Influence of Subgrade Splicing Mode and Width on Differential Settlement of Pavement Subgrade

Jiarong Liu1, Kai Wang1, Shiping Cui2 and Shiqi Shu3

1 Shandong Expressway Co., Ltd., Jinan, 250101, China
2 Shandong Transportation Research Institute, Jinan, 250102, China
3 School of Transportation Engineering, Shandong Jianzhu University, Jinan, 250101, China
Email: 315788902@qq.com

Abstract: In order to study the influence of subgrade splicing mode and width on differential settlement, the large-scale finite element analysis software ANSYS is used to establish the subgrade settlement model, in which the parameters are determined according to the actual subgrade width, widening mode and engineering geological conditions of the widening project of Anxin expressway. The influence of unilateral widening and bilateral widening on the settlement of widened subgrade, the maximum differential settlement on the top of widened subgrade and the influence on horizontal displacement of widened subgrade are systematically evaluated. The results show that for unilateral and bilateral widening, with the increase of widening width, the settlement of the middle line of the old road gradually increases, and the double side widening can make the weight of the widened embankment distribute to both sides of the old subgrade, which greatly improves the settlement coordination of the old and new Subgrade, and is beneficial to the stress of the pavement structure.

Keywords: Unilateral widening, bilateral widening, subgrade settlement, maximum differential settlement, subgrade horizontal displacement.

1. Introduction
The transportation capacity of trunk highways such as expressways that have been built and operated in China has reached or exceeded the saturation state, so it is urgent to reconstruct and expand the original highways. However, due to the consolidation settlement of the new subgrade and the structural strength difference between the old and the new subgrade, the stress at the joint is extremely unfavourable [1-2]. The splicing mode has a significant impact on the stress-strain distribution and stability of the subgrade structure. The splicing of the subgrade structure and the coordination of the new and old subgrade structure become the key technical problems to be solved in the highway reconstruction and expansion project [3]. Therefore, the influence of subgrade splicing mode and width on differential settlement needs further study. In this paper, the large-scale finite element analysis software ANSYS is used to establish the subgrade settlement model. The parameters are determined according to the actual subgrade width, widening mode and engineering geological conditions of the widening project of Anxin expressway. The results of ANSYS are used to compare the unilateral widening and bilateral widening of the subgrade, so as to analyze the influence of the splicing mode and width of the subgrade on the differential settlement. At present, scholars at home and abroad mainly focus on the reinforcement method between the new and the old subgrade, and there is little research on the influence of splicing mode and width on the differential settlement of...
subgrade. Therefore, it is one of the urgent problems to study and solve for the influence of subgrade splicing mode and width on differential settlement.

2. The Establishment of the Finite Element Model

2.1. Conditional Hypothesis

Due to the complexity of influencing factors of subgrade settlement, considering the requirements of calculation simplification and calculation accuracy, the calculation model is simplified and assumed as follows:

1. Considering the plane problem, the two-dimensional finite element analysis is carried out;
2. The soil is elastic-plastic material, and Drucker Prager model is used to simulate;
3. The contact surface between the old and the new subgrade is completely continuous without sliding;
4. The boundary conditions are as follows: the bottom of the foundation is fully constrained in both directions of XY, and both sides of the foundation width are constrained in X direction;
5. Replace the pavement load with the filling load of 1 m thick subgrade.

2.2. Solid Modeling

The parameters are determined according to the actual subgrade width, widening mode and engineering geological conditions of the widening project of Anxin expressway. The soil along the expressway is mainly composed of cohesive soil, the internal friction angle is between 10 degree and 30 degree, and the compression modulus of soil foundation is mostly between 3 MPa and 8 MPa. According to the design documents, the compression modulus of new subgrade is 40 MPa, and that of old road is consolidation and hardening, which will be increased to 50 MPa.

A section of high-speed widening project is selected for calculation and analysis. Assuming that the width of old subgrade is 26 m and the filling height is 8m, and the double side widening method is adopted, each side is widened by 8 m and the slope ratio is 1:1.5, then the width of widened embankment bottom is 66 m, the calculation depth is 20 m, and the calculated width of foundation under subgrade is 200 m (more than 3 times the width of widened embankment bottom). After construction, the consolidation degree is calculated by measured consolidation coefficient u = 60%.

The plane model is established, the symmetry is considered, and the middle line of the old subgrade is taken as the symmetry axis. The horizontal displacement is based on the slope angle before the original subgrade is moved, and the direction perpendicular to the subgrade centerline and away from the subgrade is a positive direction, and the opposite direction is a negative direction. The settlement is based on the intersection line between the subgrade surface and the middle line of the old subgrade, with a negative value in the downward direction and a positive value in the upward direction, as shown in figure 1.

![Figure 1. Broadening geometric model.](image-url)
3. Study on the Effect of Splicing Mode and Width on Differential Settlement

3.1. Unilateral Widening

According to the previous calculation model, combined with the entity project, the subgrade height is 4m, the slope is 1:1.5, the new subgrade filling compressive resilience modulus is 40 MPa, the old subgrade compressive resilient modulus is 50 MPa, and the foundation compression modulus is 4 MPa. When the unilateral widening width is 4 m, 8 m, 12 m, 16 m, namely, corresponding to one lane, two lanes, three lanes and four lanes, the impact on the splicing subgrade will be affected.

It can be seen from figure 2 that for unilateral widening, with the increase of widening width, the settlement of the middle line of the old road gradually increases. When the original four lane is changed to five lane, six lane, seven lane and eight lane, the additional settlement of the middle line of the old road is very small, but the settlement trend first increases and then decreases. With the increase of splicing width, the influence of the newly widened part on the middle line of the old road becomes greater when the increased width is small, but the settlement trend gradually decreases when the widening width is large.

The settlement of the new subgrade is obviously greater than the additional settlement of the old subgrade. With the increase of the widening width, the location of the maximum settlement gradually moves outward, showing certain regularity. With the increase of widening width, the maximum settlement value moves from the edge of widened subgrade to the shoulder of widened subgrade, and gradually moves away from the middle line of old road with the increase of widening width.

When the splicing width is less than 12 m, the maximum settlement appears at the edge of the subgrade; when the width increases to 12 m, the position of the maximum settlement changes, which does not appear at the edge of the new subgrade, but at the middle position of the hard shoulder which is 3 m inside the edge of the subgrade. That is, when the splicing width is more than 12 m, the settlement of the top surface of the subgrade begins to decrease, that is, it appears on the top of the spliced subgrade reverse slope. When the splicing width is large, the reverse slope on the top of the splicing subgrade is prone to ponding during precipitation, causing water damage and affecting the use function of the pavement [4].

It can be seen from figure 3 that the differential settlement increases with the increase of widening width. The maximum differential settlement of new and old subgrade is 5.98 m when widening 4m, while the maximum differential settlement increases to 11.8 cm when the splicing width of widened subgrade increases from 4m to 8m, and the added value is 5.82 cm. When the splicing width increases from 8 m to 12 m, the maximum settlement increases to 15.64 cm, only 3.84 cm. When the splicing width increases from 12 m to 16 m, the maximum differential settlement at 16 m increases to 18.49 cm, and the difference between them is 2.85 cm. In short, the differential settlement increases with the increase of splicing width.
Figure 3. Variation of maximum differential settlement of widened subgrade top surface with different width of unilateral splicing

Therefore, the splicing width should be limited in the process of one side road splicing, and it is recommended to splice 8 m, that is, to splice 2 lanes.

3.2. Bilateral Widening

The calculation model and calculation parameters are the same as one side splicing. As the subgrade is symmetrical, half of the subgrade is taken for calculation. When the splicing width is 4 m, 8 m, 12 m, 16 m and 24 m on both sides, the effect on the splicing subgrade is 2 m, 4 m, 6 m, 8 m and 12 m respectively, which is corresponding to the widening of one lane, two lanes, three lanes, four lanes and six lanes.

Figure 4 influence of different splicing width on widened subgrade settlement.

It can be seen from figures 4 and 5 that the differential settlement curve of bilateral widening is basically the same as that of unilateral widening. With the increase of widening width, the center settlement of the old road increases gradually. Compared with unilateral widening, the additional settlement of the middle line of the old road is larger under the same width, but the maximum differential settlement of the new and old subgrade is slightly reduced. The reason is that the forces on both sides of the old subgrade are balanced by widening on both sides, and the additional stress in the middle of the old road is increased due to the self weight load of the new subgrade, so that the center of the old road also has a large settlement, which correspondingly reduces the differential settlement of the spliced subgrade [5].
Figure 5 variation of the maximum differential settlement of the top surface of the jointed subgrade with different splicing widths on both sides

The maximum differential settlement of the new and old subgrade is 3.11 cm when the splicing width is 4 m, and the maximum differential settlement is 6.19 cm and 3.08 cm when the widened width of the jointed subgrade is increased from 4 m to 8 m; the maximum differential settlement increases to 8.78 cm and increases by 2.59 cm when the splicing width increases from 12 m to 16 m; the maximum differential settlement increases to 11.47 cm, increasing by 2.69 cm, when the splicing width increases from 16 m to 24 m (increase by 8 m), the maximum differential settlement increases to 15.01 cm and increases by 3.54 cm. In a word, with the increase of splicing width, the maximum differential settlement of old and new subgrade gradually increases.

Compared with unilateral widening and bilateral symmetrical widening, for the same splicing width, bilateral widening can make the weight of widened embankment distribute to both sides of old subgrade, greatly improve the settlement coordination state of new and old subgrade, and is also beneficial to the stress of pavement structure [6-7]. In addition, bilateral splicing can reduce the amount of earthwork required for splicing. However, the double side splicing also increases the construction difficulty and cost of the project, and brings certain difficulties to the management of open traffic during the construction period [8].

4. Conclusion
(1) For unilateral and bilateral widening, with the increase of widening width, the settlement of the middle line of the old road gradually increases.

(2) By comparing unilateral widening and bilateral symmetrical widening, for the same splicing width, bilateral widening can make the weight of widened embankment distribute to both sides of old subgrade, greatly improve the settlement coordination state of new and old subgrade, and is beneficial to the stress of pavement structure.

(3) Bilateral splicing can reduce the amount of earthwork required for splicing. However, the double side splicing also increases the construction difficulty and cost of the project, and brings certain difficulties to the management of open traffic during the construction period.

(4) In the process of one-sided highway splicing, the splicing width should be limited, and it is recommended to splice 8 m, that is, to splice 2 lanes.

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