Evaluation of FWD Load Transfer Efficiency Measurement

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Abstract. This paper presents an evaluation of load transfer efficiency (LTE) of dowel jointed concrete pavements. Measurement of load transfer efficiency of transverse joints in concrete pavements is universally conducted using Falling Weight Deflectometer (FWD). LTE is an important parameter affecting pavement performance. Due to the importance of the results for maintenance decisions, the accuracy of the measurement technique is investigated. For this purpose, FWD tests were conducted on instrumented rigid pavement section in West Virginia at different times. The state of deformation of the slabs are continuously monitored, through dowel bar bending measurements and records of the temperature gradient profiles across the slab thickness, as well as joint openings every 20 minutes. Transverse joints were tested along the slab edges as well as along the wheel-path. Trend analysis was performed to evaluate the effect of design features and site conditions on LTE.

Introduction

As a wheel load is applied near a transverse doweled joint in a PCC pavement, both loaded and unloaded slab deflect since a portion of the load applied to the loaded slab is transferred to the unloaded one. In absence of any load transfer mechanism, the slab edges at the joint would suffer excessive stresses, while the relative displacement between the loaded and unloaded slabs would severely reduce the ride quality. For this reason, many load transfer mechanisms are introduced into rigid pavement joints. The main design features in such mechanisms is to provide a better and more efficient load distribution across adjacent slabs, while reducing the relative deflection across slab joints. Load transfer mechanisms include aggregate interlock and different designs of dowel bars. Despite the presence of load transfer devices, it is very rare to find an absolutely even displacement for both loaded and unloaded slabs at their joint.

The term load transfer efficiency (LTE) is used to express the ability of a joint to transmit part of the applied load on the loaded slab to the adjacent unloaded one [1]. Several formulae for calculating load transfer efficiency have been adopted by various researchers to provide quantitative measures of pavement-system response [2]. Several measures for load transfer efficiency based on slab deflection and/or stress have been used. Based on deflection measurements, LTE is measured as:

$$LTE = \frac{d_u}{d_l}$$  \hspace{1cm} (1)

Where $d_u$ and $d_l$ are unloaded and loaded deflections at the joint respectively.

Several nondestructive testing techniques are used to measure the load transfer efficiency across rigid pavement joints and cracks. Falling Weight Deflectometer (FWD) is the most commonly used device for measuring the load transfer efficiency across joints and it was employed in this study. The main objective of this study is to examine the accuracy of measuring load transfer efficiency of transverse joints in dowel jointed concrete pavements using FWD and examine how such a deflection-based load transfer efficiency correlates with the actual shear force transmitted through mechanical load transfer devices across transverse joints.
Instrumented Pavement Section

A set of seven test concrete slabs were cast for experimental study in a designated open area at the parking lot of the WVDOT Maintenance Shop at Goshen road, West Virginia. The slabs were instrumented with a variety of sensors for long-term monitoring of the slab response to various loading conditions including seasonal and daily temperature changes. The sensory system is designed to provide continuous data from key-performance parameters that formulate the behavior of the slabs such as the distribution of strains along and across the slab centerlines, joint openings, temperature profiles through the slab thickness, dowel bending moments, dynamic shear and normal forces, strains at the concrete-dowel interface along with a continuous record of weather conditions.

In total seven full scale slabs (4.57 m × 3.65 m × 0.25 m) were constructed. Three of the seven slabs were not instrumented and act as support or joint slabs. They were laid in September 2002. The remaining four slabs are instrumented and were poured in October 2003. Data collection began in October 2003 when the first of the four instrumented slabs was poured. The site has a total of seven slabs; five jointed slabs with their joints fitted with either regular dowels or Shokbars (dowel bars fitted with steel or polymer concrete sleeves) and two free slabs.

The construction of slabs was carried out through 2 stages. The first stage consisted of placing 3 slabs that served to provide joints to the instrumented ones. Those 3 slabs were anchored to the ground to simulate the extended continuity of pavements, i.e. maximum resistant to joint movement. The second stage of construction consisted of placing the instrumentation system and casting the 4 instrumented slabs in between the wooden forms as shown in Figure 1.

FWD was used to apply dynamic loads at transverse joints. The tests were conducted along three lines: slabs edge, wheel-path, and slab centerline. The transverse joints in this instrumented pavement section were constructed to be fully opened using a foam separator to ensure that dowel bars or shokbars are the only means of load transfer device between adjacent slabs. This means that the shear force measured in this study represents the highest value of the shear force that can be transferred by the dowels as the FWD is applied at the transverse joint edge.

The FWD impacts are applied at the locations of the instrumented dowels as the strain rosette output was recorded. The data acquisition system was programmed to collect data from all sensors at a rate of 1000 sample per second during the FWD testing. The system was activated as the FWD
was about to drop and stopped after impact. Three FWD impacts were applied and recorded at each testing location. The deflection-based load transfer efficiencies were calculated from the surface deflections measured using the FWD device.

**Shear Force in Dowel Bars**

Under the effect of the impact load of the FWD, dowel bars are subjected to bending moment and shear force. The shear force since it represents the actual force transferred by the dowels to the unloaded slabs. Figure 2 illustrates a typical measured time history of the shear forces recorded in the instrumented dowel bar located at the slab corner due to applying the FWD loading pulse at the same location.

![Figure 2. Typical Shear Force History in Dowel Bars.](image)

Figure 3 illustrates the distribution of the shear forces among the dowel bars at transverse joint due to the application of the FWD load at three locations: corner, wheel-path and joint center. It can be noticed that the magnitude of the dowel shear force decreases linearly as the distance from the loading position decreases on both sides, which agrees with the assumption of Friberg [4] and the finding of Tabatabie and Bernberg [5]. A similar observation can also be made on the shokbars. However, the magnitudes of the shear force transmitted through the shokbars are higher than those transmitted through traditional dowels and the number of the active bars is less. The magnitude of the shear forces induced in the uninstrumented dowels can be calculated through the linear interpolation of the forces shown in Figure 3.

Table 1 summarizes the magnitudes of the shear forces induced in the dowel bars and shokbars at transverse joints. Noticeable that the shear force transmitted through the shokbars due to corner loading is as twice as that transmitted by regular dowels. The maximum shear force transmitted through the dowels or shokbars is obtained when the load is applied near the joint center. The results indicate the superiority of the shokbars in transmitting the corner and wheel-path loads.

| Load Position | Dowel Bar Location measured from Corner (m) | Sum (N) |
|---------------|--------------------------------------------|---------|
|               | 0.15 0.46 0.76 1.07 1.37 1.68 1.98 2.29 2.59 2.90 3.20 3.51 |
| Dowel Bars    |                                            |         |
| Corner        | 1685 1480 1275 1070 865 660 455 250 45     | 7785    |
| Wheel-Path    | 808 1083 1358 1084 808 532 256             | 5929    |
| Joint Center  | 26 458 889 1321 1753 2184 2184 1753 1321 889 458 26 | 13262   |
| Shokbars      |                                            |         |
| Corner        | 9300 5035 770                               | 15106   |
| Wheel-Path    | 1400 1380 1360 1100 800 500 200             | 6740    |
| Joint Center  | 258 506 754 1002 1250 1498 1498 1250 1002 754 506 258 | 10536   |
The percentages of the load transferred through the dowels and/or shokbars are compared with the deflection load transfer efficiency calculated based from the deflection measurements as listed in Table 2. Despite the high values of deflection-based load transfer efficiencies, the percentages of the actual shear forces transmitted through dowels/Shokbars are very low. The results in Table 2 indicate that there is no one-to-one relationship between load transfer efficiency and the deflection-based load transfer efficiency.

The large discrepancies between the deflection-based load transfer efficiencies and load transfer efficiencies illustrated in Table 2 can be explained by the following reasons:

- Slab deflections increase in the presence of dowel bar looseness while dowel shear forces decrease.
The FWD tests were conducted between 10:00 AM and 12:00 PM. During this time, the slabs are subjected to positive temperature gradient, which makes the joints in contact with the base layer. This reduces the shear forces transmitted by the dowel bars or the shokbars.

Table 2. Deflection Load Transfer Efficiency and Actual Load Transfer Efficiency.

| Load Position   | Total Force Transmitted by Dowels (KN) | Force of Drop (KN) | Load Transferred (%) | Deflection-Based Load Transfer Efficiency (%) |
|-----------------|---------------------------------------|-------------------|----------------------|-----------------------------------------------|
| **Dowel Bars**  |                                       |                   |                      |                                               |
| Corner          | 7.785                                 | 70.21             | 11.1%                | 77.03%                                        |
| Wheel-Path      | 5.929                                 | 71.75             | 8.3%                 | 89.84%                                        |
| Joint Center    | 13.262                                | 69.87             | 19.0%                | 78.51%                                        |
| **Shokbars**    |                                       |                   |                      |                                               |
| Corner          | 15.106                                | 69.17             | 21.8%                | 81.16%                                        |
| Wheel-Path      | 6.74                                  | 70.29             | 9.6%                 | 87.31%                                        |
| Joint Center    | 10.536                                | 68.97             | 15.3%                | 77.37%                                        |

Summary

The analyses of the trends reported in this study were intended to calculate deflection-based load transfer efficiency (LTE) and the percentage of load transferred through the load transferring devices mounted across the transverse joint. The effects of the seasonal temperature variations and the position of load application were examined. The following are highlights of the results obtained from this study:

1. Load transfer efficiency was found to be a complex parameter that depends on many factors that include load position, testing time, slab temperature, and load transfer device.
2. Testing time and season were found to have a significant effect on the measured load transfer efficiency. For the same joint, the load transfer efficiency measured in winter (low temperature) was found to be less than that measured in summer (high temperature).
3. Joint opening changes daily and seasonally as the ambient temperature changes. As the amount of joint opening increases due to slab contraction during winter, the measured load transfer efficiency generally decreases.
4. As the slab temperature increases, the load transfer efficiency increases.
5. Poor correlation was found between the deflection-based load transfer efficiency and the percentage of the load transferred through the load transferring devices mounted across the transverse joint.

References

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