed.

1. Introduction

Highway base course is an important part of pavement structure, which is the main bearing layer of pavement structure. Semi-rigid base pavement means that the base of road structure is made of semi-rigid material[1]. Due to its high strength and good adaptability traffic volume and axle load increase semi-rigid base pavement has a great development. According to statistics, among the existing highways in China, semi-rigid asphalt pavement accounts for 3/4[2], which is still in the development stage. The cement-stabilized soil is a kind of excellent semi-rigid material, which is widely used in asphalt pavement base course. It not only has the advantages of high strength and suitable stiffness compared with other semi-rigid materials, but also is convenient to use in construction. Good water resistance and frost resistance. The cement stabilized soil can meet the requirement of increasing traffic volume and load on the bearing capacity and durability of the road. It has good economy and adaptability to various working conditions.

At present, there are many theoretical and experimental studies on cement-stabilized soil materials at home and abroad, and cement-stabilized soil foundation has been widely used in highways, three-dimensional elasto-plastic finite element method is used to analyze the mechanical behavior and structural characteristics of cement stabilized soil base from construction to operation. The process of pavement filling and traffic load is simulated in the analysis. Combined with the construction process, the structural characteristics and mechanical behavior of cement soil base with different aggregate or aggregate gradation under the condition of asphalt concrete pavement were studied.

2. Analysis on cement-stabilized soil base pavement structure

In recent years, finite element method has been widely used in road engineering[3]. One of the main advantages of finite element method is that it has been effectively applied in multi-layer system. In multi-layer system, the material of pavement structure can be considered as linear elasticity or elasto-plastic, and the contact between layers can also be simulated. Based on the research results of
scholars at home and abroad, the simulation analysis of multi-layer elasto-plastic structure pavement under double-layer wheel load is carried out in this paper.

2.1 Material constitutive and material parameters
A large number of experiments have proved that although there are non-linear materials in the strict sense, the pavement surface layer and semi-rigid base layer are still in the linear elastic stage under the action of general traffic load. So the constitutive relation can express the thickness, Young's modulus and Poisson ratio. In this paper, Drucker-Prager criterion[4] is used to describe their elasto-plastic characteristics. Theoretical and practical results show that the Drucker-Prager criterion can be used to simulate the mechanical properties of granular materials such as concrete, rock and soil. As an improved Mises criterion, this criterion is similar to Mohr-Coulomb criterion, which holds that the yield strength increases with the increase of hydrostatic pressure. This is very consistent with the actual situation of granular materials such as gravel soil[5].

The mechanical parameters of each layer material are list in table 1[6]. The numerical model shown in figure 1.

| Layers           | Material                  | Young's Modulus /MPa | Poisson's Ratio | Cohesion /KPa | Internal Friction Angle/deg | Density /(kg/m³) | Layer Thickness/m |
|------------------|---------------------------|----------------------|-----------------|---------------|-----------------------------|-----------------|------------------|
| Surface Course   | Asphalt Concrete          | 1200                 | 0.25            | -             | -                           | 2400            | 0.15             |
| Base Course      | Cement Stabilized Soil    | 1500                 | 0.25            | -             | -                           | 2100            | 0.35             |
| Bed Course       | Aggregate Crushed Stone   | 500                  | 0.25            | 0             | 40                          | 1900            | 0.20             |
| Subgrade         | Soil                      | 50                   | 0.35            | 30000         | 25                          | 1900            | 3.00             |

2.2 Deformation and stresses of pavement structure under wheel loading
Under the action of standard axial load, pavement deformation and stress curves are shown in figure 2, figure 3 and figure 4. Positive stress represents tensile stress and negative stress represents compressive stress.
As shown in figure 2, the deflection basin of semi-rigid pavement has a large radius and a flat shape. The long and flat deflection curve indicates that the semi-rigid pavement slab has good integrity and large load distribution, which reduces the rutting depth of the pavement. According to the calculation, the maximum deflection occurs at the point directly below the wheel, rather than at the gap between the wheels. As shown in figure 3, the tensile stress of pavement structure is limited within the range of 0.3~0.6m below the wheels. The maximum tensile stress occurs 0.5m below the central clearance, that is, at the bottom of the semi-rigid base. It can be seen that the semi-rigid base is easy to crack at the bottom. As shown in figure 2 and figure 4, the bear at the bottom of the load spreads more evenly from the road surface and under the bed, and the road foundation course bearing the compression pressure is less than 100 KPa, which will keep the soil in a good working state and at the elastic stage.

As shown in table 2, the pavement deflection value considering the construction process is 20% lower than that without process simulation, the tensile stress at the bottom of the pavement is 5.3% lower, and the compression stress at the bottom of the base is 8.6% lower. In the simulated construction process, the calculated results are more close to the measured values. It can be seen from the above analysis that any simulation of pavement structure will not bring certain error to the results of pavement structure deformation and stress calculation.

| Table 2. Difference between simulating construction process |
|-----------------------------------------------------------|
| Deflection of surface /0.01mm | Tensile stress at the bottom of surface/KPa | Tensile stress at the bottom of base/KPa |
|-------------------------------|----------------------------------|----------------------------------|
| Not simulate construction     | 55.68                            | -152                             | 175                              |
| Simulate construction         | 44.54                            | -144                             | 160                              |
3. Sensitivity Analysis of Cement-stabilized Soil Base Pavement Structure

3.1 The Relative Sensitivity of Base Course Strength to the Pavement Structure

The soft base (crushed stone), semi-rigid base (cement stabilized soil) and rigid base (lean concrete) are analyzed. The Young’s moduli of the three substrates are 300MPa, 1500MPa and 2000MPa respectively. The analysis results are shown in figure 5 and figure 6.

![Figure 5. Relation curve between deflection of surface and base course modulus](image)

![Figure 6. Relation curve between tensile stress and base course modulus](image)

It can be seen from the above analysis that the semi-rigid foundation of medium strength has better structural plate integrity and better load diffusion ability than the flexible foundation and its bearing capacity is obviously improved because there is no tensile stress at the bottom of the layer. Compared with the rigid base, the tensile stress at the bottom is obviously reduced and the possibility of cracking is lower. It improves the anti-fatigue ability of the system and reduces the cost of the system. Therefore, semi-rigid base is a good choice for asphalt pavement, and its modulus should be controlled at 1300MPa-2000MPa.

3.2 The Relative Sensitivity of Base Course Thickness to the Pavement Structure

Figure 7 and figure 8 show the effect of base course thickness to deflection and stress of pavement structure.

![Figure 7. Relation curve between deflection of surface and base course thickness](image)

![Figure 8. Relation curve between tensile stress and base course thickness](image)

The thickness of base course has a great influence on the deflection of pavement and the tensile stress of base course, but the tensile stress of base course does not change much. With the increase of
base thickness, pavement deflection and base tensile stress decrease gradually. When the thickness of the base changed from 20cm to 35cm, the deflection of the pavement decreased by 40.6% and the tensile stress of the base decreased by 44.4%.

4. Conclusions
The 3D elastic-plastic finite element method (FEM) was used to analyze the mechanical behavior and structure characteristic of cement-stabilized soil base under traffic load in this paper, and the conclusions are as follows:

1) If the construction process is not simulated, the finite element method may produce some errors in analyzing the deformation and stress of pavement structure. Attention should be paid to the influence of construction process on pavement structure deformation and stress during construction.

2) Compared with flexible foundation, cement stabilized soil foundation with appropriate stiffness has better plate integrity and load diffusion ability. It can prevent the tensile stress at the bottom of the pavement and greatly improve the bearing capacity of the pavement. Compared with the rigid base, the tensile stress at the bottom of the base is obviously reduced. Therefore, it can delay cracking and improve the safety and durability of pavement. In addition, cement stabilized soil is cheaper. Cement stabilized base course is a good choice for asphalt pavement. The results show that the proper modulus is based on 1300 ~ 2000 MPa.

3) The optimal matrix thickness was found. The bearing capacity of pavement is not affected by the excess of the optimum thickness. The analysis shows that when the thickness of asphalt pavement is 15cm, the optimal thickness of base course is about 35cm.

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