ASPHALT PAVEMENT ANALYSIS NEAR BRIDGE ABUTMENTS

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Abstract: This paper investigated stress and displacement distributions of the asphalt pavement near bridge abutment by means of three-dimensional finite element methods. First, the model of asphalt pavement near bridge abutment was established. The road pavement was modelled as a linear elastic multi-layer system in three dimensions with finite boundaries. The abutment was simulated by the fixed displacement boundary conditions because of the higher stiffness of the abutment than that of the adjacent pavement. Studies have shown that the bridge abutment plays an important role in the structural behavior of the pavement. Non-homogeneous subgrade due to the improper compaction was studied. The influence length of bridge abutment was obtained. A modified design method for asphalt pavement structure near bridge abutment could be derived according to this analysis. Many figures were presented in the paper to support the conclusions.

Key words: non-homogeneous subgrade, pavement, bridge abutment

1. INTRODUCTION

It is well known that multi-layer elastic system theory is employed to determine the thickness in the design of asphalt pavement. But the assumption of infinite boundary condition makes it impossible to apply the theory directly to the design of asphalt pavement near bridge abutment. The stiffness and boundary of the abutment affect the pavement near bridge abutment in many ways. Usually, humps and cracks form in the transition section from the pavement to the abutment. In practice, the transition section is about 15m long.

The lack of proper design theory for the pavement in the transition section causes damages and accidents from time to time. A modified design theory based on the multi-layer elastic theory is needed. There are many factors influencing the functional characteristics of the pavement in the transition section, such as the settlement of the subgrade, improper compaction of the subgrade adjacent to the abutment, and the stiffness difference between the abutment and the pavement. This research mainly aimed to analyse structurally the influence of the abutment on the pavement and to determine the influence length of the end effect of bridge abutment. This research will provide the theoretical background for the pavement design near bridge abutment.

2. COPUTATIONAL MODEL

The road pavement was modeled as a linear elastic multi-layer in three dimensions with finite boundaries. The abutment was simulated by fixed displacement boundary conditions because of its higher stiffness. The boundary condition is fixed at the bottom of the subgrade. The interface between the abutment and the pavement can be bonded or free to slip depending on the friction coefficient between them. The material property is listed in Table 1.

Table1. Material Properties

Elastic Modulus of Wearing Course E_1(Mpa)	1200
Poisson Ratio of Wearing Course μ_1	0.25
Thickness of Wearing Course H_1(m)	0.15
Elastic Modulus of Base Course E_2(Mpa)	1400
Poisson Ratio of Base Course μ_2	0.25
Thickness of the Base Course H_2(m)	0.2
Elastic Modulus of Sub-base Course E_3(Mpa)	500
Poisson Ratio of Sub-base Course μ_3	0.25
Thickness of Sub-base Course H_3(m)	0.3
Elastic Modulus of Sub-grade E_0(Mpa)	50
Poisson Ratio of Subgrade μ_0	0.35

From Table 1 it can be seen that the parameters chosen to conduct the modeling and calculation are in the range of normal engineering practice. The elastic modulus of Wearing Course is tested under the temperature of 20^{o}C. All the parameters are in consistence with the Specifications for Design of Highway Asphalt Pavement in China. The loading was a double circular uniformly distributed tire pressure of 0.7Mpa. The radius of contact area was 10.67cm. This corresponds to a single axle loading of 100KN. The size of the model was 8 meters long and 3.5 meters wide. In order to minimize the influence of the depth of subgrade, the models of 8 meters long and 3.5 meters wide with different depths were analyzed The compressive stress 2m below the center of the loading is shown in Table 2.

Table 2. The Influence of the Depth of the Subgrade

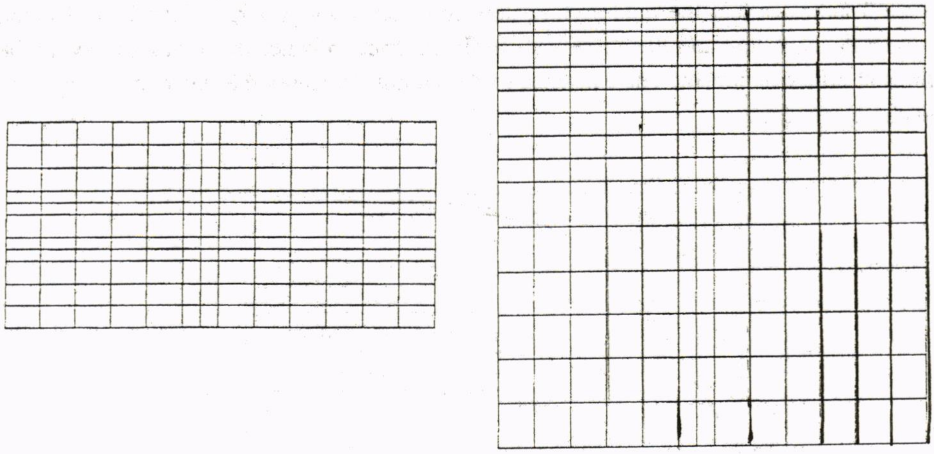
Thickness of Subgrade(m)	3	4	6	8	10.5
σ_z (Mpa)	0. 0107841	0.010885	0.010889	0.010895	0.010895

The compressive stress converges quickly with the increase of the depth of the subgrade. In the following analysis, the depth of the subgrade is selected as 6m. Table 3 is the influence of different meshes on the accuracy of the calculation.

Table 3. The Influence of Different Meshes

Number of Elements			Maximum Tensile Strength (Mpa)	Increase Ratio(%)
X Direction	Y Direction	Z Direction		
10	7	15	0.294411	
11	9	15	0.300102	1.93
13	11	15	0.301341	0.41

The X,Y,Z directions indicate the directions of pavement length, pavement width, pavement depth respectively. The finite element mesh consisting of 13 elements in the road direction, 11 elements in the width and 6 elements in the depth is chosen from Table 3. There are 2145 three-dimensional elements all together, as shown in Figure1



(a) X-Y View (b) X-Z View

Fig. 1 Three Dimensional Mesh

The size of the model was chosen to minimize the influence of the boundaries of the subgrade at the bottom. The size of the elements was designed to increase the accuracy of the numerical results. All the results were calculated by Algor software.

3. DISCUSSION OF NUMERICAL RESULTS

3.1 The Influence of the Abutment

Figure 2 shows that stress distribution in the pavement near the abutment is affected by the end effect. This is different from symmetrical stress distribution in multi-layer elastic theory. The stress decreases with the distance from the abutment. Structurally speaking, the influence length is about 5m.

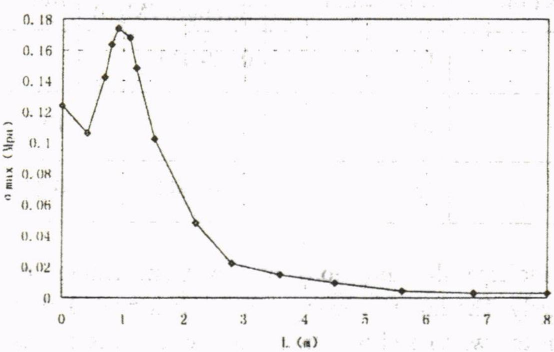


Figure 2. Stress Distribution along the Road Direction

Figure 3 indicates that the road surface deflection can be very large if the is no friction between the abutment and the pavement. Sufficient friction is needed in order to avoid the humps at bridge abutment. The existence of the humps decreases the ride quality seriously and causes accidents.

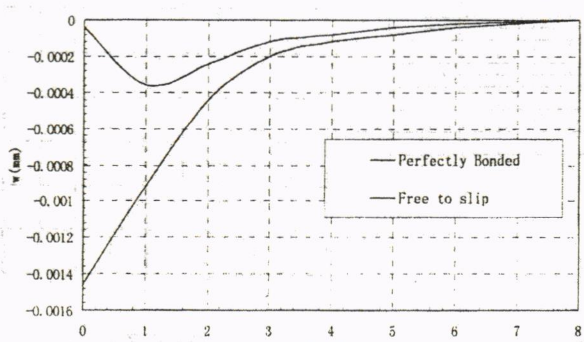


Figure 3. Displacements Distribution along the Road Direction

3.2 Non-Homogenous Subgrade

Because of the limited space near the abutment, it is difficulty to compact the subgrade properly. The elastic modulus of the subgrade is not uniform due to the improper compaction. The non-homogeneity was expressed in terms of the variation of elastic modulus of the subgrade. In this paper, four-uniform-step variation of 50Mpa, 80Mpa, 100Mpa, 150Mpa in the length of 8m away from the abutment was adopted. Tire pressure was acted in the center of each of the four steps. The influence of non-homogenous subgrade on the pavement can be very large as shown in Figure 4 and Figure 5. The road surface deflection in the case of non-homogenous subgrade is two times that in the case of homogenous subgrade. Therefore measures must be taken to guarantee the compaction quality of the subgrade.

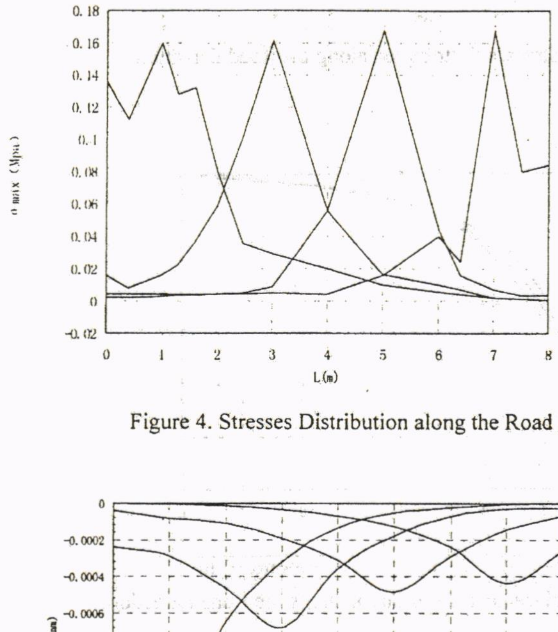


Figure 4. Stresses Distribution along the Road Direction

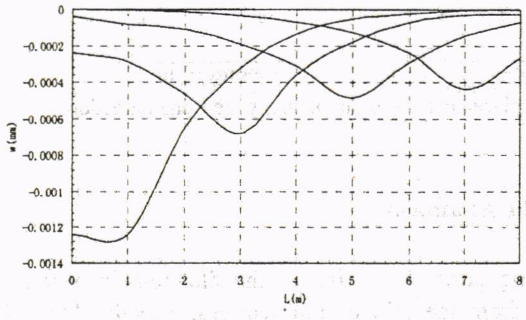


Figure 5. Displacements Distribution along the Road Direction

3.3 Contact Conditions in the Pavement

In Figure 6 and Figure 7, WC/BC denotes wearing course /base course. In loading case I, when the interface in the pavements changes, bigger difference occurs in either stresses or the surface deflection. That is to say, perfectly bonded interfaces should be guaranteed in the construction of the pavement in order to minimize the end effect of the abutment.

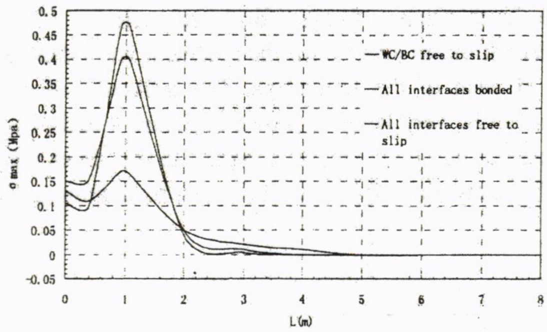


Figure 6. Stresses Distribution along the Road Direction

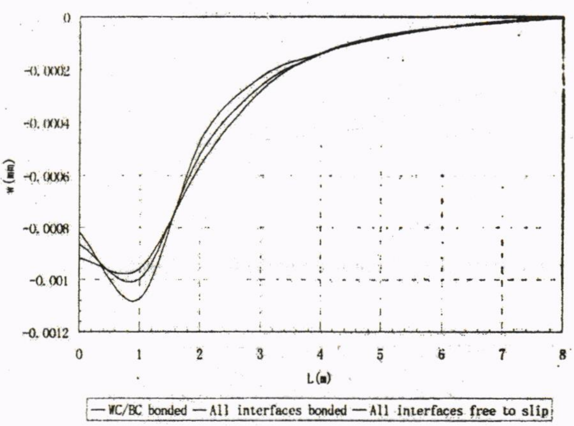


Figure 7. Displacements Distribution along the Road Direction

3.4 Pavement Design near the Abutment

In Table 4 and Table 5, loading cases Ⅰ, Ⅱ,Ⅲ are the situations in which tire pressures are 0.4m, 1.0m, 1.6m away from the bridge abutment respectively. Table 4 shows that stresses at the bottom of base course and subbase course tend to be equal when the subbase course is thicker than 2.5m ,no matter where the loading is. Therefore the existence of the abutment makes little difference in stresses of the pavements. The stresses at the bottom of the wearing course are always negative in this case.

Table 4. Tensile Stresses in the Pavement Structure (kpa)

Loading Case	Thickness of Subbase Course (m)	At the Bottom of Subbase Course		At the Bottom of Base Course		At the Bottom of Wearing Course	
		б x	б y	б x	б y	б x	б y
I	0.5	49.7	52.2	41.8	36.5	<0	<0
	1.5	18.3	11.4	20.1	20.0	<0	<0
	2.5	6.97	1.86	24.1	25.2	<0	<0
II	0.5	33.9	32.0	52.6	32.8	<0	<0
	1.5	11.3	8.29	38.6	21.6	<0	<0
	2.5	6.32	2.09	39.6	22.5	<0	<0
III	0.5	32.3	31.2	54.9	32.8	<0	<0
	1.5	8.61	5.86	42.1	22.7	<0	<0
	2.5	4.15	1.75	43.0	23.5	<0	<0

Table 5 indicates that the nearer of the tire loading to the abutment, the bigger the road surface deflection when the subbase course is thinner than 50cm.The deflections in different loading cases tend to be the same when the thickness of the subbase course is more than 2.5m. In pavement design, stresses and road surface deflection are usually selected as the criteria. In order to make sure that road surface deflection and stresses in the pavement near the abutment approach those in the normal pavement (the pavement far from the abutment), the thickness of the pavement must be increased to a certain extent, such as the thickness of the subbase should exceed 3 m.

Table 5. Road Surface Defection along the Road Direction (0.01mm)

Loading Case	Thickness Subbase Course (m)	Distance Away From the Abutments(m)					
		0	0. 4	1. 0	1. 6	2. 0	2. 6
		Deflection Along the Road Direction(0.01mm)					
I	0.5	52.0	51.7	39.8	29.7	24.3	17.3
	1.5	33.2	33.9	26.3	21.6	19.3	16.0
	2.5	26.1	26.9	20.1	16.6	15.2	13.3
II	0.5	39.2	39.8	42.2	32.3	26.4	19.0
	1.5	25.5	26.3	29.7	23.0	19.9	16.4
	2.5	19.3	20.1	24.1	18.3	15.8	13.6
III	0.5	29.3	29.8	32.3	36.2	30.3	22.1
	1.5	21.4	21.6	23.0	26.8	22.3	17.2
	2.5	16.4	16.6	18.3	22.4	18.5	11.3

In construction, the compaction of the subbase should be divided into several layers, each layer with a thickness of less than 20cm, and the compaction ratio should also be controlled to ensure its strength and stability.

3.5 Influence of the Module of the Subgrade

Table 6 displays the modulus of the subgrade has a great influence on the surface deflection, especially when the modulus is less than 50 Mpa. Thus, increase of the modulus of the subgrade helps to improve pavement behavior near the abutment.

Table 6. Deflection along the Road Direction (0.01mm)
(Loading Case I, The Thickness of Subbase 2.5m)

Elastic Modulus of Subgrade (Mpa)	Distance Away From the Abutments(m)					
	0	0.4	1.0	1.6	2.0	2.6
	Deflection Along the Road Direction(0.01mm)					
30	24.3	24.2	26.0	30.1	26.1	21.7
50	16.4	16.6	18.3	22.4	18.5	14.3
80	11.6	11.8	13.5	17.8	13.9	9.9

4.CONCLUSIONS

The three dimensional finite element methods were employed to study the structural response of the road pavements near bridge abutment. Several conclusions were reached based on the studies at this stage, they are summarised as follows:

1. The bridge abutment plays an important role in the structural behavior of the pavement

2.The humps and the cracks can be avoided to some extent when the interface between the abutment and the pavement is well bonded.

3.Non-homogeneous sub-grade due to the improper compaction causes increase of stresses and road surface deflection in the pavement.

4.From the structural point of view, the influence length of bridge abutment is about 5m.

5. The effects of the thickness of subbase course were obtained and compared.

6. The elastic modules of subgrade has a great influence on the surface deflection of pavements.

7. The structural behavior of asphalt pavement near the bridge abutment approaches thet hat of the pavement far away from the abutment when the subbase course is thicker than 3m.

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