Advanced Engineering Forum
ISSN: 2234-991X, Vol. 5, pp 277-282
doi:10.4028/www.scientific.net/AEF.5.277

Online: 2012-07-26

Load Transfer Characteristics and Durability Study of GFRP Dowels in Jointed Concrete Pavement

LI Luoke[1, a],TAN Yiqiu[1, b], GONG Xiangbing[1], LI Yunliang

[1] Harbin Institute of Technology, Institute of Transportation Science and Engineering,Harbin 150090 China

[a] llk217@126.com, [b] yiqiutan@163.com

Keywords: road engineering; concrete pavement; GFRP dowels; load transfer characteristics; ultimate bearing capacity; durability

Abstract: The corrosion of steel dowels in concrete pavement can compromise the load transfer capability of joints and lead to premature damage. To solve this problem, the non-corrosive glass fibre reinforced polymers (GFRP) bar has been used as dowels in concrete pavement instead of the steel dowels.This thesis demonstrates the Load Transfer Characteristics of a GFRP dowels with the help of a 3D finite-element model, and various evaluation method and index are studied as well, including: (1)efficiency of load transfer , (2)coefficient of shear transfer , (3) distribution ratio of shear transfer. An accelerated test is applied to examine the long-term performance of the GFRP dowel bars by using self-designed equipment.This study shows that GFRP dowels is a feasible alternative to steel dowels which can entirely meet the needs of road performance, and the research results will be useful in the design and application of GFRP dowels in jointed concrete pavements.

Introduction:

In a jointed concrete pavement, dowel bars are installed to transfer traffic wheel loads to the transverse joints without restricting the horizontal joint contraction and expansion. Dowel bars which are commonly used in jointed concrete pavement is made of steel.However, the steel dowels with the small diameter create high bearing stresses in the concrete surrounding, and cause the concrete to crush and spall locally under repeated wheel loads[1]. In addition, the corrosion of the steel dowels can reduce the load transfer efficiency of the joint and restrain vertical movement which compromise the performance of the pavement and lead to premature failure[2].To solve the problems of both corrosion and high bearing stress from conventional steel dowels,the large diameter GFRP dowel bars are now considered as a potential solution because of their resistance to the corrosive agents，high tensile strength and lower surface hardness.This paper researches the performance and feasibility of the GFRP dowel bars which are installed at the locations of transverse joints by the method of finite-element analysis together with experimental approach.

Load Transfer Characteristics of GFRP Dowels

Evaluation Indexes.In actual pavements, the displacement of the loaded slab edge and unloaded slab edge can be measured with a FED,therefore,the displacement–based load transfer efficiency (LTEδ) has been widely used in actual engineering[3].This paper use the LTEδ to directly assess the load transfer efficiency of a GFRP doweled joint and compare it with the steel dowels.,the parameter is calculated using the following equation:

$$\mathrm{LTE}_{\delta} = \frac{\omega_{\mathrm{UL}}}{\omega_{\mathrm{L}}} \times 100\% \tag{1}$$

where ω_{UL} =displacement of unloaded slab edge under the wheel load ; ω_{L} = displacement of loaded slab edge under the wheel load.

Shear force distribution shows the shear force transmitted by each dowel[4]. Shear force transfer ratio（SFTR）is defined as the amount of transferred load by the dowel group from shear force divided by the amount of applied wheel load as shown in the following equation:

$$SFTR = \frac{\sum_1^N Fs_I}{P} \times 100\% \tag{2}$$

Dowel shear ratio（DSR） gives the contribution of dowel bar system in transferring load across a joint by shear action[5]. That is s a calculation method of the relative contribution of dowels in the dowel group. That is

$$DSR = \frac{Fsi}{\sum_1^N Fsi} \times 100\% \tag{3}$$

In this paper,one dowel is considered as a engaged dowel in the load transfer system if the single DSR is larger than 1% of it.

Construction of 3D FE Model .3D Solid model has been chosen in this study,the design properties based on the Specifications of Cement Concrete Pavement Design for Highway[6]. The analysis software “ABAQUS” is used for this purpose,the structral and material detailed in Table 1.

Table 1 Structural and Material Parameters for Pavement

Layer	Dimension (m)	Elastic Modulus（Mpa）	Poisson Ratio	Density(Kg/m^3)
Concrete slab	5×4.5×0.26	30000	0.15	2400
Base	11.1×5.5×0.2	800	0.3	2000
Subgrade	11.1×5.5×2	150	0.35	2100
Steel bar	Φ0.032	210000	0.3	7800
GFRP bar	Φ0.032	30000	0.28	2600

Two concrete slab segments are supported by base and subgrade; a 5 mm wide joint is setted between the two concrete slabs for free expansion and contraction; a total of 15 dowels is included in this model with the spacing of 30cm, as illustrated in Figure 1.

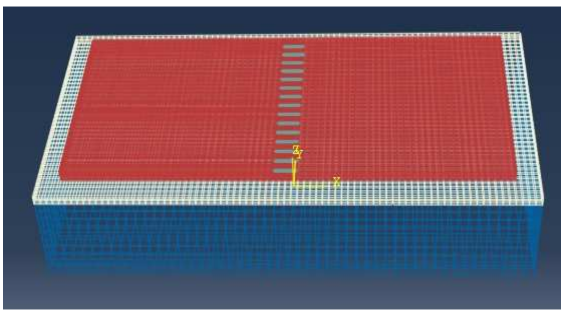


Figure 1 3-D FE Modeling of Dowel-Jointed Concrete Pavement

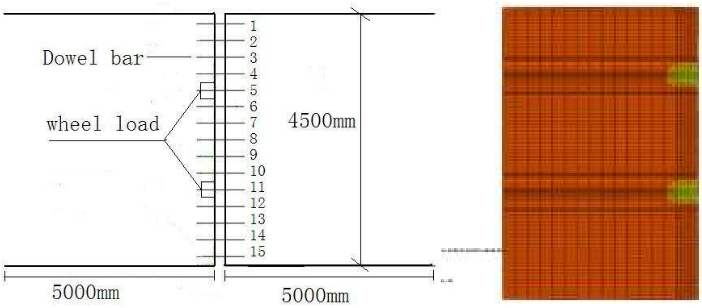
The concrete slab and the base layers are assumed to be frictional contact, and the slab-base friction value are considered as 0.05[7]; the base layers and the subgrade are assumed to be bound connection; all the dowels are setted as bound connection with the concrete slab in one side and setted frictional contact with the other concrete slab, the dowel-slab friction value considered as 0.1.

The standard axle load based on the current pavement design specifications is used as the model wheel load, and detailed in Table 2.

Table 2. Standard Axle Loading Data

Load case	Value
Single Wheel load (Kg)	5000
Tire pressure(MPa)	0.7
Tire Contact Shape	rectangular
Tire Contact Area (mm)	270×270

For the standard axle load analyse, two wheel loads are applied at the position as shown in Figure 2(a), a refined mesh zone is located at the edge of the joint[8], where wheel loads are applied, as shown in Figure 2(b).



(a) (b)

Fig.2 Wheel Load position and dowel number for pavement model

Load Transfer Efficiency of GFRP Doweled Joint . This paper has been researching into four types of dowels, including a commonly used steel dowel with 32 mm diameter and three sizes of pultruded GFRP bars with the diameters of 32 mm ,40 mm and 54 mm. Figure 3 shows the joint face suffered from traffic load at the center of the joint.

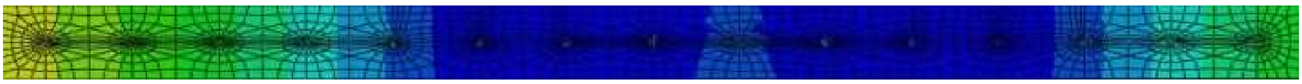


Figure 3 The joint face of loaded slab suffered from traffic load

The LTE δ of the four types of doweled joint which is calculated according to the formula 1 are respectively 95.4%, 87.3%, 95.1% and 97.2%. It can be seen that the doweled joint,which uses the 32mm GFRP dowal bars,exhibits a significantly reduction in load transfer efficiency than the 32mm steel dowels.The LTE δ of the 40 mm doweled joint is almost the same as the 32mm steel dowels. The larger diameter, 54 mm GFRP doweled joint has the highest LTE δ in this study. That means GFRP bars have been introduced as a promising alternative material to the traditional steel dowels.

Load Transfer Behaviour of GFRP Dowels. Figure4 shows the shear force distribution of four types of dowels, and each marker shows the amount of shear force transferred by a dowel at transverse joint.

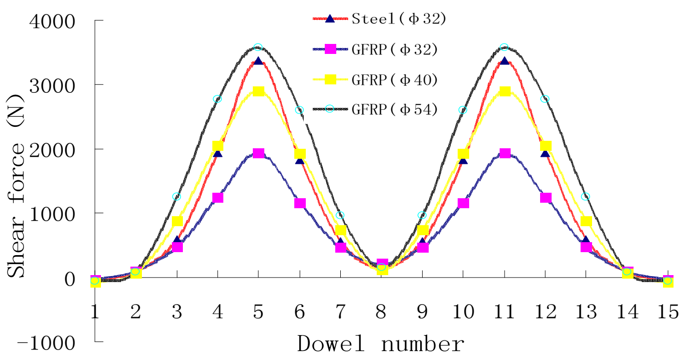


Fig.4 Shear force distribution of dowel at transverse joint

The SFTR of the four types of doweled joint which is calculated based on the formula 2 are respectively 16.8%,10.9%,17.1% and 22.5%. The SFTR of the four types of doweled joint is almost identical to the LTE δ of the joint. This ratio increases with the increase of diameter of GFRP dowels. The DSR of four types of dowels along the joint is shown in Table 3.

Table 3 DSR of four type dowel along the joint

Number	1	2	3	4	5	6	7	8
Steel（Φ32mm）	-0.3	0.5	3.5	11.5	21.9	10.9	3.4	0.9
GFRP（Φ32mm）	-0.3	0.5	4.4	11.4	17.7	10.6	4.3	1.9
GFRP（Φ40mm）	-0.5	0.6	5.2	12.1	17.0	11.3	3.3	1.7
GFRP（Φ54mm）	-0.2	0.7	5.5	12.3	15.8	11.6	2.9	1.8

From this diagram, one can clearly observe that eleven engaged dowels carry more than 99% of the transferred shear force in the dowel bar system. The contribution from the two end dowels (both sides) is inefficient no matter what type of dowels. In addition, the outer six dowels of both sides carried 7.4% shear force to the total amount of dowel bar system in the case of utilizing the 32-mm Steel dowel, 9.2% of 32-mm GFRP dowel case,10.6% of 40-mm GFRP dowel case and 12% of 54- mm GFRP dowel case. This phenomenon indicates that using the diameter of the GFRP dowel bar can increase the integrity of the doweled joint.

The results of numerical calculation in this study shows that the GFRP bars are a feasible alternative to commonly used steel dowels for using in jointed concrete pavements.The 40-mm GFRP dowels have been found to perform almost the same to the commonly used 32-mm steel dowels in load transfer efficiency of the doweled joint and load transfer behaviour of the dowel bar system. The large diameter GFRP dowels, especially the 54-mm bars, have been found to perform the best in this study.

Durability Study of GFRP Dowels

This study investigates the ultimate bearing capacity and long-term performance of the GFRP dowel bars under the condition of simulated vehicle axle loads.

Test Specimens. Four types of dowels are tested in this study, including a 32-mm steel dowel and three size of GFRP dowels with the diameters of 32mm,40mm and 54mm. All dowels are 500 mm in length and half of the lengh is embedded in a concrete slab with the dimensions of 300 mm x 400 mm x 260 mm which is the typical size standard based on the Specifications of Cement Concrete Pavement Design for Highway.The four types of dowel bars and specimen are shown in Fig.5.

Fig..5 Dowel bars and specimen

There are eight specimens for each type of dowels, four specimen are used for the static test, and the others for the long-term performance test.

Test Equipment. For all tests, the specimen is fixed under a rigid support beam to reduce the shake of the test machine during cyclic loading.The dowels are loaded in direct shear by a steel loading device to simulate the effect of the loaded panel transferring that load to an adjacent pane from the dowel bars by shear action as shown in Figure 6 below.

Fig.6 Test Equipment

Static test .. In the static test, the specimen are loaded to failure under step loading of 5KN/step by the loading device. The steel dowel reaches a maximum peak failure load of 45 kN, the failure pattern mainly is slipping pull crack as shown in Figure 7(a).The 32-mm GFRP dowel has a lower peak failure load of 30KN, the failure pattern is dowel bar broken as shown in Figure 7(b). The 40-mm and 54-mm GFRP dowels has peak failure loads of 42 kN and 55 kN respectively. The failure pattern is similar to the steel dowel specimen as shown in Figure 7(c).

(a) (b) (c)

Fig.7 Failure Pattern of Four Specimen

Test result shows that the larger diameter GFRP dowel bars are found to perform the best of ultimate load-carrying capacity.

Fatigue test . In order to research the durability of GRFP dowels , four types of specimens are conducted at fatigue loading at the frequency of 5 Hz for a total of 1,000,000 cycles at a level of 12KN. In order to simulate the amount of shear force transmitted by a dowel under treble the standard 100KN axle load calculated from FE model. The following experimental phenomena have been observed:(1) It can be seen that there is no indication of structural damage to any of the dowels or to the concrete pavement slab after the 1,000,000 cycle loading. (2) The dowel deflections are captured in fatigue experiment, the peak displacements are almost identical to the values measured in the static test provided earlier.(3) It is found a trifle debonding at the steel - concrete contact interface after the 1,000,000 cycle loading. At these locations, the concrete crushes subjected to high bearing stresses between steel dowel - concrete contact interface, which causes dowel looseness. The 40-mm and 54-mm GFRP dowels are not found any concrete crushed and dowel looseness after fatigue experiment because using of larger diameter GFRP dowel bars, even though a debonding phenomenon appears in the process.(4) The residual deflection of GFRP dowels after fatigue experiment is lower than the steel dowel, and then it recovers gradually within a day, which has better capability of fatigue resistance

Conclusions

The following major conclusions have been drawn from the present study:

(1) 3D finite element model has been chosen in this study,to investigate the load transfer characteristics of the GFRP dowels.The structural analysis package "ABAQUS" is used for this purpose. The results of numerical calculation in this study shows that the dowel shear ratio of GFRP bars is probably the same as commonly used steel dowels. The large diameter GFRP dowels, especially the 54-mm GFRP dowels, are found to perform the best in load transfer efficiency in this study.

(2) A experimental program including static and cyclic tests are carried out to study the performance of GFRP dowels.by using self-designed equipment. The static study shows that the using of larger diameter GFRP dowel bars can reduce the deflections， as well as bearing stress in the dowel-concrete contact interface. In addition, the using of larger diameter GFRP dowel could increasing the ultimate bearing capacity and durability of the doweled joint

(3) The recommendatory GFRP dowel is 20%-30% increase in diameter to traditional steel dowel because it should be more economical and reasonable in practical engineering.

Acknowledgments

The work described in this paper was fully supported by the National Natural Science Foundation of China (Grant No: 50808058) and Science and Technology Program of Heilongjiang Province (Grant No: 2010T0013-00).

References

[1] EDDIE D,SHALABY A,RIZKALLA S. Glass Fiber-Reinforced Polymer Dowels for Concrete Pavements[J]. American Concrete Institute Structural Journal,2001,98(2): 201-206.

[2] WANG Duan-yi,HU Chi-chun,RICHARD R.Assessment of Grouted Glass Fibber-Reinforced Polymer(GFRP) Tubes as Dowel Bar Alternatives[J].Highway, 2007(01):32-36.

[3] JIANG Ying-jun. Study of Conerete Pavement Materials and Strueture Under Heayv-load Transportation[D].Xi'an: Chang'an University,2005.

[4] ZHOU Zheng-feng,LING Jian-ming,YUAN Jie.3-D finite element analysis of the load transfer efficiency of joints of airport rigid pavement[J].China Civil Engineering Journal, 2009, 42(2): 112-118.

[5] SHIVA SRINIVASA. Characterization of stresses induced in doweled joints due to thermal and impact loads[D]. Morgantown，West Virginia: College of Engineering and Mineral Resources at West Virginia University,2001.

[6] FRIBERG B F. Design of Dowels in Transverse Joints of concrete Pavements[J]. American Society of Civil Engineering,1940,105(3):289-298.

[7]MURISON W S, Evaluation of Concrete-Filled GFRP Dowels For Jointed Concrete Pavements[Z]. Manitoba: University of Manitoba, 2004.

[8] ZHOU Zheng-feng,LING Jian-ming,YUAN Jie.3-D finite element analysis of the load transfer efficiency of joints of airport rigid pavement[J].China Civil Engineering Journal, 2009，42（2）：112-118.