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Research on Rutting Model of Semi-Rigid Asphalt Pavement Based on Hamburg Rutting Test

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***Abstract*：** In order to establish a more effective rutting model of semi-rigid asphalt pavement, after sampling on-site,the Hamburg rutting test was conducted to analyze the relationship between ambient temperature, load magnitude,number of load actions and rutting depth; Taking Shami model as a reference,the environmental temperature,load size,load times and asphalt thickness are taken as model parameters;the rutting prediction models of upper,middle and lower surfaces of semi-rigid asphalt pavement structure are established by multiple linear regression analysis,and the models are modified by 6 sections of 4 expressways.The model is used to test 8 sections of 5 expressways,the results show that the average error rate of the calculated value of the model is 15.16%,which is obviously lower than the average error rate of 27.32% of the calculated value of the rut model in the current standard.Therefore,the model has high accuracy and can provide theoretical guidance for the design and maintenance of semi-rigid asphalt pavement.

***Keywords*：** Semi-Rigid Asphalt Pavement; Hamburg Rutting Test; Rut; Rutting Prediction Model

Introduction

Rutting is one of the main diseases of asphalt pavement of high-grade highway in China, which not only affects the driving comfort and safety seriously,but also reduces the service life of highway[1].Semi-rigid asphalt pavement is widely used in China. With the increasing traffic volume of expressways, rutting of semi-rigid asphalt pavement has become a prominent problem, and the pavement damage caused by rutting is as high as 80%[2].The research on rutting of semi-rigid asphalt pavement and the establishment of reliable rutting prediction model can not only predict the rutting depth in highway design, but also contribute to pavement maintenance decision-making[3].

In recent years,many domestic and foreign scholars have done a lot of research on rutting model prediction. In 1987,A. Wijeratne[4] obtained the constitutive relationship between recycled asphalt concrete and original asphalt concrete through repeated load triaxial tests,and established a rutting model based on traffic volume and load;In 2004, Fwa et al[5] put forward a rutting prediction model based on *C-φ* model, and further confirmed the validity of *C-φ* model to asphalt pavement rutting prediction and evaluation; In 2008, Li Honghua[6] compared the indoors rutting test with on-site sampling, the results of the on-site sampling Hamburg rutting test and the indoor forming sample Hamburg rutting test show that the rutting depth of the on-site core sample is generally greater than that of the indoor test, moreover,Hamburg rutting test can evaluate the high temperature anti-rutting performance of asphalt mixture and monitor the construction quality of asphalt pavement;In 2015, Wang Haiyan,et al[7] tested the permanent deformation of six mixtures at different temperatures and wheel load pressures by means of a Hamburg rutting machine,the rutting prediction model considering the mixture property,axle load times, temperature,shear stress and running speed is established; In 2017, Hu Peng,et al.[8] paved a 9m long test section indoors. Through a biaxial accelerated loading test,a rutting prediction model including temperature and load action times was established.However,the test section only has an AC-13 asphalt surface layer. The test results are not applicable to high-grade highways. In 2019, Yang Yonghong, et al.[9] adopted dynamic modulus as an index to reflect the viscoelastic properties of asphalt mixture and its resistance to permanent deformation, based on the three-layer rutting test, a rutting prediction model including asphalt thickness, loading times and dynamic modulus was established.Based on the mechanical experience design method of MEPDG (Mechanical Empirical Pavement Design Guide), Chinese researchers carried out a series of technical researches such as "Research on asphalt pavement design indexes and parameters (2004-318-000-04)". On September 1, 2017, the code for design of highway asphalt pavement (JTG D50-2017)[10] was officially promulgated.The mechanical experience design method of semi-rigid base asphalt pavement suitable for China is formed.However, the rutting prediction models established by the above-mentioned researchers are all based on the test method of indoor formed specimens, which are not closely related to the actual road conditions.

In this paper, a set of rutting prediction models suitable for semi-rigid asphalt pavements will be established through the Hamburg rutting test based on site sampling, and the actual road section data will be used for correction and verification.

1. Hamburg rutting test

1.1 Design of Hamburg rutting test

Rutting test is one of the most important tests in performance test of asphalt mixture.The plan of this test is to carry out the Hamburg rutting test on the upper, middle and lower layers of the core samples of asphalt mixture.The equipment of Hamburg rutting tester[11][12] is shown in Fig. 1 ~ Fig. 2.In the test scheme, four main factors are considered, which are ambient temperature, load size, load times and thickness of specimen. At the same time, Air Bath is chosen as the test environment, finally, the degree of deformation (rutting depth) of the specimen is recorded as the test result.

Figure.1 Hamburg rutting tester

Fig.2 Testing machine roller

（1）Core specimen：In order to reflect the performance of the asphalt mixture under the working condition of the actual pavement more objectively, the cylinder asphalt mixture core samples obtained from the field of the semi-rigid asphalt pavement in Jiangsu Province were selected as the test materials, its initial properties are the same as the asphalt mixture in the Carriageway.The upper layer, middle layer and lower layer of core samples were taken as test pieces, among which the upper layer was 4 cm thick and the material was modified asphalt SMA-13, the middle layer was 6 cm thick and the material was modified asphalt AC-20, and the lower layer was 8 cm thick, the material is modified asphalt AC-25.The core specimen in test is shown in Fig. 3.

Fig. 3 Core specimen in test

（2）Ambient temperature：According to “Asphalt mixture rutting test (T 0719-2011)”in “Test code for asphalt and asphalt mixture in highway engineering”(JTG E20-2011) [13] ，the rutting test temperature adopts 60℃.At the same time, the maximum temperature of 70℃ in the temperature range provided by the Hamburg rutting test is chosen as the temperature variable.

（3）Load size：The standard load of Hamburg rutting test is 705N.According to the traffic load of the highway in Jiangsu Province, three loads of 700N for normal load, 800N and 900N for overload load are selected as the test load variables.

（4）Times of load action:The general loading method of Hamburg rutting test is to load the specimen until the number of round-trip movement of the steel wheel reaches 20000 times or until the specimen deforms to 20mm.Considering that the establishment of the model requires the data result of a certain number of groups, therefore, 10 groups of variables of 2000 times, 4000 times, 6000 times, 8000 times, 1000times, 12000 times, 14000 times, 16000 times, 18000 times and 20000 times were selected as the variables of load times.

1.2 Analysis of test results

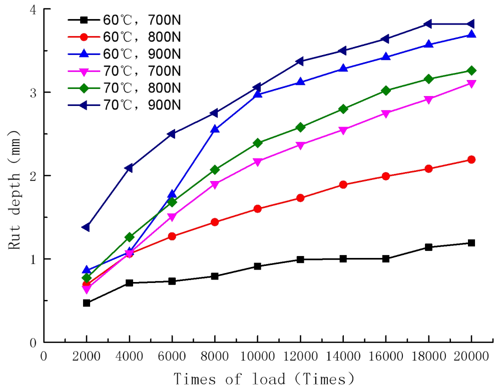

Fig. 4 Development trend of SMA-13 rut depth

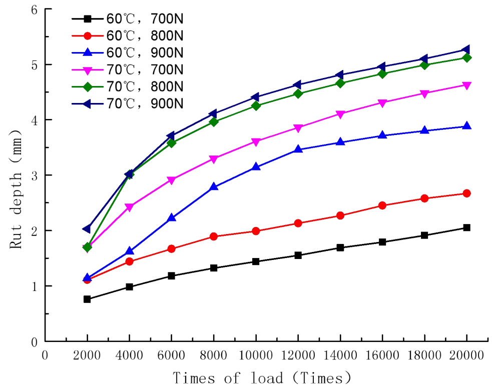

Fig. 5 Development trend of AC-20 rut depth

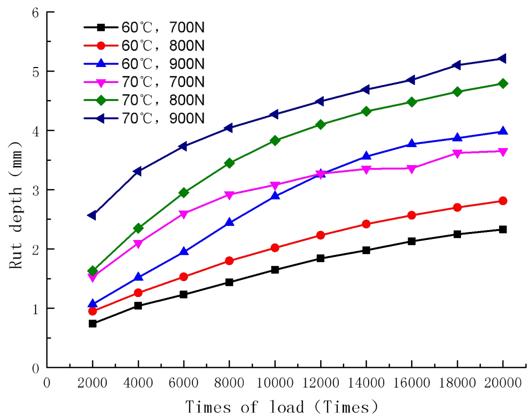

Fig. 6 Development trend of AC-25 rut depth

The results of rut tests for modified asphalt SMA-13, modified asphalt AC-20 and modified asphalt AC-25 are shown in Fig. 4 ~ Fig.6.

A total of 180 valid data were obtained from the Hamburg rutting test.From Fig. 4 to Fig. 6, it can be seen that the rutting depth increases with the increase of ambient temperature, load and load times, and the rutting depth of middle and lower layers is larger than that of upper layers.According to the test data, the initial rutting prediction model can be established by regression analysis.

2. Research on rutting prediction model

2.1 The basic form of rutting prediction model

The Shami model[14] is based on the APA test with specific temperature and load action times ,and the standard rut depth R_0 of asphalt mixture is chosen as regression factor to establish the prediction model of rut depth $R = f(R_0, T, N)$.The results show that the correlation between the results of Hamburg rutting test and actual rutting depth is more than 90% compared with APA test[15].Taking this model as reference, the APA rutting test was replaced by Hamburg rutting test of asphalt mixture, and the rutting prediction model was established by using standard rutting depth R_0 as a parameter reflecting the permanent deformation resistance of the material.The basic form of rutting prediction model for semi-rigid asphalt pavement including ambient temperature, load times, load size and asphalt thickness is obtained, as shown in Formula (1) .

$$\frac{R}{R_0} = k\left(\frac{T}{T_0}\right)^t \left(\frac{P}{P_0}\right)^p \left(\frac{N}{N_0}\right)^n \left(\frac{d}{d_0}\right)^q \quad (1)$$

In the formula:

t , p , n , q——Regression parameters;

k——Correction Factor;

R——Rutting depth of asphalt mixture（mm）;

T、P、N、d——Test conditions set in Hamburg rutting test ,they are temperature (℃), load size (N), load action times (times), and asphalt thickness (mm).

Among them, T_0、P_0、N_0 and d_0 are the standard test conditions, which are 60 °C for T_0,20000 times for N_0,60 mm for d_0 and 700 N for P_0. R_0 is the rutting test depth under standard conditions.

2.2 Establishment of initial rutting prediction model

The results of Meng Shutao[16], Lu Zhenglan[17] and He Aijun[18] show that the rutting depth increases linearly with the thickness of the rutting specimen within a certain range.Therefore, the exponent q of the（d/d_0）term in the rutting prediction model can be taken as 1.

The regression parameters of asphalt mixture with upper, middle and lower layers are obtained by multiple linear regression analysis.The value of R_0 obtained from the Hamburg rutting test is shown in Table 1.

Table 1 Rutting test depth R_0 under standard conditions (unit: mm)

layer	Upper layer	Middle layer	Lower layer
R_0	1.19	2.05	2.33

It can be concluded that the result of the initial rutting prediction model is shown in Formula (2) .

Upper layer：$$\frac{R_1}{R_0} = \left(\frac{T}{T_0}\right)^{3.595} \left(\frac{P}{P_0}\right)^{3.517} \left(\frac{N}{N_0}\right)^{0.457} \left(\frac{d}{d_0}\right)$$

Middle layer：$$\frac{R_2}{R_0} = \left(\frac{T}{T_0}\right)^{4.471} \left(\frac{P}{P_0}\right)^{1.907} \left(\frac{N}{N_0}\right)^{0.409} \left(\frac{d}{d_0}\right) \quad (2)$$

Lower layer：$$\frac{R_3}{R_0} = \left(\frac{T}{T_0}\right)^{3.523} \left(\frac{P}{P_0}\right)^{1.703} \left(\frac{N}{N_0}\right)^{0.464} \left(\frac{d}{d_0}\right)$$

2.3 Modification and verification of the initial rutting prediction model

In formula (1), k is the correction coefficient, which is used to modify the initial rut prediction model, and to establish the relationship between the initial rut prediction model and the actual highway rutting condition.In order to determine the correction coefficient k in the rutting prediction model, so that the finally obtained rutting prediction model can be used in actual design and inspection work, choose to use actual road section data to modify and verify the initial rutting prediction model.

2.3.1 Model modification based on actual pavement structure data

Considering the applicability of the final model, the Huaixu High Speed and Xinyang High speed, which have the same structure as the samples of the Hamburg rutting test, are selected.It also chooses the Huning expressway with SMA-13, SUP-20 and SUP-25 pavement structure and the Yanjiang Expressway with AK-13, AC-20 and AC-25 pavement structure to determine the correction coefficient.The pavement structure and traffic conditions of each section of the expressway are shown in Table 2.

Table 2 Road structure and Traffic conditions

Road section	Upper layer	Middle layer	Lower layer	Cumulative number of axle load(ten thousand times)	Equivalent temperature（℃）
HuNing1	4cmSBS modified asphalt SMA-13	8cmSBS modified asphalt SUP-20	8cm70# Ordinary asphalt SUP-25	2389.3	25.3
HuaiXu	4cmSBS modified asphalt SMA-13	6cmSBS modified asphalt AC-20	8cm70# Ordinary asphalt AC-25	1010.4	24.98
XinYang1	4cmSBS modified asphalt SMA-13	6cm70# Ordinary asphalt AC-20	7cm70# Ordinary asphalt AC-25	539.4	24.82
XinYang2	4cmSBS modified asphalt SMA-13	6cm70# Ordinary asphalt AC-20	7cm70# Ordinary asphalt AC-25	512.72	24.82
XinYang3	4cmSBS modified asphalt SMA-13	6cm70# Ordinary asphalt AC-20	7cm70# Ordinary asphalt AC-25	592.44	24.82
YanJiang	4cmSBS modified asphalt AK-13	6cmSBS modified asphalt AC-20	8cmSBS modified asphalt AC-25	1483.28	24.98

Through the construction of elastic layered system and mechanical calculation, to determine the upper, middle and lower layers of each section of the pressure, the results are shown in table 3.

The original rutting prediction model (2) is used to calculate the rutting depth of the above 6 groups of road sections respectively and make regression analysis with the measured value. The correction coefficient K is obtained as shown in table 4.

Table 3 Pressure on each surface layer (unit: N)

Road section	Upper layer	Middle layer	Lower layer
HuNing1	700	650	360
HuaiXu	700	645	426
XinYang1	700	653	450
XinYang2	700	653	450
XinYang3	700	653	450
YanJiang	700	653	460

Table 4 Inspection results of each road section correction

Road section	Calculated value of model (mm)	Measured value (mm)	Calculated value of the modified model (mm)
HuNing1	4.35	9.4	8.90
HuaiXu	3.45	7.2	7.05
XinYang1	3.03	6.35	6.20
XinYang2	2.96	6.2	6.06
XinYang3	3.16	6.65	6.47
YanJiang	2.86	4.4	5.85
correction coefficient *k*			2.047

The correlation coefficients between calculated and measured values are 0.996 for Multiple R and 0.991 for R Square, which indicates that the regression fitting degree is very high.The P value of Significance F (F significance statistic) is 1.805E-05, which is much smaller than the commonly used statistical significance level of 0.05. The F test is passed, and the overall regression equation is significantly effective.Therefore, the modified model has a high accuracy in predicting the actual road rutting.In the actual prediction calculation, the upper, middle and lower layers of asphalt pavement are calculated respectively by using the model, and then the rutting depth of asphalt pavement is obtained.Then the final rutting prediction model obtained after modification is shown in Formula (3).

$$\text{Upper layer：}\quad \frac{R_1}{R_0}=2.047\left(\frac{T}{T_0}\right)^{3.595}\left(\frac{P}{P_0}\right)^{3.517}\left(\frac{N}{N_0}\right)^{0.457}\left(\frac{d}{d_0}\right)$$

$$\text{Middle layer：}\quad \frac{R_2}{R_0}=2.047\left(\frac{T}{T_0}\right)^{4.471}\left(\frac{P}{P_0}\right)^{1.907}\left(\frac{N}{N_0}\right)^{0.409}\left(\frac{d}{d_0}\right) \qquad (3)$$

$$\text{Lower layer：}\quad \frac{R_3}{R_0}=2.047\left(\frac{T}{T_0}\right)^{3.523}\left(\frac{P}{P_0}\right)^{1.703}\left(\frac{N}{N_0}\right)^{0.464}\left(\frac{d}{d_0}\right)$$

Total rutting depth： $R = \sum R_{\mathrm{i}}$ （i=1，2，3）

2.3.2 Verification of model based on actual pavement structure data

Eight unmaintained sections of five expressways in Jiangsu province, including Huning, Xinyang, Ningjingyan, Suhuaiyan and lianxu, were selected as the test sections.The rutting prediction model formula (3) is used to calculate the above verified road sections, and the calculation results are compared with the rutting model calculation results in the current norm. The results are shown in Table 5.

Table 5 Comparison of calculated value of prediction model with that of standard model

Road section	Calculated value in current specification (mm)	Calculated value of rut prediction model (mm)	Measured value (mm)	Error rate of current specification (%)	Error rate of rutting prediction model (%)
HuNing2	7.04	6.51	6.45	9.14	0.93
HuNing3	10.43	9.53	9.3	12.15	2.47
XinYang4	7.3	9.32	9.84	25.81	5.28
XinYang5	6.9	9.35	9.88	30.16	5.36
XinYang6	7.4	10.31	10.33	28.36	0.19
NingJingYan	5.843	5.297	3.1	88.48	70.87
SuHuaiYan	4.72	5.73	4.6	2.61	24.57
LianXu	9.26	8.48	7.6	21.84	11.58
Average error rate (%)				27.32	15.16

It can be concluded from table 5 that the error rate of the rutting prediction model is lower than the specification error rate in 7 out of 8 sections.The average error rate of the rutting model in the current specification is 27.32%, while the average error rate of the rutting prediction model is only 15.16%.To sum up,the proposed rutting prediction model, Formula (3),has acceptable validity and accuracy.

3. Conclusion

The environment temperature, the acting pressure and the loading times all have a great influence on the rutting depth.With the increase of the environment temperature, pressure and load times, the rutting depth of the specimen strictly increases.

Taking Shami model as a reference, the prediction models of the top, middle and bottom layers of the pavement structure are established through the multiple regression analysis of the Hamburg rutting test data.

According to the revision and verification of the actual road section data, the accuracy of the rutting prediction model in this paper is higher than that in the current specification.

References

[1] Li, SK, Li, D, Fan, B., The rutting reason and prevention measures of semi-rigid base asphalt pavement[J]. Sh anxi Architecture, 2009, 35(9): 283-284.

[2] Shen, JN, Analysis and Preventive Technique of Premature Damage of Asphalt Pavement in Express-way[M]. B eiJing:People's communications publishing house,2004.

[3] Su, K, Sun, LJ, A Summary of Rutting Prediction Method on High Grade Asphalt Concrete Pavements[J]. Highway, 2006(7): 18-24.

[4] Wijeratne A, Sargious M. Prediction of rutting in virgin and recycled asphalt mixtures for pavements using triaxial tests[C]// Association of Asphalt Paving Technologists Proc,1987.

[5] Fwa, TF, Tan, SA, Zhu LY, Rutting prediction of asphalt pavement layer using C-ϕ model[J]. Journal of Transportation Engineering, 2004, 130(5): 675-683.

[6] Li, HH, Mechanism Analysis on Rutting in Asphalt Pavement and Study on Rutting Test[D]. XiAn: Chang'an University, 2008.

[7] Wang, HY, Ji, XP, Wang, YH, Cao, HL, Study of Rutting Prediction Model[J]. Highway, 2015, 60(2):40-45.

[8] Hu, P, Zhang, XN, Rutting Prediction Model of Asphalt Pavement Based on Acceleration Loading Tests by Tandem Axles[J]. Journal of Chongqing Jiaotong University:Natural Science Edition,2017,36(07):33-38.

[9] Yang, YH, Zhang, SL, Zhang, Q, Rutting depth prediction based on dynamic modulus and three-layer wheel track rutting test[J]. Journal of the Xi'an University of Architecture and Technology: Natural Science Edition, 2019, 51(05): 717-723, 762.

[10] JTG D50-2017 Specification of design of highway Asphalt Pavement[S].

[11] Mohammad, LN, Elseifi, MA, Raghavendra A, et al. NCHRP web-only document 219: Hamburg wheel-track test equipment requirements and improvements to AASHTO T324[R].Washington DC:Transportation Research Board, 2015.

[12] Swiertz, D, Ling, C, Teymourpour, P, et al. Use of the Hamburg wheel-tracking test to characterize asphalt mixtures in cool weather regions[J]. Transportation Research Record, 2017(2633): 9-15.

[13] JTG E20-2011 Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering[S].

[14] Shami, HI, Lai, JS, et al. Development of temperature-effect model for predicting rutting of asphalt mixtures using georgia loaded wheel tester[J]. SAGE Publications, 1997, 1590(1):17-22.

[15] Hall, KD, Williams, SG, Acquisition and evaluation of Hamburg wheel-tracking device[R]. Fayette-ville: Unive rsity of Arkansas, 1999.

[16] Meng, ST, Huang, XM, Fan, YW, et al. Analysis of Dynamic Stability Test for HMA High Te-mperature Per formance[J]. Journal of Highway and Transportation Research and Development, 2005(11):18-21, 53.

[17] Lu, ZL, Sun, LJ, Research on Rutting Prediction of Asphalt Pavement[J]. Journal of Tongji University:Natural Science Edition, 2007(11):1476-1480.

[18] He, AJ, The study of permanent Deformation in Asphalt Pavement by Rutting test[D]. Chong Qing:Chong qing Jiao tong University,2006.