# Study on the Pavement Structural Performance of Highways in the North China Region Based on Pavement Distress and Ground Penetrating Radar

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***Abstract*****—**With the rapid expansion of road construction mileage in China, the scale of road maintenance needs has concurrently escalated. As the service life of roads extends, the design of pavement repair and maintenance emerges as a crucial component in preserving the excellent performance of the pavement. The remaining service life of asphalt pavement structure is a vital parameter in the lifecycle maintenance design of asphalt pavements. Based on an analysis of pavement structural integrity, this study presents a characterization and assessment of the remaining life of existing asphalt pavement structures. It proposes indicators such as the transverse crack spacing and the length of longitudinal cracks. The transverse crack spacing decreases with an increase in maintenance intervals and with the extended use of semi-rigid base layer structures, although this trend becomes less pronounced after maintenance intervals exceed 4 years. The length of longitudinal cracks increases with longer maintenance intervals, but this trend weakens after five years. This system can support the enhancement of standardization and scientific design in highway maintenance decision-making processes.

***Keywords*****—**Structural integrity, highways, pavement evaluation, asphalt concrete pavement.

## I. Introduction

In recent years, with the rapid development of highway construction in China, the mileage of expressways opened to traffic has exceeded 170,000 kilometers, and the scale of highway maintenance mileage is increasing day by day. However, in the maintenance process, the judgment of maintenance time and the selection of maintenance measures are highly subjective, lacking sufficient basis support and lack of grasp of the overall status quo of road surface [1]. In the process of asphalt pavement maintenance design, its core is the evaluation of the existing pavement status and the analysis of the residual use value of the structure, which plays a role in the design process. In this paper, it is proposed to evaluate the residual use value of expressway asphalt pavement structure by using the existing pavement structural integrity, which can provide reference for the later expressway maintenance engineering design.

## II. Research Background of Pavement Structural Integrity

The remaining service life of asphalt pavement structure is an important parameter in the design of major repair and maintenance of asphalt pavement [2]. There are indirect method and direct method to evaluate the residual life of pavement structure. The indirect method evaluates the residual value of pavement structure by calculating the effective structure number of pavement structure and reflects the role that the existing pavement structure can play in the new pavement structure [3]. The direct method evaluates the residual life of pavement structure by calculating the number of residual loads. Pavement structure, as a repairable system, can accurately describe the condition of pavement structure that has been in service. As an indicator of the role of the old pavement structure in the new pavement structure, the residual value can enrich the accuracy of the characterization of the condition degree of pavement structure, which is expressed by equivalent service life [4].

In the process of service, the surface layer, base layer and soil foundation of asphalt pavement structure appear diseases, which will lead to the destruction of the integrity of pavement structure and affect the remaining life of pavement structure. The evaluation of pavement structural integrity mainly considers surface integrity, base integrity and soil foundation integrity.

## III. Study on Surface Integrity of Pavement Structure

Under the action of driving load and natural environment, the asphalt pavement surface structure produces cracks, block cracks, longitudinal cracks, transverse cracks, pits, looseness, subsidence, repair and other diseases, which reduces the driving quality of the road surface, leads to rain to accelerate the damage of the road surface, and reduces the service life of the pavement structure. At present, the Highway Technical Condition Assessment Standard uses the pavement failure rate (DR) to evaluate the pavement damage condition, and the pavement failure rate is the sum of the reduced damaged area of various damages and the percentage of the pavement survey area. In this study, the integrity evaluation of the asphalt pavement structural surface adopts the failure rate (DR) index, as shown in (1):

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$$DR = 100 \times \frac{\sum_{i=1}^{i_0} w_i A_i}{A} \tag{1}$$

DR: Pavement failure rate, which is the sum of the reduced damaged area of various damages and the percentage of the pavement survey area (%); $A_i$: Area of Type i pavement damage ($m^2$); A: Survey of the road surface area; Wi: Weight of Class i pavement damage.

## IV. Research on the Integrity of Pavement Structure Base

For semi-rigid base asphalt pavement structure, the main diseases of base are transverse crack, longitudinal crack, loose and so on. The transverse cracks are mainly caused by the shrinkage of the semi-rigid base, and are usually reflected to the asphalt surface, which is manifested as the transverse cracks throughout the whole width [5]. The longitudinal cracks are mainly due to the low strength of the base material and the insufficient bearing capacity of the base structure, the longitudinal cracks appear along the carriageway when the heavy load wheel is rolled, or the new and old pavement materials are inconsistent or the construction of improper overlap often cause the internal bearing capacity of the pavement structure to be uneven, and the longitudinal cracks appear along the connection of the new and old pavement. In order to evaluate the integrity of asphalt pavement structure base, the research is mainly based on transverse crack spacing, longitudinal crack length and base failure rate.

*(1) Transverse Crack Spacing*

Since the base layer is covered by the pavement structure, it is not easy to detect. Firstly, the relationship between the transverse crack spacing of the road surface (which can be calculated according to the detection data of the automatic detection system) and the damage condition of the base layer is studied [6].

By analyzing the data of lateral crack spacing of 3000 km expressway, it is found that the transverse crack spacing is correlated with the maintenance time interval, and the transverse crack spacing decreases with the increase of maintenance time interval, but the law of maintenance time interval is no longer obvious after more than 4 years. It shows that the transverse cracks are mostly reflected to the road surface after a certain year of maintenance engineering, and the transverse crack spacing of the road surface can reflect the integrity of the semi-rigid base structure to a certain extent.

The correlation between the transverse crack spacing and the service life of semi-rigid base structure of 3000 km expressway is analyzed. It is found that the transverse crack spacing is correlated with the service life of semi-rigid base structure, and the transverse crack spacing decreases with the increase of service life of semi-rigid base structure. The transverse crack spacing of the road surface can reflect the integrity of the semi-rigid base structure to some extent.

Xuanda Expressway was built in 2000, and the semi-rigid base structure has been used for 17 years. Except for some sections maintained in 2017, the transverse crack spacing in the upstream and downstream directions has been less than 20 meters, including the section with 4 cm cover maintenance in 2015.

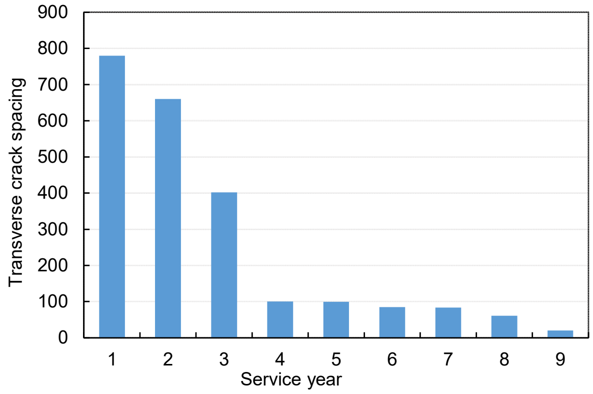


Fig. 1 Transverse crack spacing and maintenance time interval

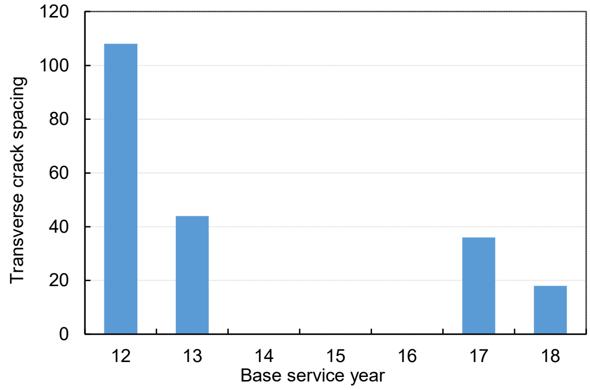


Fig. 2 Transverse crack spacing and service life of semi-rigid base

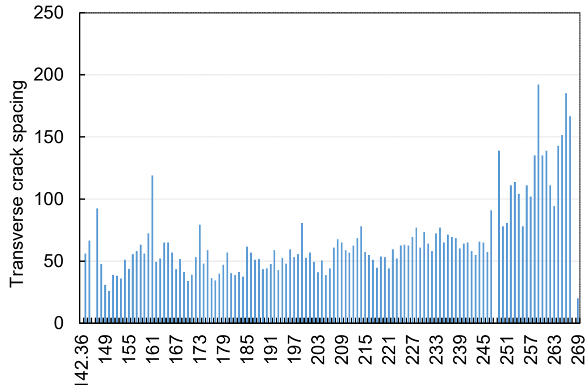


Fig. 3 Transverse crack spacing (ascending)

Another Expressway was built in 1999, and the semi-rigid base structure has been used for 18 years. Except for some sections maintained in 2016 and 2017, the transverse crack spacing in the upstream and downstream directions has been less than 40 meters.

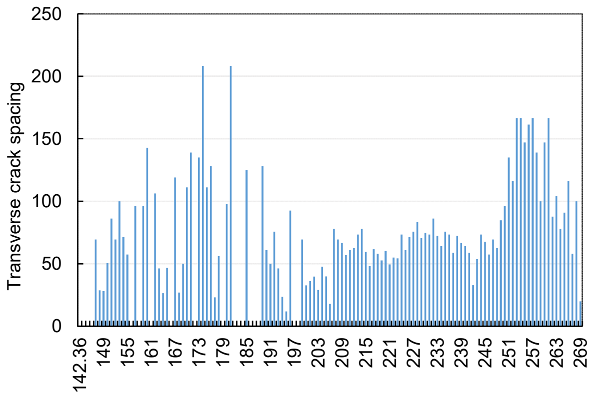


Fig. 4 Transverse crack spacing of Xuanda High speed (descending)

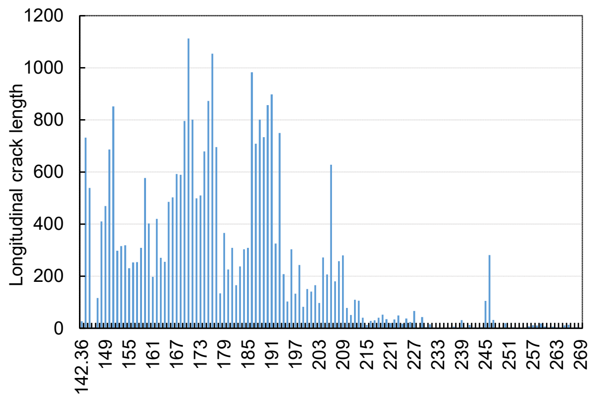


Fig. 5 Transverse crack spacing (upward direction)

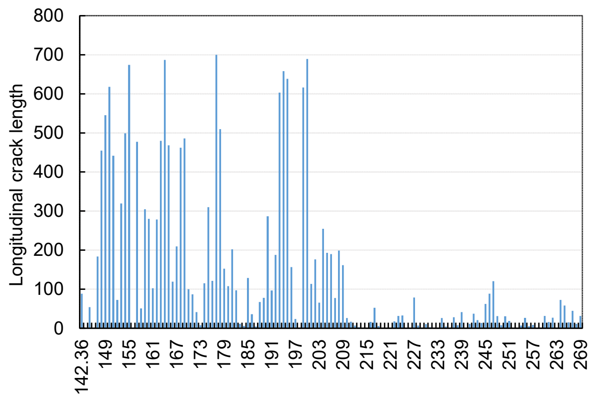


Fig. 6 Transverse crack spacing of pavement (downward direction)

*(2) Longitudinal Crack Length*

By analyzing the longitudinal crack length data of 3000 km expressway, it is found that the longitudinal crack length per kilometer is related to the maintenance time interval to a certain extent, and the longitudinal crack length per kilometer increases with the increase of the maintenance time interval, but the law is no longer obvious after more than 5 years. The longitudinal crack length per kilometer of the road table can reflect the integrity of the semi-rigid base structure to a certain extent.

The correlation between the length of longitudinal crack per kilometer and the service life of semi-rigid base structure of 3000 km expressway is analyzed, and it is found that there is no obvious relationship between the length of longitudinal crack per kilometer and the service life of semi-rigid base structure.

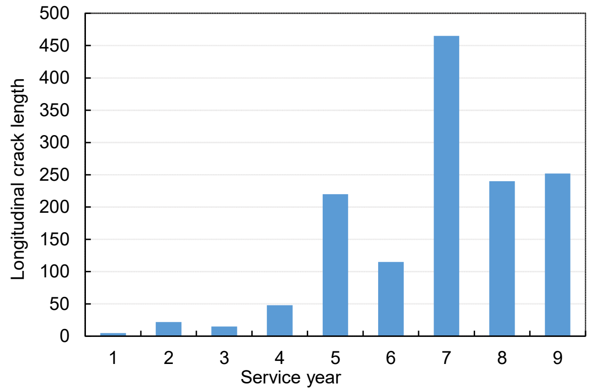


Fig. 7 Longitudinal crack length and maintenance time interval per kilometer

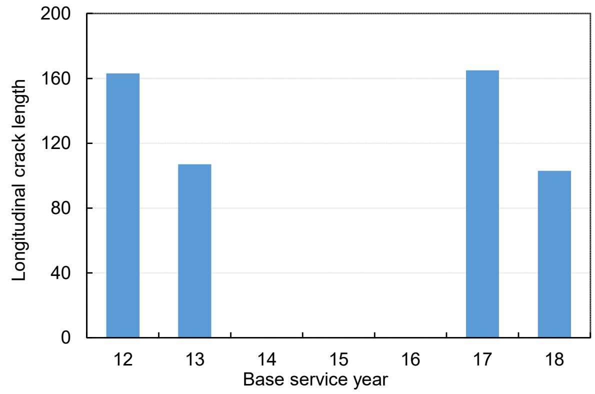


Fig. 8 Length of longitudinal crack per kilometer and service life of semi-rigid base

*(3) Base Damage Ratio*

In view of the fact that the indexes of transverse crack spacing and longitudinal crack length cannot fully reflect the integrity of semi-rigid base structure, the project team put forward the index of base failure ratio to reflect the integrity of asphalt pavement base structure [7]. Base damage ratio is the sum of the damaged area of the base structure of the pavement and the percentage of the pavement survey area. Diseases include cracks, breakage, looseness, etc.

$$SDR = 100 \times \frac{\sum_{i=1}^{i_0} A_i}{A} \qquad (2)$$

SDR: damage rate of the base, which is the sum of the damaged area of the base and the percentage of the pavement survey area (%); $A_i$: Area of damage to Class i base ($m^2$); A: the base area of the survey.

Ground-penetrating radar detection can be used to calculate the damage rate of asphalt pavement base structure [8], [9]. Firstly, a radar image database was established to detect the pavement structure, calculate the damage rate of the pavement, and evaluate the integrity of the basic structure of the project section. The integrity of the semi-rigid base can also be evaluated by using the core sampling data and the results of the road surface damage investigation [10]. The damage rate of the base is calculated according to the damage proportion of the base and the survey result of the pavement disease.

## V. Pavement Structure Subgrade Integrity Research

In the process of service, some sections of expressways will produce a certain degree of settlement, which is manifested as uneven pavement structure and uneven subgrade settlement. Some settlement roads have no obvious diseases caused by uneven settlement of soil foundation, but the pavement structure has been seriously damaged and the base structure has been damaged only a few years after opening to traffic. The reason is that the soil foundation is unstable due to high compressibility and high moisture content, such as a highway.

The highway opened to traffic on 30 December 2010. Extensive milling was carried out at the end of 2015 to resurface the middle two surfaces. The two layers of milling and paving are 5 cm and 6 cmAC-16C medium grained modified asphalt concrete respectively. The pavement structure before milling is shown in Table I. Since the opening to traffic, the highway condition characteristic index is low, so many maintenance projects have been carried out successively, and some sections have been repeated maintenance. The main maintenance measure is to implement the upper middle surface milling on the main driveway.

TABLE I
Pavement Layer Structure Types

| Type of pavement structure | Thickness |
|---|---|
| Medium grained Modified Asphalt Concrete (AC-16C) | 5 cm |
| Medium grained Asphalt Concrete (AC-20C) | 6 cm |
| Coarse grained Asphalt Concrete (AC-25C) | 8 cm |
| Lower seal coat | / |
| 4 ~ 5% cement stabilized graded gravel | 17 cm |
| 4 ~ 5% cement stabilized graded gravel | 17 cm |
| 3 ~ 4% cement stabilized gravel | 18 cm |
| Graded Gravel | 20 cm |

A radar antenna with frequency of 800 MHz was used to detect and analyze the hidden diseases of the whole road base, and it was found that the main diseases of the soil base and pavement base were loose and undense, some sections were empty, and local locations had subsidence and high water cut.

Further research on the geological drilling shows that the subgrade has no excellent grain gradation, large pore ratio, loose soil and strong compressibility, and the subgrade quality is not high. High compressibility and high moisture content of the soil foundation lead to instability of the soil foundation, loose, broken and other diseases of the pavement structure base, and diseases of the pavement structure surface.

When the soil sample of the subgrade is poorly graded, the pores are relatively large, the soil is loose, and the compressibility is strong, the quality of the subgrade is not high. It causes different degree of settlement of the subgrade, which leads to the disease of the base and affects the function of the pavement structure. In particular, it is necessary to detect the condition of roadbed for the sections with loose and broken pavement base structure and the sections with insufficient overall structural strength. The subgrade stability is evaluated according to the compression coefficient, and the qualitative evaluation criteria are as follows.

For the road section with uneven settlement of pavement structure, the stability grade of roadbed can be directly assessed as unacceptable. For the section with no uniform settlement of the pavement structure, if the pavement base structure is loosely broken or the overall structural strength is insufficient, geological drilling should be carried out on the roadbed, the materials of the lower structural layers are extracted, the morphological characteristics, physical properties and compression characteristics of the soil samples are analyzed, and the compression coefficient and water content of the roadbed are calculated to evaluate the stability level of the roadbed.

TABLE II
Subgrade Integrity Classification

| The performance of subgrade | Evaluation principle |
|---|---|
| Compression coefficient <0.1; The pavement structure is not uniformly settled | Stable |
| Compression coefficient >0.1; The pavement structure is not uniformly settled | Unstable |
| Compression coefficient >0.5; The pavement structure has uneven settlement | Damaged |

## VI. Conclusion

(1) The decay rate of residual value of asphalt pavement in different service stages is different, but the residual value in the same stage has a linear relationship with the evaluation index, and has a strong correlation with the structural integrity of pavement.
(2) When the structural integrity of asphalt pavement base is damaged, the residual value of pavement structure is in an accelerated decline stage.
(3) When the bearing capacity of pavement structure is insufficient or the integrity of soil-base structure is damaged, the residual value of pavement structure is at a low level.

## References

[1] H. Xiong, L. Wang, R. Luo, and W. Wang, "A review and perspective for research on moisture damage in asphalt pavement induced by dynamic pore water pressure," *Construction and Building Materials*, vol. 204, Apr. 2019.
[2] F. Gu, M. Ling, R. L. Lytton, and X. Luo, "Review of mechanistic-empirical modeling of top-down cracking in asphalt pavements," *Construction and Building Materials*, vol. 191, Dec. 2018.
[3] A. Mateos, F. Paniagua, J. T. Harvey, M. A. Millan, and R. Wu, "Mechanisms of asphalt cracking and concrete-asphalt debonding in concrete overlay on asphalt pavements," *Construction and Building Materials*, vol. 301, Sep. 2021.
[4] N. Kheradmandi and V. Mehranfar, "A critical review and comparative study on image segmentation-based techniques for pavement crack detection," *Constr. Build. Mater.*, vol. 321, p. 126162, 2022.
[5] H. Ozer *et al.*, "Prediction of pavement fatigue cracking at an accelerated testing section using asphalt mixture performance tests," *Int. J. Pavement Eng.*, vol. 19, no. 3, Art. no. 3, Mar. 2018.
[6] Q. Chen and G. Wang, "Research on Relationships among Different Disease Types of Cement Concrete Pavement Based on Structural Equation Model," *Mathematical Problems in Engineering*, vol. 2020, Jun. 2020.

[7] Brawijaya, “A new methodology to diagnose pavement subsurface condition using ground penetrating radar,” Rensselaer Polytechnic Institute, 2005. Online. Available: http://www.pqdtcn.com/thesisDetails/8F73AF996A2CBA775192F2E4FEA573F3

[8] S. Wang, S. Zhao, and I. L. Al-Qadi, “Real-Time Density and Thickness Estimation of Thin Asphalt Pavement Overlay During Compaction Using Ground Penetrating Radar Data,” *Surv. Geophys.*, vol. 41, no. 3, pp. 431–445, May 2020.

[9] I. L. AL-Qadi and S. Lahouar, “Measuring layer thicknesses with GPR – Theory to practice,” *Constr. Build. Mater.*, vol. 19, no. 10, pp. 763–772, 2005.

[10] M. Solla, V. Perez-Gracia, and S. Fontul, “A Review of GPR Application on Transport Infrastructures: Troubleshooting and Best Practices,” *Remote Sensing*, vol. 13, no. 4, Feb. 2021.