EVALUATION OF THE HMA PAVEMENT STRUCTURE ON A CEMENT CONCRETE BRIDGE DECK USING A COMPOUND BEAM

YING GAO, XIAOMING HUANG and TAO XU

Transportation College, Southeast University, 2 Sipailou, Nanjing, Jiangsu, 210096, P.R. China. E-mail: gy@seu.edu.cn, huangxm@seu.edu.cn and seutx@163.com

ABSTRACT

It is very important that the pavement on a cement concrete bridge deck should be long-lasting. A compound beam was used to evaluate the fatigue life of hot mixed asphalt (HMA) courses on a bridge deck. Firstly, the Finite Element Analysis (FEA) method was employed to make sure that the mechanical response of the compound beam was in accordance with that of the actual bridge deck under the same load. Next, a fatigue test was done on compound beams with different pavement structures. From the test result, it was clear that a waterproof and cohesive course is very helpful in prolonging the life of a compound beam. Fibre is also a good material for use in an HMA mixture. Stone Matrix Asphalt (SMA) on top of fibre-reinforced Asphalt Concrete (AC) was the best pavement structure in this test. In conclusion, fibre-reinforced Coarse Asphalt Concrete (AK) and fibre-reinforced AC are recommended, whichever is most convenient for construction.

1. INTRODUCTION

Asphalt pavement on a cement bridge deck should meet the requirements for the asphalt courses on a normal road, as well as the special requirements for a bridge deck pavement. The deformation should be in good agreement with that of the bridge deck. It is very important for the bridge deck pavement to be long-lasting because of the difficulties of maintenance on a bridge. The purpose of this paper is to study the fatigue characteristics of asphalt courses on bridge decks and to choose a pavement structure for Jinghang Canal Bridge on the Lianxu expressway by means of a compound beam fatigue test.

Usually, in Jianshu, the bridge deck pavement structure consists of a surface course and an intermediate course, which is the same as the upper section of the road connected with the bridge. The most common type of mixture for the surface course is 13 mm nominal maximum aggregate size (NMAS) Stone Matrix Asphalt (SMA13), Coarse Asphalt Concrete (AK13) and fibre-reinforced AK13. Mixtures for the intermediate courses are 20 mm NMAS Asphalt Concrete (AC20) and fibre-reinforced AC20. Whether or not a waterproof and cohesive course should be used is still under discussion.

Jinghang Canal Bridge is a supersize bridge on the Lianxu expressway in Jiangsu Province. The total length of the bridge is 2 577 m. The main bridge is a half-through bowstring arch bridge, of which the span is 235 m. The designed pavement structure is 4 cm AK13 and 6 cm AC20, with no waterproof or cohesive course. The very heavy traffic on the Jinghang Canal Bridge makes the reconstruction of the deck pavement very difficult, which makes it very important to construct a pavement with a long life.

2. STRUCTURES USED IN THE FATIGUE TEST

Fatigue tests were conducted on compound beams. A compound beam consists of a cement concrete beam with two HMA layers. The cement concrete beam had the same grade as that of Jinghang Canal Bridge. All samples were of the same kind of concrete beam. Seven HMA pavement structures which are commonly used in Jiangsu Province were chosen to be evaluated in this study. The typical structures are listed in Table 1.

Table 1. Structures used in the test.

Sequence number	Surface HMA course	Intermediate HMA course	Waterproof and cohesive course	Sample numbers/thickness
1	AK13 + fibre[1]	AC20+ fibre[2]	No	3 (4 cm + 6cm)
2	AK13 + fibre	AC20+ fibre	Epoxy asphalt	3 (4 cm + 6 cm)
3	AK13A + fibre	AC20+ fibre	SBS MB[3]	3 (4 cm + 6 cm)
4	AK13A	AC-20	SBS MB	3 (4 cm + 6 cm)
5	AK13A	AC20+ fibre	SBS MB	3 (4 cm + 6 cm)
6	AK13A + fibre	AC20+ fibre	SBS MB	3 (5 cm + 6 cm)
7	SMA13	AC20+ fibre	SBS MB	3 (5 cm + 6 cm)

Notes: 1. AK13 + fibre = fibre-reinforced AK13.
2. AC20 + fibre = fibre-reinforced AC20.
3. SBS MB = SBS modified asphalt.

The gradings of the HMA layers are illustrated in Table 2. Tests were done firstly on samples with the same HMA structure but different waterproof and cohesive courses. Thereafter, tests were done with the same waterproof and cohesive course, but samples with different HMA structures were tested.

Table 2. HMA gradations.

Mixtures	Percentage passing sieve (mm)												P_a
	26.5	19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075	
SMA13	100	100	100	95	68	28	19	17	15	13	12	10	5.8
AK13	100	100	100	93.2	74.9	42.9	27.9	21.3	16.9	12.4	8.7	6.0	4.8
AC20	100	92.4	82.6	73.1	57.6	46.1	36.0	20.7	15.4	9.8	7.5	6.4	4.4

Notes: 1. P_a = percentage of asphalt content
2. Fibre-reinforced AK13 has the same grading as AK13, while the P_a is 5.0%.
3. Fibre-reinforced AC20 has the same grading as AC20, while the P_a is 4.6%.
4. All mixtures use the same kind of asphalt, namely PG70-22.

3. TEST METHOD

At present, for fatigue testing, the actual test bridge, a straight or circular model of the bridge deck, a compound beam, etc., can be tested. The former two test methods are much more costly and time-consuming than the last one. The compound beam test method is simple and uses small samples. It is easy to control the load and measure the stress or strain during the test. For these reasons, the compound beam test method was chosen for this research.

3.1 Sample Selection

A previous study conducted by Huang (Huang, 2003) indicated that the maximum tensile stress occurs at the surface of the pavement at the top of the strength-providing parts of the U-rib and the cross-slab, as shown in Figure 1. The results showed that the surface course is subjected to the maximum tensile stress at point O. The bridge deck and the pavement around it were taken as the object of the research. Compound beam samples were made to simulate the structures of the pavement around point O.

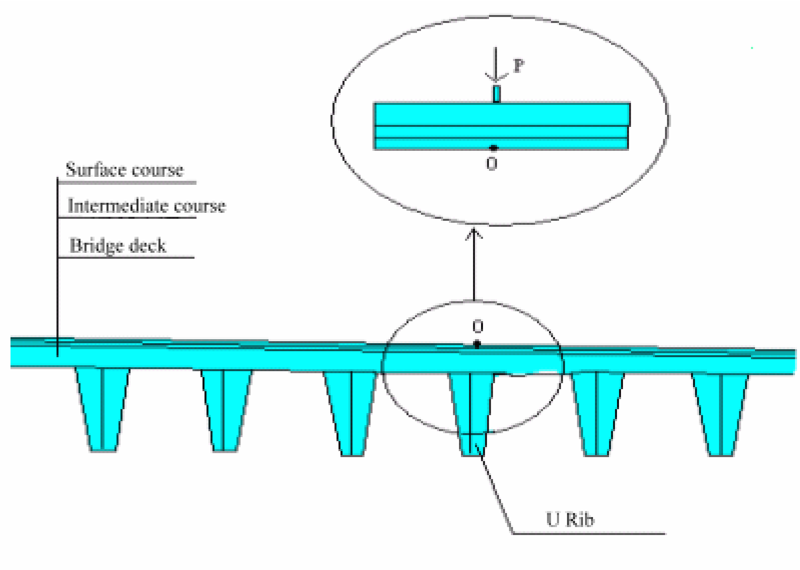

Figure 1. Choice of sample.

The size of the sample was set at a length of 380 mm (along the span) and a width of 100 mm in order to allow comparison with the test results of other researchers (AASHTO, 1994). If the sample is turned upside down and a load is applied to the middle of the cement concrete beam, the surface of the HMA course will be put under a tensile stress.

A three-dimensional FEA model was developed, as shown in Figure 2, to see whether the stress response in the compound beam would be similar to that in the HMA courses of the bridge deck under the same load. The stress calculation results are plotted in Figure 3.

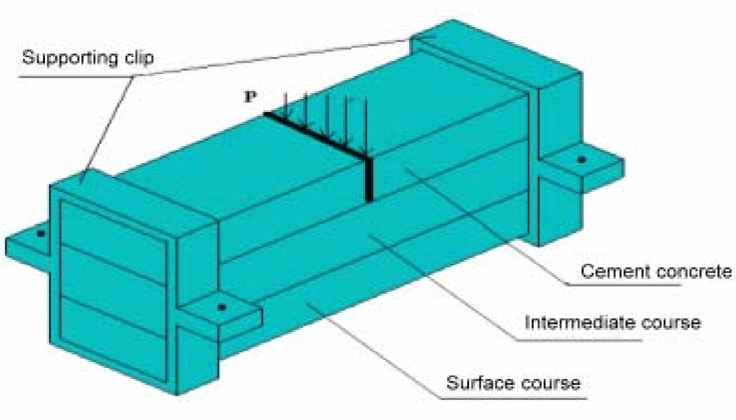

Figure 2. The three-dimensional FEA model for the compound beam.

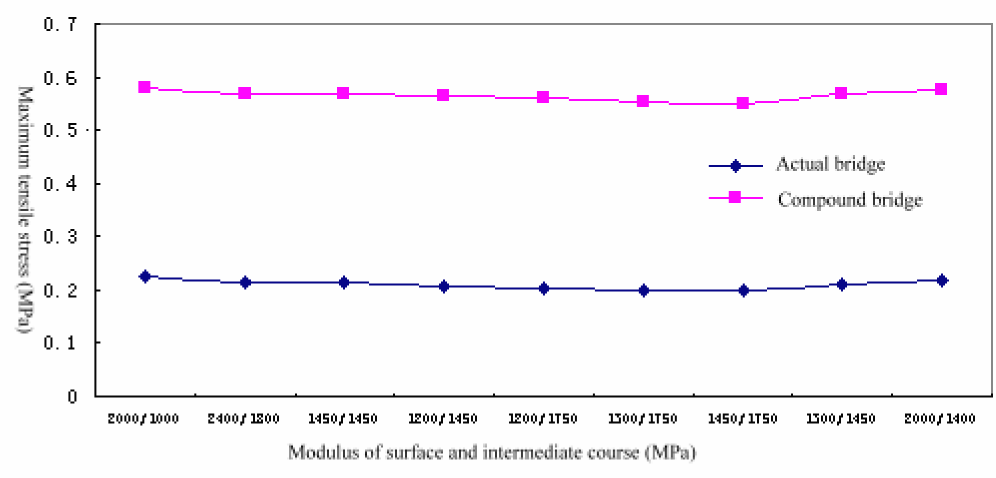

Figure 3. Maximum tensile stresses in the compound beam and the actual bridge deck.

Figure 3 shows the maximum tensile stresses in the compound beam and the actual bridge deck under the same load. There is a constant deviation between these two structures, no matter what the modulus of the HMA courses. Although the maximum tensile stress of the compound beam is much higher than that of the bridge deck because of the size difference, the trend lines of stress are quite similar. A light load on the compound beam causes the same effect as heavy traffic on the bridge deck. The compound beam shows a stress response similar to that of the bridge deck. The result of the compound beam fatigue test could be used to predict the fatigue life of the real bridge deck pavement. It could also be used to distinguish between structures with different lifespans.

3.2 Sample Preparation

The procedure used to prepare the samples simulated the construction of an actual bridge deck pavement.

The main steps include:

- Make the cement concrete beam with the same strength grade as the bridge deck.
- Clean the surface of the concrete beam after curing. Brush the waterproof and cohesive layer onto the beam using the same method as used for the bridge deck. (This step may be skipped for structure No. 1 which has no waterproof and cohesive course in the compound beam samples.)
- Mix the intermediate HMA mixture in the usual way. Decant the mixture at the required temperature into the mould. Press the mixture with a static load to get an original compaction measurement. Then, compact the mixture with an air hammer. The voids in the sample should vary by less than 1% from the voids in the Marshall samples for the same mixture.
- Make the surface course using the same method as in Step 3 when the bottom HMA course has cooled down.

Remove the sample from the mould after 48 h. An example of a compound beam sample with a supporting clip and a strain gauge is shown in Figure 4.

Figure 4. Example of a compound beam sample.

3.3 Test Parameters

The tests were conducted using the Material Test System (MTS810). The sample was laid upside down on the supporting frame. The load input and the acquisition of the stress and strain data were controlled by a computer program.

It is believed that the properties of HMA change with temperature. Researchers have indicated that the damage to HMA above the normal temperature is caused mainly by accumulative deformation (Pell and Cooper, 1975; Tangella, *et al.*, 1990; Transportation Institute of Chongqing, 1990). Another researcher from Harbin University of Architecture and Engineering showed that most fatigue failure occurs when the temperature is between 13 and 15 ^{o}C (Transportation Department of Harbin University of Architecture and Engineering, 1993.). The test temperature here was set at 15 ^{o}C to allow the test results to be compared with those of other researchers.

Much research has been done on the relationship between loading time or frequency and traffic speed. Ideally, the frequency should be set according to the actual traffic loading time on the bridge deck and the intervening time between two vehicles, but this is nearly impossible. Many researchers have thought that a loading frequency 10 Hz approximates the actually loading time of a standard vehicle at normal driving speed (Walter *et al*., 1981; Xu *et al*., 1995; Xu *et al*., 2001). The load frequency in this test was set at 10 Hz.

The choice of load must obey the principle of stress equivalence. The maximum tensile stress in the surface course of the compound beam must be the same as that in the actual bridge deck pavement. Through FEA, it is known that the maximum tensile stress in the surface course of a bridge deck under a standard vehicle is equal to that on the compound beam under a load of 5.0 kN. The test time will be greatly reduced if the load is increased. The purpose of this test is to choose a structure with a long life. It is not necessary to investigate the fatigue functions. The load was set at 7.0 kN. All samples were tested under the same conditions. The sample with the longest fatigue life would have the best structure.

4. TEST RESULTS

The compound beams were made according to the steps given in Section 3.2. Fatigue tests were conducted with the setting given in Section 3.3. The results are shown in Table 3.

Table 3. Fatigue life of each HMA structure.

Sequence number	1	2	3	4	5	6	7
Fatigue life (cycles)	53 068	73 031	454 460	328 950	416 258	475 060	504 268

During the test, cracks appear first at the surface of the cement concrete beam. However, in most samples, the HMA courses are still cohesive with the concrete beam. The cracks stop extending when they meet the steel in the concrete beam. The concrete beam still holds, despite the cracks, just as it does on an actual bridge deck.

With time and as the loading cycles increase, another crack occurs at the top of the surface HMA course. It develops solely in the intermediate course under the repeated action of the load. Finally, the crack extends to the surface of the cement concrete beam and then the test ends.

The form and development of the cracks in the compound beam samples are very similar to those of cracks in actual bridge decks. This also proved the rationality of the compound beam fatigue test method.

During the test, the HMA courses separated from the cement concrete beam in structure No. 1, which had no waterproof and cohesive course, when the loading cycles reached 10 000. This structure has the shortest fatigue life. It is very strange that the same thing happened in structure No. 2, which has epoxy asphalt as the waterproof and cohesive course, when the loading cycles were close to 20 000. Structure No. 3, which has SBS modified asphalt as the waterproof and cohesive course, has a very long fatigue life. It has the same structure as that of No. 1, except for the waterproof course. However, the fatigue life of structure No. 3 is 8.5 times longer than that of No. 1. It is concluded that a proper waterproof and cohesive course is very helpful in prolonging the life of bridge deck pavements.

Fibre-reinforced HMA has a longer life than that of the same HMA without fibre. Table 2 shows that structures No. 5 and No. 3 have 26.5% and 38.2% longer lives than that of No. 4. This indicates that fibre is a good additive for HMA.

Thickness also affects fatigue life. Structure No. 6 has exactly the same structure as No. 3, except that the thickness of surface course in No. 6 is 5 cm, whereas it is 4 cm in No. 3. However, structure No. 6 has a 4.5% longer fatigue life than No. 3.

Structure No. 7 had the longest life in these tests. The reason may be that SMA13 has a higher asphalt content than other HMA mixtures, and the surface course also is thicker. Fibre-reinforced AK13 and fibre-reinforced AC20 also had long lives, second only to structure No. 7.

The roads connected with Jinghang Canal Bridge consist of AK13 and AC20 as the surface and intermediate courses. It will be very convenient for construction if the HMA courses on the Jinghang Canal Bridge deck have the same structure as that of the normal road. Fibre-reinforced AK13 and fibre-reinforced AC20 are suggested for the structure of the Jinghang Canal Bridge deck.

5. CONCLUSIONS

- A waterproof and cohesive course is very helpful in prolonging the life of a cement concrete bridge deck pavement.
- Fibre is a good additive for hot mix asphalt (HMA) to improve its fatigue life.
- The structure of SMA + fibre-reinforced AC20 + an SBS modified asphalt waterproof and cohesive course was found to have the longest fatigue life. A structure with a similar fatigue life is fibre-reinforced AK13 + fibre-reinforced AC20 + an SBS modified asphalt waterproof and cohesive course.
- It is recommended that fibre-reinforced AK13 + fibre-reinforced AC20 + an SBS modified asphalt waterproof and cohesive course be used on the Jinghang Canal Bridge deck, provided this construction is convenient.

6. ACKNOWLEDGEMENTS

This study was supported by the Jiangsu Department of Transportation. The authors would like to acknowledge the help of Chen Xianhua and Lu Changbin with setting up the MTS to conduct the tests, Wang Juan for providing the material, and Zhao Yongli and Shen Heng for advising on sample preparation.

7. REFERENCES

[1] AASHTO Provisional Standard, 1994. Standard test method for determining the fatigue life of compacted hot mix asphalt (HMA) subjected to repeated flexural bending [S]. AASHTO Designation: TP8294 Edition 1B.

[2] Huang, Xiaoming and Gao, Ying, 2003. Research on Structure and Construction of Large Bridge Deck Asphalt Pavement. Nanjing, China [R].

[3] Pell, PS and Cooper, K, 1975. The effect of testing and mix variables on the fatigue performance of bituminous materials. Proceedings of AAPT, Vol. 44.

[4] Tangella, SCS Rao, Craus, J, Deacon, JA, and Monismith, CL, 1990. Summary report on fatigue response of asphalt mixtures. Paper prepared for Strategic Highway Research Program Project A-003-A, Institute of Transportation Studies, University of California, Berkeley, California, USA.

[5] Transportation Department of Harbin University of Architecture and Engineering, 1993. Research on fatigue principle of asphalt pavements. Harbin.

[6] Transportation Institute of Chongqing, 1990. Research on fatigue characteristics of asphalt mixture and semi-rigid material. Report 75-24-01-01.

[7] Walter, JL, Hicks, R, and Wilson, J E, 1981. Impact of variations in material properties on asphalt pavement life evaluation of Warren-Scappoose project. Report FHWA2OR28127 [R]. Oregon: Oregon State University, pp 62–72.

[8] Xu, Yongming, Zhang, Dengliang and Liu, Wubin, 1995. Study on the effect factors of asphalt mixes fatigue properties. Xi'an, Asphalt, 9:4, pp 8–15.

[9] Xu, Zhihong, Li, Shuming, Gao, Ying and Feng, Xiao, 2001. Research on fatigue characteristics of asphalt mixtures. Journal of Traffic and Transportation Engineering, Xi'an, China, 1:1, pp 20–24.