Research on Permanent Deformation and Maintenance Measures of Existing Asphalt Payment Based on Rut Damage

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Abstract. In order to study permanent deformation of Expressway Asphalt Payment and the corresponding maintenance counter measures which have run away. In this paper, full thickness loading test of asphalt surface is used to analyze the cumulative run deformation capacity and residual bearing capacity of the existing pavement with different run depths and analyze the deformation layer of the core sample after loading and the test results after painting and curing. It is included that the peak rutting depth of existing pavement line to structural damage is 17.6 mm and the permanent rutting deformation depth is 27.3 mm. At the same time, the pavement maintenance counter measures and evaluation standard for permanent deformation of existing asphalt pavement are observed for the three rutting depth ranges.

Keywords: Existing Aspect Payment · Rutting Deformation · Residual Carrying Capacity · Maintenance Countermeasure

1 Introduction

Transportation is the foundation of national economic development and an important criterion for measuring a country's level of modernization [1, 2]. But with the increasing vehicle load, overloading, and complex and ever-changing environmental effects, diseases such as ruts on asphalt pavement on highways are also increasing. The appearance of rutting diseases will to some extent shorten the service life of the road surface, cause economic losses, and even cause local structural damage in a short period of time. This not only affects the service performance of the road surface, but also affects the comfort of road driving. In serious cases, it can pose a threat to safe driving and affect personal safety [3–5]. Based on this background, this article focuses on the rutting disease of existing highways. Through indoor asphalt surface layer full thickness accelerated loading tests, a set of evaluation methods for permanent deformation of existing asphalt pavement is studied. At the same time, reasonable maintenance strategies are specified

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according to different rutting depths. The research results of this article are helpful for maintaining the good service function of existing pavement. The preservation, preservation, and even extension of the service life of existing pavement assets are of great significance.

2 Research Sample

This article focuses on on-site sampling of a highway in Jiangsu Province, and the pavement structure types are shown in Table 1.

Table 1. Types of Study Road Section Structures

Horizon	Thickness/cm	Material type
Upper layer	4	Modified asphalt AK-13
Middle surface layer	6	Modified asphalt AC-20
Lower layer	8	Ordinary asphalt AC-25
basic level	40	Cement stabilized crushed stone
Soil foundation	20	Lime stabilized soil

The highway is currently in the middle and later stages of its design life. With the increasing traffic volume and the increasing proportion of trucks, overloading and over limit phenomena are severe. The road surface has been operating under overload for a long time, and some sections have already experienced serious rutting diseases. The various performance of the road surface is still declining, and the depth of rutting on the road surface is increasing year by year. The material performance of the road surface is declining, and the overall performance of the structural layer is declining.

In order to study the development trend of rutting diseases on the expressway and formulate different maintenance plans to prevent further development of pavement diseases. On the basis of highway road condition detection data, this study first selected suitable sections for research, and then used a three meter straightedge (0.1 mm level) to measure on-site. Samples were taken in a gradient of 1 mm. Take 2 different rut depths at the same position on the right wheel track of the driving lane Φ 300 mm core samples were used for parallel testing. In order to facilitate subsequent research, core samples with the same rut depth were assigned the same number. The core sample numbers are shown in Table 2.

Table 2. Core sample number

Disease type	rut depth						
Rutting	8 mm	9 mm	10 mm	11 mm	12 mm	13 mm	14 mm
Sample number	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}
Disease type	rut depth						
Rutting	15 mm	16 mm	17 mm	18 mm	19 mm	20 mm	21 mm
Sample number	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}	X_{20}	X_{21}

Note: The rut depth measured on site is rounded off using the rounding method for the convenience of this study

3 Research on the Development Trend of Existing Road Rutting Diseases

3.1 Experimental Design

The rutting disease is one of the main forms of asphalt pavement diseases in China. The factors affecting pavement rutting are complex, and many influencing factors overlap with each other [6–9]. It is difficult to simulate the actual environment and stress situation of the pavement using simple indoor tests. Therefore, combined with relevant research results [10–12], this paper develops the full thickness accelerated loading test of asphalt pavement layer, which can effectively simulate the environment and stress situation of the pavement, It is also possible to obtain data on changes in road performance in a relatively short period of time.

The full thickness accelerated loading test of asphalt surface layer adopts specimens as Φ 300 mm core sample, core sample and test mold are shown in Fig. 1, and the equipment used for the test is the standard rut testing machine (RP-0719A). This experiment applies a load of 0.7 MPa to the core sample under 70 °C conditions and repeatedly applies it, while automatically recording the rutting depth value under loading. The experiment is conducted until the core sample structure is completely damaged, and the general loading can reach more than 200000 times.

The full thickness accelerated loading test of the asphalt surface layer adopts an iron mold with a length of 30 cm * width of 30 cm * height of 18 cm. The mold is detachable around it, and to prevent the deviation of the rut trajectory during the test, cement mortar [13] (by weight, cement: sand: water = 1:3:0.5) is used to fill the gaps around the core sample and the mold. The middle and lower layers are wrapped in tin paper to prevent mortar from infiltrating the gaps of the core sample opening. The test starts after 24 h of room temperature curing.

Fig. 1. Accelerated loading test with full thickness of asphalt surface

3.2 Analysis of Accumulated Rutting Deformation

The standard rut testing machine (RP-0719A) [14] was used for the test. Based on past experience, after 72 h of loading (180000 times), the core sample basically exhibits collapse type failure or stable rut depth. The unified plan for continuous loading of the pavement core sample in this design is 72 h. Under the premise of controlling the loading time to be consistent, the variation trend of the rut depth of the pavement core sample after continuous loading is analyzed. The typical curve of the comprehensive layer thickness asphalt mixture rutting test is shown in Fig. 2.

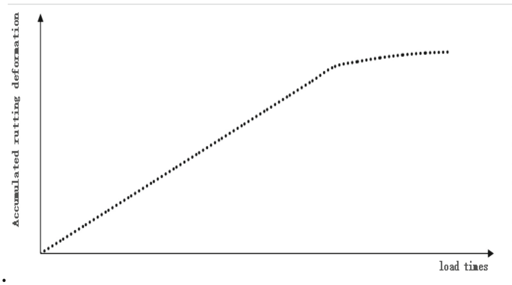

Fig. 2. Typical curve of full layer thickness aspect mixture rutting test

The full thickness accelerated loading test of asphalt surface layer can be idealized into two stages, as shown in Fig. 3. In the first stage (rapid development zone), with the increase of loading times, the cumulative rutting deformation increases rapidly, and develops to the second stage (stable/collapse period). The cumulative rutting deformation tends to stabilize, and the slope of the curve is significantly smaller than that of the first stage. The transition node from the first stage to the second stage is called the stable/collapse node.

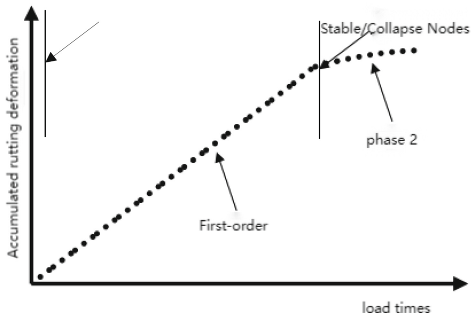

Fig. 3. The relationship between cumulative rutting deformation and loading time

After the on-site core sample underwent the full thickness accelerated loading test of the asphalt surface layer, the loading rut depth and stable collapse/collapse nodes are shown in Table 3. The relationship between the on-site rut depth and the loading rut depth is shown in Fig. 4, and the relationship between the on-site rut depth and stable/collapse nodes is shown in Fig. 5.

Table 3. Cumulative total rutting depth and stability/collapse node

number	Load rut depth (mm)	Stable/Collapse Nodes	number	Load rut depth (mm)	Stable/Collapse Nodes
X_8	five point two	64 h	X_{15}	fifteen point two	44 h
X_9	seven point nine	60 h	X_{16}	fifteen point three	32 h
X_{10}	nine point four	56 h	X_{17}	sixteen point two	36 h
X_{11}	eleven point eight	48 h	X_{18}	thirteen point eight	28 h
X_{12}	twelve point five	52 h	X_{19}	fourteen point one	24-h
X_{13}	fourteen point four	48 h	X_{20}	sixteen point eight	28 h
X_{14}	fourteen point nine	40 h	X_{21}	fifteen point two	20 h

The depth of on-site rutting and the depth of on-site core asphalt surface layer under full thickness accelerated loading test are regressed using polynomial regression, and the regression equation is shown in formula (1):

$$y = -0.1087x^2 + 3.8248x - 17.784 \quad \left(R^2 = 0.9231\right) \tag{1}$$

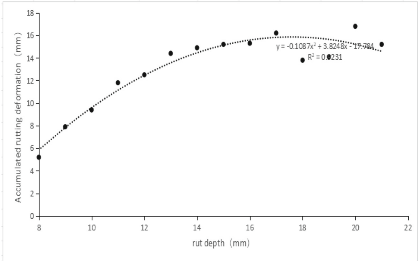

Fig. 4. Relationship between total rutting depth and total rutting depth

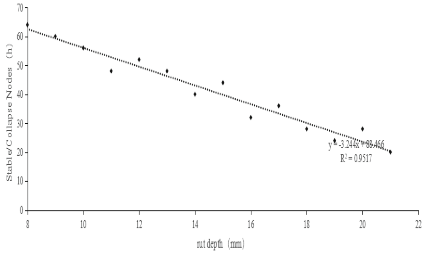

Fig. 5. Relationship between running depth and stability/collapse node

Linear regression is used to determine the stability/collapse node between the on-site rutting depth and the full thickness accelerated loading test of the asphalt surface layer of the on-site core sample. The regression equation is shown in formula (2):

$$Y = -3.244x + 88.466$$
$$\left(R^2 = 0.9517\right) \tag{2}$$

Regression formulas (1) and (2) both show high correlation.

From Fig. 6, it can be seen that the larger the on-site rut depth, the greater the loaded rut depth. From regression formula (1), it can be calculated that the on-site rut depth corresponding to the curve turning point is 17.6 mm. It can be inferred that when the on-site rut depth reaches 17.6 mm, the maximum vertical deformation borne by the road surface gradually stabilizes and obvious lateral deformation begins to appear. When loaded, the observation of the core sample change state indicates that bulges begin to appear on both sides of the rut.

From Fig. 4, it can be seen that as the depth of on-site ruts increases, the stable/collapsed nodes show a gradually decreasing trend. From regression formula (2), it can be calculated that the on-site rut depth corresponding to the stable/collapsed node of 0 h is 27.3 mm, which corresponds to the permanent deformation of road structure ruts [15–17] studied in this paper being 27.3 mm. Therefore, when the rut depth reaches 27.3 mm, with the increase of vehicle load, the road surface no longer compresses and deforms, and structural damage begins to occur, which poses great risks to driving safety.

3.3 Research on Rut Deformation Rate

The full thickness accelerated loading test of asphalt surface layer was used to analyze the rutting deformation rate of existing asphalt pavement [18–20]. This article uses the rutting deformation rate, which is the amount of deformation caused by each loading, as the evaluation index for permanent deformation of asphalt pavement. Due to the fact that the rutting depth in the second stage (stable/collapse period) no longer increases with the increase of loading times, the permanent deformation of asphalt pavement is not closely related to it. Therefore, this section only studies the rutting deformation rate in the first stage (rapidly developing zone). Assuming that after the first stage (rapid development zone) of loading, the permanent deformation of the pavement core sample has been achieved, the experimental loading variation is shown in Table 4. The relationship between the rutting deformation rate of the loading test and the number of loading cycles is shown in Fig. 6.

Table 4. Rutting deformation rate of road core specifications after loading

number	Load rut depth/mm	Stable/Collapse Nodes	Loading times (10000 times)	Rut deformation rate (μ M/time)
X_8	five point two	sixty-four	sixteen point one	zero point zero three
X_9	seven point nine	sixty	fifteen point one	zero point zero five
X_{10}	nine point four	fifty-six	fourteen point one	zero point zero seven
X_{11}	eleven point eight	forty-eight	twelve point one	zero point one zero
X_{12}	twelve point five	fifty-two	thirteen point one	zero point one zero
X_{13}	fourteen point four	forty-eight	twelve point one	zero point one two
X_{14}	fourteen point nine	forty	ten point one	zero point one five
X_{15}	fifteen point two	forty-four	eleven point one	zero point one four
X_{16}	fifteen point three	thirty-two	eight point one	zero point one nine
X_{17}	sixteen point two	thirty-six	nine point one	zero point one eight
X_{18}	thirteen point eight	twenty-eight	seven point one	zero point two zero
X_{19}	fourteen point one	twenty-four	six	zero point two three
X_{20}	sixteen point eight	twenty-eight	seven point one	zero point two four
X_{21}	fifteen point two	twenty	five	zero point three zero

According to the linear regression equation between the change in each loading test and the number of loading tests, the R2 reaches 9.65, indicating a high correlation between the two. From Fig. 6, it can be seen that as the depth of on-site ruts increases, the rut deformation rate gradually increases, indicating that the larger the depth of on-site ruts, the greater the rut deformation rate.

In order to propose the evaluation criteria for permanent deformation of asphalt pavement with different rutting depths in the full thickness accelerated loading test of asphalt surface layer, the difference between the rutting deformation rate of each core sample and the average rutting deformation rate of all core samples is used as the interval node. The difference between the two is shown in Table 5.

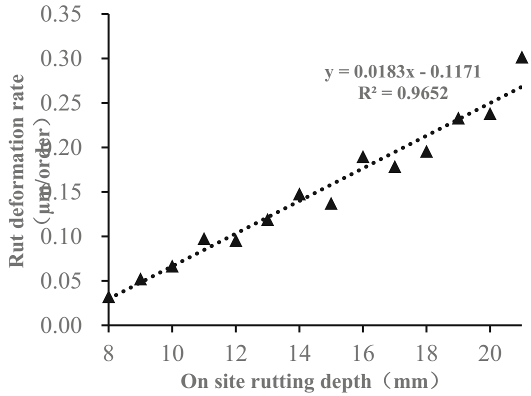

Fig. 6. Relationship between running deformation rate and loading times

Table 5. Difference between average rutting deformation rate and rutting deformation rate

number	Difference	number	Difference	number	Difference	number	Difference	number	Difference
X_8	-0.1	X_{11}	-0.1	X_{14}	zero	X_{17}	zero	X_{20}	zero point one
X_9	-0.1	X_{12}	-0.1	X_{15}	zero	X_{18}	zero	X_{21}	zero point two
X_{10}	-0.1	X_{13}	zero	X_{16}	zero	X_{19}	zero point one		

According to the difference in the table above, it can be roughly divided into three intervals, which are less than or equal to 12 mm, less than or equal to 18 mm if it is greater than 12 mm, and greater than 18 mm. The corresponding rutting rate is less than or equal to 0.1, respectively μ M/time, greater than 0.1 μ M/time less than or equal to 0.2 μ M/time, greater than 0.2 μ. Based on the previous conclusion, the evaluation criteria for permanent deformation of the pavement are proposed as follows:

(1) When the rut deformation rate is ≤0.1 μ At m/time, the old road surface has good resistance to rutting deformation;
(2) When the rut deformation rate is greater than 0.1 μ M/time, ≤0.2 μ At m/time, the resistance of the old road surface to rutting deformation weakens, posing a risk of accelerated damage;
(3) When the rut deformation rate RD is greater than 0.2 μ At m/time, the old road surface has poor resistance to rutting deformation, and timely measures should be taken to treat the existing road surface.

4 Research on Maintenance Strategies

The use of a new asphalt surface layer as an overlay on an existing road surface is a very typical reinforcement method, which has been widely used both domestically and internationally. However, before adding pavement, it is necessary to treat the existing pavement diseases reasonably to prevent unnecessary economic losses caused by the insufficient anti rutting deformation ability of the lower bearing layer in the short term. Therefore, this article focuses on all core samples after the full thickness accelerated loading test of the asphalt surface layer, and uses a concrete drilling and coring machine (HZ-20 type) along the center position of the rut for coring (Φ 100 mm), the loaded specimen and drilled core sample are shown in Fig. 7. After drilling the core sample, the deformation layer after loading can be determined to guide the treatment layer of road surfaces with different rut depths before paving. In order to study the pavement overlay schemes under different rutting deformation rates, this paper also conducted secondary on-site core sampling work.

Fig. 7. Loaded specifications and drilled core sample

By manually observing the rutting deformation of the drilled core sample, combined with the evaluation criteria of the road surface's resistance to rutting deformation in Sect. 2.3, the results are as follows:

(1) When the rut deformation rate is ≤0.1 μ At m/time, the rutting deformation layer occurs in the middle and upper layers, without involving the lower layer;
(2) When the rut deformation rate is greater than 0.1 μ M/time, ≤0.2 μ At m/time, 66.7% of the rutting deformation layer occurs in the middle and upper layers, and 33.3% involves the lower layer;
(3) When the rut deformation rate is greater than 0.2 μ At m/time, the rutting deformation layer occurs in the upper, middle, and lower layers.

In order to determine the layers that need to be treated before adding pavement for different rut deformation rates, this article adopts Φ The 300 mm core sample cutting method is used to simulate milling at different layers on site, and the full thickness accelerated loading test of the asphalt surface layer is also used (the test conditions are consistent with the previous text), combined with the rut rate to determine the overlay scheme for different rut depth ranges on the road surface.

For different rutting deformation rates, this article proposes the following three overlay schemes:

- Option 1: Directly lay 4 cm modified SMA-13 mixture;
- Option 2: Milling and planning the 4 cm original upper layer, backfilling with 4 cm modified SMA-13 mixture, and then adding 4 cm modified SMA-13 mixture;
- Option 3: Milling and planning 10 cm of the original upper and middle surface layer, backfilling 6 cm of modified AC-20 mixture, and then adding 4 cm of modified SMA-13 mixture.

Three schemes involve fully coating modified emulsified asphalt with a solid content of 0.2 kg/m^2 between layers. The deformation rate of ruts in the indoor loading test of the core sample after laying is shown in Table 6.

Table 6. Rutting deformation rate after additional payment

Plan number	Range of rutting deformation rate	Load rut depth (mm)	Stable/Collapse Nodes	Rut deformation rate（ μ M/time)
Plan One	≤ 0.1	thirteen point three	sixty-eight	zero point zero seven eight
	(0.1, 0.2)	eighteen point five	sixty	zero point one two two
	> 0.2	twenty point five	fifty-six	zero point one four five
Option 2	≤ 0.1	ten point four	sixty	zero point zero six nine
	(0.1, 0.2)	twelve point eight	sixty-four	zero point zero seven nine
	> 0.2	sixteen point eight	fifty-two	zero point one two eight
Plan Three	≤ 0.1	nine point eight	sixty-eight	zero point zero five seven
	(0.1, 0.2)	twelve point seven	seventy-two	zero point zero seven zero
	> 0.2	fourteen point five	sixty-eight	zero point zero eight five

From Table 6, it can be seen that after adding the overlay, the core sample undergoes the full thickness accelerated loading test of the asphalt surface layer, and the rutting deformation rate decreases. This indicates that adding the overlay causes the existing layer to move downwards, increasing the overall deformation resistance of the pavement structure. According to the research conclusion in Sect. 2.3, it is believed that the rutting deformation rate is ≤0.1 μ At m/time (blue background in Table 6), the old road surface has good resistance to rutting deformation. According to the rutting deformation rate, it can be seen that the more layers of treatment before paving, the greater the tolerance for existing road ruts. Scheme 3 is applicable to all road rut sections studied in this article. Based on economic considerations, this article proposes the following maintenance strategies for different road rut sections:

(1) When the rut deformation rate is $\leq 0.1\ \mu$. When m/time, adopt scheme one;
(2) When the rut deformation rate is greater than 0.1 μ M/time, $\leq 0.2\ \mu$. When m/time, scheme 2 is adopted;
(3) When the rut deformation rate is greater than 0.2 μ. When m/time, scheme three is adopted.

5 Conclusion

The main conclusions drawn from this article are as follows:

(1) This article studies the full thickness accelerated loading test of asphalt pavement, which can be effectively used for permanent deformation of existing asphalt pavement.
(2) Through the analysis of permanent deformation of asphalt pavement, this article proposes the rutting deformation rate index, and proposes evaluation standards for permanent deformation of asphalt pavement for different rutting deformation rate ranges.
(3) Through maintenance strategy research, three different types of overlay maintenance strategies are proposed for the pavement structure studied in this article:
    a) When the rut deformation rate is $\leq 0.1\ \mu$. When m/time, adopt scheme one;
    b) When the rut deformation rate is greater than 0.1 μ M/time, $\leq 0.2\ \mu$. When m/time, scheme 2 is adopted;
    c) When the rut deformation rate is greater than 0.2 μ. When m/time, scheme three is adopted.
    d) The experiment studied in this article is time-consuming and the sample size is limited. Readers can further expand their research.

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References

1. Wang, Y.: Looking Back at the 30 Years of Reform and Opening Up and Looking Forward to the New Scale of Highway Construction - Press Conference on the Achievements of Highway Transportation Development in the 30 Years of Reform and Opening Up by the Ministry of Transport. Transportation World (2008)
2. Sha, Q.: The phenomenon, causes, and prevention of early damage to asphalt pavement on highways. Transportation World (U09) 17–18 (2004)
3. Huang, X., Fan, Y., Zhao, Y., et al.: Investigation and experimental analysis of high-temperature rutting on asphalt pavement of highways. Highw. Transp. Technol. **24**(5), 5 (2007)
4. Highway Incident Report: Motorcoach Medical Crossover and Collision with Sport Utility Vehicle, Hewitt, Texas, 14 February 2003 (2005)
5. Xu, S.: The rutting depth of asphalt pavement and driving safety. J. Beijing Inst. Arch. Eng. **10**(1), 5 (1994)
6. Shen, J., Li, F., Chen, J.: Analysis and prevention measures for early damage of asphalt pavement on highways. People's Transportation Press (2004)

7. Eisenmann, J., Hilmer, A.: Influence of wheel load and impact pressure on the rusting effect at asphalt pavement experiences and theoretical investments. In: Sixth International Conference, Structural Design of Asphalt Pavement, vol. i, Procedures, University of Michigan. Publication of Michigan University, Ann Arbor (1987)
8. Dawley, C.B., Hogewiede, B.L., Anderson, K.O.: Mitigation of facility rutting of asphalt concrete payments in letterbridge, Alberta, Canada (with discussion and closure). J. Assoc. Asphalt Payment Technol. 59 (1990)
9. Kim, J.R., Drescher, A., Newcomb, D.E.: Rational test methods for predicting permanent deformation in asphalt concrete pavement. Final report Compression (1991)
10. Zhang, Z., Zhang, Y., Li, D., et al.: Exploration of using rutting as a design indicator for asphalt pavement. J. Beijing Inst. Technol. **34**(8), 4 (2008)
11. Wu, J., Ye, F.: Analysis of rutting deformation on asphalt pavement based on MLS66 accelerated loading test. J. Build. Mater. **17**(3), 8 (2014)
12. Ji, X., Zheng, N., Liu, Y., et al.: Prediction of rutting under full scale accelerated loading on asphalt pavement. J. Beijing Inst. Technol. **39**(3), 5 (2013)
13. Wang, J.: The strength characteristics of "cement sand." Northwest Water Res. Water Eng. **8**(1), 6 (1997)
14. Liu, Z.: Rut testing machine: CN2357036Y (2000)
15. Zhang, J.: Numerical simulation of permanent deformation of asphalt pavement and prediction of rutting. J. Hebei Univ. Technol. **40**(4), 4 (2011)
16. Peng, S.: Research on rutting tests at different temperatures and analysis of permanent deformation parameters. Abstract Highw. Transp. (10), 39–41
17. Cao, L., Li, L., Sun, D.: Prediction of permanent deformation of asphalt layer based on rutting test. J. Build. Mater. **12**(5), 4 (2009)
18. Zhang W.: Research on the Ultimate Bearing Capacity and Service Life Prediction of Asphalt Pavement. Hunan University (2009)
19. Sun, Y.: Analysis of bearing capacity and residual life evaluation of pavement structure. Heilongjiang Transportation Technology **3**, 2 (2010)
20. Cao, D., Xu, B., Ding, R., et al.: An indoor evaluation method for the bearing capacity of drainage asphalt pavement: CN108896421A (2018)
21. Ni, L.: New Concept and Detection Technology Application in Maintenance Design of Asphalt Pavement on Freeways. Highway Transportation Technology: Applied Technology Edition (2006)
22. Wang, C.: Research on Asphalt Pavement Overlay Technology. Chang'an University (2008)
23. Lai is full Research on the Structure and Material Properties of Asphalt Overlay on Old Cement Concrete Pavement. Southeast University