Research on Reasonable Thickness Design of Expressway Pavement Structure Based on Grey Relation Analysis of Subgrade Soil Improvement

Commented [T1]: AU: Here is a listing of the types of issues corrected in this paper:

1.Passive tense changed to active.
2.Usage of articles
3.Correcting non-idiomatic word choices
4.Reorganizing sentences for simpler, more direct expression
5.Removing unnecessary capitalizations
6.Consistent hyphenation of compound terms
7.Sentence punctuation
8.Plurals and subject-verb agreement
9.Standard style for units of measure and variables

Abstract:

During the design of pavement structures, determining the reasonable thickness for pavement layers is normally rather important and also difficult. As to ~~the~~ designing an expressway in areas with poor soil foundation, a reasonable subgrade treatment will help to build ~~a~~ more durable pavement. However, determining the thickness of subgrade treatment is always a ~~hard work~~ difficult task for the designer. Thicker treatment means ~~to~~ a huge cost increase ~~of~~ for the project, ~~while~~ whereas thinner treatment can~~-~~not ~~show a~~ achieve significant improvement ~~of~~ in the mechanical behavior of pavement structures. ~~In this manuscript,~~ This study used the finite-element method ~~was utilized~~ to analyze the mechanical response of ~~a~~ real field pavement~~, which~~ with ~~had experienced a~~ subgrade treatment at ~~a~~ certain depths. ~~The orthogonal~~ The study used orthogonal design and grey relational theory ~~were used~~ to analyze the design indicators and make a better design ~~on~~ for the pavement structure of a field expressway. The numerical calculation index and theoretical analysis results ~~can fully~~ show that the treatment depth of subgrade soil has significant influence on the stresses within an ~~of~~ asphalt pavement structure and the bottom tensile strains of the asphalt layers. Therefore, in order to design a pavement structure with equal structural strength, using a reasonable depth for the cement-treated ~~depth of~~ subgrade, instead of increasing the asphalt layer's thickness, will be a more cost-effective solution.

Key~~-~~words: ~~Subgrade~~ subgrade ~~Soil~~ soil ~~Improvement~~improvement; ~~Grey~~ grey ~~Relational~~ relational ~~Analysis~~analysis; ~~Orthogonal~~ orthogonal ~~Test~~test; ANSYS; ~~Reasonable~~ reasonable ~~Thickness~~thickness;

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1 .Introduction

At present, in the construction process of highway subgrade, builders often encounter the phenomenon of stress concentration caused by insufficient subgrade soil layer~~ is often encountered~~, which causes early damage ~~of~~ to the pavement structure.~~—~~ In engineering, a common technical measure~~s~~ is using lime to treat bad subgrade sections to improve soil-based elastic modulus.~~,~~ The effect of the treatment has been recognized by ~~the road industry~~ designers in the industry [1-3]. However, ~~In terms of Pavement Stress and strain design index,~~ factors such as lime treatment, roadbed depth, and reasonable thickness of each layer of pavement structure have great influence on the pavement stress and strain design index ~~it~~ [4-6]. So far, ~~There is~~ little research has been conducted on the relationship between the depth of lime-treated soft soil subgrade and the internal stress of asphalt pavement structures.~~,~~ The lime-treated soft soil subgrade in the actual project is blind and random. For example, in the design and construction, regardless of the thickness of the pavement structure layer of the asphalt, a treatment depth is selected according to ~~the~~ experience to improve the subgrade soil. As a result, the rebound modulus of the top of the road is too small, and the pavement structure is easily damaged. When the processing depth is too large, it causes economic waste. Therefore, this study investigates ~~according to the characteristics of the pavement structure,~~ the relationship between subgrade depth treated with lime and pavement structure according to the characteristics of the pavement structure~~is studied~~. It is particularly important to determine the reasonable depth of lime-~~-~~treated soil to guide design and construction [7-9]. Therefore, this paper takes the Changchun~~-~~–Fuyu Expressway reconstruction and expansion project as an example. Through indoor and outdoor experiments and finite-~~-~~element (FE) numerical simulation analysis, we studied the influence of the depth of lime treatment for the internal stress and strain of the pavement structure~~ is deeply studied,~~ and proposed the reasonable thickness of the pavement structure of each layer ~~is proposed to the~~ for analysis ~~of~~ using grey correlation theory [10-12]. ~~This is~~ The results of this study hold great practical significance ~~of~~ for improving design specifications, ensuring road engineering quality, and saving engineering construction costs.

2 FE model of pavement structure

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Commented [T4]: AU: Whose experience is being used to make this selection?

The study used the FE software ANSYS17.0 ~~was used~~ for numerical simulation calculation. The FE analysis was carried out for a given flexible base asphalt pavement structure. The orthogonal test design method was used to analyze the factors affecting the mechanical response of the pavement structure.

2.1 Loads and forms of action

The pavement model uses a 100 KN single-axis double wheel as the design axle load, and the calculated axle load parameters are determined according to Table 1.

Table 1: Design axle load parameters

Design of axle load（KN）	Tire ground pressure（Mpa）	Equivalent radius of single wheel grounding（mm）	Two wheel center distance（mm）
100	0.7	213.0	319.5

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2.2 Pavement geometry model and boundary conditions

Fig. 1 shows the pavement structure used for FE calculation. The geometry of the 3D model is 10 × 7.5 × 4 m. In the typical structure of ~~the~~ traditional pavement, a cold recycled asphalt ATB-25 flexible base layer is added to form a composite pavement structure [13-15]. The material parameters and thickness parameters are shown in Table 2.

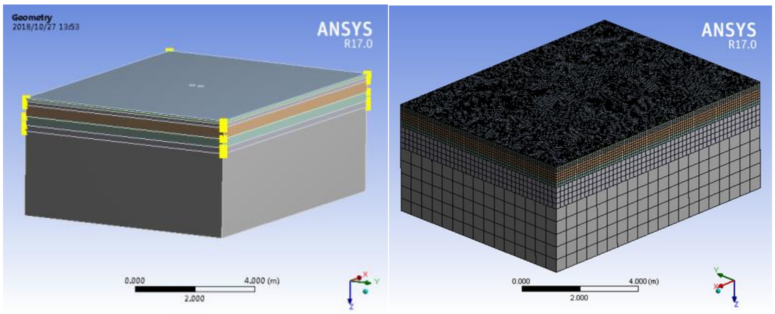

Figure 1: Asphalt pavement structure model and grid division diagram

Table 2: Pavement structure layer thickness and material composition

Project	Material type	Modulus	Poisson's ratio	Scheme of orthogonal experimental data modeling					
Asphalt surface	Stone Matrix Asphalt with Modified Bitumen (SMA-13)	10000 Mpa	0.25	40mm	100 mm	40mm	110 mm	50mm	120 mm
	Mesograin asphalt mixture modified asphalt concrete (AC-20)	11500 Mpa	0.25	60mm		70mm		70mm	
ATB-25 base layer	Dense-graded cold recycling bituminous mixture （ATB-25）	9000 Mpa	0.25	80mm	80 mm	120mm	120 mm	130mm	130 mm
Inorganic Binding Materials	Cement treated base 7%	11500 Mpa	0.25	300mm	500 mm	380mm	580 mm	380mm	680 mm
	Cement treated base 5%	8000Mpa	0.25	200mm		200mm		300mm	
Subgrade		40Mpa	0.4	Improved subgrade modulus 120Mpa					

For convenience of analysis, the pavement FE model is based on four boundary conditions~~:-~~: (1) ~~The~~ the surface of the pavement structure is used as a free surface without any constraints~~.~~; (2) ~~T~~the model has no displacement in the ~~X~~*x*-axis direction of the two sides along the advancing direction of the vehicle~~.~~; (3) ~~There~~ there is no displacement in the ~~Y~~*y*-axis direction on both sides in the width direction~~.~~; and (4) ~~The~~ the bottom surface of the model has no displacement along the ~~Z~~ *z*-axis. For the asphalt pavement structure, considering the time that the vehicle load acts on the asphalt pavement is very short, it is feasible to analyze the asphalt layer and the cement-treated layer as a linear elastomer.

3 Determination of control indicators and program

3.1 Determination of control indicators

According to the latest asphalt pavement design specifications in China, anti-deformation performance and anti-fatigue cracking performance of asphalt concrete are two important design indicators for asphalt pavement design~~ in China~~. Therefore, the difference in depth of subgrade treatment will affect the performance of the road surfaces against rutting, and the shear stress is the main factor causing the rutting ~~disease~~problem. ~~Therefore,~~ So we take the shear stress of the asphalt layers and the asphalt stabilized base layer ~~are taken~~ as ~~an~~ indicators. In addition, the bottom

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Formatted: Font: Bold, Complex Script Font: Bold tensile strain of the asphalt layer and asphalt stabilized base layer, ~~and~~ as well as the bottom tensile stress of the cement~~-~~-treated base layer are also important indicators reflecting the anti-fatigue cracking performance of the structural layer. For this reason, we also include these three indicators ~~are also included~~ in the stress control index system.

3.2 Determination of ~~Orthogonal~~ orthogonal factors ~~determination~~

There are many factors affecting the structural performance of asphalt pavement. We selected four factors as the influencing factors of the stress calculation: ~~The~~ (1) the improvement depth of subgrade soil, (2) the thickness of the asphalt layer, (3) the thickness of the asphalt~~-~~-stabilized base layer, and (4) the thickness of ~~Cement~~cement-treated base layer ~~are selected as the influencing factors of stress calculation~~. We measured ~~Each~~ each factor ~~was taken~~ at three levels~~,~~ and from this data obtained a four-factor, three-level test form ~~was obtained~~. In order to efficiently find out the influence of soil depth on the structural stress of pavement, this paper ~~intends to~~ uses the $L_9(3^4)$ orthogonal test analysis method to analyze and calculate the influencing factors. Factor levels and orthogonal experimental schemes are shown in Tables 3 and 4.

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Table 3: Factors and levels

Level	Factor			
	A Improvement depth of subgrade soil (cm)	B Asphalt layer thickness (cm)	C ATB-25 base thickness(cm)	D Cement treated base thickness (cm)
1	200	10	80	500
2	500	11	120	580
3	800	12	130	680

Table 4: Orthogonal scheme

Model	Stone Matrix Asphalt with Modified Bitumen (SMA-13)（m）	Mesograin asphalt mixture modified asphalt concrete (AC-20)（m）	Dense-graded cold recycling bituminous mixture（ATB-25）(m)	Cement treated base 7%（m）	Cement treated base 5%（m）	Improvement depth of subgrade soil（m）
1	0.04	0.06	0.08	0.3	0.2	0.2
2	0.04	0.07	0.12	0.38	0.2	0.2
3	0.05	0.07	0.13	0.38	0.3	0.2
4	0.04	0.06	0.12	0.38	0.2	0.5
5	0.04	0.07	0.13	0.38	0.3	0.5
6	0.05	0.07	0.08	0.3	0.2	0.5
7	0.04	0.06	0.13	0.38	0.3	0.8
8	0.04	0.07	0.08	0.3	0.2	0.8
9	0.05	0.07	0.12	0.38	0.2	0.8

4 Grey relational calculation and analysis

This study uses ~~As a reference factor of the design of highway asphalt pavement structure,~~ the asphalt layers shear stress, asphalt stabilized base shear stress, asphalt layer tensile strain, asphalt stabilized base tensile strain, and inorganic binder stabilized base layer tensile stress as reference factors for the design of highway asphalt pavement structures. ~~are used,~~ The orthogonal experimental model is used to solve the gray correlation degree ~~between~~ among soil depth, ~~and~~ shear stress, and tensile stress [17-21]. The main control indicators for the depth of ground improvement are determined mathematically.

This paper takes the typical design structure ~~of~~ for an expressway in Northeast China as the basis of analysis.~~;~~ The shear stress of the asphalt surface layer, the layer bottom strain of the asphalt mixture, the tensile strain of the flexible base layer, and the tensile stress of the inorganic binder layer are taken as design parameters. Mathematical grey relational analysis method is used to determine the main control indicators of subgrade processing depth.

4.1 Interval processing of raw data

According to the orthogonal scheme, nine test results are calculated for each control index, such as defining shear stress of asphalt upper layer, as follows:

$X_1 = \{x_1(1), x_1(2), x_1(3), x_1(4), x_1(5), x_1(6), x_1(7), x_1(8), x_1(9)\}$ ={125600， 115190，133460，113510，122980，115060，121260，116160，127240}

All the ~~rests~~ others are determined in the same way, and the calculation results are summarized in Table 5.

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Table 5: Stress calculation results and gray correlation calculation definition data column summary table

Parameter name	$X_i(k)$	k									$X_{min}(i)$	$X_{max}(i)$
		1	2	3	4	5	6	7	8	9		
Subgrade improvement depth （m）	0	0.2	0.5	0.8	0.2	0.5	0.8	0.2	0.5	0.8	0.2	0.8
SMA-13 shear stress（pa）	1	125600	115190	133460	113510	122980	115060	121260	116160	127240	113510	133460
AC-20 shear stress（pa）	2	248610	269410	277320	261740	272070	260070	240780	259030	271460	240780	277320
ATB-25 base layer shear stress（pa）	3 i	209600	212730	195670	221280	211280	185420	201860	200580	192480	185420	221280
Asphalt layer bottom tensile strain	4	1.47E-08	1.44E-08	9.46E-09	1.54E-08	1.21E-08	9.20E-09	1.52E-08	1.18E-08	9.55E-09	9.2E-09	1.54E-08
ATB-25 layer bottom strain	5	5.00E-06	3.62E-06	1.66E-06	2.08E-06	1.70E-06	2.35E-06	1.79E-06	2.44E-06	1.78E-06	1.66E-06	0.000005
Cement treated base layer bottom tensile stress（pa）	6	134130	73577	69915	77491	72252	106830	54703	112210	67896	54703	134130

The number of values after the interval value processing is calculated according to ~~formula~~Formula (1), ~~（1），~~and the results are summarized in Table 6.

$$y_i(k) = \frac{x(k) - x_{min}(k)}{x_{max}(k) - x_{min}(k)} \quad (1)$$

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Table 6: Summary of the series after the interval value processing

$Y_i(k)$		k								
		1	2	3	4	5	6	7	8	9
	0	0.0000	0.5000	1.0000	0.0000	0.5000	1.0000	0.0000	0.5000	1.0000
	1	0.6060	0.0842	1.0000	0.0000	0.4747	0.0777	0.3885	0.1328	0.6882
	2	0.2143	0.7835	1.0000	0.5736	0.8563	0.5279	0.0000	0.4995	0.8396
i	3	0.6743	0.7616	0.2858	1.0000	0.7211	0.0000	0.4584	0.4228	0.1969
	4	0.8871	0.8387	0.0419	1.0000	0.4677	0.0000	0.9677	0.4194	0.0565
	5	1.0000	0.5868	0.0000	0.1257	0.0120	0.2066	0.0389	0.2335	0.0359
	6	1.0000	0.2376	0.1915	0.2869	0.2209	0.6563	0.0000	0.7240	0.1661

4.2 Difference sequence

The absolute difference between each index of the object to be evaluated (comparison sequence) and the corresponding element of the reference sequence is calculated one by one.

$$|x_0(k)-x_i(k)| \quad (k=1,\dots,9,\ i=1,\dots,6). \tag{2}$$

Table 7: Summary of difference sequence

Δi(k)		k									Δ_{min} (k)	Δ_{max} (k)
		1	2	3	4	5	6	7	8	9		
	1	0.6060	0.4158	0.0000	0.0000	0.0253	0.9223	0.3885	0.3672	0.3118	0.0000	0.9223
	2	0.2143	0.2835	0.0000	0.5736	0.3563	0.4721	0.0000	0.0005	0.1604	0.0000	0.5736
i	3	0.6743	0.2616	0.7142	1.0000	0.2211	1.0000	0.4584	0.0772	0.8031	0.0772	1.0000
	4	0.8871	0.3387	0.9581	1.0000	0.0323	1.0000	0.9677	0.0806	0.9435	0.0323	1.0000
	5	1.0000	0.0868	1.0000	0.1257	0.4880	0.7934	0.0389	0.2665	0.9641	0.0389	1.0000
	6	1.0000	0.2624	0.8085	0.2869	0.2791	0.3437	0.0000	0.2240	0.8339	0.0000	1.0000

4.3 Finding the maximum difference and the minimum difference between the two poles of each column.

The range is calculated according to ~~the formula~~Formula ~~(~~(3)~~)~~ and ~~the formula~~Formula ~~(~~(4)~~)~~. As can be seen from Table 8, min Δ*i*(*k*) = 0, max Δ*i*(*k*) = 1.

$$\min \Delta i(k) = \min_{i=1}^{6} \min_{k=1}^{9} |x_0(k)-x_i(k)| \tag{3}$$

$$\max \Delta i(k) = \max_{i=1}^{6} \max_{k=1}^{9} |x_0(k)-x_i(k)| \tag{4}$$

4.4 ~~Calculate~~ Calculating the correlation coefficient

According to ~~the formula~~Formula ~~(~~(5)~~)~~

$$\zeta_i(k) = \frac{\min_i \min_k |x_0(k)-x_i(k)| + \rho \cdot \max_i \max_k |x_0(k)-x_i(k)|}{|x_0(k)-x_i(k)| + \rho \cdot \max_i \max_k |x_0(k)-x_i(k)|}$$

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$$k = 1, \cdots, 9 \quad (5)$$

The correlation coefficients of the corresponding elements of the comparison sequence and the reference sequence ~~is~~ are ~~respectively~~ calculated, respectively, where ρ is the resolution coefficient and take the value in (0,1). If the ρ is smaller, the difference between the correlation coefficients is larger, and the discrimination ability is stronger. In this paper, ρ is taken as 0.5, and the calculation results are summarized in Table 8.

Table 8: Summary of correlation coefficient and relevance

	$\xi_i(k)$	k									Correlation	Proportion of factors
		1	2	3	4	5	6	7	8	9	γ_m	
i	1	0.4521	0.5460	1.0000	1.0000	0.9518	0.3515	0.5628	0.5766	0.6159	0.6730	0.1879
	2	0.7000	0.6381	1.0000	0.4657	0.5839	0.5144	1.0000	0.9989	0.7571	0.7398	0.2066
	3	0.4258	0.6565	0.4118	0.3333	0.6933	0.3333	0.5217	0.8662	0.3837	0.5140	0.1435
	4	0.3605	0.5962	0.3429	0.3333	0.9394	0.3333	0.3407	0.8611	0.3464	0.4949	0.1382
	5	0.3333	0.8520	0.3333	0.7990	0.5061	0.3866	0.9278	0.6523	0.3415	0.5702	0.1592
	6	0.3333	0.6558	0.3821	0.6354	0.6418	0.5926	1.0000	0.6906	0.3748	0.5896	0.1646

The correlation coefficient between the corresponding elements of the comparison sequence and the reference sequence is ranked according to the correlation coefficient of the soil depth improvement according to various factors: 0.7398 > 0.6730 > 0.5896 > 0.5702 > 0.5140 > 0.4949, and $\gamma_2 > \gamma_1 > \gamma_6 > \gamma_5 > \gamma_3 > \gamma_4$ can be obtained.

4.5 Calculate the proportion of the importance of each factor

Table 9: Summary of the proportion of each factor

SMA-13 shear stress (pa)	AC-20 shear stress (pa)	ATB-25 shear stress (pa)	Asphalt mixture layer bottom strain	ATB-25 base layer bottom strain	Cement treated base layer bottom tensile stress (pa)
18.79%	20.66%	14.35%	13.82%	15.92%	16.46%

5 Analysis of ~~Orthogonal~~ orthogonal experimental results ~~analysis~~

In this paper, we need to examine four test factors at the same time. If a comprehensive test is carried out, the scale of the test will be large, and it is often difficult to implement due to the limitations of the test conditions. Orthogonal test~~ed to~~ design is a high-efficiency test design method that arranges multi-factor tests and seeks optimal combination of levels.

According to the results of gray correlation analysis, the orthogonal test method

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is used to distinguish the primary and secondary order of the influence of various ~~influencing~~ factors on the mechanical indicators, and to find out the optimization plan~~,~~ ~~(~~that is, what level of each factor is considered to meet the requirements of the test indicators~~).~~, ~~Analyze~~ analyze the relationship between factors and indicators, and find out the rules and trends of indicators with factors.

1) ~~Determine~~ Determining the calculation coefficient b_{ki}

Calculate the variation range of each indicator, that is, the difference D between the maximum value and the minimum value, and calculate the correlation coefficient by $b_{ki} = \text{ratio}/D$.

The results are summarized in Table 10:

Table 10: Range of variation of various indicators and calculation of correlation coefficient table

Index	SMA-13 shear stress (pa)	AC-20 shear stress (pa)	ATB-25 shear stress (pa)	Asphalt mixture layer bottom strain	ATB-25 base layer bottom strain	Cement treated base layer bottom tensile stress (pa)
Range of variation D	19950	36540	35860	6.2E-09	3.34E-06	79427
b_{ki}	9.41876E-06	5.6531E-06	4.00192E-06	22286104.84	47669.75991	2.07274E-06

2) Comprehensive evaluation of pavement performance

According to $Y_k = \sum b_{ki} \times X_{ki}$ ($K = 1, \ldots, 9$; $i = 1, \ldots, 6$) [16], the performance index of each FE model is calculated and the results are ~~filled~~ given in Table 11.

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Table 11: Orthogonal test performance index summary table

Test number		A	B	C	D	Test results
		1	2	3	4	Performance index Y_k
1		1	1	1	1	4.27
2		1	2	2	2	4.11
3		1	3	3	3	4.04
4		2	1	2	3	4.04
5		2	2	3	1	4.04
6		2	3	1	2	3.83
7		3	1	3	2	3.85
8		3	2	1	3	3.97
9		3	3	2	1	3.94
Level sum	K1	12.4191	12.1570	12.0786	12.2553	
	K2	11.9141	12.1206	12.0843	11.7883	T=36.096
	K3	11.7633	11.8189	11.9336	12.0529	
Mean Value	k1	4.1397	4.0523	4.0262	4.0851	P=144.77
	k2	3.9714	4.0402	4.0281	3.9294	Q=144.92
	k3	3.9211	3.9396	3.9779	4.0176	S_T=0.1431
Range R		0.2186	0.1127	0.0502	0.1557	
Factors sum of squares S		0.0787	0.0230	0.0049	0.0366	

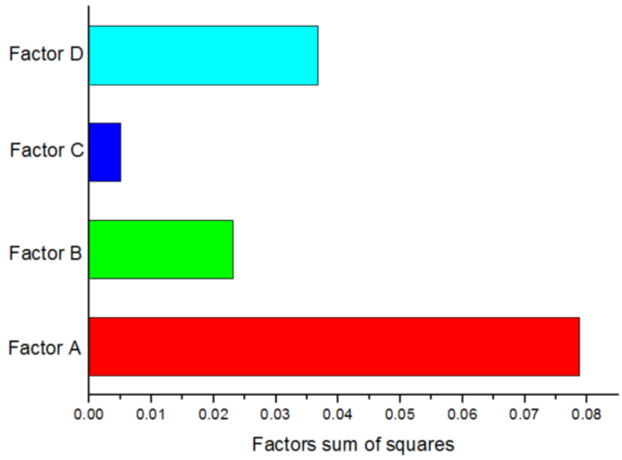

Figure 2: Comparison of the significance of each factor

~~Since~~ Because the degrees of freedom of ABCD are the same, both are $r - 1 = 2$, so the squared size can be used to represent the mean square size to judge the relative size of each factor (see Figure 2) [17].

It can be seen from Fig. 4 that the main order of the factors (main → sub) is as follows: ADBC, the depth of the subgrade soil improvement → the thickness of the inorganic binder stabilized base layer → the thickness of the asphalt layer → the thickness of the ATB base layer.

Then draw the relationship between various factors and the road performance index (see Figures 3 ~~–~~through Figure 6).

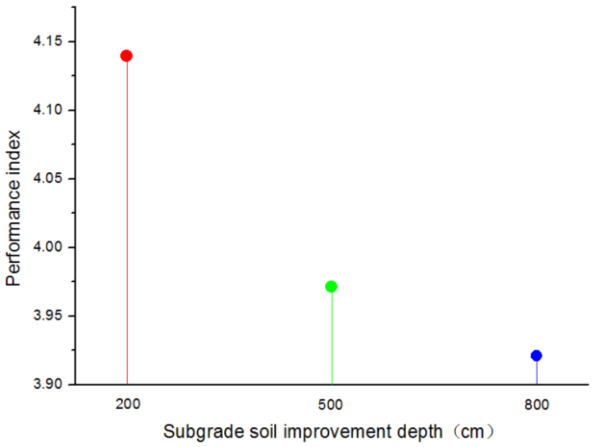

Figure 3: Effect of subgrade soil improvement depth on pavement performance index

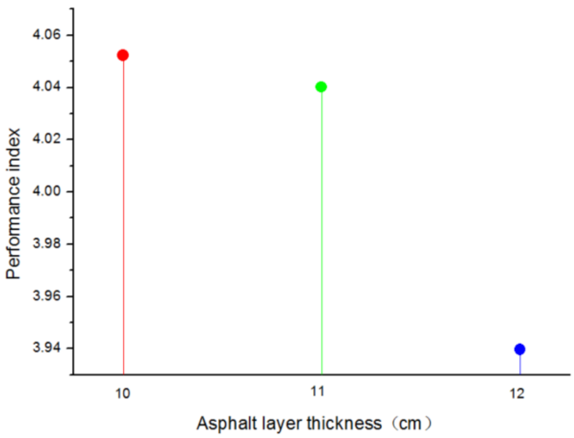

Figure 4: Influence of asphalt layer thickness on pavement performance index

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Commented [T17]: AU: This statement is a command. Should this be part of the numbered list?

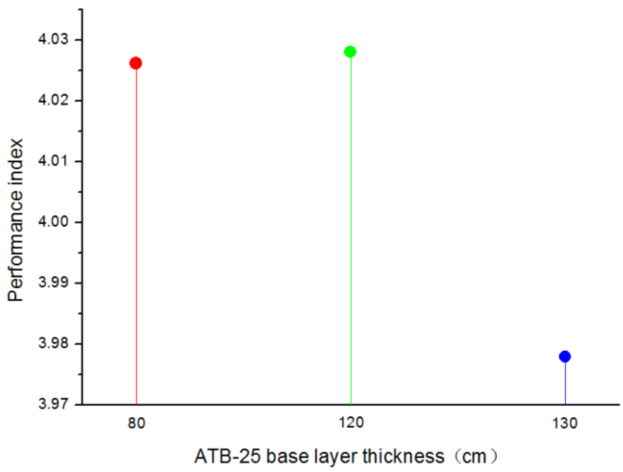

Figure 5: Effect of ATB-25 base thickness on pavement performance index

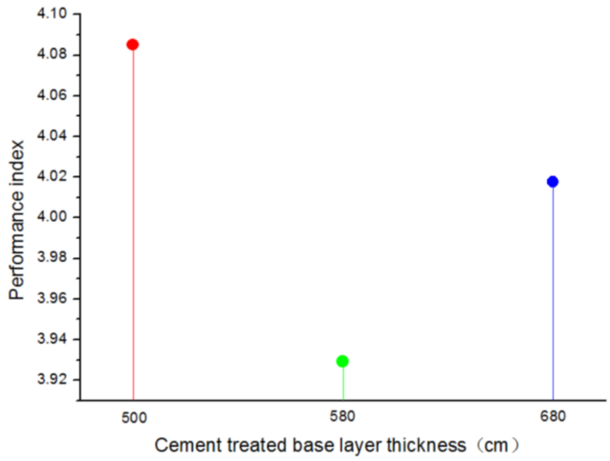

Figure 6: Effect of cement-~~-~~treated base layer thickness on pavement performance index

The thickness of each structural layer of asphalt pavement is one of the important indexes of pavement design. If ~~The~~ the thickness of the pavement structure layer is too thin, the internal stress and strain of the structure is too large, ~~and~~ or the pavement structure layer is too thick, the pavement cost will be too high and uneconomical.

Commented [T18]: AU: If any one of these factors is not optimal, would it not cause the pavement cost to be too high? Thus, shouldn't you use "or" rather than "and" here?

Therefore, in the case of a certain modulus parameter of each structural layer, finding a reasonable thickness is an important part of the pavement structure design.

According to the uniform and comparable properties of the orthogonal test design, ~~it~~ two observations can be seen from the above data and diagram:

(1) The thickness of the ATB-25 base layer has little effect on the stress and strain of the asphalt pavement structure, indicating that the increase in the asphalt pavement layers and the thickness of the ATB-25 base layer on the overall performance of the pavement is not as high as the increase in the cost. The design can be selected with reasonable thickness according to the relevant specifications. The subgrade improvement depth has a great influence on the stress and strain of asphalt pavement structure. When the subgrade improvement depth is 200 cm, the performance index is 4.1397; when the subgrade improvement depth is 500 cm, the performance index is 3.9714; when the subgrade improvement depth is 200 cm, the performance index is 3.9211. It shows that with the increase of the subgrade improvement depth, the strength of the subgrade is improved, and the overall variation of stress and strain inside the pavement structure is gradually reduced. However, as the depth of the subgrade treatment increases, the internal stress and strain reduction of the pavement structure is obviously slowed down. The thickness of the inorganic binder~~-~~-stabilized ~~the~~ base layer also has an effect on the stress and strain of the asphalt pavement structure. As the thickness of the inorganic binder layer increases, the internal stress and strain of the pavement structure decreases first and then increases. When the thickness of the inorganic binder is 580 ~~-~~cm, The internal stress and strain values of the pavement structure are the smallest.

~~-~~(2) The smaller the stress and tensile strain, the better the structure and material combination. Therefore, the smallest value of K1, K2, and K3 is selected, and the optimal combination is A3 B3 C3 D2. ~~when~~ When the modified subgrade soil depth is 800 cm, the asphalt layer thickness is 12 cm, the ATB-25 base layer thickness is 130 cm, and the inorganic binder~~-~~ ~~stabilizes~~ stabilized ~~the~~ base layer thickness is 580 cm, it is the optimal structure and material design combination. Compared with the conventional design method, the stress and layer tensile strain obtained by the gray correlation analysis method are smaller, and the obtained structure and material combination are more reasonable. Considering that the asphalt layer thickness and the thickness of ATB-25 have little effect on the internal stress and strain of the pavement structure, from the perspective of cost performance, the final structural scheme of the Changyu Expressway Reconstruction Project takes 11 cm ~~of~~ for the asphalt layer thickness and 120 cm ~~of~~ for the ATB-25 base layer thickness.

6 Conclusions

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(1) The depth of subgrade soil improvement has the most significant influence on the stress of asphalt pavement structures and the bottom strain of the asphalt layer. Second~~ly,~~ in order of significance is the thickness of the cement-treated base layer, ~~and again~~ followed by the thickness of the asphalt layer~~,~~. ~~and the~~ The influence of the thickness of the ATB-25 base layer is the smallest.

(2) The optimum structure and material designs combination of the asphalt pavement from Changchun–~~to~~ Fuyu Expressway is selected when the depth of soil improvement is 800 cm, the thickness of asphalt layer is 11 cm, the thickness of ATB-25 base layer is 120 cm, and the thickness of cement-treated base is 580 cm.

(3) According to the previous design ideas, the stress and strain of asphalt pavement structures gradually decrease with the increase of the depth of the structure layer. According to the results of the orthogonal test, ~~the increase~~ increasing ~~of~~ the thickness of the asphalt layer has little effect on the stress and strain of the pavement interior, and the reasonable thickness of cement-treated material needs to be calculated to be determined ~~finally~~.