Research on the Design of Asphalt Pavement Structure with Semi-Flexible Low-Dose Cement Stabilized Base

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Abstract. With the development of the transportation industry, the requirements for pavement structures are increasingly demanding. Traditional semi-rigid base asphalt pavement structures often suffer from early damage issues. This paper proposes a semi-flexible low-dose cement-stabilized crushed stone base, which modifies the material properties of traditional semi-rigid bases by incorporating rubber powder, turning them into semi-flexible low-dose cement-stabilized bases. Based on the analysis of existing asphalt pavement structure design theories and methods, this study conducted an in-depth exploration aimed at the characteristics of the semi-flexible low-dose cement-stabilized base structure. The results show that the resilient modulus of the semi-flexible low-dose cement-stabilized crushed stone materials is lower than that of the semi-rigid base. Secondly, this study used finite element models to calculate and analyze the asphalt pavement with semi-flexible low-dose cement-stabilized bases under different structural parameters. By comparing the road surface deflection and stress conditions under different thickness and modulus base conditions, a reasonable pavement base structure form was derived, and reasonable thickness and modulus values were given in combination with pavement structures of different road grades.

Keywords: Semi-flexible low-dose cement-stabilized crushed stone; Rubber powder; Resilient modulus; Pavement structure

1 Introduction

With the rapid development of road transportation in China, especially the acceleration of highway and urban trunk road construction, stricter requirements have been imposed on pavement performance[1]. Semi-rigid base asphalt pavements, known for their excellent slab characteristics, strong bearing capacity, and efficient load distribution, have been widely used to address the challenges posed by increasing traffic volumes. However, long-term use has revealed issues such as early damage, rutting, potholes, and cracking[2]. To address these, semi-flexible base materials have emerged as a research

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focus due to their unique advantages, combining flexibility with rigidity while maintaining strength. By incorporating modifiers, semi-flexible low-dose cement-stabilized crushed stone, which includes rubber powder, enhances pavement performance and durability[3-7]. This paper refers to the addition of rubber powder to low-dose cement-stabilized crushed stone as semi-flexible low-dose cement-stabilized materials.

This study is committed to in-depth exploration of the design of asphalt pavement structures with semi-flexible low-dose stabilized bases, aiming to create a new type of pavement structure that is excellent in performance and economical and environmentally friendly. This paper uses a variety of research methods such as indoor experiments and numerical simulations to propose scientific and reasonable pavement structure combinations and design strategies, providing solid theoretical support and technical guidance for actual engineering projects[8]. In addition, this study will also conduct detailed mechanical analysis of the asphalt pavement structure with semi-flexible low-dose stabilized bases under different traffic conditions, summarizing typical structural patterns applicable to various traffic conditions, and providing valuable reference for pavement optimization design. Semi-flexible low-dose stabilized crushed stone bases have the characteristics of granular bases while also possessing the properties of monolithic materials, making the positioning of the design characteristics of semi-flexible low-dose stabilized crushed stone bases very important. This paper summarizes the resilient modulus test and summarizes domestic and foreign popular design indicators and methods, ultimately proposing a design method for semi-flexible low-dose cement-stabilized crushed stone bases[9]. In summary, the research on the design of asphalt pavement structures with semi-flexible low-dose stabilized bases is of great significance for improving pavement performance, extending service life, reducing engineering costs, and reducing environmental pollution. Through the in-depth implementation of this study, we hope to open up new technical paths for the vigorous development of China's road traffic industry and contribute to the sustainable development of transportation infrastructure construction.

2 Simulation and Analysis

2.1 Method for Selecting Pavement Design Indicators

In China's asphalt pavement design method, pavement deflection is used as a design indicator, with the allowable deflection value serving as the criterion for pavement failure. Prior to the 1997 edition of design specifications, allowable deflection was the primary design indicator. The 1997 edition introduced the concept of design deflection value, which corresponds to the minimum deflection value in the second summer after pavement construction, when the overall pavement strength is optimal. The 2006 edition retained this design deflection indicator, while the 2017 edition proposed a multi-indicator design approach. According to the "Specifications for Design of Highway Asphalt Pavements" (JTG D50-2017), pavement structure design should consider mechanical and functional characteristics, long-term performance degradation, and damage features, ensuring safety, durability, and economic feasibility[10-14]. The pavement structure consists of surface, base, subbase, and functional layers. Inorganic binder-stabilized bases are suitable for various traffic loads. Bases and subbases must have adequate bearing capacity, fatigue resistance, durability, and water stability. Asphalt and granular bases should also resist permanent deformation. Elastic layered continuum theory under biaxial vertical loads is often used for pavement structure checking, with design indicators tailored to semi-flexible low-dosecement-stabilized crushed stone bases, as shown in Table 1.

Table 1. Design Indicators for Inorganic Bound Pavement Materials

Base course type	Subbase type	Design indicators
Chemically stabilized	Granular	Horizontal tensile stress at the bottom of chemically stabilized layers, permanent deformation of asphalt mixture layers
	Chemically stabilized	

The elastic layered system consists of several elastic layers, with each upper layer having a certain thickness, and the bottom layer being an elastic half-space, as shown in Fig 1, which illustrates the mechanical response and calculation points.

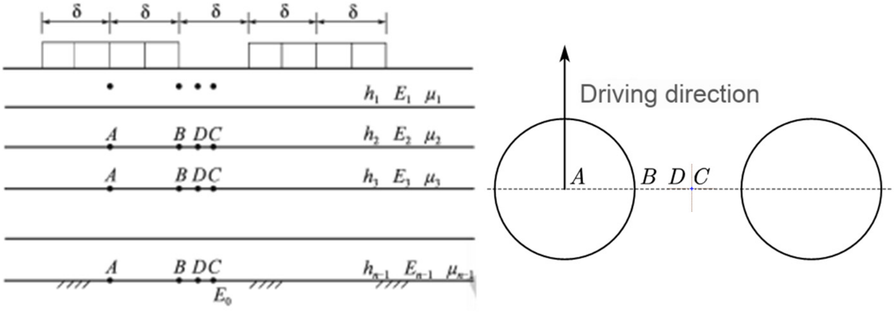

Fig. 1. Schematic of Mechanical Response and Calculation Point Locations

Based on the calculation of various points in the figure, the tensile stress at the bottom of the inorganic binder-stabilized layer and the permanent deformation of the asphalt mixture are used to verify the pavement structure.

According to the domestic highway asphalt pavement design specifications (JTG D50—2017), for the base course type of inorganic binder-stabilized material, the design indicators need to be considered from two aspects: the tensile stress at the bottom of the inorganic binder layer and the allowable permanent deformation of the asphalt mixture layer. The requirements are as shown in Table 2.

Table 2. Permissible Permanent Deformation of Asphalt Mixture Layers

Base Course Type	Expressways and First-Class Highways	Second-Class and Third-Class Highways
Chemically stabilized	15mm	20mm
Other Base Courses	10mm	15mm

2.2 Establishment of Pavement Structure Model

A 5m×5m×5m three-dimensional finite element model was established using ABAQUS, with the origin centered and the coordinate axis directions clearly defined. The load is applied as a double-circle uniform distribution, with both the radius and wheel gap being 0.1065m, an axle load of 100KN, and an equivalent pressure of 0.7MPa. Boundary conditions include fixing the bottom surface and constraining displacements in all directions on the surfaces perpendicular to the X-axis, while considering the layers as fully continuous between them. The model and its mesh division are shown in Figure 2.

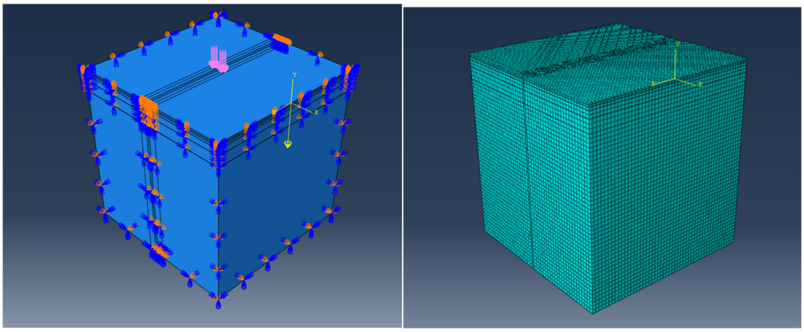

Fig. 2. Geometric Model and Mesh Division of Pavement Structure

2.2.1 High-Grade Highway Pavement Structure Forms And Pavement Structure Parameters. pavement Structure Forms

This project has four high-grade highway structure pavement design parameters as shown in Tab 3 to 6, and the figures are shown in Fig 3 and 4. By comparative analysis, this study investigates the impact of parameter variations in the four structures on the internal stress distribution and road surface deflection of high-grade highway pavement structures. It summarizes the influence patterns of structural parameters on the stress distribution of high-grade highway pavements, providing theoretical support for the design of semi-flexible low-dose cement-stabilized crushed stone base asphalt pavements.

Table 3. Design Parameters of Structure 1 High-speed Highway Pavement Structure

Structural Layer	Thickness (cm)	Elastic Modulus (MPa)	Poisson's Ratio
Fine-grained Asphalt Concrete	4	1400	0.25
Medium-grained Asphalt Concrete	5	1200	0.25
Coarse-grained Asphalt Concrete	7	900	0.25
Semi-flexible Low-dose Cement Stabilized Crushed Stone Base Course	18	1000	0.3
Semi-flexible Low-dose Cement Stabilized Crushed Stone Subbase Course	20/25/30/35/40/45	800/900/1000/1100/1200	0.3
Subgrade Soil		60	0.35

Table 4. Design Parameters of Structure 2 High-speed Highway Pavement Structure

Structural Layer	Thickness (cm)	Elastic Modulus (MPa)	Poisson's Ratio
Fine-grained Asphalt Concrete	4	1400	0.25
Medium-grained Asphalt Concrete	5	1200	0.25
Coarse-grained Asphalt Concrete	7	900	0.25
Semi-rigid base course	18	1500	0.3
Semi-flexible Low-dose Cement Stabilized Crushed Stone Subbase Course	20	800	0.3
Subgrade Soil		**60**	**0.35**

Table 5. Design Parameters of Structure 3 High-speed Highway Pavement Structure

Structural Layer	Thickness (cm)	Elastic Modulus (MPa)	Poisson's Ratio
Fine-grained Asphalt Concrete	4	1400	0.25
Medium-grained Asphalt Concrete	5	1200	0.25
Coarse-grained Asphalt Concrete	7	900	0.25
Semi-flexible Low-dose Cement Stabilized Crushed Stone Subbase Course	18/25/30/35/40	800/900/1000/1100/1200	0.3
Semi-rigid base course	32	1500	0.3
Subgrade Soil		60	0.35

Table 6. Design Parameters of Structure 4 High-speed Highway Pavement Structure

Structural Layer	Thickness (cm)	Elastic Modulus (MPa)	Poisson's Ratio
Fine-grained Asphalt Concrete	4	1400	0.25
Medium-grained Asphalt Concrete	5	1200	0.25
Coarse-grained Asphalt Concrete	7	900	0.25
Semi-rigid base course	18	1500	0.3
Semi-rigid base course	32	1500	0.3
Subgrade Soil		60	0.35

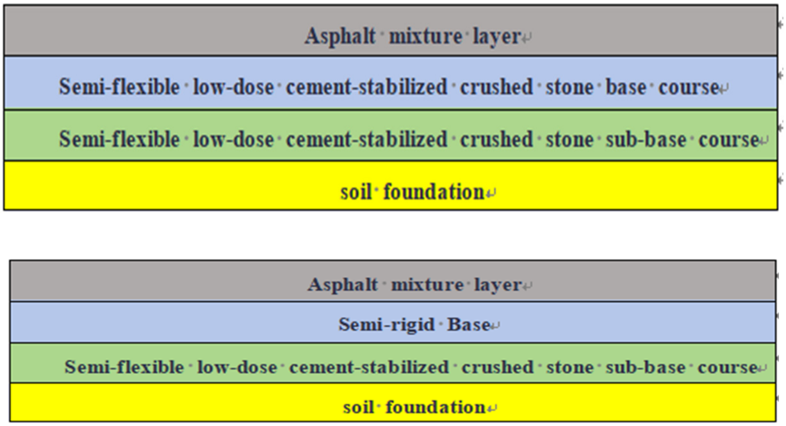

Fig. 3. Pavement Structures of High-grade Highway for Structures 1 and 2

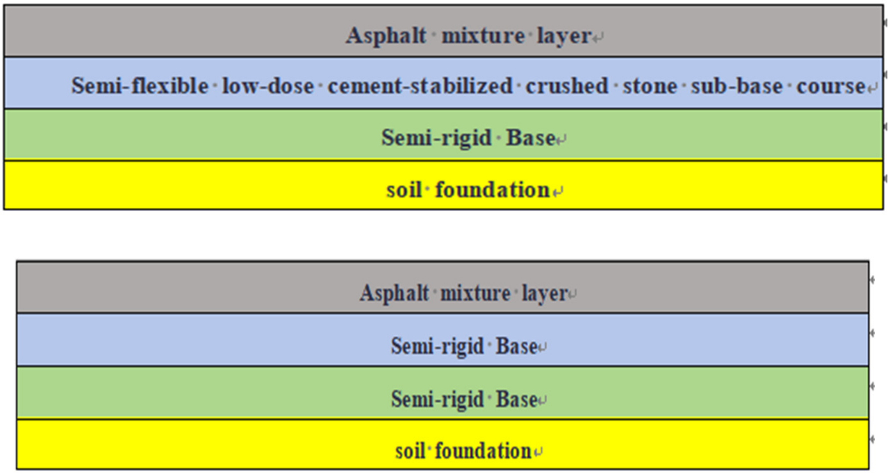

Fig. 4. Pavement Structures of High-grade Highway for Structures 3 and 4

2.2.2 Low-grade Highway Pavement Structure Forms and Pavement Structure Parameters.

This project has two low-grade highway pavement design parameters as shown in Tables 7 to 8, and the schematic diagrams of the two structures are shown in Fig 5. By comparative analysis, this study investigates the impact of changes in the structural parameters of semi-flexible low-dose cement-stabilized crushed stone on the internal stress distribution and road surface deflection of low-grade highway pavement structures. It summarizes the influence patterns of structural parameters on the stress distribution of low-grade highway pavements, providing theoretical support for the design of semi-flexible low-dose cement-stabilized crushed stone base asphalt pavements.

Table 7. Design Parameters of Structure 5 Low-grade Highway Pavement Structure

Structural Layer	Thickness (cm)	Elastic Modulus (MPa)	Poisson's Ratio
Fine-grained Asphalt Concrete	4	1400	0.25
Coarse-grained Asphalt Concrete	5	900	0.25
Semi-flexible Low-dose Cement Stabilized Crushed Stone Subbase Course	20	800/900/1000/1100/1200	0.3
Semi-flexible Low-dose Cement Stabilized Crushed Stone Subbase Course	18/22/26/30/32	1000	0.3
Subgrade Soil		60	0.35

Table 8. Design Parameters of Structure 6 Low-grade Highway Pavement Structure

Structural Layer	Thickness (cm)	Elastic Modulus (MPa)	Poisson's Ratio
Asphalt Mixture	5	1400	0.25
Semi-flexible Low-dose Cement Stabilized Crushed Stone Subbase Course	20	800/900/1000/1100/1200	0.3
Semi-flexible Low-dose Cement Stabilized Crushed Stone Subbase Course	20	1000	0.3
graded crushed stone	20	400	0.3
Subgrade Soil		60	0.35

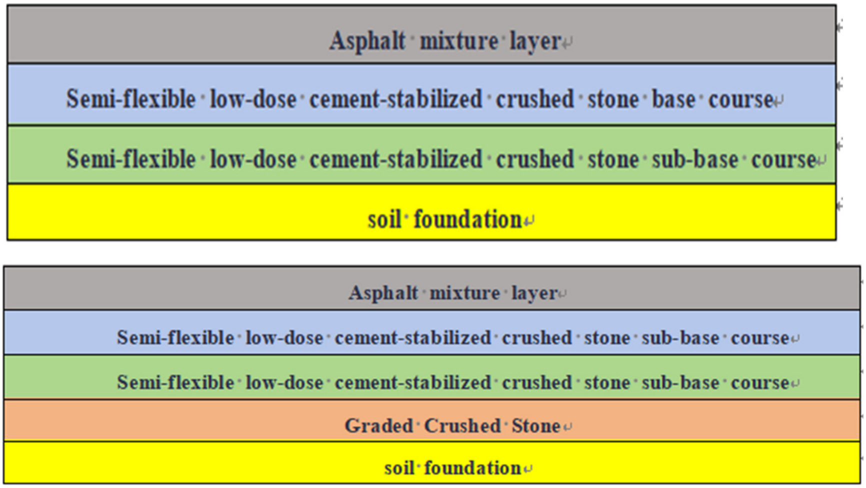

Fig. 5. Pavement Structure of Low-grade Highway for Structures 5 and 6

3 Analysis Results

3.1 Analysis of the Semi-Flexible Low-Dose Cement Stabilized Crushed Stone Base on High-Grade Pavement Structures

3.1.1 Analysis of the Modulus Variation of Semi-Flexible Low-Dose Cement Stabilized Crushed Stone on High-Grade Pavement Structures. The calculation of the influence of the modulus variation of semi-flexible low-dose cement stabilized crushed stone used as a subbase on the tensile stress at the bottom of each layer of the pavement structure, where L/0.01mm represents the road surface deflection value, σ_t represents the tensile stress at the bottom of the lower layer, σ_b represents the tensile stress at the bottom of the base course, and σc represents the tensile stress at the bottom of the subbase.The changes of the tensile stress at the bottom of each layer are shown in Table 9. From Fig 6 to 9, it can be observed that asThe changes of the tensile stress at the bottom of each layer caused by the modulus changes of the subbase of each layer.

Table 9. Variation of Tensile Stress at Layer Bottoms Due to Modulus Changes of the Subbase Course

Design Indicators	subbase modulus(MPa)				
	800	900	1000	1100	1200
Road Surface Deflection Value L (0.01mm)	32.96	32.43	32.00	31.65	31.34
Subbase Modulus σ_t (MPa)	-0.0500	-0.0520	-0.0525	-0.0530	-0.0534
bottom tensile stress of base course σ_b (MPa)	-0.004	-0.0046	-0.005	-0.0056	-0.0061
tensile stress at the bottom of the subbase σ_c (MPa)	0.060	0.064	0.067	0.069	0.070

Note: The analysis is conducted with a base course thickness of 18cm and a modulus of 1000MPa.

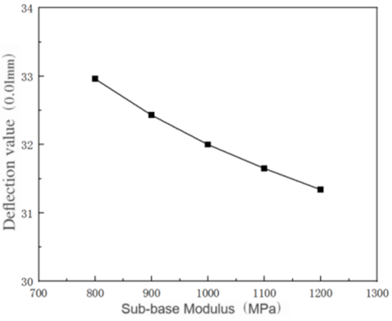

Fig. 6. Road Surface Deflection Value

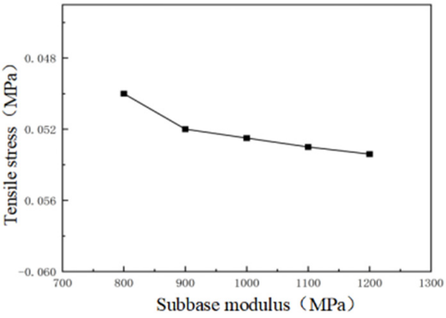

Fig. 7. Subbase Modulus

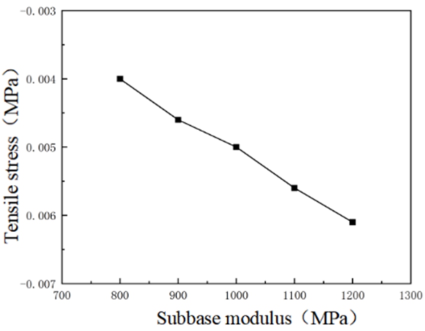

Fig. 8. bottom tensile stress of base course

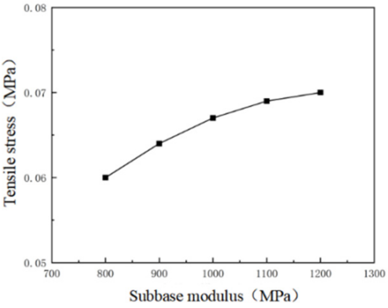

Fig. 9. tensile stress at the bottom of the subbase

From Fig 10 to 13, it can be observed that as the modulus of the semi-flexible low-dose cement stabilized crushed stone subbase increases, the road surface deflection, the tensile stress at the bottom of the asphalt layer, and the tensile stress at the bottom of the base course all gradually decrease, while the tensile stress at the bottom of the subbase gradually increases. The modulus of the semi-flexible low-dose cement stabilized crushed stone base is calculated to be 800, 900, 1000, 1100, 1200, and 1500 MPa.The influence of the modulus change of the base course on the tensile stress at the bottom of each layer is shown in Table 10.

Table 10. Impact of Base Course Modulus Variation on Tensile Stress at Layer Bottoms

Design Indicators	Base Course Modulus(MPa)					
	800	900	1000	1100	1200	1500
L/0.01mm	27.75	27.43	27.17	26.94	26.75	26.32
σt/MPa	-0.0458	-0.0460	-0.0463	-0.0479	-0.049	-0.052
σb/MPa	-0.0230	-0.0240	-0.0250	-0.0253	-0.0259	-0.0277
σc/MPa	0.0630	0.0628	0.0627	0.0626	0.0625	0.0623

Note: The calculations are based on a subbase thickness of 32 cm with a modulus of 1500 MPa and a base course thickness of 18 cm.

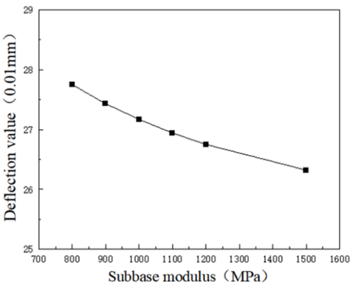

Fig. 10. Road Surface Deflection

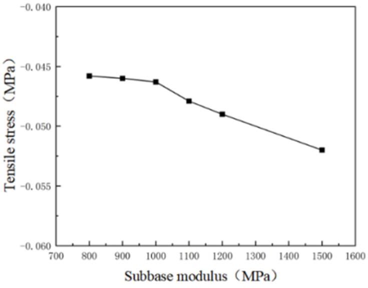

Fig. 11. bottom tensile stress of asphalt layer

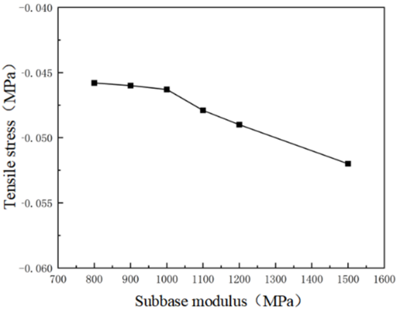

Fig. 12. Tensile Stress at the Bottom of the Base Course

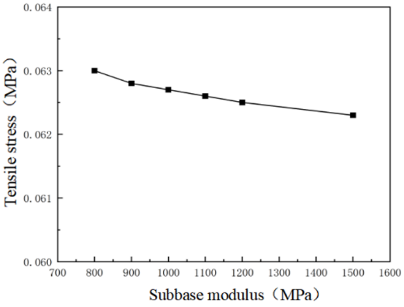

Fig. 13. Tensile Stress at the Bottom of the Subbase Course

From Fig 14 to 17, it can be seen that as the modulus of the semi-flexible low-dose cement stabilized crushed stone base increases, the road surface deflection, the bottom tensile stress of the asphalt layer, the tensile stress at the bottom of the base course, and the tensile stress at the bottom of the subbase course all gradually decrease.

Combining the above two analyses, it is known that when the modulus of the base course is fixed, an increase in the modulus of the subbase course will lead to an increase in the tensile stress at the bottom of the subbase course, making it more prone to cracking. Conversely, when the modulus of the subbase course is fixed, an increase in the modulus of the base course will result in a decrease in the tensile stress of the pavement structure layers. Therefore, when selecting materials for the base course, it is advisable to choose materials with a higher modulus, while for the subbase course, materials with a lower modulus should be selected, but the modulus ratio of the base course to the subbase course should not exceed 3.0. Compared with the semi-rigid base, the semi-flexible low-dose cement stabilized crushed stone has a lower modulus, making it more suitable for use as a subbase course.

3.1.2 Analysis of the Impact of Thickness Variation of Semi-Flexible Low-Dose Cement Stabilized Crushed Stone on High-Grade Pavement. In this section, the calculations are conducted with semi-flexible low-dose cement stabilized crushed stone as the subbase, and the impact of thicknesses of 20/25/30/35/40 cm on road surface deflection, bottom tensile stress of the asphalt layer, bottom tensile stress of the base course, and bottom tensile stress of the subbase course is explored.The changes of the tensile stress at the bottom of each layer caused by the change of the subbase thickness are shown in Table 11.

Table 11. Variation of Tensile Stress at Layer Bottoms Due to Changes in Subbase Thickness

Design Indicators	Base Course Modulus (MPa)				
	20	25	30	35	40
L/0.01mm	32.00	31.1	29.5	28.8	27.6
σ_t/MPa	-0.0525	-0.0511	-0.0496	-0.0488	-0.0474
σ_b/MPa	-0.005	-0.005	-0.0049	-0.0048	-0.0047
σ_c/MPa	0.067	0.065	0.061	0.058	0.056

Note: The modulus of the subbase is selected to be 1000 MPa.

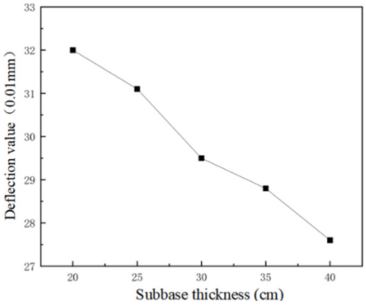

Fig. 14. Road Surface Deflection

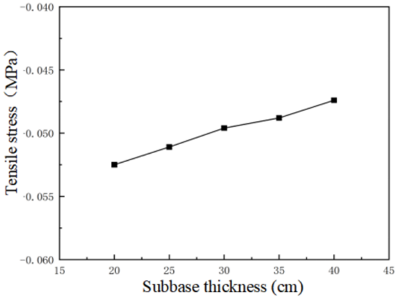

Fig. 15. bottom tensile stress of asphalt layer

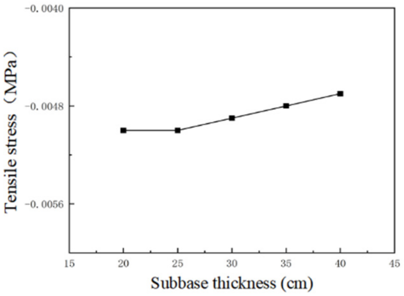

Fig. 16. Tensile Stress at the Bottom of the Base Course

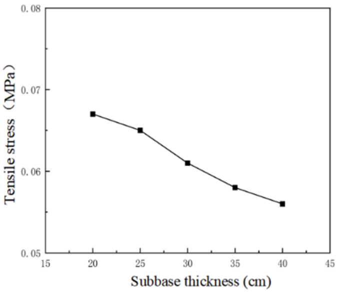

Fig. 17. Tensile Stress at the Bottom of the Subbase Course

From Fig 18 to 21, it is observed that when semi-flexible low-dose cement stabilized crushed stone is used as a subbase, both the surface layer and base course of the simulated pavement structure are subjected to compressive stress, while only the subbase is subjected to tensile stress, and the tensile stress experienced is less than 0.1 MPa. The degree of impact decreases insignificantly with the increase in the thickness of the subbase, and it is recommended to use the minimum thickness when semi-flexible low-dose cement stabilized crushed stone is used as a subbase.

Secondly, the semi-flexible low-dose cement stabilized crushed stone is calculated as the base course, and the impact of thicknesses of 18/25/30/35/40 cm on road surface deflection, bottom tensile stress of the asphalt layer, bottom tensile stress of the base course, and bottom tensile stress of the subbase course is explored. The changes of the tensile stress at the bottom of each layer caused by the change of the base course thickness are shown in Table 12.

Table 12. Variation of Tensile Stress at Layer Bottoms Due to Changes in Base Course Thickness

Design Indicators	Base Course Modulus (MPa)				
	18	25	30	35	40
L/0.01mm	27.17	26.98	25.32	24.21	23.20
σ_t/MPa	-0.0463	-0.0452	-0.0443	-0.0432	-0.0423
σ_b/MPa	-0.0250	-0.0234	-0.0221	-0.0198	-0.0184
σ_c/MPa	0.0627	0.061	0.060	0.058	0.057

Note: The modulus of the base course is selected to be 1000 MPa.

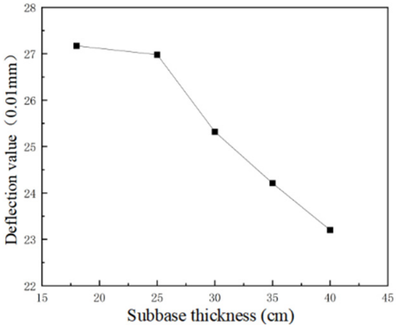

Fig. 18. Road Surface Deflection

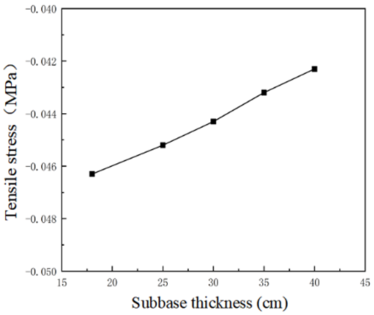

Fig. 19. bottom tensile stress of asphalt layer

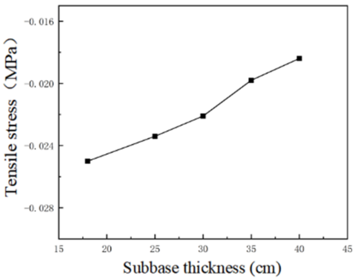

Fig. 20. Tensile Stress at the Bottom of the Base Course

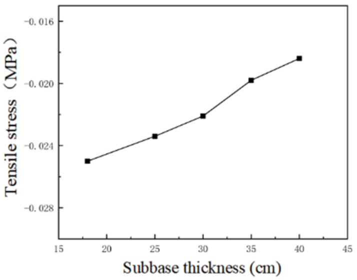

Fig. 21. Tensile Stress at the Bottom of the Subbase Course

As shown in Fig 22 to 25, when semi-flexible low-dose cement stabilized crushed stone is used as the base course, its impact on the bottom stress of the asphalt pavement and the tensile stress of the subbase is relatively small, and the tensile stress of the subbase is less than 0.1 MPa. Therefore, it is recommended to appropriately reduce the thickness of the semi-flexible low-dose cement stabilized crushed stone base course.

3.2 Analysis of the Impact of Modulus Variation of Semi-Flexible Low-Dose Cement Stabilized Crushed Stone on the Mechanics of Low-Grade Pavement Structures

Calculations were conducted to analyze how the modulus variation of semi-flexible low-dose cement stabilized crushed stone, when used as a base course for low-grade highways, affects the tensile stress at the bottom of each structural layer. Here L/0.01mm represents the road surface deflection value, σt represents the tensile stress at the bottom of the asphalt layer, σb represents the tensile stress at the bottom of the base course,σc represents the tensile stress at the bottom of the subbase course, and σd represents the tensile stress at the bottom of the functional layer.

The design involves analyzing the stress on low-grade highways due to modulus variations of semi-flexible low-dose cement stabilized crushed stone used as the base course for Structure 5 of low-grade roads.The changes of the tensile stress at the bottom of each layer caused by the variation of the base course modulus are shown in Table 13.

Table 13. Variation of Tensile Stress at Layer Bottoms Due to Changes in Base Course Modulus.

Design Indicators	Base Course Modulus (MPa)				
	800	900	1000	1100	1200
L/0.01mm	36.56	35.98	35.52	35.13	34.80
σ_t/MPa	-0.095	-0.097	-0.099	-0.1	-0.11
σ_b/MPa	-0.033	-0.034	-0.034	-0.035	-0.035
σ_c/MPa	0.077	0.078	0.079	0.080	0.081

Note: The thickness of the subbase is 18 cm with variations in the modulus of the base course.

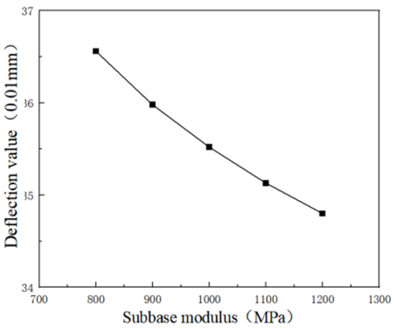

Fig. 22. Road Surface Deflection

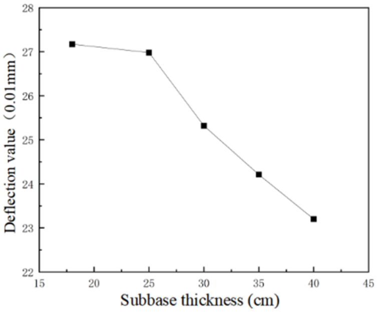

Fig. 23. bottom tensile stress of asphalt layer

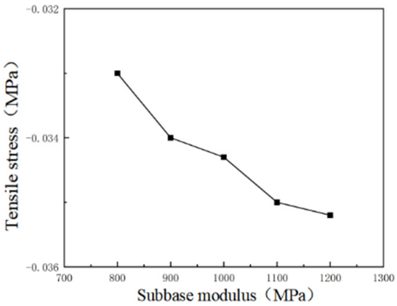

Fig. 24. Tensile Stress at the Bottom of the Base Course

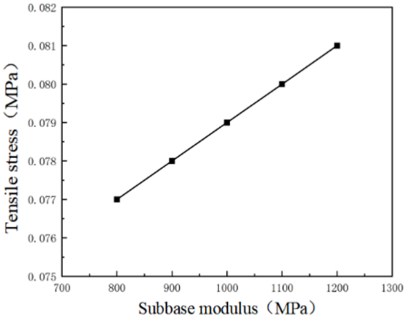

Fig. 25. Tensile Stress at the Bottom of the Subbase Course

In low-grade highways, as the modulus of the semi-flexible low-dose cement-stabilized crushed stone base increases, the road surface deflection, the bottom tensile stress of the asphalt layer, and the bottom tensile stress of the base course gradually decrease, while only the bottom tensile stress of the semi-flexible low-dose cement-stabilized crushed stone increases. Therefore, when used as a low-grade highway, the modulus of the semi-flexible low-dose cement-stabilized crushed stone should not be too high; otherwise, the increase in the bottom tensile stress of the subbase can easily lead to cracking and damage. The design involves analyzing the stress on low-grade highways due to modulus variations of the semi-flexible low-dose cement-stabilized crushed stone used as the base course for Structure 6 of low-grade roads. The changes of the tensile stress at the bottom of each layer caused by the variation of the base course modulus are shown in table 14.

Table 14. Variation of Tensile Stress at Layer Bottoms Due to Changes in Base Course Modulus.

Design Indicators	Base Course Modulus (MPa)				
	800	900	1000	1100	1200
L/0.01mm	31.74	31.07	30.52	30.06	29.66
σ_t/MPa	-0.1766	-0.1765	-0.1765	-0.1764	-0.1763
σ_b/MPa	-0.0525	-0.0537	-0.0547	-0.0560	-0.0566
σ_c/MPa	0.032	0.034	0.034	0.035	0.036
σ_d/MPa	0.03	0.0298	0.0298	0.0297	0.0296

Note: The thickness of the subbase is 20 cm with variations in the modulus of the base course.

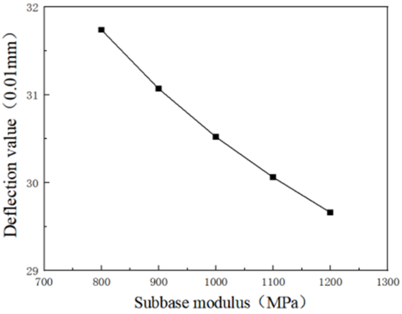

Fig. 26. Road Surface Deflection

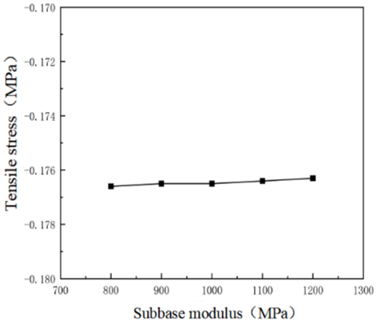

Fig. 27. bottom tensile stress of asphalt layer

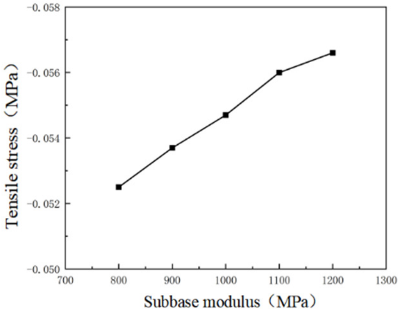

Fig. 28. Tensile Stress at the Bottom of the Upper Layer

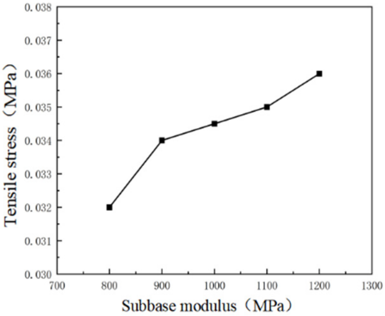

Fig. 29. Tensile Stress at the Bottom of the Base Course

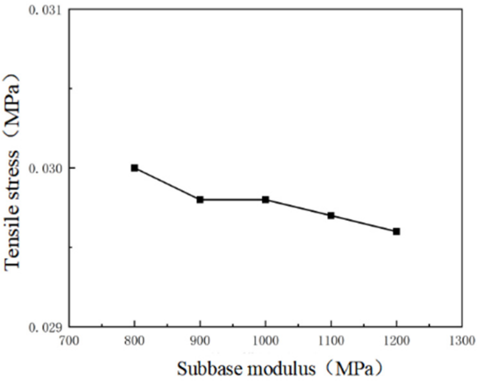

Fig. 30. Tensile Stress at the Bottom of the Graded Crushed Stone Layer

As can be seen from Figures 26 to 30.When the semi-flexible low-dose cement-stabilized crushed stone base is used as part of the low-grade highway structure 6, an increase in modulus leads to an increase in the tensile stress at the bottom of the semi-flexible low-dose cement-stabilized crushed stone layer and a decrease in the tensile stress of the graded crushed stone. This indicates that when using semi-flexible low-dose cement-stabilized crushed stone for low-grade highways, it is important to control the modulus to avoid levels that are either too high or too low. A modulus that is too high can cause excessive tensile stress at the bottom of the subbase, leading to cracking, while a modulus that is too low can result in cracking of the graded crushed stone layer. Therefore, it is recommended that the base course modulus be around 1000 MPa.

3.2.1 Analysis of the Impact of Thickness Variation of Semi-Flexible Low-Dose Cement Stabilized Crushed Stone on the Mechanical Analysis of Low-Grade Pavement Structure. The changes of the tensile stress at the bottom of each layer caused by the change of the subbase thickness are shown in Table 15.

Table 15. Variation of Tensile Stress at Layer Bottoms Due to Changes in Subbase Thickness.

Design Indicators	Subbase Thickness (cm)				
	18	22	26	30	32
L/0.01mm	35.52	33.38	31.66	30.28	28.93
σ_t/MPa	-0.099	-0.094	-0.090	-0.085	-0.081
σ_b/MPa	-0.034	-0.039	-0.0410	-0.0412	-0.0413
σ_c/MPa	0.069	0.066	0.064	0.062	0.061

Note: The modulus of the semi-flexible low-dose cement-stabilized crushed stone is selected to be 1000 MPa.

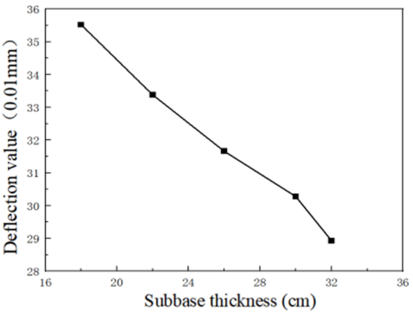

Fig. 31. Road Surface Deflection

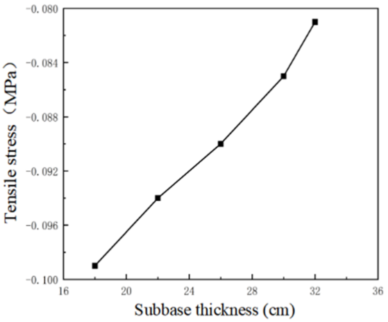

Fig. 32. Tensile Stress at the Bottom of the Asphalt Layer

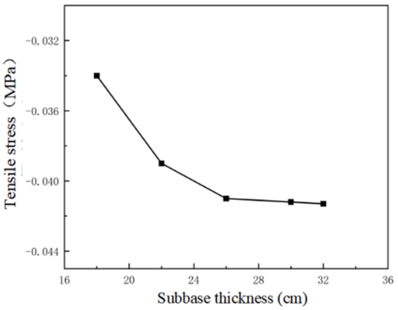

Fig. 33. Tensile Stress at the Bottom of the Base Course

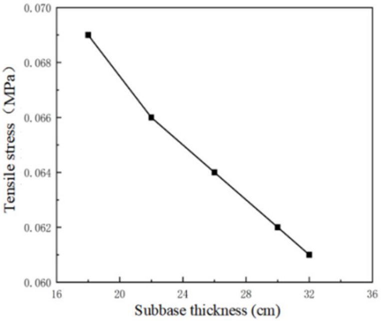

Fig. 34. Stress at the Bottom of the Subbase Course

Fig 31 to 34 show that as the thickness of the subbase in Structure 5 increases, the road surface deflection, the tensile stress at the bottom of the base course, and the tensile stress at the bottom of the subbase gradually decrease. When the thickness is around 26 cm, the tensile stress at the bottom of the base course tends to stabilize. Therefore, when selecting the thickness of the subbase, a thickness of around 26 cm should be chosen.

4 Conclusions

Based on modulus of resilience tests on semi-flexible low-dose cement-stabilized crushed stone and a review of domestic and international asphalt pavement design methods, this study explored the structural design of asphalt pavements with semi-flexible low-dose cement-stabilized crushed stone bases, considering the mechanical properties of the material and China's traffic characteristics. The main conclusions drawn from mechanical analysis of the pavement structure are as follows:

When used as the subbase of high-grade highways, as the modulus of semi-flexible low-dose cement-stabilized crushed stone increases, the pavement deflection, tensile stress at the bottom of the asphalt layer, and tensile stress at the base layer bottom gradually decrease, while the tensile stress at the subbase bottom gradually increases. When used as the base layer, an increase in modulus leads to a gradual reduction in all these stresses.

An increase in subbase modulus results in increased tensile stress at the subbase bottom, increasing the risk of cracking. When the subbase modulus is fixed, an increase in base modulus reduces tensile stress at all structural layer bottoms. Therefore, materials with higher modulus should be selected for the base layer, while those with lower modulus are preferable for the subbase. Thus, semi-flexible low-dose cement-stabilized crushed stone, which has a relatively low modulus, is more suitable for use as a subbase.

When used as the base layer of low-grade highways, excessive modulus can lead to cracking at the subbase bottom due to increased tensile stress, while too low modulus may cause cracking in the graded crushed stone layer. Therefore, the modulus of the base layer is recommended to be around 1000. Additionally, for subbases of low-grade highways, a thickness of around 26cm is advisable to minimize tensile stress and deflection.

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