Evaluation of Dowel Bar Alternatives Based on Similarity Model Test

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ABSTRACT: In this study, to overcome the high cost of accelerated loading test, a small-scale laboratory experiments were developed and conducted toward the potential dowel bar alternatives. Similarity theory and Accelerated Pavement Analyzer were used to evaluate dowel bars with different materials and cross-sections. The test results showed that larger FRP dowel is required to produce the same load transfer efficiency and differential deflection which would be produced with given size of round steel dowel. Moreover, steel dowel with large diameter can effectively improve the ability of joints to transfer vertical shear forces and reduce the internal stress, thereby extending the service life of dowel load transfer system.

Keywords: dowel bar, similarity model test, FRP dowel, load transfer efficiency

INTRODUCTION

The performance of jointed concrete pavements is often closely related to the load transfer capacity of dowel bars at the pavement joints. Faulting is frequently seen in the pavement joints without dowel bars, because the load transfer provided by aggregate interlock alone is insufficient. Steel dowels are commonly used to enhance load transfer in the concrete pavements. However, the issue of high bearing stress and corrosion of steel dowel has a significant impact on long-term performance. There have been efforts to improve dowel durability through the use of alternate shapes (other than round) to further reduce dowel-concrete bearing stresses and to use alternative materials for improved corrosion-resistance (Porter and Braun, 1997; Wang et al. 2006; Maitra et al. 2009; Snyder, 2011).

Usually, the laboratory experiments of dowel bar include: static and fatigue elemental shear, bending strength, accelerated loading test, pull-out, alkalinity aging, and chemical properties (Porter, 2003). Due to relative low cost and time consumption and relative high reliability, evaluation of joint performance and dowel alternatives using laboratory accelerated loading has attracted many interests in the past 20 years.

Among those researchers, Buch and Zollinger (1996) conducted a laboratory study to evaluate the dowel looseness across a saw-cut joint, concrete specimens 610 mm×254 mm×915 mm were molded. The fatigue load application system consisted of a pair of hydraulic rams that pulsed alternately on either side of the joint to produce loads of up to a maximum of 40 kN, which can closely simulated that of a truck tire loading a joint.
The total duration of the load and unload cycle was 1.5 seconds, of which the rest period lasted for 0.98 seconds. Melhem et al. (1999) studied the performance of FRP and steel dowels in jointed slabs using a pulse load system. Both slabs, the one with steel dowels and the one with FRP dowels, were tested side-by-side such that load was applied simultaneously. The load was applied by each actuator in a sinusoidal-shape function, with the two functions 180 degrees out-of-phase. Using this setup a speed of 9000 applications per hour can be achieved which is 15 times faster than the rolling axles. Bian et al. (2008) performed Heavy Vehicle Simulator (HVS) tests of several types of dowels at Palmdale's dowel bar retrofitted concrete pavement test sections. Channelized, bidirectional loading was conducted on the wheelpath over the center of the dowel group. The result showed that four epoxy-coated steel dowels per wheelpath had much smaller joint vertical deflections than did the alternatives (four FRP dowels, four hollow stainless steel dowels).

As mentioned above, the pulse load system can significantly shorten duration of time while HVS can exactly replicate the rolling wheel effects. But both of them need specialized equipments, which limits the laboratory study and practical application of dowel alternatives. The object of this research is to develop a small-scale accelerated loading test to evaluate dowel alternatives based on the similarity model and Accelerated Pavement Analyzer, combining the advantage of pulse load system and HVS. Therefore, a economical similarity model test is introduced, the corresponding test program is described, and dowel bars with different materials and cross-sections are evaluated.

MODEL DESIGN

The geometric similarity constant was 1/3.5 in the model test. Based on similarity principle, the dimension parameters of the scaled model can be obtained, as shown in Table.1.

<table>
<thead>
<tr>
<th></th>
<th>Prototype</th>
<th>Scaled model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length of concrete slab (mm)</strong></td>
<td>520</td>
<td>148.5</td>
</tr>
<tr>
<td><strong>Width of concrete slab (mm)</strong></td>
<td>437.5</td>
<td>125</td>
</tr>
<tr>
<td><strong>Thickness of concrete slab (mm)</strong></td>
<td>262.5</td>
<td>75</td>
</tr>
<tr>
<td><strong>Joint width (mm)</strong></td>
<td>10</td>
<td>2.9</td>
</tr>
<tr>
<td><strong>Dowel length (mm)</strong></td>
<td>450</td>
<td>129</td>
</tr>
</tbody>
</table>

In the experiment, steel dowels and FRP dowels are considered, and the cross-section of the dowel bar is round, elliptical and rectangular (See Table.2). Among them, φ10 round steel bar, elliptical steel bar (12.5×8) and rectangular steel bar (8.9×8.9) have the same cross-section area, so as to evaluate the optimal cross-section with respect to the same material consumption. A non-standard third point bending test and a double shear test were performed to evaluate the bending capacity and shear strength of the dowel bar. The test result is presented in Table.2.
Table 2. Materials, Cross-section and Size of Dowels.

| Materials | Cross-section | Code   | Prototype size (mm) | Scaled Model |   |   |   |
|-----------|---------------|--------|---------------------|--------------|---------------|-----------|-----------|-----------|
|           |               |        |                     | Dimensions (mm) | Cross-section area (mm²) | Maximum bending load (kN) | Shear strength (MPa) |
| Steel     | Round         | Steel35 | φ35                 | φ10          | 80 | 5.7 | 102.5 |
|           |               | Steel42 | φ42                 | φ12          | 110| 12.3| 156.5 |
|           |               | Steel56 | φ56                 | φ16          | 200| 27.8| 245.2 |
| FRP       | Round         | FRP35  | φ35                 | φ10          | 80 | 2.1 | 19.8 |
|           |               | FRP56  | φ56                 | φ16          | 200| 6.2 | 42.9 |
| Steel     | Ellipse       | Ellipse35 | 43.8               | 12.5         | 80 | 6.5 | 110.1 |
|           | Major axis    |         |                     | Minor axis   |     |      |      |
|           | Minor axis    |         |                     |              |     |      |      |
|           | Ellipse       | Ellipse35 | 28                 | 8            | 80 | 7.4 | 106.4 |
| Steel     | Rectangular   | Rectangular35 | 31.2×31.2 | 8.9×8.9 | 80 |      |      |

MODEL MANUFACTURE

As shown in Fig.1, the mould of the scaled model consists of expansion joint plate, support of dowel bar, removable ears, rubber bearing and connecting steel bar. The rubber bearing is used to simulate the subgrade of pavement structure and the connecting steel bar is used to simulate the dowel bar of the adjacent slab. Before making specimen, vaseline was smeared in the inner wall of the formworks to prevent leaking.

![Figure 1. Placing concrete into the formwork.](image)

All the FRP dowels and steel dowels were instrumented with strain gauges to monitor strains on dowel bars. The strain gauges were located on the top and bottom of the dowel bars on both sides, at a distance of 1.2 cm from the centreline of the 13 cm long dowel bars (See Fig.2). Strain gauges are temperature compensated by use of the dummy gauge technique. A dummy gauge is wired into a Wheatstone bridge on an adjacent arm to the active gauge so that the temperature effects on the active and dummy gauges counteract each other.
ACCELERATED LOADING TEST

Test program
In the scaled model, Asphalt Pavement Analyzer (APA) is used to perform accelerated loading test. The APA tracks a loaded aluminum wheel back and forth across a pressurized linear hose over a beam sample which can simulate the traffic load of actual pavement. In the study, the wheel is tracked across the sample for 864,000 cycles using a $1113\pm4.5$ N load and a 200 MPa hose pressure. Samples with a dimension of $75 \text{ mm} \times 125 \text{ mm} \times 300 \text{ mm}$ were prepared and DH3817 dynamic strain acquisition system is used.

The procedure of accelerated loading test is as follows: First, set the hose pressure and load cylinder pressure to the desired levels. Second, insert three sets of beam samples into the chamber and place the dial indicators over the sample. Third, clear the gauge and take initial strain and deflection readings. Finally, start the test and collect data at every 48,000 load cycles, as shown in Fig. 3.

Data processing
As described in the previous section, 200 MPa is used for hose and 1.1 kN is used for the load while the axle load of the prototype weight 50 kN. According to a basic formula of the similarity principle, the following equation can be obtained:

$$c_\varepsilon = \frac{c_F}{c_l^2 c_E} = 1$$

(1)

$$c_F = c_E c_l^2 = 12.25$$

(2)

where $c_\varepsilon$ is the strain similarity constant; $c_E$ the elastic modulus similarity constant; $c_l$ the length similarity constant; and $c_F$ the dynamic similarity constant.
From $F = 50/3.5^2 = 4.08KN$, hence $c_F = \sqrt{\frac{4.08}{1.1}} = 1.9$. The following equation can be obtained.

$$f_{\text{origin}} = f_0 \cdot c_F \cdot c_F$$

which means

$$f_{\text{origin}} = 6.65f_0$$

where $f_{\text{origin}}$ and $f_0$ are the deflection of the slab of the prototype and model, respectively, 0.001mm.

When the axle load of the prototype weighing 50 kN is shared by 5 dowel bars, the shear force carried by the central dowel (beneath the load) can be calculated as follows.

$$F_{\text{bear}} = F_{\text{car}} / 2.78 = 17.99KN$$

From formula (3), we can get

$$F = F_{\text{bear}} / c_i^2$$

Hence, $F = 1.47KN$ and $c_i = \sqrt{\frac{1.47}{1.1}} = 1.16$. The following equation can be obtained.

$$\varepsilon_{\text{origin}} = 1.16\varepsilon_0$$

where $\varepsilon_{\text{origin}}$ and $\varepsilon_0$ are the strain of the dowel bar of the prototype and model, respectively, $\times 10^{-6}$.

**Test results**

![Figure 4. Load transfer efficiency on load cycles for different dowels.](image)

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Figure 5. Differential deflection on load cycles for different dowels.

Figure 6. Strain of dowel at loaded side.

Figure 7. Strain of dowel at unloaded side.
Fig. 4 presents the load transfer efficiency (LTE) and the corresponding number of wheel cycles for each type of dowel bar in the prototype. As shown in Fig. 4, the average LTE of FRP35 observed in the accelerated loading test is 87.7%, which is smaller than the average LTE of Steel35, 91%. After 864,000 cycles, the LTE of FRP35 decreased from 90.7% to 82.8%, while LTE of Steel35 decreased from 94.8% to 87%, indicating that the use of FRP dowel has a significant impact on the performance of pavement joint. A comparison between FRP56 and Steel42 was also conducted. The average LTE of FRP56 and Steel42 is 93.4% and 93.1%, respectively, which means those two have very close load transfer performance. A literature review, presented in Table 3, indicates the similarity model test developed in this study is effective.

<table>
<thead>
<tr>
<th>Table 3. Steel Dowel and FRP Dowel Having the Same Performance.</th>
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<tbody>
<tr>
<td>diameter</td>
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<td>----------</td>
</tr>
<tr>
<td>diameter</td>
</tr>
<tr>
<td>Steel</td>
</tr>
<tr>
<td>Steel42</td>
</tr>
<tr>
<td>FRP56</td>
</tr>
</tbody>
</table>

For the joints with Steel35, Steel42 and Steel56, the average LTE is 91%, 93.1%, 96.6%, respectively. It shows that the dowel diameter strongly influences the load transfer capability and it is very reasonable and necessary for Chinese specification to increase the dowel diameter. The result also shows that the average LTE of Steel35, Ellipse35 and Rectangular35 is 91.0%, 91.6%, 92.5%, respectively. Therefore, the dowel bar with cross-section of ellipse and rectangle can be selected as the preferred alternatives in practice. A research done by Cable et al. (2008) showed that medium elliptical steel dowel bars (major axis = 42.0, minor axis = 28.32) performed equally to standard round dowel bars (38.10 mm) when wheel path baskets were used, which can also verify the effectiveness of our similarity model test.

Concerning the deformation of dowel bar, the strain was plotted against load cycles. The result of Steel35 and FRP35 reported in Fig. 6 and Fig. 7 shows that the strain of Steel35 is smaller than the strain of FRP35 under the same wheel load due to the difference in elastic modulus. Comparison of the average strain of Steel35, Steel42 and Steel56, which is 169, 122 and 69 με, respectively, indicated that dowel bar with large diameter can effectively reduce the internal stress, thereby extending the service life of dowel load transfer system.

CONCLUSIONS
The aim of this study is to develop a small-scale accelerated loading test to evaluate dowel bar alternatives, combining the advantage of pulse load system and HVS. Thus, a small-scale accelerated loading test based on the similarity model is developed, the corresponding test program is described, and dowel bars with different materials and cross-sections are evaluated. The following conclusion can be obtained:

1. The result of LTE indicated that the use of FRP dowel has a significant impact on the performance of pavement joint. Moreover, FRP56 and Steel42 have very close load transfer efficiency.
2. Under the same wheel load, the strain of Steel35 is smaller than the strain of FRP35 due to the difference in elastic modulus. Comparison of the strain of steel bar showed that dowel bar with large diameter can effectively reduce the internal stress, thereby extending the service life of dowel load transfer system.

3. The result of LTE and strain both revealed that dowel bar with cross-section of ellipse and rectangle can be preferentially considered in practice.

4. Similarity model test developed in this study is effective.

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