EXPERIMENTAL STUDY AND NUMERICAL ANALYSIS OF THE RUTTING PROBLEM OF AN ASPHALT PAVEMENT

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ABSTRACT

Premature rutting distress of a freeway in south China was systemically surveyed. The influence of rutting on the smoothness and roughness of pavement is analysed in this paper. A RLWT (Rotary Loaded Wheel Tester) was first used to analyse the pavement rutting performance. The anti-rutting performance of each course of asphalt concrete from different sections of rutting depth was appraised with the RLWT. The total anti-rutting performance of the pavement and the trends of rutting were analysed from the rutting test results of each course. A pavement numerical simulative mechanical structure model was constructed with the finite element method. In this paper the stress state of asphalt pavement under tyre load was analysed. The overload influence on the stress state of asphalt pavement was analysed using several loads, and the influence of temperature on the stress state of asphalt pavement was also investigated. The influence of the depth and distribution character of the stress state of the asphalt pavement are summarised. The experimental results and numerical analyses show that the anti-rutting performance of each asphalt pavement course has an obvious influence on the performance of the whole asphalt pavement structure. According to the experimental results and numerical analysis, a rehabilitation rutting pavement scheme was devised. The rehabilitation scheme proved to be successful after three years of testing. The research results show that RLWT can be effectively used to appraise the anti-rutting performance of asphalt pavement and construction quality control.

Keywords: asphalt pavement, rutting, experimental study, finite element; computer simulation, RLWT, sub-modelling

1. INTRODUCTION

Rutting is of one of the main types of distress in asphalt pavement in China. The standard of anti-rutting performance of asphalt pavement is becoming higher due to the increase of traffic, heavy tyre load and overloading in recent years (Proceedings, 1987; De Beer et al., 1996). There is an urgent need for research on the repair of rutted pavement, although many studies have been done on improving the anti-rutting performance. This paper describes a study of the rutting distress of one expressway using finite element analysis to provide support for the scheme of pavement rutting repair.

2. SURVEY OF RUTTING IN ASPHALT PAVEMENT

The serious rutting described in this paper occurred in an expressway in Guangdong Province in China only one year after it had been opened to traffic. The most serious rutting is shown in Figure 1. The pavement structure of this expressway includes three courses of base asphalt mixture (up 40 mm + 50 mm + 60 mm down) on a semi-rigid base. The rutting depth distribution curve of three bad sections is shown in Figure 2. The curve in Figure 2 shows that the rutting of section A is most serious and section B is least serious.

An eight-wheel profilograph was used to determine rutting influence on smoothness. A curve showing the smoothness standard deviation of the rutted lane (R^2=0.89) is shown in Figure 3. Rutting leads not only to transverse deformation, but also to asymmetric longitudinal deformation where the material is segregated in the construction.

Figure 1. Rutting deformation of the cut edge.

The surface texture depth of the wheel path and middle lane was determined by the Sand Patch method. The curve of the texture depth distribution is shown in Figure 4. The texture depth of section A is the smallest and the texture depth of section B is the biggest. Asphalt spill occurred in section A. The reason that the rutting has a different influence on the texture depth of the pavement is that the rutting of section A is mainly due to compaction deformation and the rutting of section C is mainly due to shear flow deformation (Lai, 1993; Zhang and Li, 1995).

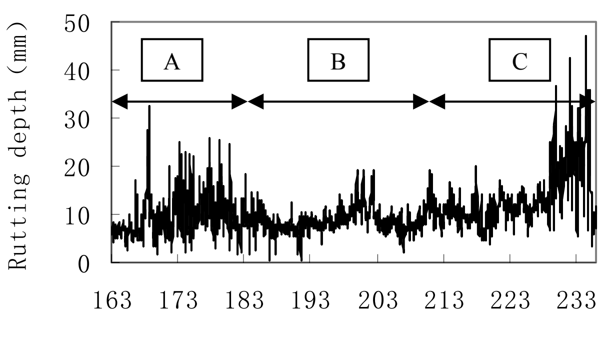

Figure 2. The rutting depth distribution curve of three bad sections.

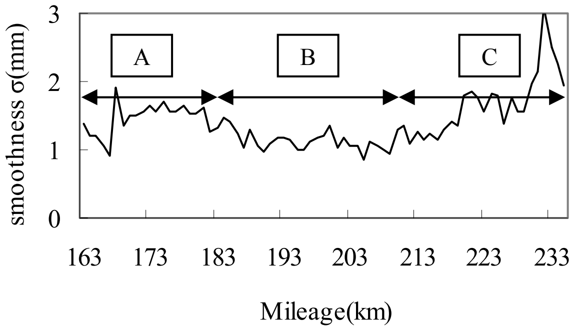

Figure 3. The curve of smoothness distribution.

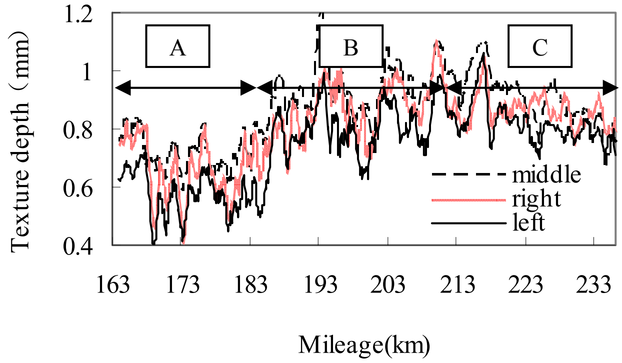

Figure 4. The curves of texture depth distribution.

3. ANTI-RUTTING PERFORMANCE OF THE ASPHALT PAVEMENT EVALUATION TEST

To design a rutting repair scheme, we need to determine in which layer rutting has occurred, the unsubstantial layer and the rutting trend through Accelerated Laboratory Rutting Tests (ALRT). It is hard to cut samples from pavement, and cutting a sample of 300 mm X 300 mm will destroy the pavement for the rutting test standard of China. The height of a specimen for the Asphalt Pavement Analyzer (APA) is 80 mm higher than the height of the pavement layer of this expressway (40 mm, 50 mm, 60 mm separately). The RLWT（Rotary Loaded Wheel Tester, or Rutmeter）can evaluate a specimen of diameter 100 mm and height 50 mm. So the RLWT could be used to evaluate the rutting performance of each layer of the rutted asphalt pavement by adding a 20 mm mat or cutting short. The specimen for RLWT is easy to obtain less destructively. The RLWT is applied to evaluate the performance of each asphalt mixture layer.

3.1 Description of the RLWT（Rotary Loaded Wheel Tester or Rutmeter）

The RLWT（Rotary Loaded Wheel Tester, or Rutmeter, which evaluates samples of a diameter of 100 mm and 150 mm, was first used in the 1990s in the USA. The RLWT was developed by CPN International, Inc. The RLWT automatically measures the plastic deformation of HMA samples as a function of repetitive wheel loadings. The RLWT uses a unidirectional rotary load wheel and most testing is carried out to 16 000 individual wheel loadings. The RLWT is capable of applying 125 N loads to each spinning single wheel in the load application assembly. The load is provided by static weight such that no external load calibration is required, and is designed to approximate a contact pressure of 690 kPa (100 psi). The loading model of an RLWT test is shown in Figure 5. The standard with the RLWT to evaluate rutting performance is the rutting depth under a certain number of loadings or the loading number to a certain rutting depth. For comparison, **RN** (rutting dynamic stability number) is defined as the representation of the loading number to the rutting depth per 1 mm.

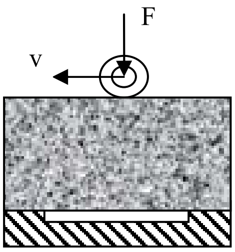

Figure 5. The loading model of an RLWT test.

The application of RLWT compared with APA and the Hamburg loaded wheel tester has been studied in the National Center for Asphalt Technology (NCAT) test track (Powell, 2003). The curve of the total depth of ARAN-measured track rutting and the total depth of rutting in laboratory simulations in Figure 6 show that RLWT can give reasonable results for evaluating the rutting performance of asphalt pavement.

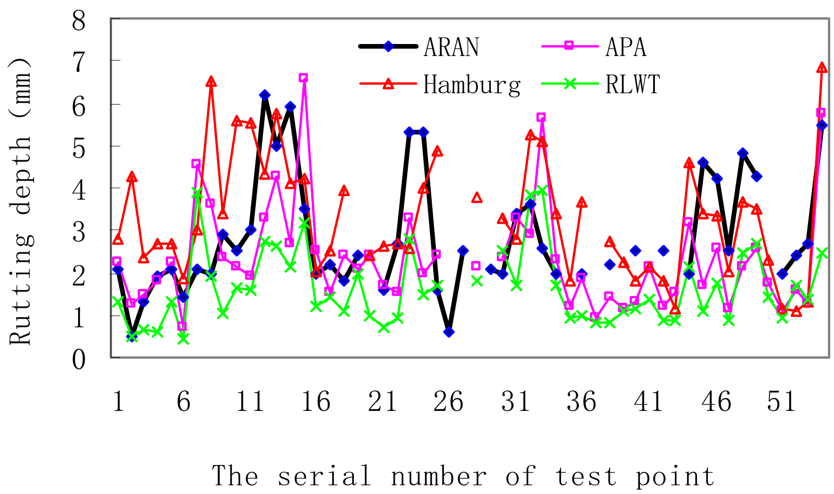

Figure 6. The curve of total ARAN-measured track rutting and total rutting in laboratory simulations.

<u>3.2 The Rutting Evaluation Test</u>

It is hard to determine the rutting depth of asphalt pavement only from laboratory rutting performance testing (Cooley et al., 2000). But the laboratory rutting performance testing could evaluate the trend of rutting and the high temperature stability of asphalt pavement. The comparative method is used to evaluating the rutting performance of asphalt pavement. The two upper courses of modified asphalt and the lower course of base asphalt in section D next to section C are taken for comparison.

3.3 Wheel Tracking Test Procedure of the Core Sample from the Pavement

First core samples were drilled from the pavement in the driving and overtaking lanes in sections A, B, C, D. The height of the standard specimen for RLWT is 50 mm. According the thickness of the pavement layers, the height of the sample from the upper course was cut to 30 mm with a 20-mm-high mat at the bottom and the height of the standard sample from the middle and lower courses was cut to 50 mm. The wheel tracking test stops after 16 000 passes or the rutting depth reaches 6.35 mm. The procedure of the wheel tracking test of cut core samples is shown in Figure 7.

Figure 7. Wheel tracking test procedure of cut core samples.

3.4 Analyses of the Wheel Tracking Test Results and Rutting Depth Data from the Survey

The core specimens from sections A, B, C and D were tested for rutting performance to 16 000 wheel passes or to a 6.35 mm rutting depth. Data of the wheel tracking test and the rutting depth data where the core samples were cut are list in Table 1.

Table 1. Rutting depth in pavement and wheel tracking test results.

Section	Lane	Rutting depth mm	RN (rutting dynamic stability number) (wheel passes/mm)			Total RN of three courses (wheel passes/mm)
			Upper course	Middle course	Lower course	
A	Overtaking lane	3	1 199	1 953	2 725	5 875
	Driving lane	20	644	3 769	3 263	7 675
B	Overtaking lane	3	4 278	1 617	2 004	7 897
	Driving lane	8	7 281	7 367	2 571	17 220
C	Overtaking lane	3	1 296	1 270	1 159	3 724
	Driving lane	25	3 776	4 966	1 403	10 145
D	Overtaking lane	2	11 079	5 229	5 933	22 241
	Driving lane	4	31 976	58 395	4 269	94 640

Analysis of the data in Table 1 shows the following:

1) The anti-rutting performance of the driving lane samples is greater than that of the overtaking lane samples except for the upper course of section A as the asphalt mixture of the driving lane was compacted more densely for better high temperature stability. The asphalt content was so high in section A upper course that asphalt spill had occurred and the high temperature stability of the asphalt mixture had been affected. The performance and rutting developing trend of asphalt mixture depend on the grade, asphalt content and air voids (Huber, 1998). The wheel tracking test curves of the lower course sample from A and C sections are shown in Figure 8. The curves of the overtaking lane sample show that the rutting depth develops faster before 3 000 wheel passes and the development rate is close to that of the sample from the driving lane. The rutting was mainly due to compaction deformation before 3 000 wheel passes and from shearing flow deformation after 3 000 wheel passes.

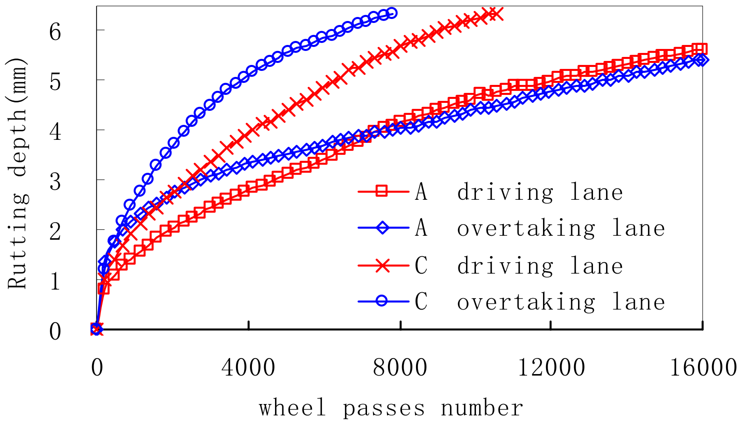

Figure 8. Wheel tracking test curves of A and C sections.

2) To reflect the anti-rutting performance of the whole asphalt pavement, the RN of the upper, middle and lower courses are summed up as the total RN shown in Table 1. The relationship of the rutting depth in the pavement and the wheel tracking test results of the overtaking lane sample are shown in Figure 9. The sample from the overtaking lane is near the original state of the asphalt mixture**.** The relationship curve in Figure 9 shows that the RLWT can evaluate the anti-rutting performance of asphalt mixture effectively. Comparing the total RN of three courses from sections A, B, C and D in Figure 10 shows that the anti-rutting performance of sections A and C is still comparatively low and the rutting in sections A and C will potentially become deeper.

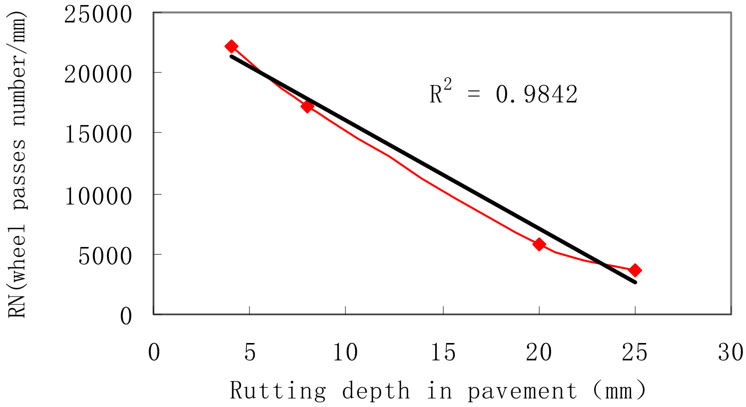

Figure 9. Relationship of rutting depth in pavement and wheel tracking test results.

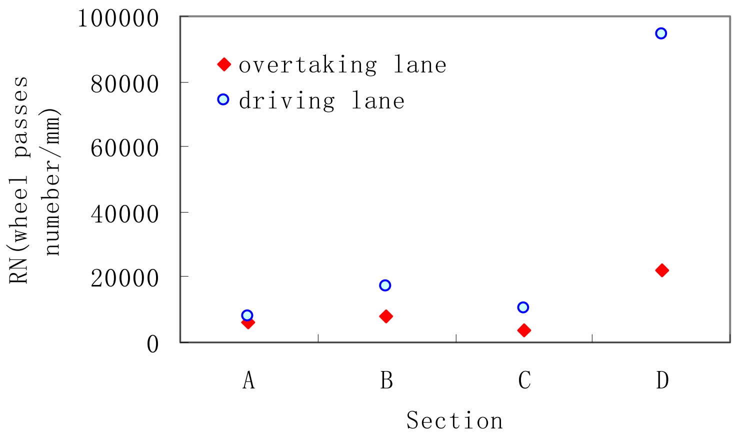

Figure 10. Comparison of the total RN of deferent sections.

3) The anti-rutting performance of each course in Table 1 is compared to show which is the weak layer. Comparative analyses show that the RN of the upper course of section A and the lower course of section C is comparatively low. The results are coincident with the measurement of the rutting source in the cut section plane shown in Figure 1. The high-temperature performance of each course of sections A, B and C is lower than the performance of section D.

4) Modified asphalt can improve the high-temperature performance of asphalt mixture according to the comparison of the anti-rutting performance between sections A, B, C and D under the same temperature and traffic conditions.

4. MECHANICAL ANALYSIS OF THE PAVEMENT STRUCTURE MODEL USING THE FINITE ELEMENT METHOD

4.1 Application of the Sub-Model Method in Computing the Stress of Asphalt Pavement

The finite element model has large numbers of small elements to compute the local effect under tyre load in the complete pavement model. This large finite element model has very high computing requirements and the computing efficiency is low. The independent local pavement section cannot represent the integrity of the whole structure and boundary conditions. Sub-modelling of the finite element method can solve this problem (Xu et al, 2004). Sub-modelling is a finite element technique used to get more accurate results in a region of the model. Sub-modelling is also known as the cut-boundary displacement method or the specified boundary displacement method. The process of the sub-modelling method is: first to analyse the whole coarse model with a large grid and elements, and then to build the sub-model with a small grid and elements to be studied in detail and then to calculate the DOF values (displacements) at boundary nodes, interpolating results from the full (coarse) model. Finally, detailed information is obtained form the sub-model.

In this paper, the whole pavement model is 12 m wide, 12 m long and 6 m high, and represents the whole pavement structure as shown in Figure 11. The sub model is 1.2 m wide, 1 m long and 0.6 m high cut from the whole pavement model shown in Figure 12. The vertical tyre load applied is 0.7 MPa in two areas of 0.2m×0.25 m as shown in Figure 12.

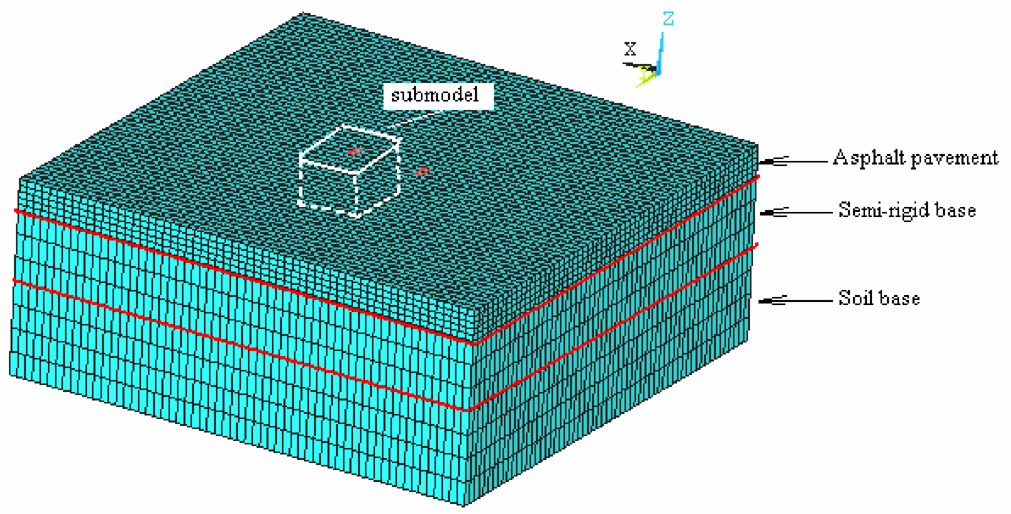

Figure 11. The complete finite element model of the pavement structure.

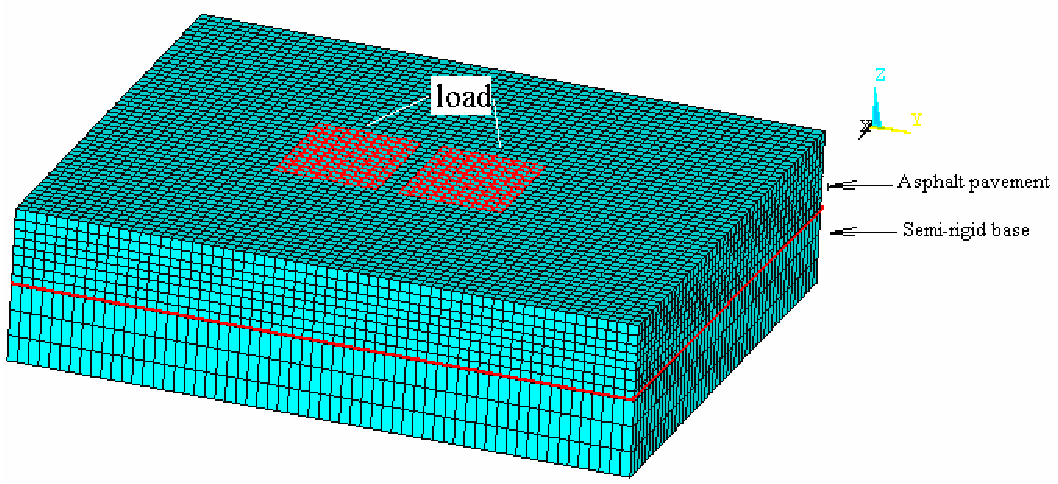

Figure 12. The finite element sub-model of the pavement structure.

4.2 Analysis of Stress on the Asphalt Pavement

The distribution of asphalt pavement stress-z is analysed using one section plane cut through the transverse middle line of the load area shown in Figure 13. The distribution of stress-z is shown in Figure 14. The distribution curves of stress-x, stress-y, stress-z, shear stress-yz and 1st principal stress along path A are shown in Figure 15. The stress distribution in Figures 13, 14 and 15 shows that stress-z is maximal and the influence range of stress-z occurs throughout the pavement. The stress-z has a bigger influence in the upper and middle courses of the pavement. The anti-rutting performance of the three courses of the pavement are quite important, especially the upper and middle courses.

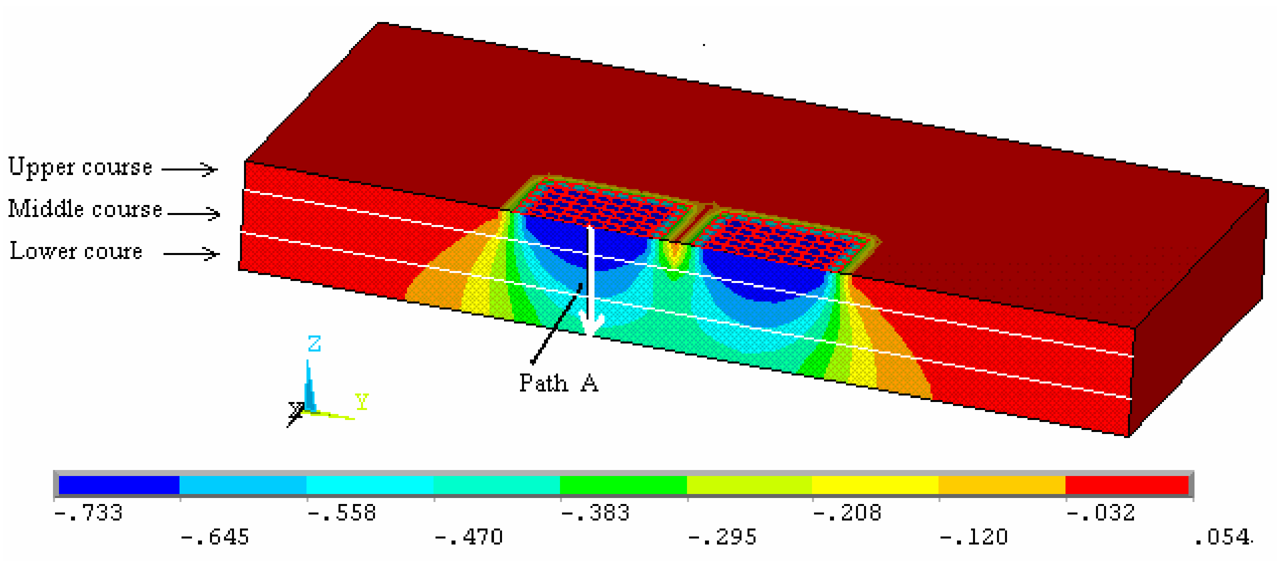

Figure 13. Section plane of stress-z distribution in the asphalt pavement.

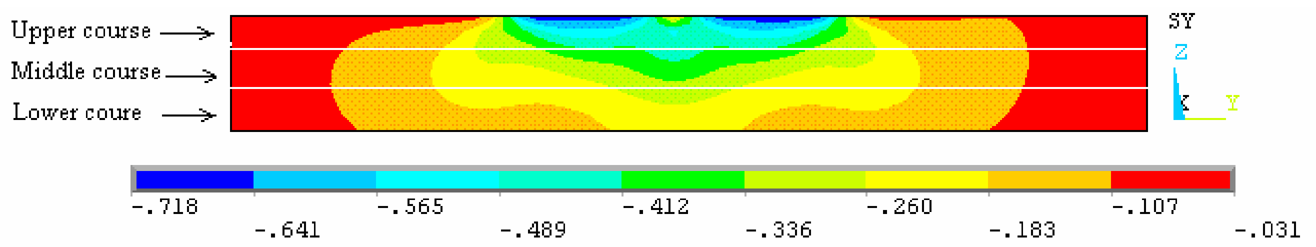

Figure 14. Section plane of stress-y distribution in the asphalt pavement.

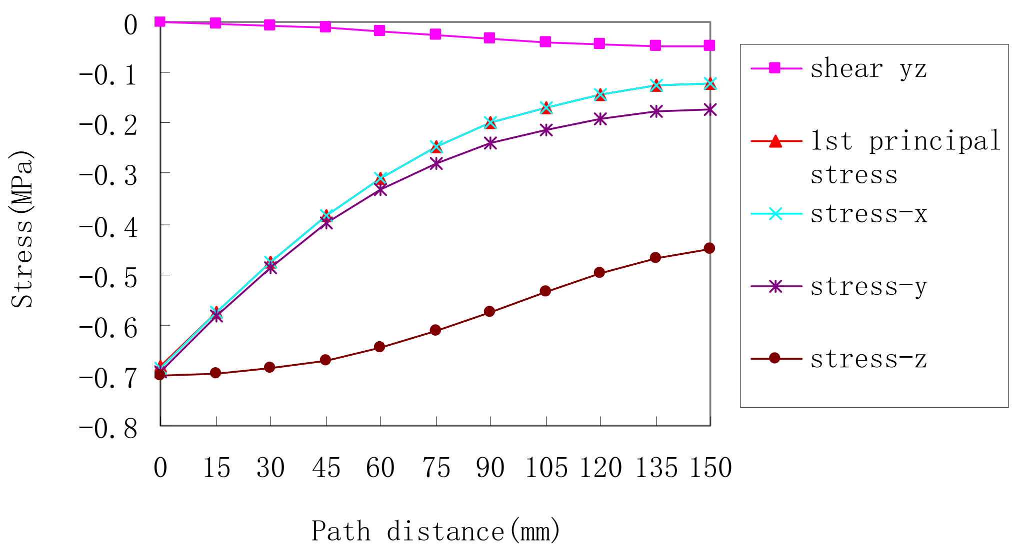

Figure 15. The stress distribution in path A of the asphalt pavement.

4.3 Analysis of the Influence of Overloading and Temperature on the Stress of Asphalt Pavement

Overloading is serious on the Chinese mainland and its influence is analysed using the comparative method. The curve of the influence of overloading on stress-z at the top of the pavement is shown in Figure 16. This shows that overloading has a linear influence on the stress of the pavement, so overloading should be rigorously controlled.

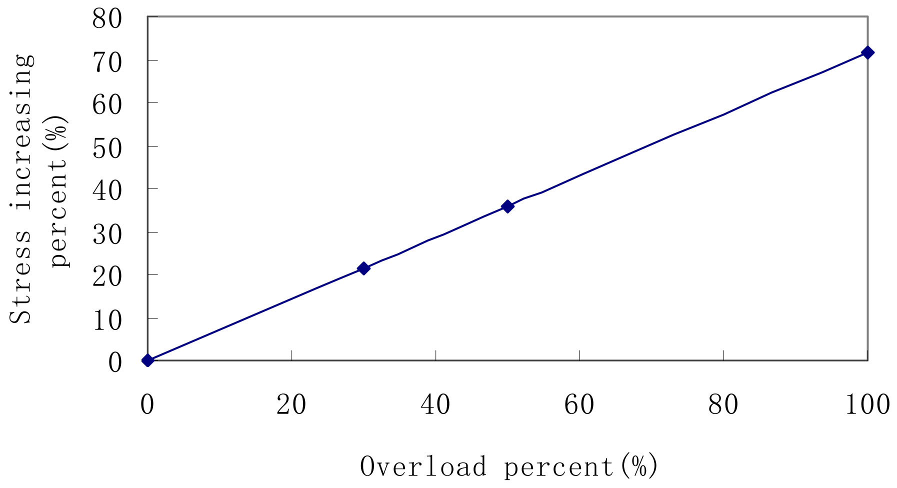

Figure 16. Influence of overloading on the stress-z at the top of the asphalt pavement.

The modulus of the asphalt mixture decreases when the temperature increases. The influence of temperature can be analysed through influence of the modulus. The curves of the influence of the modulus on stress-z at the top of the pavement are shown in Figure 17. A higher modulus of the asphalt mixture can lower the stress level of the lower course of the pavement. The stress of an asphalt mixture with higher modulus is greater, but an asphalt mixture with a higher modulus commonly has better anti-rutting performance.

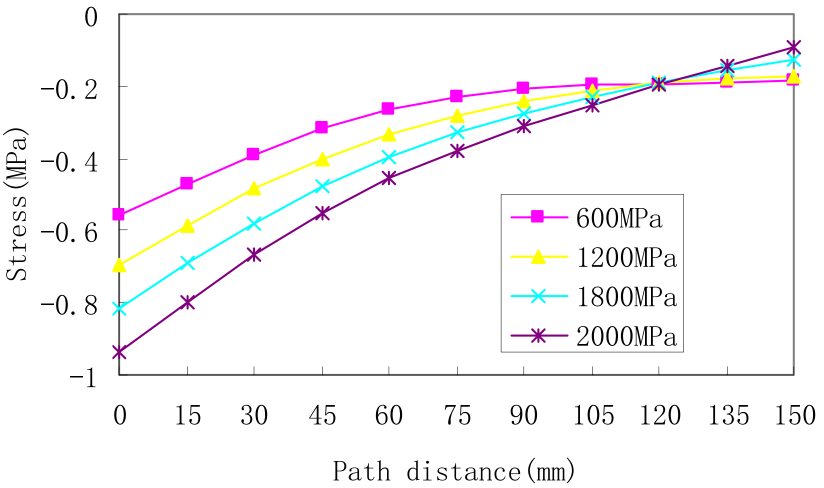

Figure 17. The influence of the modulus on stress-z at the top of the asphalt pavement.

5. ANALYSIS OF THE SCHEME FOR DEALING WITH RUTTING PAVEMENT

One of the main methods of dealing with serious rutting in asphalt pavement is milling off the rutted pavement and then paving with a new overlay. The main problem of this method is to select the depth of milling as this has direct influence on the cost and time for repairing. The finite element analysis shows that the anti-rutting performance of the three courses of asphalt pavement are all important, especially that of the upper and middle course, and that a higher modulus of the asphalt mixture can lower the stress level of the lower course. From the wheel tracking test analyses, the upper course of section A and the lower course of section C are weakest, but the layer may need to be replaced. The anti-rutting performance of each course of sections A, B and C is lower than the performance of section D that performs very well in situ. The rutting in sections A, B and C will potentially become deeper. To select the right method to deal with rutting and save repair costs, several test sections milled off to different depths and with different modified asphalt were proposed. The final repair plan depended on the test section. The repair plan for section A was that the top two courses be repaved with modified asphalt mixture. The rehabilitation scheme proved to be successful after three years of project testing.

6. CONCLUSIONS

Premature rutting distress of a freeway in south China was systemically surveyed and the influence of rutting on the smoothness of the pavement was analysed. A RLWT（Rotary Loaded Wheel Tester） was used to analyse pavement rutting performance. The stress state of asphalt pavement under tyre load was analysed with the finite element method.

1) The texture depth and smoothness of asphalt pavement may be largely influenced by rutting.
2) The RLWT can evaluate the anti-rutting performance of asphalt mixture effectively and expediently. The RLWT is also suitable as a QC/A test method in asphalt pavement construction.
3) The finite element analysis showed that the anti-rutting performance of three courses of asphalt pavement are all important, especially the upper course and middle course, and that a higher asphalt mixture modulus can lower the stress level of the lower course of asphalt pavement.
4) Overloading evidently has a linear influence on the stress in asphalt pavement, so overloading should be rigorously controlled.
5) A higher asphalt mixture modulus can decrease the stress level of the lower course of asphalt pavement.

7. REFERENCES

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