Study on the Influence of Mixture Uniformity on Asphalt Pavement based on ABAQUS

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Abstract: Using ABAQUS finite element software to simulate the 3D asphalt pavement model, the strain, stress and displacement of each layer are calculated under the action of traffic load, then the influence of asphalt mixture uniformity on the mechanical response of asphalt pavement was obtained. The results show: the uniformity of asphalt mixture has an influence on the mechanical response of pavement; under the same environmental factors and traffic load, the displacement of the flexible base asphalt pavement is larger than that of the semi-rigid base asphalt pavement; the tensile stress generated in the asphalt pavement is basically on the surface of the base layer and the pavement layer, the tensile stress of semi-rigid base asphalt pavement is larger than that of the flexible.

Keywords: Road engineering; Asphalt pavement; Uniformity; Mechanical response; Finite element method

1. Introduction

Road engineering structure analysis is a necessary and important part in the design of asphalt pavement. The main purpose is to determine the pavement structure under the environmental factors (temperature and humidity) and the driving load under the action of some of the mechanical response (strain, stress and displacement). Among many common pavement design methods, such as the design method of shell asphalt pavement, asphalt pavement design method and so on, mechanical response is the most basic control index or design index. In the analysis of pavement structure, basing on the ABAQUS finite element software and other kinds of numerical simulation software in the simulation of indoor test, heavy load traffic pavement stress analysis, special sect-ion of Pavement Stress analysis, asphalt overlay to prevent reflection cracks and other research areas demonstrates the particularity of numerical simulation analysis, high efficiency. At present, this kind of analysis method is widely used in our country.

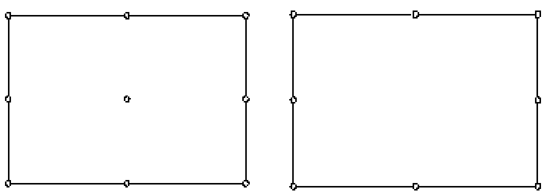
The service life of asphalt pavement and pavement performance are directly influenced by the uniformity of asphalt mixture and the maintenance cost of asphalt pavement is also affected. In the past people did not put the asphalt mixture as a serious problem to treat, so that the depth of the study is far from enough, the relevant research results are relatively small. Using ABAQUS finite element software to build three-dimension-al asphalt pavement model. In this paper, the structure of asphalt pavement is analyzed, and the different structure layers of asphalt mixture are calculated. The mechanical response of each layer under the vehicle load is studied, and then the influence of asphalt mixture on the mechanical response of asphalt mixture is evaluated.

2. Basic Assumption

Some studies have indicated that the uniformity of asphalt mixture has an influence on the mechanical properties of asphalt pavement, but in fact, there is no necessary connection between the absolute value of the mechanical properties and the uniformity of asphalt mixture. In the nc-hrp-441 report pointed out: for the asphalt mixture segregation is moderate, its strength will be reduced by about 20%~50%. Basing on this rep-ort, in the present study, assuming that in moderate segregation of asphalt mixture, its strength will be reduced by 50%. In order to facilitate the research on the uniformity of asphalt mixture an-d the mechanical response of pavement, here is assumed beforehand: moderate segregation phenomenon in asphalt mixtures, namely resilient modulus of asphalt pavement structure layer reduce to 50% before segregation[1] .

3. Establishment of Three-dimensional Finite Element Calculation Model

According to the Design Standard of High-way Asphalt Pavement(JTG D50-2006) in China, in the modeling of pavement structure the load surface is a double circulars load. Uniformly distributed load of P is applied to 0.7Mpa/25kN in the double circles, when equivalent circle radius 10.65cm, double round center distance=31.95cm. Finite element model uses 6m × 6m quadrilateral. Based on the symmetry of structure and load, the desirable model of 1/2 is analyzed. But in order to be consistent with the analysis of the frcture mechanics, the whole model is still used. The finite element model is a two-dimensional mo-del of plane stress, and there are four kinds of elements in the two-dimensional model: Triangular element, Lagrange rectangular element, Hermite rectangular element and Serendipity quadrilateral element. In general, the rectangular element is more convenient and effective than the tri-angular element. So when the element is divided, the rectangular element is considered. The main differences between the Lagrange rectangular element, the Hermite rectangular element and the Serendipity quadrilateral element are embodied in the structure of the difference functions. Lagrange rectangular element is simple and convenient to construct the interpolation function, but t-here are some disadvantages in the unit of this type. It is mainly that the internal nodes which are increased with the increase of the interpolation function, which increases the degree of freedom of the element, and the increase of these degrees of freedom cannot improve the accuracy of the unit[2]. The interpolation function of Hermite rectangular element is constructed by using the method of constructing a Lagrange element similar to the one dimensional Hermite polynomials. The Serendipity quadrilateral element is more complex than the previous two elements. The following is the two unit node diagram of the Lagrange rectangular element and the Serendipity quadrilateral element.



Lagrange rectangular element   Serendipity quadrilateral element

Figure 1. The legend of finite element

4. Pavement Structure and Structural Layer Parameters

Two typical pavement structures are considered in this paper:

(1) Semi rigid base asphalt pavement structure parameters as is shown in Table 1, and the structure of the composite layer is shown in Figure 2.

Table 1. Semi rigid base asphalt pavement

Structure sheaf	Material name	Thickness (cm)
Upper layer	AC-13	5
Middle layer	AC-20	6
Bottom layer	AC-25	7
Basic layer	5% Cement stabilized crushed stone	25

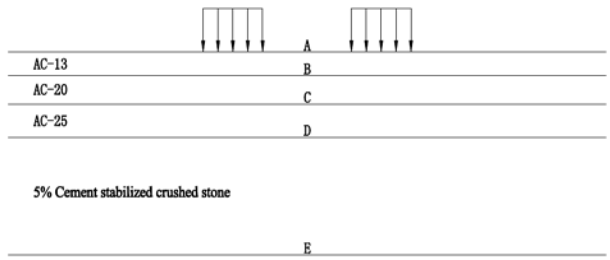


Figure 2. Schematic diagram of semi rigid base asphalt pavement

(2)The flexible base asphalt pavement structure parameters are shown in Table 2, and t-he structure layer combination is shown in Figure 3.

Table 2. Flexible base asphalt pavement

Structure sheaf	Material name	Thickness (cm)
Upper layer	AC-13	5
Bottom layer	AC-25	6
Basic layer	ATB-25	30

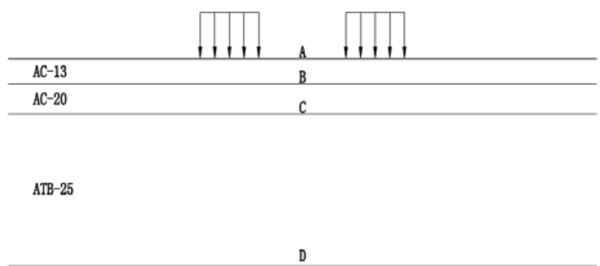


Figure 3. Sketch map of flexible base asphalt pavement

Even if the pavement structure layer, the thickness of the same, using different uniformity asphalt mixture will form different pavement structures. Changing the uniformity of asphalt mixture, adjusting the parameters of each structure layer, pavement structure(I) ,pavement structure (II) obtain 8 different conditions. Each condition can be considered as a kind of pavement structure. Parameters of pavement structure(I), pavement structure(II) in each structural layer under different working conditions are shown in Table 3, Table 4[3] .

In the above pavement structure(I), Condition (1) indicates that the asphalt mixture of each structure layer is uniform; Condition (2) ~ (8) shows 1 layer or 2 layers, 3 layers, or 4 layers of asphalt mixture is not uniform, moderate segregation; In working conditions (2) (3) and working conditions (4), only 1 layer of asphalt mixture in the surface layer were nonuniform; in conditions (5), working conditions (6) and working conditions (7), there are 2 layers of asphalt mixture in the surface layer; in the working conditions (8), the 3 layers of asphalt mixture in the surface layer are nonuniform. In pavement structure(II), the situation is similar to the pavement structure (I), just less a layer structural layer.

Table 3. Structural parameters of pavement structure (I)

Work Conditions	Structure layer thickness(cm)				Modulus of resilience (pa)					Poisson's ratio				
	H1	H2	H3	H4	E1	E2	E3	E4	E0	μ1	μ2	μ3	μ4	μ0
1	5	6	7	25	1400	1200	1000	1300	45	0.25	0.25	0.25	0.2	0.35
2	5	6	7	25	700	1200	1000	1300	45	0.25	0.25	0.25	0.2	0.35
3	5	6	7	25	1400	600	1000	1300	45	0.25	0.25	0.25	0.2	0.35
4	5	6	7	25	1400	1200	500	1300	45	0.25	0.25	0.25	0.2	0.35
5	5	6	7	25	1400	600	500	1300	45	0.25	0.25	0.25	0.2	0.35
6	5	6	7	25	700	1200	500	1300	45	0.25	0.25	0.25	0.2	0.35
7	5	6	7	25	700	600	1000	1300	45	0.25	0.25	0.25	0.2	0.35
8	5	6	7	25	700	600	500	1300	45	0.25	0.25	0.25	0.2	0.35

Table 4. Structural parameters of pavement structure (II)

Work Conditions	Structure layer thickness (cm)			Modulus of resilience (Pa)				Poisson's ratio			
	H1	H2	H3	E1	E2	E3	E0	μ1	μ2	μ3	μ0
1	5	6	30	1400	1200	1000	45	0.25	0.25	0.25	0.35
2	5	6	30	700	1200	1000	45	0.25	0.25	0.25	0.35
3	5	6	30	1400	600	1000	45	0.25	0.25	0.25	0.35
4	5	6	30	1400	1200	500	45	0.25	0.25	0.25	0.35
5	5	6	30	1400	600	500	45	0.25	0.25	0.25	0.35
6	5	6	30	700	1200	500	45	0.25	0.25	0.25	0.35
7	5	6	30	700	600	1000	45	0.25	0.25	0.25	0.35
8	5	6	30	700	600	500	45	0.25	0.25	0.25	0.35

5. Uniformity and the mechanics response of asphalt pavement

Using ABAQUS finite element software, t-he stress, strain and displacement of each measuring point in the center of the wheel gap are calculated. The mechanical responses of each measuring point in the above conditions, as shown in Table 5, Table 6. The data of Table 5 and Table 6 shows that the uniformity of asphalt mixture directly affects the mechanical response of pavement. In table 5,the displacement at the bottom of semi-rigid base layer ,tension strain and tensile stress are: condition(2), condition(3) and condition(4)<condition(5) ,condition(6) and condition(7) <condition(8). Pavement structure(I), in semi-rigid base asphalt pavement, the displacement, tensile strain and tensile stress of the asphalt pavement are increasing with the increase of the nonuniform range of the mixture in the asphalt surface layer, and the specific location of the occurrence of nonuniform has not too much direct relationship. In table 6, the tensile stress at the bottom of flexible base asphalt pavement is: condition(4), condition(5), condition(6) and condition(7)<condition(2),condition(3) and condition(8). Pavement structure(II), in the flexible base asphalt pavement, its displacement, tensile strain and tensile stress are not directly related to the range of the occurrence of nonuniformity, but its relationship with the specific location is quite large. When the mixture is nonuniform, for the base asphalt layer and the asphalt surface layer, the latter has a great influence on bottom tensile stress[4] .

Table 5. Stress, strain and displacement of the measuring points of pavement structure (II) under various working conditions

Measure point Working condition	A			B			C			D		
	displacement	stress	strain	displacement	stress	strain	displacement	stress	strain	displacement	stress	strain
1	0.03	54.49	30.89	-0.43	-260.7	31.14	-0.21	-127.4	30.97	0.2	144.64	27.36
2	0.02	39.0	33.40	-0.27	-327.2	33.71	-0.26	-160.7	33.72	0.21	153.67	30.08
3	0.15	149.97	33.11	-0.61	-387.6	33.32	-0.15	-150.3	32.62	0.21	149.44	29.01
4	-0.01	53.36	42.54	-0.43	-258.8	42.97	-0.20	-141.5	42.68	0.14	210.85	35.55
5	0.12	152.56	44.80	-0.61	-392.5	45.07	-0.15	-175.3	44.23	0.14	214.96	37.04
6	-0.01	40.67	45.70	-0.27	-321.8	46.13	-0.27	-192.6	46.05	0.15	222.75	38.71
7	0.09	151.29	35.98	-0.39	-484.1	36.24	-0.18	-190.3	35.87	0.22	159.38	32.27
8	0.07	154.87	48.24	-0.40	-490.0	48.62	-0.20	-238.8	48.16	0.15	227.32	40.86

Table 6. Stress, strain and displacement of the measuring points of pavement structure (I) under various working conditions

Measure point / Working condition	A			B			C		
	displace-ment	stress	strain	displacement	stress	strain	displace-ment	stress	strain
1	0.05	67.97	29.1	-0.41	-251.1	29.77	-0.22	-131.1	29.57
2	0.03	57.92	31.79	-0.25	-312.1	32.13	-0.27	-160.9	32.10
3	0.18	162.5	31.74	-0.59	-376.0	31.96	-0.16	-153.0	31.20
4	0.06	88.74	32.44	-0.4	-274.9	32.70	-0.26	-169.3	32.39
5	0.19	184.3	34.66	-0.54	-380.8	34.88	-0.18	-204.5	33.98
6	0.04	87.31	34.84	-0.25	-300.3	35.18	-0.32	-212.6	35.06
7	0.11	170.2	34.36	-0.37	-465.2	34.64	-0.18	-189.9	34.20
8	0.12	201.3	37.47	-0.37	-464.7	37.76	-0.22	-257.9	37.2
Measure point / Working condition	D			E					
	displace-ment	stress	strain	displacement	stress	strain			
1	-0.08	-30.73	28.68	0.20	118.83	26.58			
2	-0.10	-43.82	31.27	0.21	125.72	29.10			
3	-0.10	-41.21	30.35	0.21	123.12	28.20			
4	-0.08	-41.11	30.37	0.21	124.94	28.23			
5	-0.09	-52.26	32.0	0.22	128.44	29.83			
6	-0.09	-56.59	33.09	0.22	131.76	30.88			
7	-0.12	-56.84	33.44	0.22	130.70	31.24			
8	-0.10	-70.76	35.32	0.23	136.0	33.10			

Under the same environmental factors and driving load, the displacement of the flexible base asphalt pavement (deflection) is larger than that of the semi-rigid base.

In addition, from the table 5 and table 6, it can be seen: the tensile stress in the asphalt pavement is always in the bottom of the layer and the road surface. Moreover, the tensile stress of the asphalt pavement on semi rigid base is generally larger than that of the flexible. Main reason producing the latter in the semi rigid base asphalt road surface is more likely to produce the micro crack phenomenon, the former is one of the reasons why the tensile stress appears on the surface of the road[5]. Both the flexible base asphalt pavement and semi-rigid base asphalt pavement, in which the tensile stress of the pavement surface is always relatively large when the pavement is nonuniform. So, from the point of reducing even aviding the surface tensile stress of asphalt pavement, it is necessary to control the uniformity of asphalt mixture in the surface layer (lower layer).

5. Conclusion

(1)The uniformity of asphalt mixture has a direct influence on the mechanical response of pavement.

(2)Under the same environmental factors and driving load, the displacement of flexible base asphalt pavement (flexure) is larger than that of semi-rigid asphalt pavement.

(3)The tensile stress of asphalt pavement often appears on the bottom of the base course and the surface of the asphalt pavement, and the tensile stress of the asphalt pavement on semi rigid base is generally larger than that of the flexible.

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