Journal of Southeast University (English Edition) Vol. 28, No. 3, pp. 321 - 326 Sept. 2012 ISSN 1003—7985

Mechanical properties of epoxy asphalt mixture pavement with lightweight aggregate applied on bascule bridge

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Abstract: The high temperature anti-rutting performance, water stability and low temperature bending property of epoxy asphalt mixture with 0%, 15%, 25%, 40%, and 70% granulated and circular lightweight aggregates by weight are tested, respectively. The dynamic responses under the vehicle load and in the opening process are analyzed to obtain the mechanical responses of pavements by using the finite element method. The complicated structure including a steel deck and a waterproof adhesive layer is made to verify the bond strength of the 2451-type epoxy asphalt binder. Research results show that the epoxy asphalt mixtures with lightweight aggregate replacement percentages from 0% to 70% all satisfy the requirements for steel bridge pavements. The epoxy asphalt mixture with a 70% circular lightweight aggregate replacement percentage is recommended because of its smaller density when compared with other epoxy asphalt mixtures. The shear stress increases with the increase in the opening angle and achieves its maximum at the maximum opening angle of 85°. Test results show that the Tianjin Bascule Bridge can be used for first opening after a 3 d pavement conditioning.

Key words: bascule bridge; steel bridge deck pavement; lightweight aggregate; mechanical response; shear stress
doi: 10.3969/j.issn.1003-7985.2012.03.012

A lightweight (sintered) aggregate may be a kind of ideal material for steel deck paving engineering because of the multiplicity of its raw materials and the benefit of converting wastes into useful materials.

Lightweight asphalt concrete was first studied in the 1950s in the USA[1-2], and the first lightweight asphalt concrete design guide was established for highway pavement in 1998[3]. Mallick et al.[4] studied the influences of the mass ratio of fly ash and lightweight aggregates in HMA on the bulk density, theoretical maximum density, elastic modulus and indirect tensile strength. Yu et al.[5] studied the bonding strength and stability of asphalt mixtures with diatomite lightweight aggregates. High strength expanded shale is used in asphalt concrete instead of granite, and the asphalt concrete is paved in the test road which has been studied by Liu et al[6]. To the best of our knowledge, the use of epoxy asphalt concrete with a lightweight aggregate on a steel deck has not been reported until now.

In this paper, the granulated lightweight aggregate (GLWA) and the circular lightweight aggregate (CLWA) are chosen to replace some fine aggregate in epoxy asphalt concrete. The key mechanical properties of the pavement material are analyzed by laboratory tests. The finite element analysis of the pavement on the Tianjin Bascule Bridge is carried out to prove the applicability of epoxy asphalt pavement with lightweight aggregate. Finally, the lab experiments of interface shear strength between pavement and steel deck are carried out to verify the applicability of epoxy asphalt concrete with lightweight aggregate on the steel deck.

1 Mechanical Tests

GLWA and CLWA from the Baozhu Lightweight Aggregate Development Co., Ltd of Yichang in China are chosen for laboratory tests. According to the test methods of aggregates for highway engineering of China and the service conditions of steel deck pavements in China, the key technical indices of the lightweight aggregate are listed in Tab. 1.

The GLWA and the CLWA are used to replace 70%,

Tab. 1 Key technical indices of lightweight aggregate used on steel deck

Technical indices	Test results		Technical requirements
	GLWA	CLWA	
Los Angeles abrasion loss/%	30.8	21.2	≤40
Cylinder compressive strength/MPa	7.6	7.3	≥6.5
Flakiness particle content/%	16.8	1.2	≤18
Clay content (washing method)/%	0.9	0.7	≤1.0
Crushing value/%	20	15	≤28
Water absorption (24 h)/%	4.3	4.1	≤5
Sturdiness/%	15	12	≤18

Received 2012-02-24.
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Foundation items: China Postdoctoral Science Foundation (No. 20110491342), Jiangsu Postdoctoral Science Foundation (No. 1101018C), the National Natural Science Foundation of China (No. 51178114, 50908054).
Citation: Liu Yun, Qian Zhendong, Zhang Lei, et al. Mechanical properties of epoxy asphalt mixture pavement with lightweight aggregate applied on bascule bridge[J]. Journal of Southeast University (English Edition), 2012, 28(3): 321 -326. [doi: 10.3969/j.issn.1003-7985.2012.03.012]

40%, 25%, 15% and 0% (by mass) of the original fine aggregates in the epoxy asphalt mixture, which can be coded as GLEAC-70, GLEAC-40, GLEAC-25, GLEAC-15, GLEAC-0 and CLEAC-70, CLEAC-40, CLEAC-25, CLEAC-15, CLEAC-0. The maximum theoretical relative densities of the GLEAC and the CLEAC decrease with the increase in the lightweight aggregate content.

1.1 High temperature rutting test

The wheel rolling method is used to fabricate rutting test specimens, and it is fully cured under 120°. The test temperature is 60°, and the applied wheel pressure is 0.7 MPa. The dynamic stability as shown in Fig. 1 obviously satisfies the technical requirements in Tab. 1. Laboratory results show that the lightweight aggregate slightly increases the dynamic stability of the mixture.

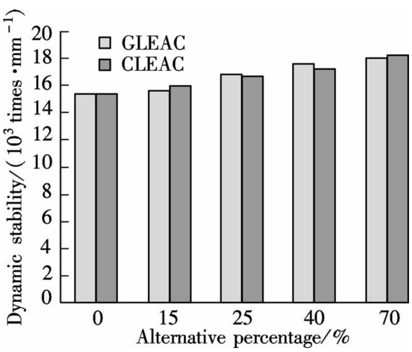

Fig. 1 Rutting test results of GLEAC and CLEAC

1.2 Water stability

The freeze thaw split test is carried out to evaluate the water stability of the mixture. As can be seen from Fig. 2, compared with the GLEAC-0 or CLEAC-0, the water stability of the epoxy asphalt mixture with lightweight aggregate is significantly improved, but it meets the water stability requirements for steel bridge deck pavements.

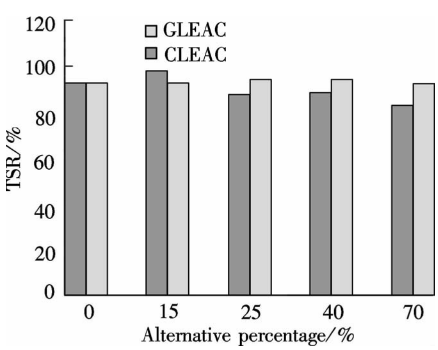

Fig. 2 TSR of GLEAC and CLEAC

1.3 Low temperature bending property

The rolling molding method is used to fabricate specimens with a dimension of 320 mm × 320 mm × 150 mm. The test is carried out on the universal test machine with a loading speed of 50 mm/min at −15°. The test results of the GLEAC and the CLEAC are shown in Tabs. 2 and 3.

Tab. 2 Bending property of GLEAC

Material	Fracture strength/MPa	Maximum strain
GLEAC-0	28.5	1.245×10^{-2}
GLEAC-15	31.7	3.624×10^{-3}
GLEAC-25	29.2	6.678×10^{-3}
GLEAC-40	23.8	6.871×10^{-3}
GLEAC-70	15.8	7.228×10^{-3}

Tab. 3 Bending property of CLEAC

Material	Fracture strength/MPa	Maximum strain
CLEAC-0	28.5	1.245×10^{-2}
CLEAC-15	23.9	6.195×10^{-3}
CLEAC-25	22.4	8.259×10^{-3}
CLEAC-40	19.3	7.991×10^{-3}
CLEAC-70	18.3	6.105×10^{-3}

With the increase in the lightweight aggregate content, the fracture strength of the GLEAC increases first and then decreases. The value of the fracture strength of the GLEAC is higher than that of the CLEAC with the same content of lightweight aggregate. The GLEAC and the CLEAC both have excellent low temperature properties and deformation properties.

The epoxy asphalt mixture with a 70% circular lightweight aggregate replacement percentage is recommended because of its smaller density when compared with other epoxy asphalt mixtures.

2 FE Modeling

2.1 Project overview

Tianjin Bascule Bridge is located in the Binhai business area in Tianjin, China. The girders of the steel box structure are symmetric. According to design requirements, the largest opening angle is 85°, and the opening process of the bridge should be completed within 5 min. The cross-section of the box girder structure is shown in Fig. 3, and the vertical elevation of the half girder is shown in Fig. 4.

Based on the requirements of light weight and test results of the GLEAC and the CLEAC, CLEAC-70 is

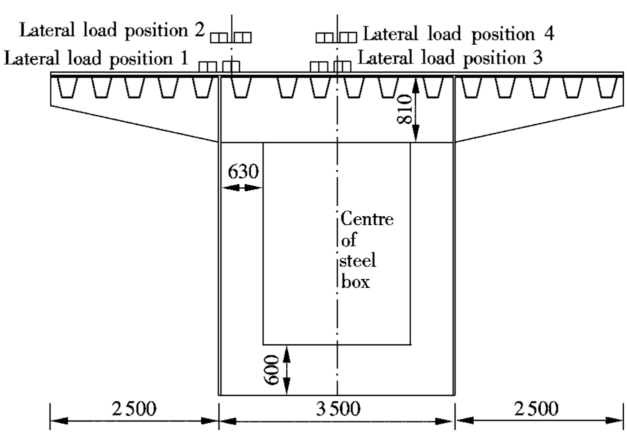

Fig. 3 Half cross-section of girder and lateral load positions (unit: mm)

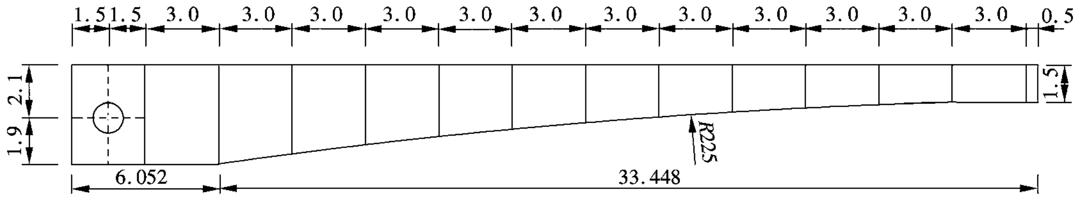

Fig. 4 Vertical view of half girder (unit: m)

chosen as the pavement material.

2.2 Calculation parameters and FE model

The 3-D solid element is chosen to establish the FE model of the pavement on the orthotropic steel deck by using ADINA. The steel bridge deck, longitudinal ribs and steel box are simulated by shell elements. The rigid links are used to make the pavement and steel deck deform together. The selection of pavement material parameters is based on the study of a lightweight aggregate epoxy asphalt mixture made by the research group at Southeast University in China[7]. Q345-D steel is applied to bridge decks, diaphragms and trapezoidal stiffeners. The calculation parameters are shown in Tab. 4. The pavement thickness is 30 mm. The number of FE models of the pavement system as shown in Fig. 5 is 21 546. A sensitivity analysis of stress is then conducted to determine the FE mesh size by reducing the element size gradually until the calculated stresses are stable[8-9].

Tab. 4 Calculation parameters of pavement system

Calculation parameters	Value
Thickness of bridge deck/mm	20
Spacing of diaphragms/mm	3 200
Thickness of diaphragm/mm	16
Thickness of U-rib/mm	6
Opening width of U-rib/mm	294
Closed width of U-rib/mm	171
Spacing of U-ribs/mm	500
Height of U-rib/mm	251
Density of steel/($kg \cdot m^{-3}$)	7 850
Density of pavement/($kg \cdot m^{-3}$)	1 500
Poisson ratio of steel plate	0.3
Poisson ratio of pavement	0.25
Elastic modulus of steel plate/GPa	210
Elastic modulus of asphalt pavement/MPa	1 000

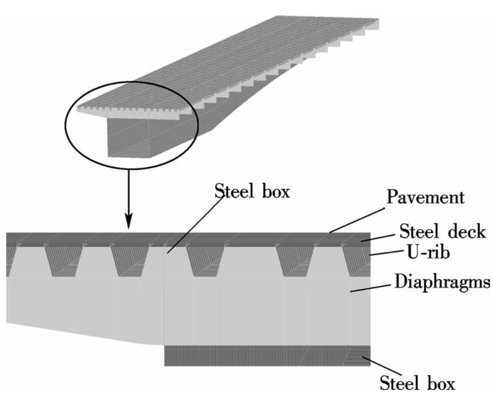

Fig. 5 FE model of bascule bridge

When the bridge is open to traffic, the ends of the model along the longitudinal direction of the bridge are fixed. When the bridge is in the opening process, the rotation of the shaft in the vertical direction should be free.

The highway I-level two-wheeled rear axle model is adopted to simulate the traffic loading for the bascule bridge according to the General Code for Design of Highway Bridges and Culverts (JTG D60—2004)[10], and the loading pressure is uniformly distributed in the entire tire contact area on the surface of the pavement, as shown in Fig. 6. The contact areas of the dual tires are simulated by two rectangles with a space of 10 cm between the two tires, and each rectangle has a dimension of 25 cm × 20 cm[11]. The four transversal vehicle load positions are chosen in order to determine the most unfavorable loading position, as shown in Fig. 3. The centre of load position 1 is located above the vertical web. The centre of load position 2 is located above a side of the stiffening rib. The centre of load position 3 is located above a side of the stiffening rib near the centre of the steel box. The centre of load position 4 is located above the centre of the steel box.

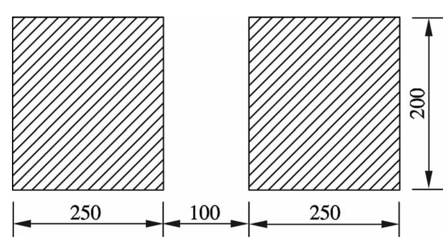

Fig. 6 Uniform load area of single rear axle (unit: mm)

2.3 Dynamic response of pavement

2.3.1 Dynamic response under vehicle load

According to the design documents of the bascule bridge, the vehicle speed is set as 60 km/h. The load is supposed to move from one transversal diaphragm to another. As shown in Fig. 7, the maximum tensile stress increases, and its increase rate drops continuously. The peak value of the dynamic maximum tensile stress is 0.803 MPa, which is 7.21% higher than the static value.

2.3.2 Dynamic response in opening process

The dynamic response, especially the shear stress, is calculated. The results show that, as the opening angle is 10°, the peak value of shear stress appears at the pavement exactly above the steel box whose height changes, as shown in Fig. 8(a). The peak value of shear stress at

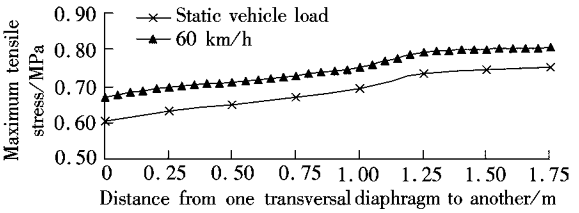

Fig. 7 Maximum longitudinal tensile stress under static and moving load

the pavement above the shaft appears when the opening angle reaches 25°, as shown in Fig. 8(b). When the opening angle is at 85°, the maximum shear stress appears at the cantilever end of the girder with a value of 0.192 MPa, as shown in Fig. 8(c).

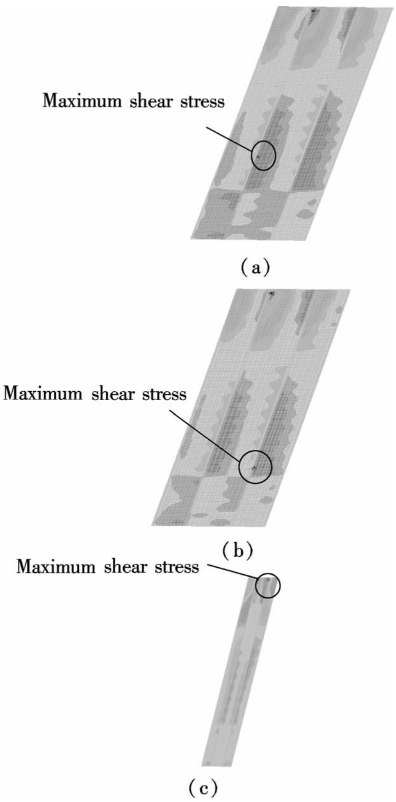

Fig. 8 Peak shear stress in the opening process. (a) Shear stress with an opening angle of 10°; (b) Shear stress with an opening angle of 25°; (c) Shear stress with an opening angle of 85°

3 Experiments of Synergistic Effect of Pavement

3.1 Material selection for waterproof adhesive layer

With consideration of serious overload conditions, 2451-type epoxy asphalt is chosen for the waterproof adhesive layer with reference to the Nanjing Yangtze River Bridge, the Runyang Yangtze River Bridge, and the Wuhan Yangluo Yangtze River Bridge. The technical standards are shown in Tab. 5.

3.2 Pull-off adhesion test

The CLEAC-70 epoxy asphalt mixture is paved onto the surface of the steel deck after sand-blasting and

Tab. 5 Technical requirements of epoxy asphalt binder

Specifications	Technical requirement	Test method
Tensile strength (20 ℃)/MPa	≥5.0	ASTM D 638
Elongation (20 ℃)/%	≥190	ASTM D 638
Thermosetting (300 ℃)	Not melt	
Water absorption (7 d, 20 ℃)/%	≤0.3	ASTM D 570

rust-proofing. The test specimen is made according to the pavement structure of practical engineering. The pull-off adhesion test is conducted to determine the interface pull-off strength, as depicted in Figs. 9 and 10. The test samples include a CLEAC-70 cylinder with a diameter of 50 mm. The CLEAC-70 cylinder and steel slab are bonded with 2451-type epoxy asphalt as an interlay. Tab. 6 shows that the bond strength of the 2451-type epoxy asphalt binder can satisfy the calculated tensile stress with a peak value of 0.803 MPa.

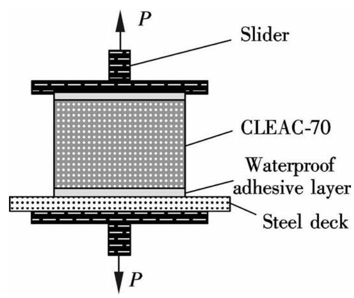

Fig. 9 Drawing test

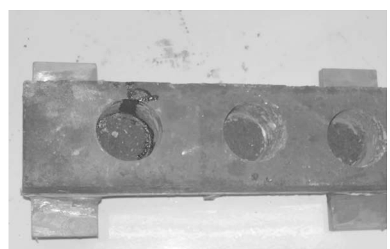

Fig. 10 Specimen after drawing

Tab. 6 Drawing test results of epoxy asphalt binder

Temperature/℃	No.	Damage tension/kN	Bond strength/MPa	Average value of bond strength/MPa
0 ± 2	1	9.1	4.62	4.61
	2	8.5	4.32	
	3	9.6	4.88	
23 ± 2	1	5.81	2.96	3.04
	2	6.2	3.15	
	3	5.94	3.02	
60 ± 2	1	4.01	2.04	1.98
	2	3.83	1.95	
	3	3.85	1.96	

3.3 Skew-shear adhesion test

The skew-shear adhesion test is conducted to determine the interface shear strength, as depicted in Fig. 11. The calculated maximum shear stress between the pavement and the steel deck can reach a value of 0.192 MPa in the opening process. Based on the code for the design of concrete structures[12], the safety factor of the shear strength can be defined as 2.48. This means that the value of the shear strength of the waterproof adhesive layer should reach 0.484 MPa before the first opening of the bascule bridge.

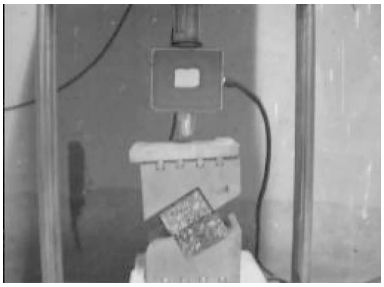

Fig. 11 Skew-shear adhesion test

As can be seen from Tab. 7, the shear strength of the waterproof adhesive layer cannot reach 0.51 MPa until the waterproof adhesive layer has been preserved under normal temperature for 3 d so as to meet the reqirements of the shear strength of the waterproof adhesive layer. In other words, Tianjin Bascule Bridge can be used for opening after 3 d conditioning. In order to verify the shear strength test results, the specimen including the steel deck, the waterproof adhesive layer and the pavement are made to simulate the opening process as shown in Fig. 12, and the results show that there is no slip between the pavement and the steel deck.

Tab. 7 Shearing test results of epoxy asphalt binder

Conditioning time/d	No.	Failure load/kN	Shear strength/MPa	Average value of shear strength/MPa
1	1	0.86	0.13	0.17
	2	1.12	0.18	
	3	1.00	0.19	
2	1	1.91	0.38	0.36
	2	1.88	0.34	
	3	1.98	0.37	
3	1	2.79	0.51	0.51
	2	2.67	0.48	
	3	2.77	0.53	

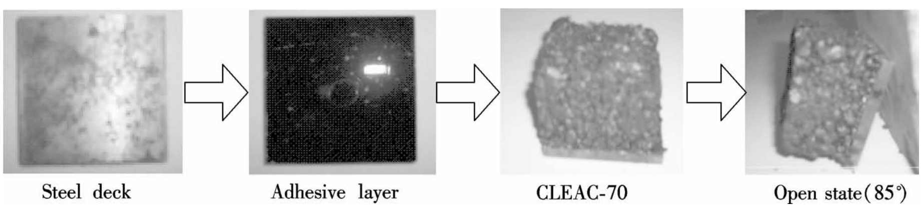

Fig. 12 Test to simulate opening process

4 Conclusions

1) The test results show that the lightweight aggregate slightly increases the dynamic stability of the mixture. The water stability of the epoxy asphalt mixture with the lightweight aggregate is not significantly improved. With the increase in the lightweight aggregate content, the fracture strength of the GLEAC increases first and then decreases. However, the mechanical properties of the GLEAC and the CLEAC both satisfy the technical requirements of pavement on the steel bridge deck.

2) The 3D finite element model of Tianjin Bascule Bridge in China is established with the CLEAC-70 for the material of pavement on the steel deck. The dynamic responses under the vehicle load and in the opening process are analyzed. The calculated results show that the peak value (0.803 MPa) of maximum tensile stress under a moving vehicle load is 7.21% higher than that under a static load. In the opening process of the bridge, the shear stress increases with the increase in the opening angle, and the peak value appears when the angle reaches 85°. The maximum shear stress appears at the cantilever end of the girder with a value of 0.192 MPa.

3) The complicated structure including the steel deck, the waterproof adhesive layer and the CLEAC-70 is made to verify the bond strength of the 2451-type epoxy asphalt binder. The bond strength of the 2451-type epoxy asphalt binder can satisfy the calculated tensile stress with a peak value of 0.803 MPa. The value of the shear strength of the waterproof adhesive layer cannot reach 0.51 MPa until the waterproof adhesive layer has been conditioned under normal temperature for 3 d so as to meet the requirements of the shear strength of the waterproof adhesive layer.

References

[1] Wycoff J C. Suitability of lightweight aggregate for bituminous plant mix [J]. *ASTM Bulletin*, 1959, **235**: 33 – 36.

[2] Lehmann H L, Adam V. Use of expanded clay aggregate in bituminous construction [C]//*Highway Research Board Proceedings*. Washington DC, USA, 1959: 398 – 407.

[3] Bob M, Gallaway P E. *Expanded shale clay and slate reference manual for asphalt pavement systems* [M]. Salt Lake City: Expanded Shale Clay and Slate Institute, 1998: 20 – 26.

[4] Mallick R B, Hooper F P, O'Brien S, et al. Evaluation of use of synthetic lightweight aggregate in hot-mix asphalt [J]. *Transportation Research Record*, 2004, **1891**: 1 – 7.

[5] Yu Shumin, Luo Bingli. Bond strength and stability be-

tween asphalt mixture and diatomite lightweight aggregate [J]. *Highway*, 1998(12): 46－47. (in Chinese)
[6] Liu Qihua, Li Cuibin, Zhang Chuanmei, et al. Experimental study and application on high-strength shale ceramsite prepared asphalt ceramsite concrete [J]. *Journal of Guangzhou University: Natural Science Edition*, 2007, **6**(3): 77－81. (in Chinese)
[7] Qian Zhendong, Chen Leilei, Jiang Chenlong, et al. Performance evaluation of a lightweight epoxy asphalt mixture for bascule bridge pavements [J]. *Construction and Building Materials*, 2011, **25**(7): 3117－3122.
[8] Xu Qinwu, Zhou Qinghua, Cesar M. Experimental and numerical analysis of a waterproofing adhesive layer used on concrete-bridge decks [J]. *International Journal of Adhesion and Adhesives*, 2009, **29**(5): 525－534.
[9] Xu Qinwu, Sun Zengzhi, Wang Hu. Laboratory testing material property and FE modeling structural response of PAM-modified concrete overlay on bridges [J]. *Journal of Bridge Engineering*, 2009, **14**(1): 26－35.
[10] CCCC Highway Consultants Co., Ltd. JTG D60—2004 General code for design of highway bridges and culverts [S]. Beijing: Ministry of Transport of the People's Republic of China, 2004. (in Chinese)
[11] Qian Zhendong, Luo Jian, Jing Miaomiao. Mechanical analysis of asphalt concrete paving projects on steel bridge deck [J]. *China Journal of Highway and Transport*, 2005, **18**(2): 61－64. (in Chinese)
[12] Ministry of Housing and Urban-Rural Development of the People's Republic of China. GB 50010—2002 Code for design of concrete structures [S]. Beijing: Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2002. (in Chinese)

用于开启桥的轻质环氧沥青混凝土桥面铺装力学性能

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摘要:拟定质量替代百分数分别为0%, 15%, 25%, 40%, 70%的碎石型陶粒环氧沥青混合料和圆型陶粒环氧沥青混合料,进行高温抗车辙性能、水稳定性及低温弯曲性能试验.采用有限元方法分析开启桥在行车和开启2种状态下的力学响应.最后成型含钢桥面板、防水黏结层及环氧沥青混凝土的复合结构试件来验证2451型环氧沥青黏结料的界面黏结强度.研究结果表明,质量替代百分数分别为0%, 15%, 25%, 40%, 70%的陶粒环氧沥青混合料均能满足钢桥面铺装的力学性能要求.替代百分数为70%的圆型陶粒环氧沥青混合料由于其在减轻铺装质量等方面的优势被推荐为开启桥桥面铺装用的首选材料.桥面铺装层间剪应力随着开启角度的增大而增大,并在开启角度达到最大值85°时达到峰值.通过室内试验结果可知,天津响螺湾立转式开启桥在桥面铺装铺筑完成并养生3 d后可进行首次开启.

关键词:开启桥;钢桥面铺装;轻质集料;力学响应;剪应力
中图分类号:U443.33