Application of Bituminous-Concrete with Frame-Separation in Steel Bridge Deck Pavement

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Abstract: This paper describes a new type of bituminous concrete bridge deck pavement with frame–separation, the lower layer of which is designed to have a frame-separation structure in order to obtain bituminous concrete units that are independent from each other, while the upper layer is paved with fiber bituminous concrete. Pavement with this new structure has been successfully applied to a steel bridge with double decks for dual purposes of highway and railway uses, which is able to restrain the pavement deformation within an acceptable limit and settle the maintenance and repair problem of the bridge.

Keywords: Frame-separation; bituminous concrete; Deck pavement steel bridge with double decks; Deformation

1 Introduction

Most of bridges with dual purposes for both highway and railway uses in China were built in the years before 70s' of 20th century, which were constructed for a primary purpose of railway use together with a secondary purpose of highway use. Most of the bridges with such style were designed to have steel truss structures, where the bridge decks were laid on the steel plates forming the roof of the steel truss or on the pre-casting reinforced concrete slabs. As the deck pavement of the bridge vibrates rather greatly, the deck pavement is very easy to be damaged, and in case of damage, the repair is very difficult to carry out. This paper researches the vibration of Guangdong Xijiang Highway-Railway Double-Level Bridge, purpose of it is to analyze the effects of vibration of the bridge deck on the payment structure and puts forward the related repairing method.

2 Theory

Located in Zhaoqing City of Guangdong Province, Guangdong Xijiang Bridge is a bridge with double decks for dual purposes of highway and railway uses (See Figure 1.a and Figure 1.b), the main deck of which is for railway use, while the upper deck of which is for highway use, with a main bridge of 720 meters in length and a spacing of 136 meters between two adjacent piers. Vibration test points of the bridge deck are set at locations between the first pier and the second pier. According to deflection calculation of the bridge beams and vibration test of the bridge deck, when a train with load passes by the bridge, the maximum deflection between cross-points of the two piers is 15.6 cm, the relative vertical vibration amplitude of the testing section of the bridge deck is 5.9 mm, the horizontal Lateral vibration amplitude is 3.8 mm, the vibration frequency is 10 Hz and 2 Hz respectively, which mean that a material point in the bridge deck vibrates relatively and irregularly 10 times per second, as well as upwards and downwards over a vertical distance of 5.9 mm.

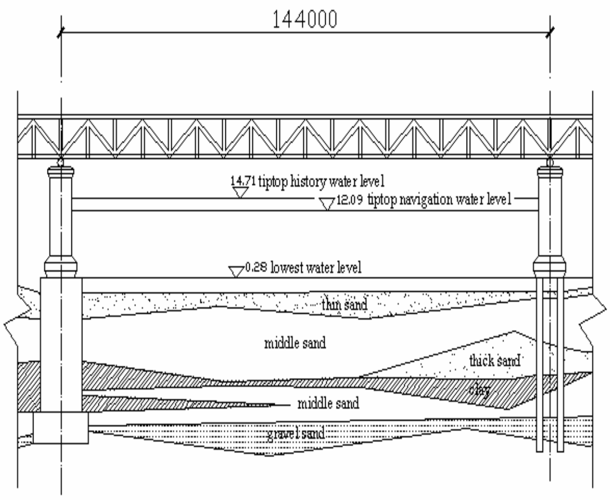

Figure.1.a Xijiang Highway-Railway Double-Level Bridge unit(mm)

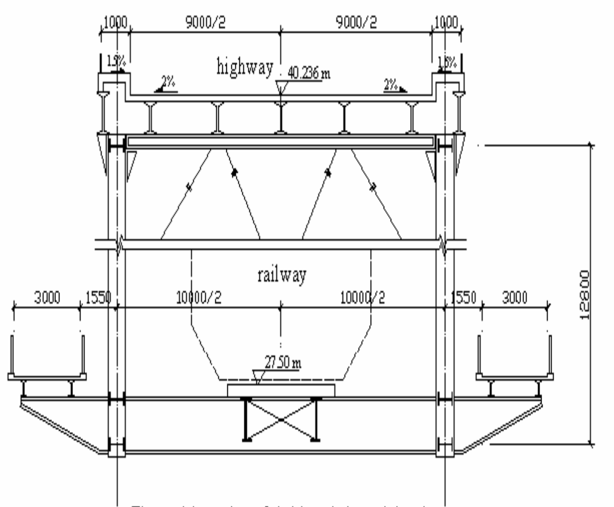

Figure.1.b section of bridge girder unit(mm)

2.1 Vibration of the Bridge Increases the Stress to the Bridge Deck Pavement

Assuming that the bridge deck pavement is an elastic body, meanwhile, the concrete of the deck pavement and the steel truss of the bridge deck are included in a same vibration system, then, the stress "σ_d" caused by forced vibration is:

$$\sigma_d = \sigma_j (1 + \frac{B}{\Delta_j}) \qquad (1)^{[1]}$$

Where, "σ_j" represents actual stress to the pavement of generic road; "σ_d" represents stress arising from vibration of a bridge with dual purposes for highway and railway uses; "B" represents integrated vibration amplitude, which is 5.9 mm based on actual measurement; "Δ_j" represents average deflection of the steel truss. The spacing between two adjacent expansion Joints is 32m, and the average deflection of the steel truss is 20 mm.

Replace symbols in the formula with data, and the result is:

$$\sigma_d = \sigma_j (1 + \frac{5.9}{20}) = 1.295\sigma_j \qquad (2)$$

The result indicates that the vibration of a bridge with dual purposes for highway and railway uses causes the stress of the bridge deck pavement to increase to 1.295 times its original value, therefore, when carrying out design of pavement materials and structure layer for a bridge, 30% of additional effects caused by vibration should be taken into account so as to meet the special requirement by the bridge deck pavement.

2.2 Repeatedly Bending and Deforming of Bridge Deck Pavement Results in Road Pavement Fatigue and Shortens Service Lifetime

Under a condition of controlled stress, action times of load that can reach the fatigue failure of the bituminous concrete is:

$$N_1 = k(\frac{1}{\sigma_j})^{n_1} \qquad (3)^{[2]}$$

$$N_d = k(\frac{1}{1.295\sigma_j})^{n_2} \qquad (4)$$

Where "N_1" represents action times of load that can reach the fatigue failure of bituminous concrete of generic bridge deck; "N_d" represents action times of load that can reach the fatigue failure of bituminous concrete of generic bridge deck that is caused by vibration; "k" represents characteristic coefficient of compositions comprising the bituminous concrete; n represents gradient factor, the n of modified bituminous concrete is 1.5～2.5.

In case of the same compositions comprising bituminous concretes, unchanged "K" and approximate gradient factor "n" , the additional stress caused by vibration is: $\sigma_d = 1.295\sigma_j$, and according to formula（3）, the result is:

$$N_d / N_1 = \frac{k(\frac{1}{1.295\sigma_j})^{n_2}}{k(\frac{1}{\sigma_j})^{n_1}} \cong 0.55 \sim 0.65 \qquad (5)$$

$$N_d = (0.55 \sim 0.65) N_1 \qquad (6)$$

It is obvious that the fatigue lifetime of bridge deck pavement is only 55~65% of that of generic road pavement. According to the above-mentioned test and analysis, traditional method for maintenance and repair can not fully solve the problems of Xijiang Highway-Railway Double-Level Bridge.

3 Experiment

The vehicle lane on the upper deck of Xijiang Bridge is combined by pre-casting reinforced concrete slabs with dimension 4.5 meters in length and 3.6 meters in width. The spacing between adjacent expansion Joints is 32m, and total 16 pieces of pre-casting slabs have been used. The original pavement of the bridge deck for highway includes a layer of ferrocement concrete with thickness of 5cm plus a wearing layer of bituminous concrete with thickness of 3 cm. See Figure 2 for the structure of the deck pavement..

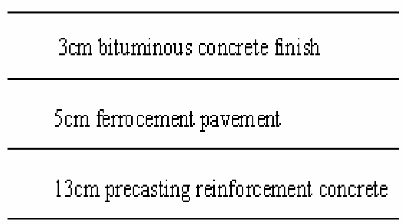

Figure 2 Original pavement of bridge deck

The average daily traffic flow has reached 10000 vehicles, and after its operation for tens of years, most portion of the bituminous wearing layer has been damaged, ferrocement concrete section has been damaged, and as a result of which, rainwater has infiltrated to the steel railway truss, thus damages have been caused to railway facilities. As the deck pavement on the bridge mainly shows a characteristic of rigidity, its maintenance and repair can only be conducted with bituminous concrete under the condition or requirement that no impact or obstruction may be caused to current traffic. In order to settle the technical problems involved in maintenance and repair more successfully, this paper suggests a structure scheme shown in Figure 3 and Figure 4.

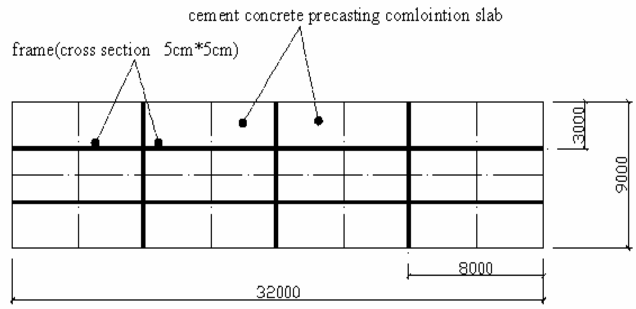

Figure 3 The separation figure of the under layer bituminous concretunit(mm)

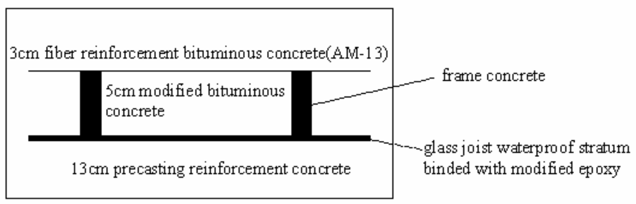

Figure 4 Section of the repairing project

In this scheme, a glass joist waterproof stratum bounded with modified epoxy is applied to the surface of pre-casting slabs comprising the bridge deck. Modified bituminous concrete is applied to the lower layer, and the bituminous concrete stratum is separated as rectangle units with dimension of 8 m × 3m by means of polysulfide rubber modified epoxy resin concrete. A fiber reinforcement bituminous concrete stratum with a thickness of 3 cm is applied to the upper layer, which forms a frame structure.

The width of a frame-separation concrete unit is 5cm, with a depth equal to the lower layer, and the construction method for which is as follows: Before paving bituminous concrete, place a channel steel member with a cross-section dimension of 5cm×5cm at an expected separation location, lay and pave bituminous concrete, and then roll it to form its shape. After completion of the final rolling, take out the channel steel members to obtain a frame channel in the bituminous concrete stratum, then, inject the polysulfide rubber modified epoxy resin to form a frame.

4 Results and Discussion

4.1 Propagation of vibration in separated bituminous concrete is obstructed and thus fatigue strength caused by vibration is reduced

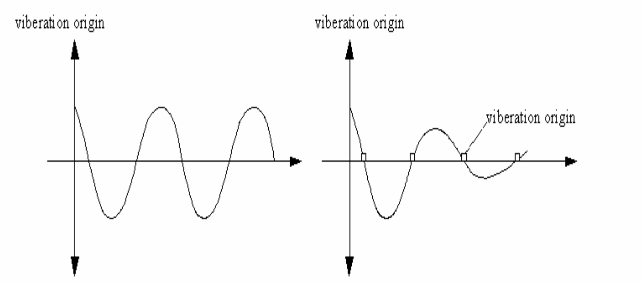

Figure 5 a propagation of viberation in same matter   Figure 5 b Propagation of viberation in separated matter

Figure 5.a illustrates vibration propagating in a same matter, while Figure 5.b shows vibration propagating in a separated matter, which reveals that the propagation of vibration is obstructed at the separation point and thus the vibration attenuate quickly, in other words, the affects on Block B caused by vibration arising from Block A of the separated bituminous concrete has been lightened.

Elasticity modulus of the polysulfide rubber modified epoxy resin frame-separation concrete is $E_{rubber}=10\times10^3$Mpa. Elasticity modulus of the bituminous concrete $E_{bitumen}=1.2\times10^3$Mpa. As each of the two materials has an elasticity modulus different from the each other, a portion of the energy is consumed during the propagation course of the kinetic energy, and therefore, lesser vibration energy is propagated. This is a measure suitable for isolation of vibration and will be helpful in increasing fatigue lifetime.

4.2 Bending-tensile stress and strain of separated bituminous concrete are reduced and thus the fatigue lifetime is increased

Separation of bituminous concrete by means of frame is able to reduce fatigue tensile stress of the bridge deck pavement and is also able to increase the fatigue lifetime of the bridge deck pavement, which may be further proved through a fatigue test or endurance test on bituminous concrete. Bending-tensile deformation and bending-tensile stress of bituminous concrete is expressed as below:

$$\sigma = \frac{3aP}{bh^2} \qquad (7)^{[2]}$$

Where, "a" represents the horizontal distance from the load to the support; "P" represents the dynamic load that bends the beam; "b" represents the width of the test piece or test sample; "h" represent the thickness of the test piece or test sample.

The test results show that, incase that "P" , namely the dynamic load bending the girder keeps unchanged, while "a", namely the horizontal distance from the load to the support shortens, then, "σ", namely the fatigue bending-tensile stress also reduces accordingly. As shown in Figure 6, when the test beam has been divided into three segments, the distance from the load on each segment to the support also reduces by 1/3.

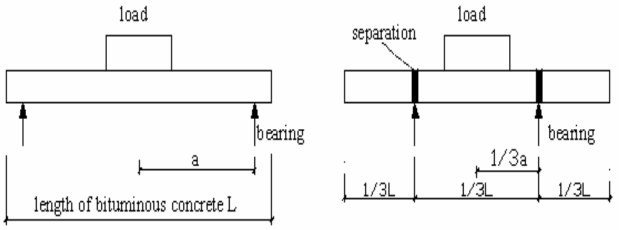

Figure 6 Variation of the distance a between load and bearing.

Differences exist between the test beam and the bridge deck slabs. When the slab has shortened by 1/3 in length, the fatigue bending-tensile stress on the bottom of the slab reduces by10～15 % only. Calculation based on formula（3）indicates that action times of load will increase by 20-50% after the slab surface has been separated.

In addition, as deduced from the basic characteristics of the materials, we know that, when "E", namely the bending-tensile modulus of bituminous concrete materials keeps unchanged, the level of fatigue stress lowers, and its strain "ε" also lowers accordingly.

The above-mentioned experiment and analysis reveal that separating bituminous concrete of bridge deck pavement is one kind of the effective method whereby to lower stress level, reduce deformation, and eliminate fatigue failure.

4.3 Deformation of bituminous concrete within the separation frame restrained

Calculation based on the expansion and shrinkage deformation of materials caused by temperature variation reveals that the variation of materials by temperature variation is:

$$\Delta L = L \cdot \alpha \qquad (8)$$

Where: "α" represents the linear expansion coefficient of a material work-piece, and for bituminous concrete, α =0.00002; for cement concrete, α =0.00001. "L " represents the length of a material work-piece ; "ΔL" represents the expansion variation.

The experiment shows that α is hardly affected by temperature, while ΔL will rise when the length of a material work-piece gets large. Therefore, reducing the length or width of a material work-piece will help greatly to reduce the linear expansion variation.

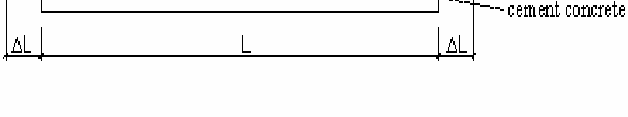

Figure.7.a Free stretch of two kinds of materials in high temperature

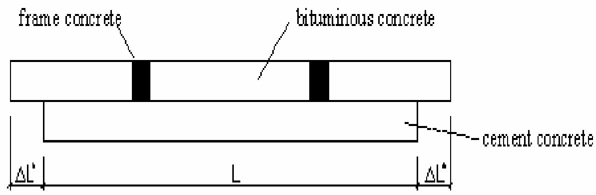

Figure.7.b Free stretch is restrained of after bituminous conrete being separated

Figure 7 indicates that when two kinds of compound material work-pieces stretch freely, the longer the length of a work-piece is, the larger its variation ΔL is (See Figure 7.a). As the deformation of a bituminous concrete stratum will be restrained after it has been separated, the overall deformation of a bituminous concrete stratum will accordingly reduce to 1/3 as much as its original deformation(See Figure 7.b).Deformation variation after separation:

$$\Delta L^{\circ} = \tfrac{1}{3} L\alpha = \tfrac{1}{3}\Delta L \qquad (9)$$

Research and analysis indicate that separation of the bridge-deck bituminous concrete, with frames inserted into seams between two adjacent block units on which a layer of fiber reinforcement bituminous concrete is paved, not only can restrain the deformation of the bituminous concrete pavement and weaken propagation of vibration in the bituminous concrete, but also can increase the overall strength of the bridge deck pavement and improve the overall anti-vibration ability.

4.4 Two-Dimensional Sizes of Bituminous Concrete Structure with Frame-Separation

The measure described in this paper is aimed at the maintenance and repair of Xijiang Highway-Railway Double-Deck Bridge for the purpose to reduce the effects of vibration in bridge deck on the pavement.. Theoretically, the smaller a separation size is, the more the advantage is. But a too small separation size will increase the costs and make the construction difficult.. For this reason and based on the actual conditions in connection with dimensions of bridge deck of Xijiang Bridge and the design wheel space of road vehicle, i.e. the wheel space of a heavy vehicle is 6.5m, the wheel space of a semi-trailer is 8.8m, total width is 2.5m, the two-dimensional separation sizes suitable for the maintenance and repair of the Xijiang Bridge are determined as (Figure 3): 8m long and 3m wide. Vibration tests have proved that separating a single-body material is one of the measures whereby to facilitate or improve the fatigue vibration-resistance of the pavement.

5 Conclusion

Based on the results of lab experiments, a comparison test on three different schemes for the maintenance and repair of Xijiang Bridge was carried out in December 2000. The test sample used in each scheme is 96 meter in length and 9 meter in width. After six years of operation, the tested segment of bridge-deck pavement made of bituminous concrete with frame separation is still in good status, while the tested segment of bridge-deck pavements in the other two schemes have been damaged to different extent.. Practice has testified that the above mentioned maintenance and repair technique is effective for a highway-runway bridge that vibrates frequently and greatly.

Separating bridge deck pavement made of bituminous concrete is a new topic, where the frames for separation shows the function of obstructing the propagation of vibration, thus, the bending stress to the bridge deck is reduced,, and therefore lower and increase the acting times of the fatigue failure, which may be rated as one measure where by to extend the service lifetime of the pavement..

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