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Research Article

Mechanical Characteristics of Asphalt Pavement Pothole Maintenance

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Traditionally, potholes are mainly paved for maintenance, and the asphalt mixture needs to be compacted. But due to the construction quality problem, the compacting degree of asphalt mixture may not be enough and the void ratio of asphalt mixture may not meet the requirements, resulting in the premature damage of the potholes after repair. If the repair material can be prefabricated, this problem will be well solved. So, based on the structure form of the prefabricated rapid maintenance of asphalt pavement, this paper aims to determine the most unfavorable loading position in pothole repair, which was established by the ANSYS software with the finite element model. The results show that the most unfavorable loading position of tensile stress for patch materials and joint filling material is C1-1 (A2-2) and the most unfavorable loading position of shear stress for joint filling material and leveling layer is B2-1 and C1-5. Subsequently, the influences of the material modulus, size, thickness, and modulus of the old pavement material on the potholes are calculated by using the finite element model under the most unfavorable loading position.

1. Introduction

Potholes are one of the most common diseases of asphalt pavement, and they will affect the comfort and safety of driving, if it not repaired in time [1, 2]. At present, the maintenance methods of asphalt pavement potholes are generally divided into cold repair, hot repair, and hot regeneration repair. Cold repair, as a temporary repair, has a short construction time and can quickly open traffic. Hot repair and hot regeneration repair, as the main repair methods, can ensure the quality of pothole repair and extend service life. But none of the three repair methods can meet the requirements of fast open traffic and good quality at the same time. Due to its advantages of high efficiency, and high quality, prefabricated construction has been applied widely in civil engineering. In road engineering, the research achievements of prefabricated cement concrete pavement provide new ideas for the maintenance of potholes on asphalt pavement [3–6].

Based on the current maintenance method of asphalt pavement, Ehsan et al. [7] calculated the stress state of pothole joints under the direct tensile test, indirect tensile test, and four-point bending test by ABAQUS. Yang et al. [8] established the simplified model of pothole repair of the composite beam; the calculations show that the lateral and longitudinal stress increased sharply at the position of the joint, so cracking and debonding are easy to occur at this position. Byzyka et al. [9] focused on the problem of lack of durability in executed pothole repairs, many of which arise from inadequate heating of the host pavement during the repair process, and used a three-dimensional finite element analysis to model the temperature distribution in hot mix asphalt (HMA) pothole repairs. Outcomes demonstrate that boundaries of the formed repair cool substantially faster than the central region and that repair thickness has a substantial influence on this. Zhang et al. [10] focused on fatigue damage existing along the bonding surface of pothole repairing structure and established a fatigue damage model to analyze the effects of material damage on pothole repairing structures; the results indicated that the fatigue life of repairing composite beams is typically affected by the bonding material and the stress ratio. Yuan et al. [11, 12] employed DCPD resin (dicyclopentadiene, $C_{10}H_{12}$) with a ruthenium-based catalyst to develop controlled properties that are compatible with aggregates and asphalt binders and analyzed micromechanics of materials. At the same time, a multilevel numerical micromechanics-based model was developed to predict the viscoelastic properties and dynamic moduli of these innovative nano-molecular resin reinforced pothole patching materials. Most of these research results are based on conventional maintenance methods, and the repairing materials need to be compacted; if the repairing materials can be directly used in the field by compacting in advance, pothole repair will save time or money. At the same time, to reduce the influence of the new and old pavement and temperature on the pavement, this paper proposes a new pothole maintenance structure of asphalt pavement, which is shown in Figure 1. So, the work about analyzing mechanical characteristics of asphalt pavement pothole maintenance is meaningful.

In this study, the finite element model is established to find the most dangerous loading position and calculate the influence of material modulus, thickness, size of patch block, and pavement materials on repair structure of potholes, so as to provide theoretical support for the development of the key materials for pit and groove assembly maintenance of asphalt pavement.

2. Establishment of Finite Element Model

2.1. Selection of Pavement Structure. According to the structure and characteristics of high-grade highway pavement in China, a typical structure using semirigid base and asphalt pavement is selected to establish the model. The material parameters and thickness of each layer are shown in Table 1.

2.2. Model Parameters. The X-axis (transverse direction of the road) and Y-axis (traveling direction) sizes of the road model are 5.54 m and 5.04 m, respectively, and the depth of Z-axis takes the actual road surface thickness which is 4.76 m. The pothole is located in the middle of the road with a size of 1.5 m × 1 m × 0.05 m, and the joint width around the hole is 2 mm. The finite element model is shown in Figure 2(a). According to "specifications for design of highway asphalt pavement" (JTG D50-2017), standard axle load BZZ-100 is adopted, contact pressure of the tire is 0.7 MPa, single-wheel contact equivalent circle diameter is 213.0 mm, and the center distance between the two wheels is 319.5 mm. After simplifying the wheel load, it is a 20 cm × 18 cm rectangular uniform load, and the center distance is 30 cm. The load model is shown in Figure 2(b). The contact between the layers is completely continuous. SOLID45 unit is used for division, with all constraints except the upper surface.

3. Numerical Simulation Results and Analysis

3.1. Determination of the Worst Loading Position

3.1.1. Loading Position. When the vehicle is driven on the road, each point of the repair material is in the state of alternating changes of tensile and compressive stress. Under shear stress, the joint between the patching material and the pit wall and the joint at the bottom surface of the patching material may be cracked. So, the tensile property of the patch block, the tensile stress and shear stress at the joint, and the shear condition of the leveling layer are mainly considered. Therefore, this study selects three load action forms (represented by A, B, and C, respectively) of the load center acting on the edge of the patch block and the load acting on the outer and the inner edges of the wall joints and determines the most unfavorable loading positions as shown in Figure 3.

3.1.2. Calculation and Analysis of the Most Unfavorable Loading Position. After preliminary calculation, different load action forms are selected for the most unfavorable loading position analysis according to different indexes, and the results are shown in Figures 4–11. From the results shown in Figures 4 and 5, the following can be seen. (1) When the load type of A and C changes position horizontally along the patch block, the transverse tensile stress called SX is greater than the longitudinal tensile stress called SY, and SX gradually decreases with the change. At this time, the unfavorable loading position for the tensile stress of the patch is C1-1. (2) When the load type of A and C changes lengthwise position along the patch block, SX is greater than SY, and SX increases first and then decreases. In this change, the transverse tensile stress SX has an inflection point, and the load acting position at the inflection point is A2-2. (3) The movement of loading positions in two forms of A and C shows that the transverse tensile stress SX is greater than the longitudinal tensile stress SY, and the most unfavorable loading position of the patch tensile stress is C1-1 (A2-2) where load acts on the inner edge of the transverse wall joint, and the wheel gap center coincides with the longitudinal edge of the patch block.

From the data shown in Figures 6–9, the following can be seen. (1) Comparing with the stress of joint filling under three forms of loading position (A, B, C), the maximum values of joint filling's tensile stress appear at C1-1. so the most dangerous loading position of tensile stress is C1-1. (2) Under forms of loading position (B, C), the most maximum value of joint filling's shear stress is 0.9 MPa on B2-1. This is because the elastic modulus of the patch is greater than the modulus of asphalt pavement surface layer.

As can be seen from Figures 10 and 11 and Table 2, when the load type of A and C changes position horizontally along the patch block, shear stress of leveling layer can get the maximum values on C1-5; if loading position is changed vertically, the loading position of the maximum shear stress of leveling layer can meet on C2-2, and the most dangerous position is C1-5 through comparing.

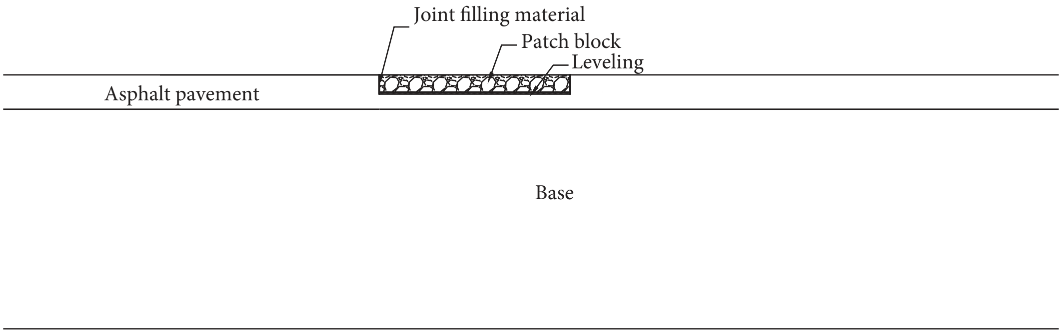
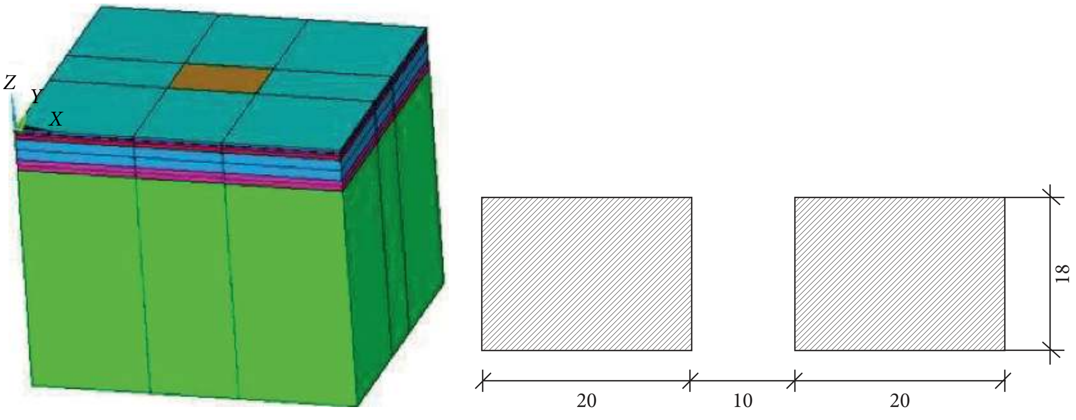


Figure 1: Pothole maintenance structure.

Table 1: Pavement structure parameters.

Structural layer	Material	Thickness (cm)	Modulus (MPa)	Poisson's ratio
Upper layer	SMA-13	4	10000	0.25
Midlayer	AC-20 (modified)	6	11000	0.25
Lower layer	AC-25	8	11000	0.25
Surface base	Cement stabilized graded broken stone	38	12000	0.25
Bottom base	4% cement stabilized stone powder slag	20	8500	0.25
Subgrade	Soil	400	40	0.4



(a) (b)

Figure 2: (a) Finite element model. (b) Double-wheel uniform load (unit: cm).

3.2. Influence of Material Modulus of Patch Blocks on Repaired Structures. The elastic layered theory system is adopted in the calculation of asphalt pavement; the parameters involved in the material are mainly resilient modulus and Poisson's ratio. Poisson's ratio of asphalt mixture remains relatively stable when the load is not large enough. So, the article only considers the modulus parameters of repair materials. We choose the original pavement materials and high-performance materials to study effect of material modulus of patch blocks on repaired structures, whose modulus ranges from 5000 MPa to 25000 MPa. The effect of material modulus on tensile stress of patch block and joint filling materials is shown in Figures 12 and 13. As can be seen from Figure 12, the tensile stress of the patch increases gradually with the increase of the modulus of the patch material. When the modulus of the patch material is small, the elastic modulus increases from 5000 MPa to 8000 MPa, and the tensile stress of the patch increases by 9.48%. When the elastic modulus is larger, the tensile stress of the patch increases by 1.88% when the elastic modulus increases from 22000 MPa to 25000 MPa. This shows that the small modulus of the patch will cause obvious changes in the tensile stress of the patch block. From Figure 13, when the elastic modulus of the joint filling material is constant, with the increase of the material modulus of the patch block, the tensile stress of joint filling material will reduce gradually; the reason is that the deformation ability of the patch block becomes worse with the increase of the material modulus of the patch block, its tensile strain decreases, and the tensile stress of the joint filling material also decreases. The results show that increasing the modulus of the repair material can reduce the influence of load on the tensile stress of the joint filling material.

Considering that the modulus of the patch block material may change the dangerous loading position of the shear stress of joint filling materials, C1-2 and B2-1 are

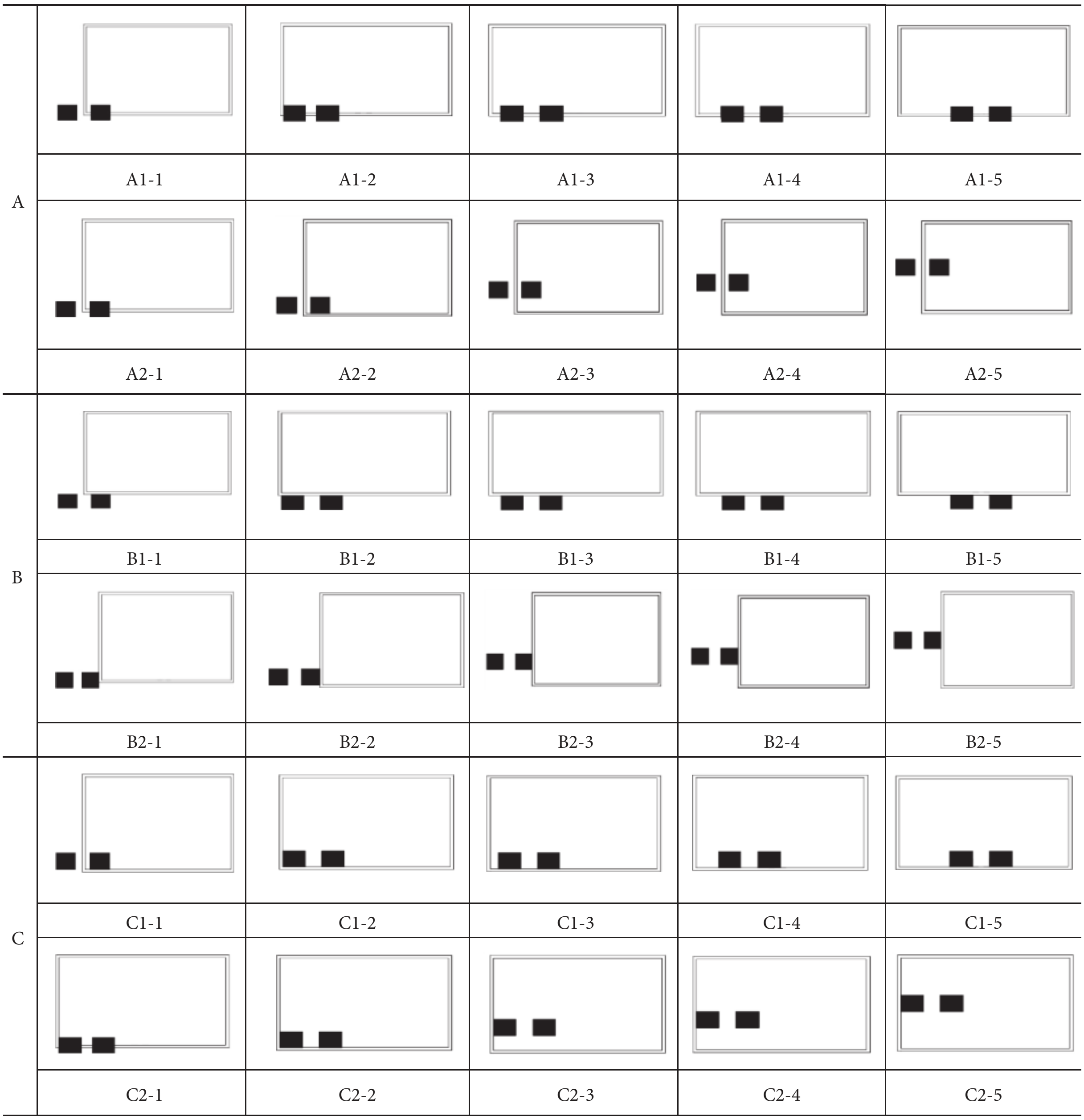


Figure 3: Load distribution.

selected to analyze the effect of patch material modulus on shear stress of joint filling materials, and the results are shown in Figure 14. From Figure 14, it can be seen that the shear stress of the joint filling material gradually decreases with the increase of the material modulus of the patch when the loading position is C1-2, but it gradually increases with the increase of the material modulus of the patch when the loading position is B2-1; the shear stress at the two loading positions is the same when patch material modulus is about 14433 MPa. When E (the material modulus) $\leq$ 14433 MPa, the unfavorable loading position is C1-2; when $E > 14433$ MPa, the unfavorable loading position is B2-1. Figure 15 shows the changes of shear stress of leveling layer over the modulus of repair block from 500 MPa to 25000 MPa. From the results shown in Figure 15, it can be seen that the shear stress of the leveling layer gradually increases with the increase of the material modulus of the patch.

3.3. *Effect of Patching Thickness on Patching Structure.*

In this study, 3 cm, 4 cm, 5 cm, 7 cm, 9 cm, and 10 cm deep pits are selected to determine the effect of patching thickness on patching structure, in which 1 cm leveling layer is designed at the bottom of each pits. Figures 16 and 17 show the change of the tensile stress of the patch block and joint filling materials under different patching thicknesses. The tensile stress of the patch decreases gradually with the increase of the patch thickness, as shown in Figure 16. However, when the depth of the pit is 5 cm and the thickness of the patch is 4 cm, the tensile stress of the patch is only reduced by 7.03% by increasing the thickness of the patch, which indicates that when the thickness

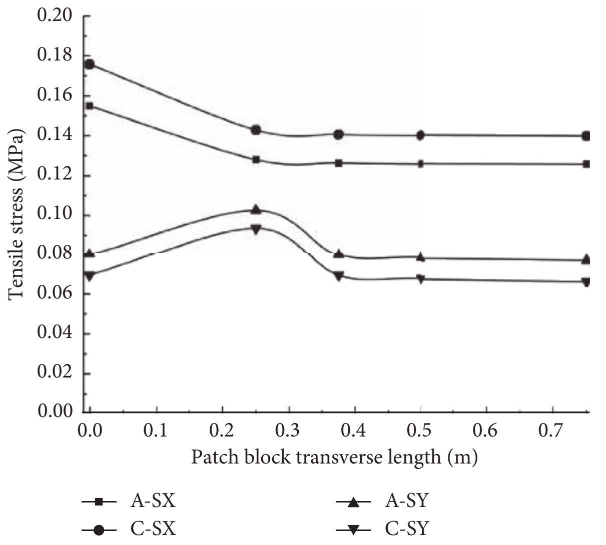


Figure 4: The effects of lateral movement of different loading positions on tensile stress of patch block.

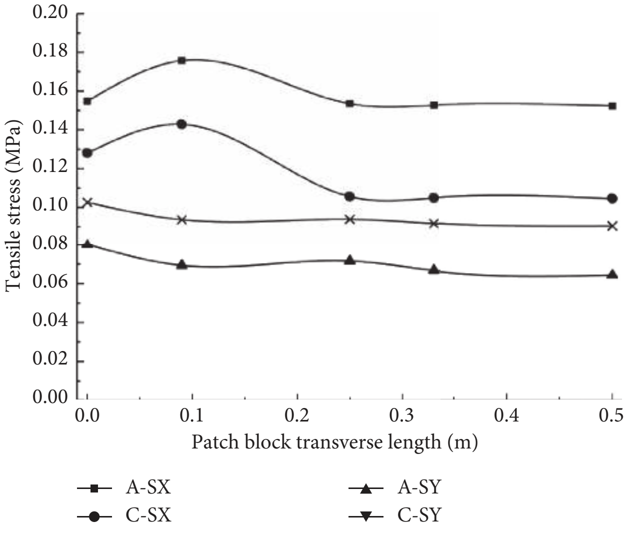


Figure 5: The effects of longitudinal movement of different loading positions on tensile stress of patch block.

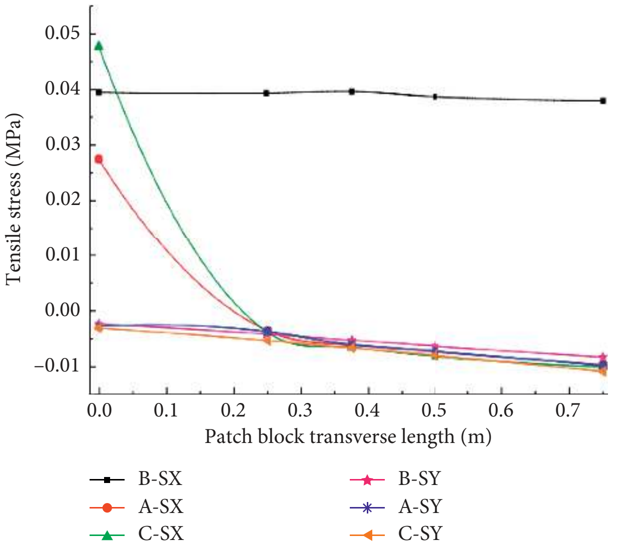


Figure 6: The effects of lateral movement of different loading positions on tensile stress of joint filling material.

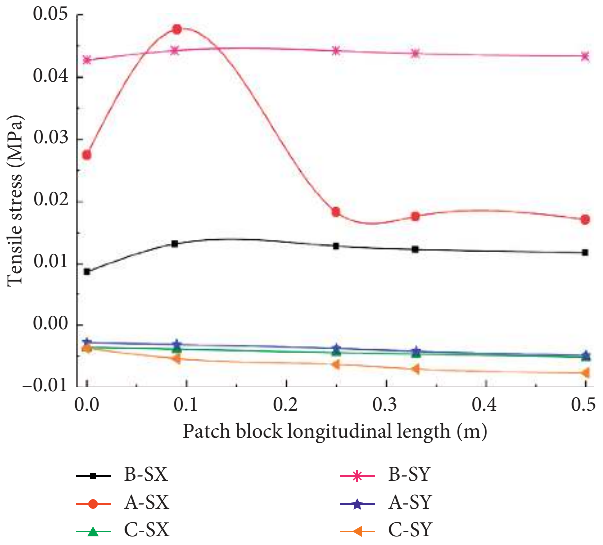


Figure 7: The effects of longitudinal movement of different loading positions on tensile stress of joint filling material.

of the patch reaches a certain degree, the patch thickness is no longer the main factor affecting the tensile stress of the patch. At the same time, the tensile stress of the joint filling materials decreases gradually with the increase of the patch thickness, as shown in Figure 17. When the hole depth is less than or equal to 5 cm, the tensile stress of the joint filling materials decreases obviously with the increase of the patch thickness, but the tensile stress of the joint filling materials decreases by 0.006 MPa when the pit depth increases from 5 cm to 10 cm. This indicates that the increase of thickness has no obvious influence on the tensile stress of the joint filling materials of pit depth more than 5 cm.

The shear stress of joint filling materials and leveling layer under different depths of pothole is shown in Figures 18 and 19. As shown in Figure 18, the shear stress of the joint filling material shows a trend which decreases at first and then increases with the increase of the repair thickness, where the inflection point is the patch thickness of 5 cm. The shear stress of leveling layer firstly decreases and then increases and then decreases with the increase of repair thickness, as shown in Figure 19, which indicates that the shear stress of leveling layer can be effectively reduced with the increase of patch thickness. When the patch thickness is 5 cm, the leveling layer shear stress will slightly increase compared with the patch thickness of 4 cm because the thickness of the asphalt pavement surface layer is 4 cm, the thickness of the patch block is equal to that of the old asphalt pavement surface layer, and the interlayer stress distribution of the old pavement surface layer and the middle surface layer has an impact on shear stress of the leveling layer.

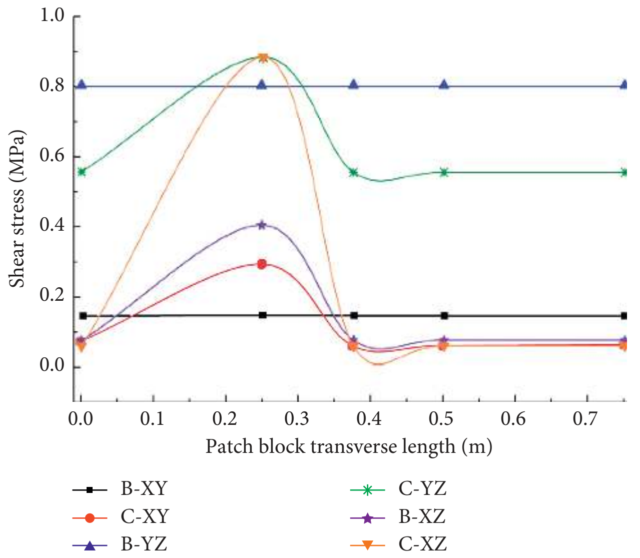


Figure 8: The effects of lateral movement of different loading positions on shear stress of joint filling material.

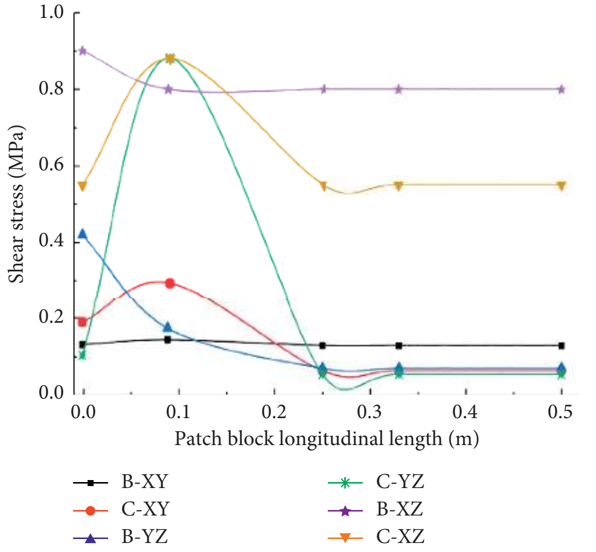


Figure 9: The effects of longitudinal movement of different loading positions on shear stress of joint filling material.

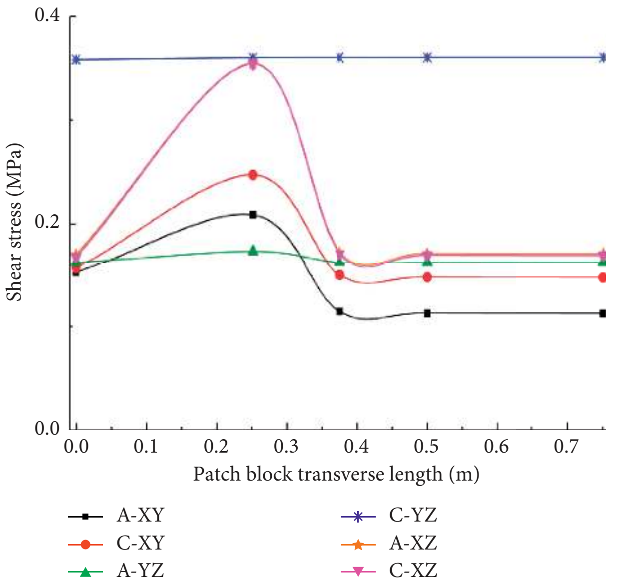


Figure 10: The effect of lateral movement of different loading positions on shear stress of leveling layer.

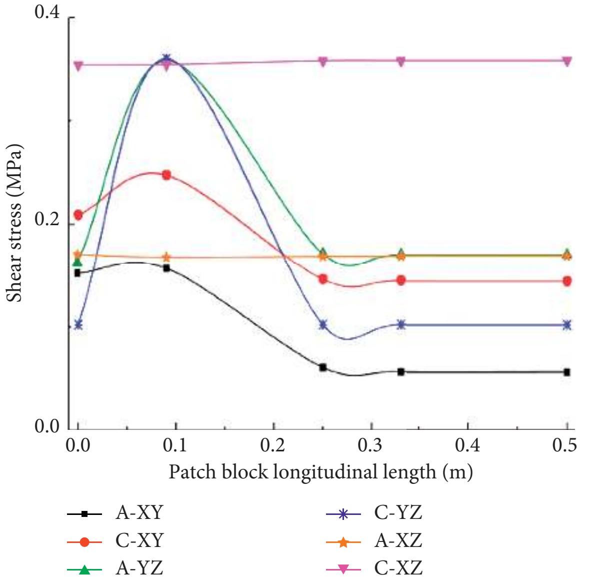


Figure 11: The effects of longitudinal movement of different loading positions on shear stress of leveling layer.

Table 2: Shear stress value at C1 loading position.

Loading position	C1-1	C1-2	C1-3	C1-4	C1-5
τyz	0.3584	0.3602	0.3603	0.3604	0.3605

3.4. Influence of Repair Size on Repair Structure. According to the different damage degrees of the pothole, different sizes are selected to study the influence of pothole's size on the mechanical properties of the repaired structure in this paper. Firstly, the horizontal dimension is unchanged and the longitudinal dimension is continuously increased. Firstly, the horizontal dimension remains unchanged at 1 m and the longitudinal dimension is continuously increased from 0.3 m to 3 m. Secondly, the longitudinal direction remains unchanged at 1m, and the horizontal dimension is increased from 0.5 m to 2 m. According to the results of Figures 20 and 21, when the transverse dimension is unchanged, the change of the tensile stress when the size of potholes changes is described and when the horizontal dimension is unchanged, the tensile stress of patch and joint filling material decreases rapidly at first and then changes slowly with the increase in the longitudinal dimension. This shows that when the transverse dimension of the pit is constant, increasing the longitudinal repair dimension of the pit can reduce the influence of load on the tensile stress of the patch and the joint filling material. When the longitudinal

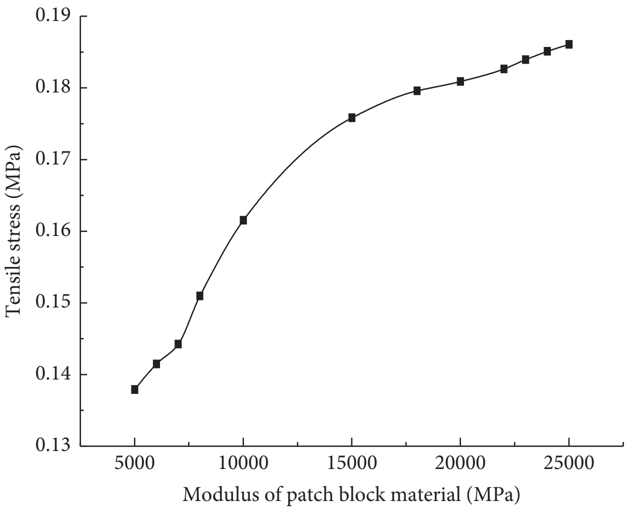


Figure 12: The effect of material modulus on tensile stress of patch block.

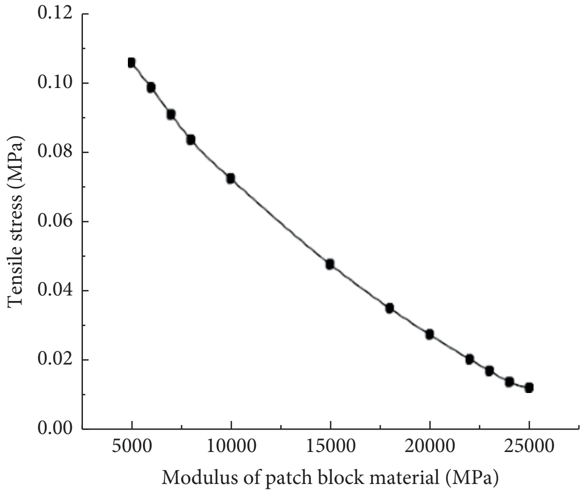


Figure 13: The effect of patch material modulus on tensile stress of joint filling materials.

dimension is fixed, with the increase of the transverse dimension, the tensile stress of the patch will decrease at the very beginning and then increase. The tensile stress of the joint filling material shows a trend of decreasing first and then increasing. This shows that when the pit area is larger than 1 m^2, the longitudinal dimension is unchanged, and the transverse dimension should be as small as possible.

The effect of repair size on shear stress is shown in Figures 22 and 23. When the transverse dimension of the patch is invariant, the shear stress of the joint filling material tends to increase first and then decrease with the increase of the longitudinal dimension. When the longitudinal dimension is constant, the shear stress of the joint filling material gradually decreases with the increase of the transverse dimension, but the shear stress is greater than the shear stress caused by the change of the longitudinal dimension, which indicates that the change of the transverse dimension has obvious influence on the shear stress

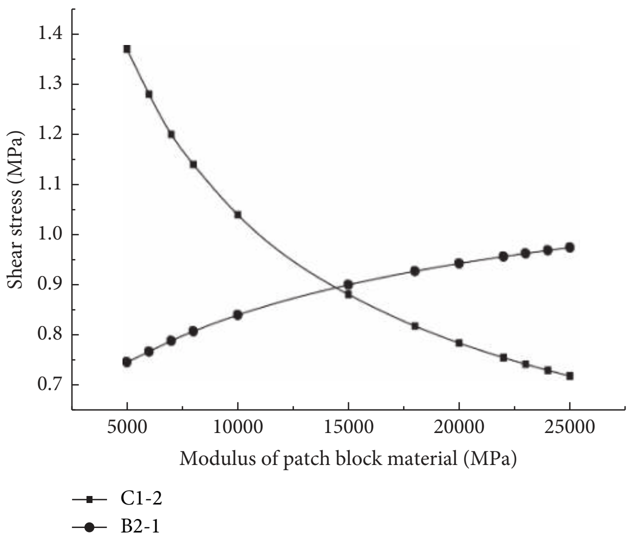


Figure 14: The effect of patch material modulus on shear stress of joint filling materials.

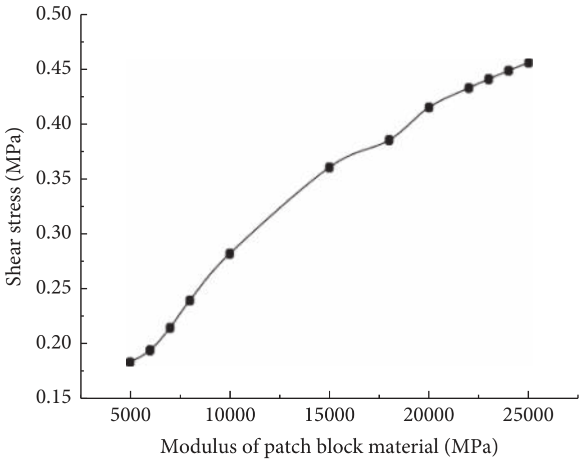


Figure 15: The effect of patch material modulus on shear stress of leveling layer.

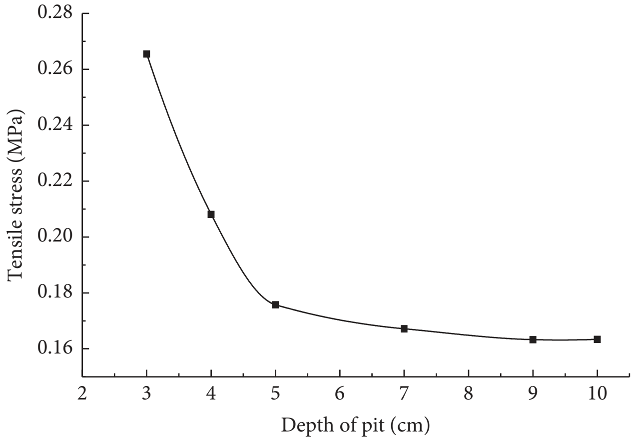


Figure 16: The effect of depth of pit on tensile stress of patch block.

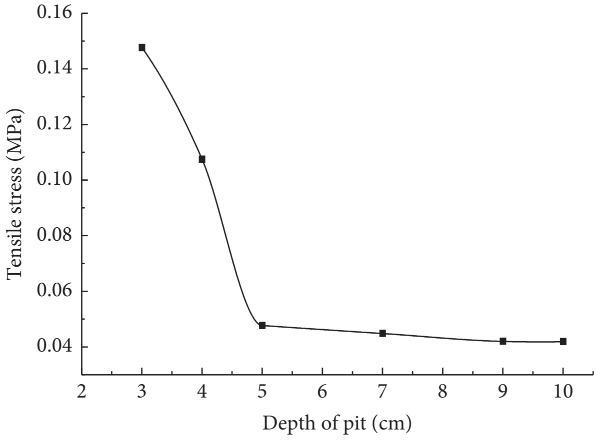


Figure 17: The effect of depth of pit on tensile stress of joint filling materials.

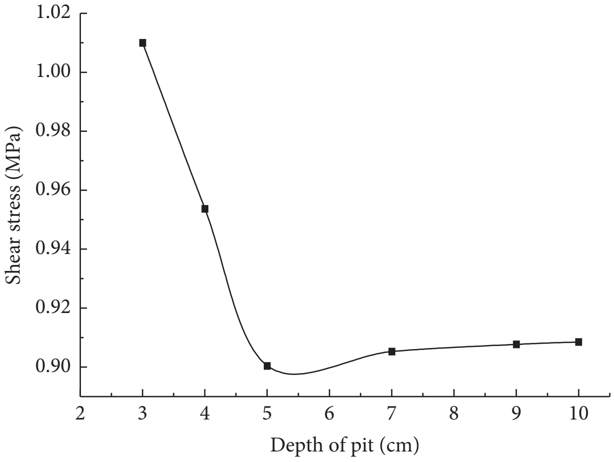


Figure 18: The effect of depth of pit on shear stress of joint filling materials.

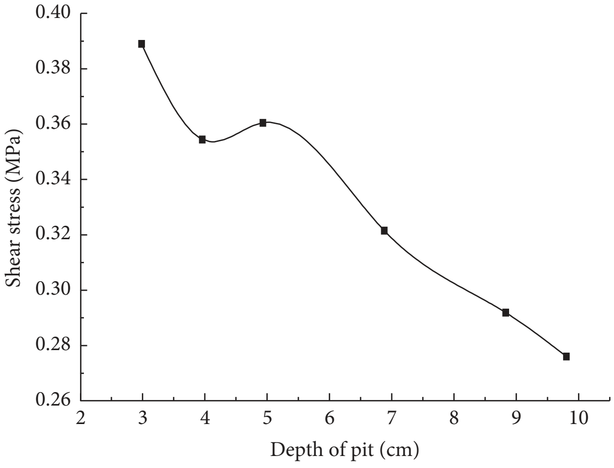


Figure 19: The effect of depth of pit on shear stress of leveling layer.

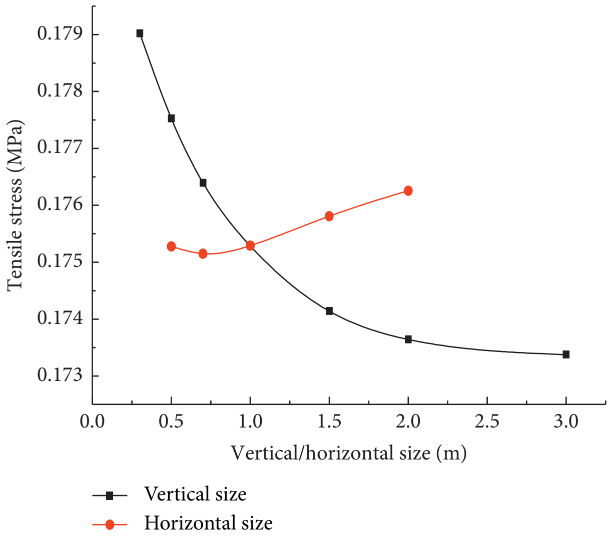


Figure 20: The effect of horizontal/vertical size on tensile stress of patch block.

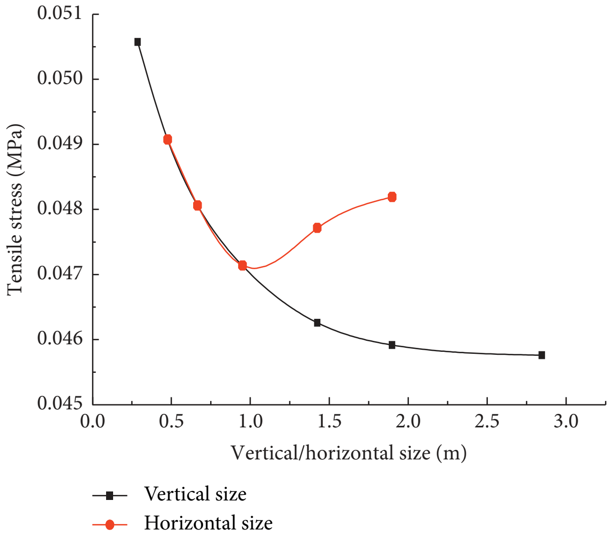


Figure 21: The effect of horizontal/vertical size on tensile stress of joint filling material.

of the joint filling material. Keeping the transverse dimension unchanged, the increase of the longitudinal dimension will lead the shear stress of the leveling layer to increase, but the shear stress of the leveling layer will only increase by 0.008% during the increase of longitudinal dimension from 1m to 3m, indicating that the follow-up increase of the longitudinal dimension has no obvious influence on the shear stress of the leveling layer. Keeping the longitudinal dimension unchanged, with the increase of the transverse dimension, the shear stress of leveling layer decreases firstly and then continuously increases, which indicates that the transverse dimension should not be too small or too large.

3.5. Influence of Pavement Material Modulus Change on Patch Structure. SMA-13 is selected as the material for the upper layer of asphalt pavement. According to other documents

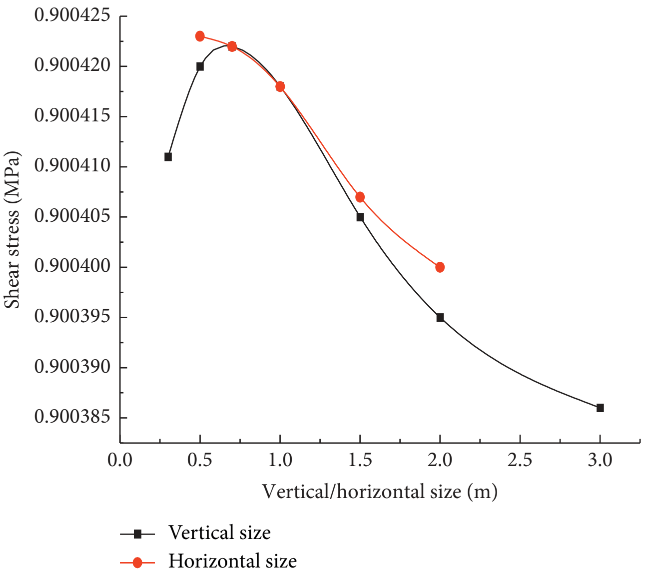


FIGURE 22: The effect of horizontal/vertical size on shear stress of joint filling material.

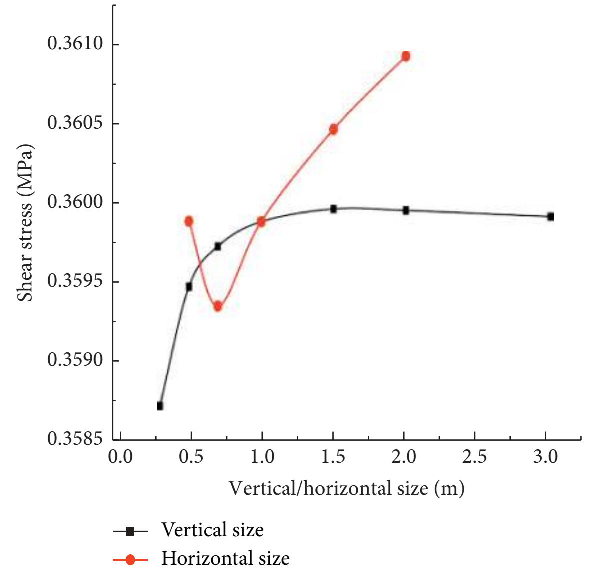


FIGURE 23: The effect of horizontal/vertical size on shear stress of leveling layer.

[13, 14], the influence of pavement material modulus change (from 500 MPa to 50000 MPa) on patch structure is studied.

Figures 24 and 25 show the influence of pavement material modulus on tensile stress. As shown in Figure 24, the tensile stresses SX and SY of the patch decrease sharply first, then slowly, and finally gradually with the modulus of the pavement material. When the modulus of pavement material is less than or equal to 1000 MPa, the longitudinal tensile stress is more than the transverse tensile stress. When the temperature is high and the frequency is low, the pavement material has obvious influence on the tensile stress of the patch, and a small increase in modulus will cause a sharp decrease in the tensile stress of the patch. When the temperature is low and the frequency is high, the modulus of pavement material greatly increases and the tensile stress of the patch decreases by 3.39%, while the pavement material has little influence on the tensile stress of the patch. From Figure 25, it can be seen that the transverse tensile stress SX is greater than the longitudinal tensile stress SY of the joint filling material, and the transverse tensile stress SX of the joint filling material first decreases sharply and then gradually flattens with the gradual increase of the pavement material modulus. When the temperature is high or the frequency is low, the modulus of pavement material has obvious influence on the tensile stress of joint filling material, while when the temperature is low and the frequency is high, the tensile stress of joint filling material has no obvious change.

Figures 26 and 27 show the effect of original pavement materials on shear stress. In Figure 26, $\tau_{yz} > \tau_{xz}$, τ_{yz} decreases rapidly and then slowly with the increase in original

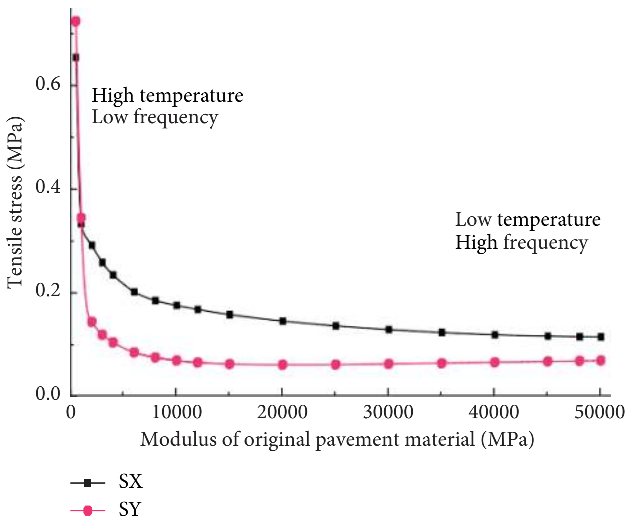


FIGURE 24: The effect of original pavement material modulus on tensile stress of patch block.

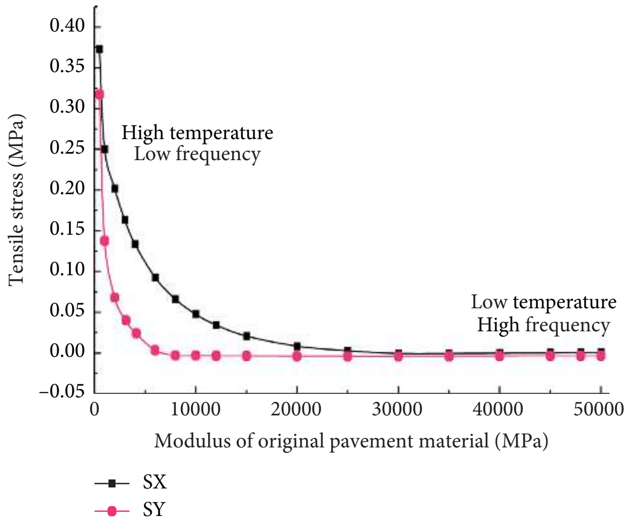


FIGURE 25: The effect of original pavement material modulus on tensile stress of joint filling materials.

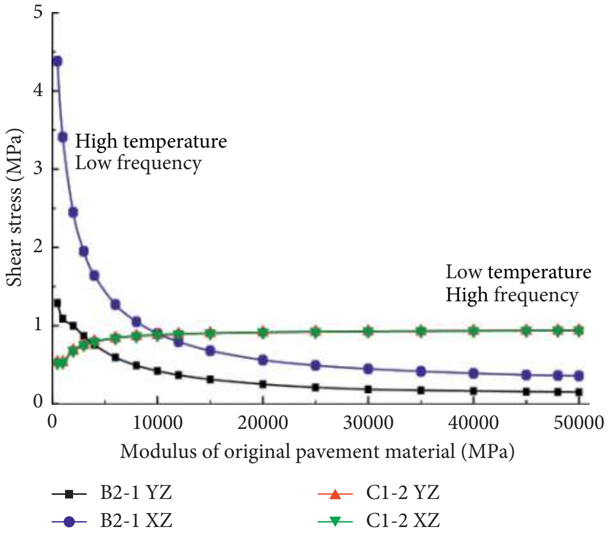


Figure 26: The effect of original pavement material modulus on shear stress of joint filling materials.

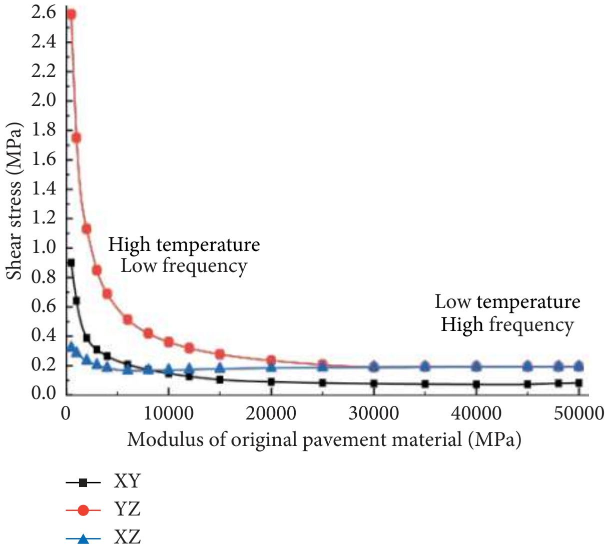


Figure 27: The effect of original pavement material modulus on shear stress of leveling layer.

pavement material modulus when the loading position is B2-1. However, when the loading position is C1-2, $\tau_{yz} \approx \tau_{xz}$, the material will gradually increase with the increase in pavement material modulus. So, when the pavement material modulus is less than or equal to 10000 MPa, the unfavorable loading position of the shear stress of the joint filling material is B2-1, and when it is more than 10000 MPa, the unfavorable loading position of the shear stress of the joint filling material is C1-2. The results of shear stress about leveling layer in Figure 27 show that τ_{yz} is the most maximum value than τ_{xy} and τ_{xz} and τ_{yz} decrease gradually with the increase in the pavement material modulus. When the temperature is high and the frequency is low, the leveling layer decreases rapidly with the increase of modulus. When the temperature is low and the frequency is high, the leveling layer decreases slowly with the increase of modulus, and there is almost no obvious change.

4. Conclusions

According to the typical asphalt pavement in China, this study determines the most unfavorable loading position in pothole repair through establishing a finite element model by ANSYS and analyzes the influences of the material modulus, size, thickness, and the modulus of the old pavement material on the potholes, and the results are as follows:

(1) After repairing the potholes, A2-2 (C1-1) is the most unfavorable loading position for tensile stress of repair block and joint filling material, B2-1 is the most dangerous loading position for the shear stress of the joint filling material, and C1-5 is the most unfavorable loading position for the shear stress of the leveling layer.

(2) Under the most dangerous loading position, by increasing the material modulus of the patch block, the stress of the patch block and the leveling layer obviously increases, but the tension of the joint filling material will be weakened. The variation of the material modulus changes the most unfavorable loading position of the shearing stress of the joint filling material. The increase of repair thickness will obviously weaken the stress of the repaired structure. Changes in the transverse and longitudinal dimensions of the patch will have different degrees of influence on the stress of the patch structure. Under the condition of high temperature or low frequency, the repaired pothole is easy to be damaged again.

(3) When repairing the potholes, appropriate repair materials should be selected. Choosing the right size and thickness, the repair material and pavement material should have good compatibility, so as to improve the repair effect of pit and groove.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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