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Discussion on the Structural Design Index and Design Method of Widening and Splicing Lane of Old Asphalt Pavement

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ABSTRACT

The splicing design of the existing road and the new road in the expansion project is an important part of the design work. Based on the analysis of the characteristics and the load effect of pavement structure on splicing, this paper points out that tensile crack or shear failure may occur at the splicing under the repeated action of the traffic load on the new/old pavement. According to the current structure design code of asphalt pavement in China, it is proposed that the horizontal tensile stress at the bottom of the splicing layer and the vertical shear stress at other layers of the splicing line should be controlled by adjusting the position and size of the excavated steps in addition to the conventional design index, and put forward the corresponding technical requirements and design process. It can be used for reference in the design of asphalt pavement reconstruction and expansion projects.

Keywords: Reconstruction and expansion project, Road widening, Design index, Design standard, Design method.

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مناقشة حول مؤشر التصميم الإنشائي وطريقة تصميم لتوسيع وربط مسار رصيف الأسفلت القديم

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الخلاصة

يعتبر تصميم الوصله الرابطة بين الطريق الاسفلتي الحالي و الجديد في مشروع التوسعة جزءا" مهما" من أعمال التصميم. بناءً على تحليل خصائص وتأثير الحمل المسلط لهيكل الرصيف على الربط تشير هذه الدراسة إلى احتمالية حصول تشققات الشد أو فشل القص عند وصلة الربط تحت تأثير الحمل المروري المتكرر على الطريق الاسفلتي الجديد/القديم. يقترح كود التصميم الأنشائي الحالي لرصف الأسفلت في الصين، بأن التحكم في إجهاد الشد الأفقي في الجزء السفلي من طبقة الوصلة الرابطة وإجهاد القص العمودي في الطبقات الأخرى من خط الوصلة يتم عن طريق ضبط موضع وحجم الخطوات المحفورة بالإضافة إلى مؤشر التصميم التقليدي، وتقديمها كمتطلبات تقنية متعلقة بعملية التصميم الخاصة بالوصلة الاسفلتية. يمكن استخدام الكود كمرجع في تصميم مشاريع إعادة بناء وتوسيع الطرق الأسفلتية.

الكلمات المفتاحية: مشروع إعادة الإعمار والتوسع, توسيع الطريق, مؤشر التصميم ,معيار التصميم, طريقة التصميم

1. INTRODUCTION

In recent years, with the increase in traffic volume, expressways have gradually reached the upper limit of their carrying capacity, so how to implement effective reconstruction and expansion of expressways has aroused many concerns **(Yang et al., 2023; Shakir et al., 2022; Li et al., 2021; Tian et al., 2021; Cheng et al., 2020; Zhang et al., 2020; Sarsam et al., 2016)**. Among them, splicing the new/old subgrade and pavement becomes a key problem **(Liu et al., 2021; Weng et al., 2011)**. If the splicing of the new/old subgrade is not properly handled, it will produce a large differential settlement, destroying the pavement structure **(Zhan et al., 2014; Al-Kalili et al., 2022)**. Similarly, suppose the joint between the widening pavement and the old pavement structure needs to be properly handled. In that case, the corresponding position of the asphalt overlay is prone to damage, resulting in reflection crack **(Wang et al., 2011; Weng et al., 2013)**.

There are many researches on the splicing of new/old subgrade, and the technology is relatively mature **(Chen et al., 2020; Xia et al., 2016; Ahmed et al., 2013; Sarsam et al., 2014; Li et al., 2015; Gao et al., 2021; Ding et al., 2017; Wang, 2012)**. For the splicing of new/old pavement, Jia used ABAQUS to analyze the mechanical response of pavement with different splicing widths, observed and analyzed the variation rules of tensile stress and shear stress of corresponding layers, to obtain the optimal splicing width, and suggested that the top crack avoid the position of wheel track zone **(Jia, 2019)**. Zhang calculated the

mechanical response of pavement with different splicing widths under the condition of loading position change through finite element analysis and determined the splicing form of pavement **(Zhang, 2012)**. Zhou proposed the reasonable step size of the surface layer and the basic size of the common concrete rigid-flexible composite pavement reconstruction and expansion project **(Zhou, 2015)**. Nan used finite element software ANSYS to analyze the three-dimensional model of typical spliced pavement structure. The results show that the stress of pavement without splicing is significantly greater than that of splicing, and with the increase of splicing width and maximum tensile stress is to increase the decreases. At the same time, the maximum shear stress will decrease, and the reduction the maximum shear stress will decrease with the increasing of the splicing width. When the splicing width increases to a certain extent, improving the internal stress of pavement structure is meaningless **(Nan, 2018)**. These studies are aimed at the influence of the position and size of the splicing steps on the load effect of the pavement structure when the new/old pavement is spliced, and based on this, a better new/old pavement splicing scheme is proposed, but the splicing design method of the spliced pavement has not been involved.
Based on the analysis of the characteristics and load effect of the widening splicing of pavement structure, this paper puts forward the pavement structure design index and calculation method of the splicing lane to reasonably determine the position and size of the splicing steps of new/old pavement structure, and ensure the pavement performance and service life.

2. THE CHARACTERISTICS OF THE OLD ROAD WIDENING PAVEMENT STRUCTURE

The widened pavement structure of the old road, as shown in **Fig. 1,** is quite different from that of the conventional newly built asphalt pavement.

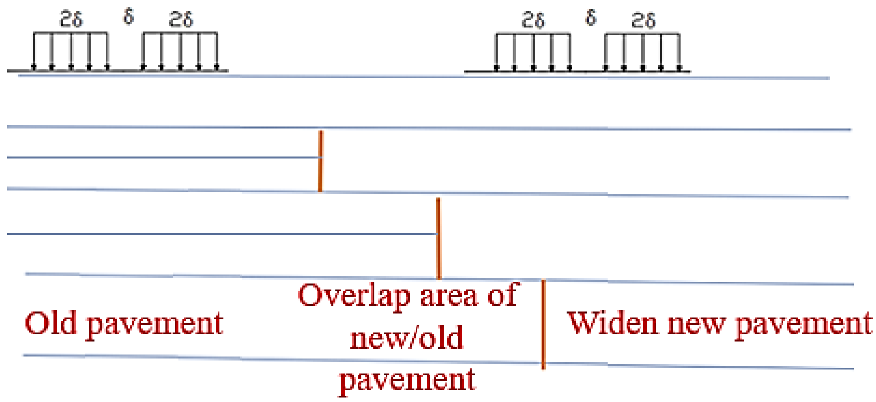

Figure 1. The pavement structure of the old road widening

(1) The initial structure state is different.
The initial state of the newly built road surface is in good condition, and it can be assumed that each layer's materials are completely continuous without any defects **(Ge et al., 2022)**. However, artificial joints exist in the new/old pavement splicing area, which makes the pavement structural layer no longer straight. Moreover, due to the large amount of coarse aggregate, difficulty in rolling, and insufficient compaction at the joint, if no special treatment is carried out, the bond performance at the interface could be stronger and can be almost

ignored **(Xu et al., 2012)**. Therefore, under the repeated action of driving load, the joint can easily produce tensile cracks and shear failure **(Zhang et al., 2016)**.
(2) The calculation methods of the load effect of pavement structure are different.
The new pavement can assume that each structural layer is a continuous material, and the elastic layered system theory can be used to analyze the structural load effect. However, the elastic layered system theory is no longer applicable to the pavement in the splicing area because of the different materials on both sides of the joint at the same layer. When anti-cracking measures are installed in the splicing area, the analysis of the load effect will be more complicated **(Wang, 2021; Mishra et al., 2022)**.
(3) The failure modes and mechanisms of pavement structures are different.
The current standard mainly considers the conventional failure forms, such as fatigue failure and rutting of each integral structural layer **(JTG D50-2017)**. However, for the new/old pavement splicing area, in addition to the conventional failure types such as fatigue and rutting of each structural layer, the possible failure of pavement structure due to splicing joints should be considered, which has its particularity. Due to the joint's weak tensile and shear strength, the bonding effect at the interface can be almost ignored without special treatment. Under the action of external load, it is easy to produce tensile cracks or shear damage and then accelerate the pavement structure of the spliced lane to injury **(Xie et al., 2021)**.

3. DESIGN INDEX AND TECHNICAL REQUIREMENT OF ASPHALT PAVEMENT OF SPLICING LANE

As mentioned above, the structure and materials of the pavement in the splicing area are different from those of the newly-built pavement, and their damage is different from that of ordinary newly-built pavement, with its particularity. Therefore, the corresponding control indicators should be adopted in the design of the pavement structure in the splicing area to ensure that the damage to the pavement structure in the splicing area can be slowed down or avoided. In view of the characteristics of the pavement structure in the splicing area and combination with the current standard **(JTG D50-2017)**, the design indexes of the asphalt pavement structure in the splicing lane are proposed as follows.

3.1 Conventional Design Index

The design indexes of newly built asphalt pavement structures include rutting, bending, and tensile stress (fatigue cracking) at the bottom of the pavement, vertical compressive strain at the top of the subgrade, and low-temperature cracking. The pavement damage corresponding to the above four design indicators for spliced pavement also exists, so these four indicators should also be adopted. This needs to be pointed out that, in general, the joining together of new/old pavement area is located in the old road of the hard shoulder, and the hard shoulder of the road surface structure and thickness. Therefore, it should be considered in the design of the old road surface because of the bearing capacity of the hard shoulder place and the residual fatigue life of each layer.
In addition, as the old road has been open to traffic for many years, the pavement structure and materials have some aging and damage. Therefore, the bearing capacity and remaining service life of the materials of the old road should be based on the performance of the actual old road materials rather than the performance parameters of the new mixture.

3.2 Particularity Index

(1) For the spliced pavement, it is generally required that the road performance and service life of the old pavement after the overlay is added are equivalent to that of the new pavement. Therefore, the technical requirements for the conventional design indicators of the spliced road surface are the same as the control standards of the new road surface.
(2) The horizontal tensile stress at the bottom of the structural layer of the joint: the horizontal tensile stress generated under the action of driving load should be controlled not to exceed the tensile fatigue life at the joint. When the joints do not use tensile performance enhancement measures, the tensile performance of the joints is poor and almost can be ignored, so it should be made under the action of external factors that do not produce tensile stress, that is, the place should be in a state of compression, so that the road will not have a horizontal crack.
(3) The vertical shear stress of each continuous structural layer at the joint: to prevent the pavement structure of the splicing lane from shear failure at the joint, the vertical shear stress of other integral material layers along the joint line under the action of the traffic load should not exceed the shear fatigue strength of the material layer. The shear fatigue life is longer than the design service life of the road surface so that the pavement structure in the joint area will not produce shear damage during the design service life of the road surface. Because the shear strength of the joint is very weak, as well as its tensile strength, the shear strength of the joint can be directly ignored in the vertical shear stress analysis of the joint, and the vertical shear stress of the other structural layers of the pavement structure on the extension line of the joint can be calculated.

4. CALCULATION PARAMETERS AND LOAD EFFECT ANALYSIS METHOD

4.1 Calculated Parameters

(1) Material modulus: new material: measured or referred to as the "specification" value; Old pavement: FWD reverse calculation or coring measurement;
(2) Strength: new material: measured, or refer to the "specification" value; Old pavement: coring measurement;
(3) The allowable tensile stress [σ] or fatigue reduction factor K of the strength of each layer of material in the original hard shoulder structure is: After years of operation, the material performance of each layer of the actual hard shoulder has been degraded to some extent, and its bearing capacity and fatigue performance must be different from that of the new mixed material. Therefore, the allowable tensile stress, fatigue life, and fatigue reduction coefficient of each layer of the old pavement should be determined by the actual residual fatigue life (equation) of each layer of the old pavement during the reconstruction and expansion design.

4.2 Load Effect Analysis Method

For the mosaic structure of old road widening, due juncture, and different materials on either side of the seam (even when the design can be part of the new pavement structure and the material type is set to the same as that of the old pavement, which has been operating for many years, but as the old pavement material the properties of each layer is different from the early performance for larger, so on both sides of the material and cannot be completely the same), It does not accord with the basic hypothesis of elastic layered system theory, so it cannot be used for structural analysis of elastic layered system theory. Given the maturity of finite element technology, it has been widely used in the road field so that it can be calculated by the finite element method **(Deng et al., 2020; Gupta et al., 2020; Nega et al., 2022; Mușat et al., 2022)**.

5. DESIGN PROCESS AND EXAMPLES

5.1 The Design Process

According to the design mentioned above indexes and standards, the basic design process of widening spliced pavement is as follows:

(1) To draw up the material and structure plan for widening new pavement.
According to the actual climate, environment, hydrology, and traffic situation of the project location, combined with the pavement structure, materials, and use of the old road, according to the current "Highway Asphalt Pavement Design Code."

(2) Formulate the asphalt concrete layers and thickness of the same type and thickness for each lane.
Generally, it is required to keep the type and thickness of the top 1-2 layers of asphalt mixture of each lane consistent, which can make the appearance of each lane consistent, and can ensure the smoothness and integrity of the road surface because of continuous construction.

(3) Formulate the new/old road joint position, step size, and whether to set anticrack measures and other lap schemes.
According to the load effect analysis results of the splicing pavement structure, it is suggested that the joint between the old shoulder surface layer and the newly broadened pavement should be located at the middle line of the third lane. The splicing joint of other layers should also avoid the wheel track zone to reduce the vertical shear stress inside the structure layer.

(4) The load effect of the proposed road widening scheme is calculated and analyzed, and the value of each design index is calculated.

(5) According to the corresponding technical requirements of each design index, determine whether the proposed pavement structure meets the requirements. Because the current design specifications of asphalt pavement in China allow a rut damage repair within the design period of use, and the rut depth needs to be more consistent, only control the rut depth of each lane in the same order of magnitude. When the calculation results of other indicators do not meet the technical requirements, adjust the proposed pavement structure and material, the position and size of steps, and other parameters, and continue to calculate. Until the calculation results of each design index align with the service life requirements after the renovation and expansion.

5.2 The Design Example

5.2.1 Response of Pavement Structure when Loading Position Fix

Based on the finite element theory **(Wang, 2003; Oukaili et al., 2023; Han, 2004; Guo et al., 2020)**, MATLAB is used to write the design and analysis program of the new/old road splicing lanes, and its main interface is shown in **Fig. 2.**

In the design parameter table at the bottom of the interface, set the old road structure and material, the new road structure and material, and the joint position (the inner edge of the hard shoulder is 0), which can be modified based on the default parameters.

Figure 2. Pavement structure analysis program interface for new/old pavement splicing area

In the calculation, the traffic load BZZ-100 simultaneously acts on the middle of the third and fourth lanes, the left and right sides of the model can be set as free edges, and the subgrade depth at the bottom of the road can be 10 meters, and the subgrade bottom is completely constrained. The changes in horizontal tensile stress and vertical shear stress along the thickness of joints in the splicing pavement structure are shown in **Figs. 3 and 4**, respectively.

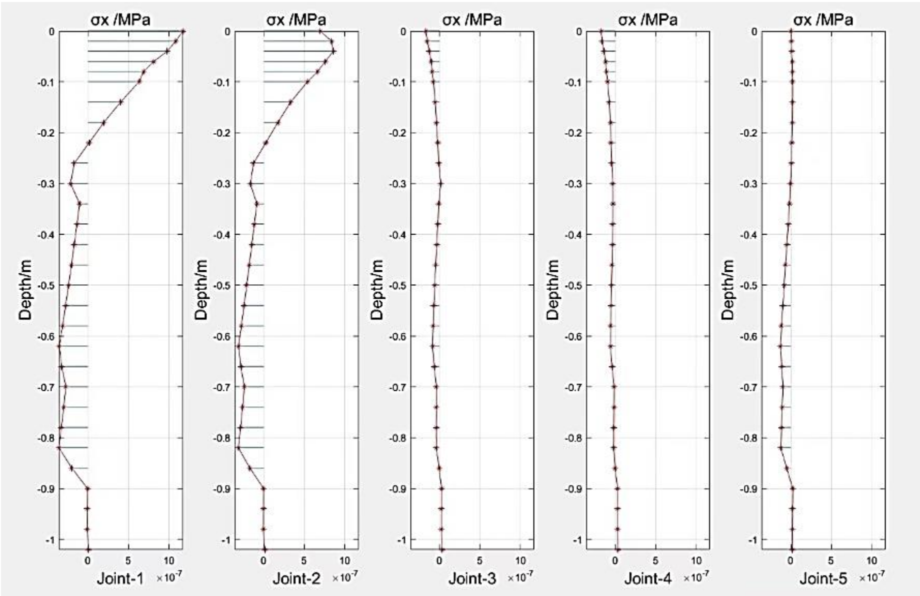

Figure 3. Horizontal tensile stress at each splicing in the pavement structure

Per the step setting scheme of the new/old pavement structure shown in **Fig. 3,** and the scheme of the material and thickness of each layer of the new pavement shown in **Fig. 2**, the bottom of the structural layer at joint 2 is in a state of tension and is easy to be split. Therefore, the position or size of the digging steps should be further adjusted.

As seen in **Fig. 4**, the vertical shear stress at all joints is large, especially the shear pressure at the first joint under the old hard shoulder. The shear fatigue failure at the joint should be delayed or avoided by adjusting the position of the steps, enhancing the shear resistance of the overlaying asphalt mixture, or adding a rigid layer to bear the larger vertical shear stress.

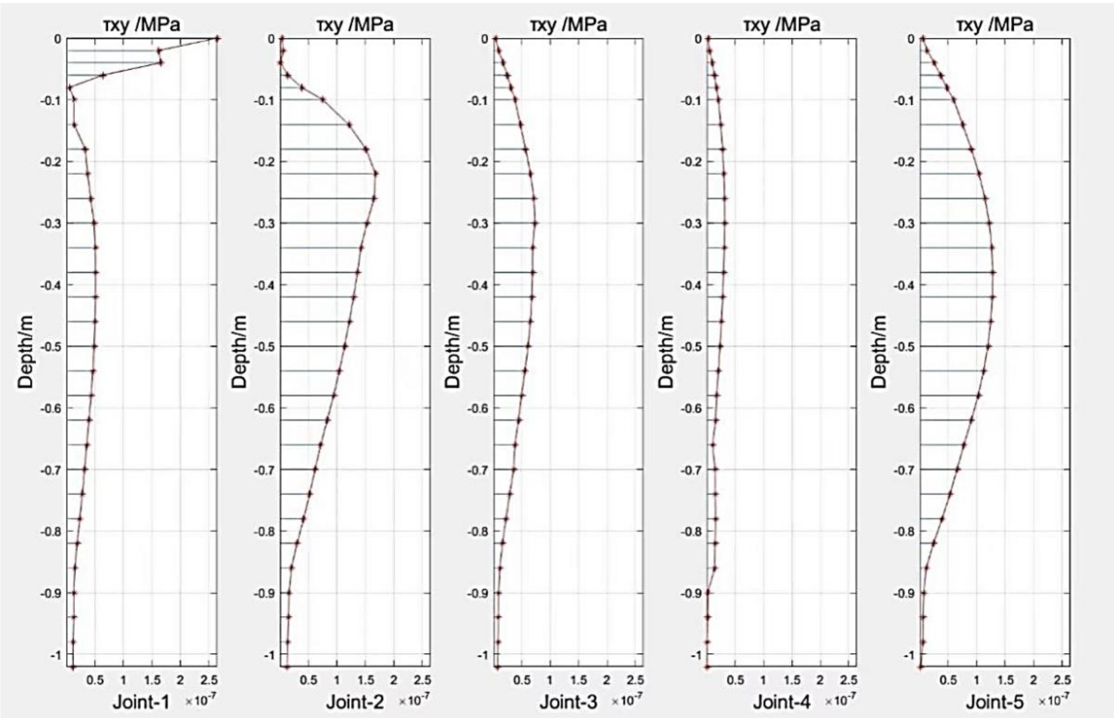

Figure 4. Vertical shear stress at each splicing in the pavement structure

5.2.2 Response of Pavement Structure when Loading Position Change

To study the influence of vehicle loading position on the pavement structure, the maximum vertical shear stress of the pavement structure when loads are applied to different splicing positions is extracted, as shown in **Table 1.**

Table 1. The maximum shear stress of different joints under different positions of load.

Loading position	Maximum shear stress of integral structure layer /MPa	Maximum shear stress of asphalt layer /MPa
Joint 1	0.07124	0.07124
Joint 2	0.06051	0.06051
Joint 3	0.05202	0.05202
Joint 4	0.04927	0.04912
Joint 5	0.06842	0.04911

As shown in **Table 1**, when the wheel load is applied to the asphalt layer joints (such as joints 1 and 2), the maximum shear stress of the asphalt layer along the joint direction is located at the bottom side of the joint. When the wheel load is applied to the joint of the base layer (such as joints 3, 4, 5), the maximum shear stress in the asphalt layer is located at the bottom of the asphalt layer that intersects the new pavement structure layer along the joint at the position of loading. **Fig. 5** shows the maximum horizontal tensile stress at the bottom of the base layer when loads are applied to different joints.

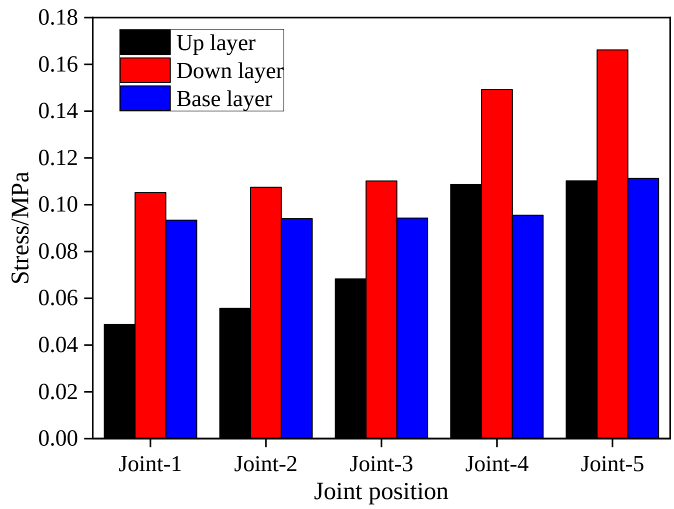

Figure 5. The maximum horizontal tensile stress of the bottom base layer in the spliced pavement structure

It can be seen from **Fig. 5** that when wheel loads are applied to different joints, the bottom of the base layer is subjected to tensile stress, and the order of the maximum tensile stress of the third layer is as follows: down layer > up layer > base layer. When the tensile stress at the bottom of the base layer moves from joint one on the left to joint 5 on the right with the load, the maximum tensile stress at the bottom of the base layer moves with it and has a

relatively obvious following phenomenon.
When the vehicle load acts on the joint of the base layer, the bottom tensile stress of the up-layer and down-layer layers increases significantly. For example, when the vehicle load acts on joint 5 of the road(the base layer), the maximum value of the bottom tensile stress of the down layer increases by 58% compared with that of joint 1. To sum up, in the design of the splicing scheme, the maximum tensile stress and vertical shear stress at the bottom of the joint at different load positions should be considered.

6. CONCLUSIONS

Based on the analysis of the characteristics of the old road widening structure, this paper puts forward the design index, technical requirements, and load effect calculation method of the pavement structure design in the splicing area. The main conclusions are as follows:

(1) There are joints in the pavement of the splicing area, and the types and properties of new/old materials on both sides of the joints are different, so the commonly used elastic layered system theory and its corresponding programs are no longer applicable to the load effect analysis of the structure.

(2) When no special technical measures are taken, due to the old/new pavement joints tensile performance, the shear performance is very weak, under the action of external factors, it is easy to produce tensile cracking and shear failure, thus causing the pavement structure of other layers under the repeated action of external factors to have damage.
Therefore, in the design of pavement structure in the joint area, in addition to controlling rutting, the tensile stress at the bottom of the layer and the compressive stress at the top of the subgrade, the horizontal tensile stress at the bottom of the structural layer at the joint and the shear stress at the extension line of each structural layer should be controlled.

(3) Because of each layer of the old pavement structure has produced certain aging and damage in the operation process for many years, when determining the stress standard of each layer of the old pavement, it should be based on the fatigue performance of the old material, rather than the fatigue performance of the new material.

(4) The pavement failure in the splicing area may be a shear fatigue failure, but there are few studies on the shear fatigue performance of pavement materials, which should be studied.

7. ACKNOWLEDGMENTS

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