EVALUATION OF BEARING CAPACITY OF INTERLOCKING BLOCK PAVEMENTS USING HFWD

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ABSTRACT

Roadway pavement using interlocking (IL) block sometimes experiences defects including pulverization of bedding sand, insufficient bearing capacity of the base course and structures below it, and various kinds of distress resulting from deflection of pavement and width of joint. A nondestructive test method that allows multiple deflection measurements in a short time is needed for when IL block is installed or when such defects occur, to enable bearing capacity evaluation and appropriate work execution control. The authors used HFWD, a small FWD that is generally used to evaluate the bearing capacity of asphalt pavement and the strength control of soil base course of railway, to measure deflection at the base course and at the surface of IL block pavement on a municipal road. We found that the deflection measured by HFWD can be used to estimate bearing capacity of base course and structures below it, to compare bearing capacities in the cross-sectional direction when rutting occurs, to evaluate joint width, to determine the necessity of adding joint sand, and to evaluate distress of blocks. Consequently we confirmed that deflection measurements using HFWD are useful for evaluation of bearing capacity of pavement materials with joints, such as IL block, and for their work execution control.

1. INTRODUCTION

Interlocking (IL) block pavement used for roadways may experience defects for various reasons related to quality of bedding sand, insufficient bearing capacity of the base course and structures below it, deflection magnitude at pavement surface, and width of joint. Reduction of such failures during construction or use of IL block pavement requires a non-destructive test method that can carry out multiple deflection measurements easily and efficiently, thereby enabling evaluation of the pavement bearing capacity and appropriate work execution control. Common methods of bearing capacity evaluation for work execution control include plate bearing test, deflection measurement by Benkelman beam, and C.B.R. test. These methods, however, can measure only a limited number of items

per day, and require reaction equipment and a load source.

The authors used a HFWD (Handy Falling Weight Deflectometer), a small FWD, to test IL block pavement. The device is one commonly used for strength control of soil base of railway as well as for evaluation of the bearing capacity of asphalt pavement. Testing was carried out on IL block pavement, with deflection being measured at the base course and at the block surface of the roadway.

This paper describes HFWD-based deflection measurement of IL block pavement with multiple joints, and the subsequent evaluation of bearing capacity and work execution control.

2. OUTLINE OF HFWD

HFWD is a proven, portable diagnostic percussion device for pavement. Technicians often carry it in the field to obtain information on pavements. HFWD has the following features.

(1) Its weight of only 22 kg makes it easy to carry.

(2) It takes only one second for it to measure one point, enabling the user to gather large volumes of data in a short time.

(3) Measurement of base course deflection is possible by removing only one block (100 mm x 200 mm).

(4) Measurement can be taken even in relatively restricted spaces.

(5) It is possible to examine the degree of compaction of subgrade and base course material in the field.

This device consists of a falling weight and a measuring section. Measurement is made by free fall of an 8-kg weight, which creates an impact load of 300 to 500 kg. The device is capable of simultaneously measuring the deflection at two points, one immediately beneath the impact and the other at any distance from the loaded spot.

The overview and schematic drawings of HFWD are shown in Figures 1 and 2, respectively. Table 1 shows related specifications.

Table 1 Specifications of HFWD

total weight	22kg
weight	8kg
loading plate diameter	9cm
drop height	80cm
loading time	5 ~ 30msec
load	0-500kg
deflection measurement range	0~2mm
deflection resolution	0.001mm

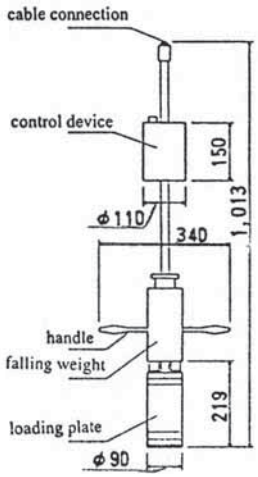

Figure 1 HFWD (external view)

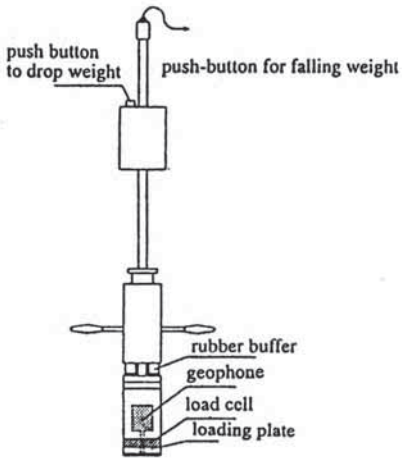

Figure 2 HFWD (schematic)

3. CORRELATION BETWEEN HFWD AND BENKELMAN BEAM

An experiment, sought to reveal a correlation between HFWD and Benkelman beam, toward putting HFWD to use in evaluation of the bearing capacity of IL block pavement with multiple joints as well as in work execution control of such pavement.

Using an HFWD (loading capacity of 0.5 ton, loading plate diameter of 9 cm) and a Benkelman beam (loading capacity of 5 ton), deflection was measured for IL block pavement with different structures that had been in service for one year, a period normally required for the deflection of IL block pavement to stabilize.

Figure 3 shows deflection measured by Benkelman beam and by HFWD for IL block pavement (block of 10 cm, bedding sand of 2 cm) of seven different structures, with each pavement section measured at the same point. The deflection values measured by these devices have a linear approximation, with a high correlation coefficient of 0.93.

$$Y = 0.230X + 0.025$$

where, Y = deflection measured by HFWD (mm) and X - deflection measured by Benkelman beam (mm).

4. EVALUATION OF THE BEARING CAPACITY OF IL BLOCK PAVEMENT

4.1 Identification of Boundary Between Different Pavement Structures

Toward addressing the rutting problem of asphalt pavement, the surface course of asphalt pavement was cut away and replaced with IL blocks. Although that asphalt pavement was known to be of two different structures (Figure 4), it was not known where was the

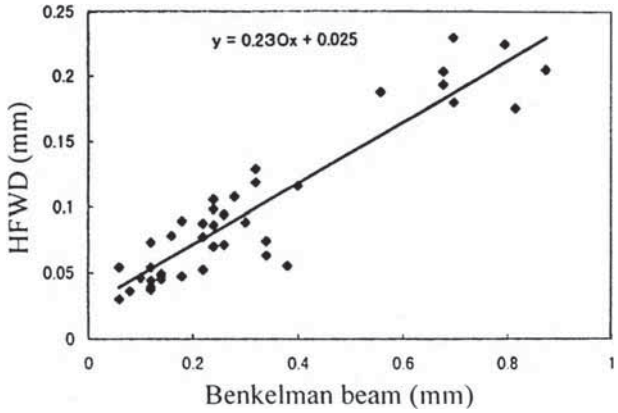

Figure 3 Correlation between HFWD and Benkelman beam deflection values

boundary between them. In an attempt to locate the boundary, deflection measurement was taken by HFWD at 17 points, each 50 cm apart. The deflection profile (Figure 5) that was obtained indicates a boundary at 14.5 m from the measuring origin.

It is possible to locate the boundary of different pavement structures by observing profiles of measured deflection.

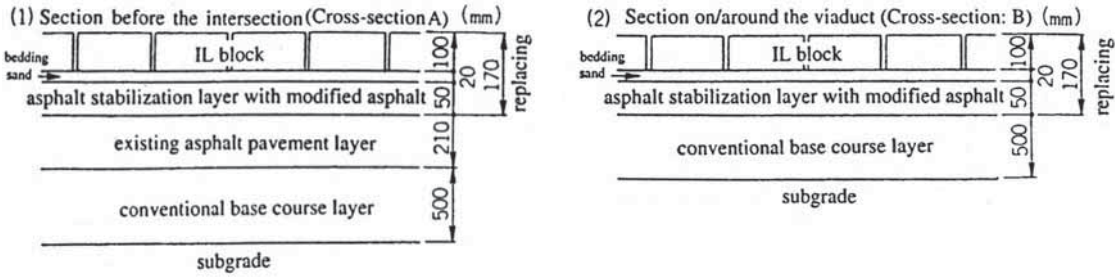

Figure 4 Structures of IL block pavement

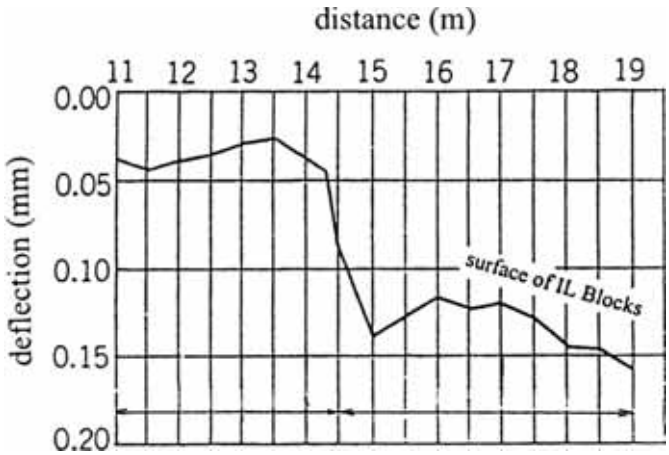

Figure 5 Profile of measured deflection of roadway with traffic volume C

4.2 Estimating Possible Causes of Rutting

In sections of the IL block-paved roadway mentioned above, rutting occurred where the thickness of asphalt mixture was low. Toward identifying the cause, pavement profile and deflection were measured by leveling string from the top of both the IL block and the asphalt stabilization layer at intervals of 20 cm along the same transverse line. Figure 6 shows the measured cross-sectional profile. Figure 7 shows the profile of measured deflection.

The deformation of the asphalt stabilization layer also was observed where rutting occurred (Figure 6). The deflection in rutted sections tends to exceed that in non-rutted sections for both the IL block and asphalt stabilization layer (Figure 7). Consequently, it was estimated that in rutted sections, the bearing capacity of the existing asphalt concrete layer and the layers below it including the base course decreased. In addition, it was confirmed that the bearing capacity fluctuates transversely.

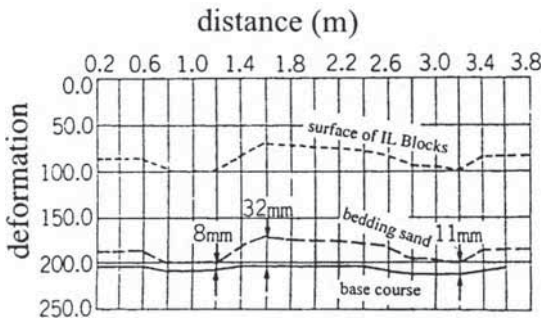

Figure 6 Cross-sectional profiles of respective pavement layer

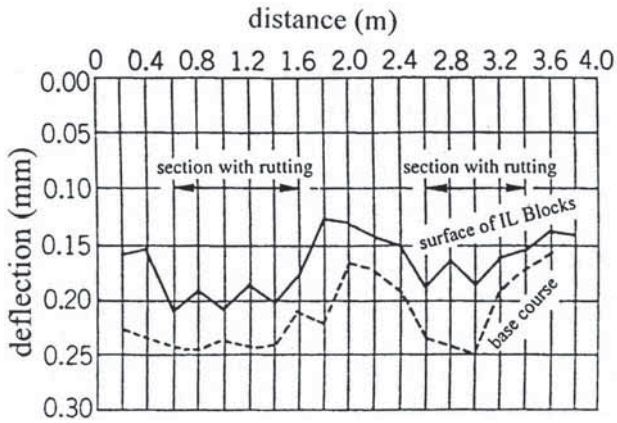

Figure 7 Deflection profile measured by HFWD

4.3 Difference in Bearing Capacity Along a Transverse Line

On roadway with traffic volume B (traffic volume of large vehicles: 250 - 999 / day - direction) where rutting occurred, deflection was measured along longitudinal and transverse lines at intervals of 11 cm (corresponding to the shorter side of the IL block). A three-dimensional graph representing the results of the deflection measurement (Figure 8) shows that the deflection becomes larger in the order of rutted section, non-rutted section, upheaved section and center of upheaved section. The relatively larger deflection in the upheaved section is attributed to the large increase in the joint width, which resulted in the loss of joint sand.

It was confirmed that in places where IL block pavement becomes rutted, thereby causing

subsidence and upheaval, there is a substantial difference in bearing capacity in the transverse direction.

On a roadway with traffic volume A (traffic volume of large vehicles: 100 - 249 / day - direction) where rutting occurred, deflection was measured along longitudinal and transverse lines at intervals of 11 cm (corresponding to the shorter side of the IL block). The results are shown as a three-dimensional graph (Figure 9), in which deflection in the rutted section exceeds that in the non-rutted section. Toward identifying the cause of the rutting, blocks and bedding sand were removed, revealing geotextile 7 mm in thickness under the bedding sand layer. The base course had not been deformed. Thus, the rutting was thought to have been caused by excessive thickness of the geotextile, which had caused repeated deflection in the rutted section - deflection that was amplified and that resulted in the deformation of the bedding sand layer.

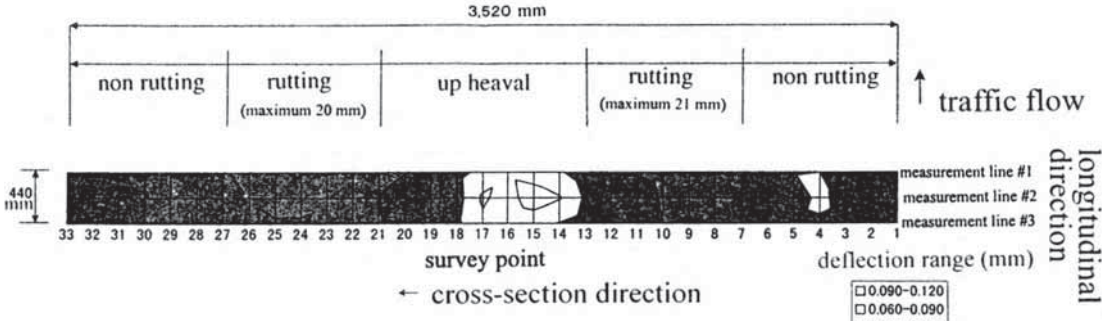

Figure 8 Three-dimensional graph of deflection (1)

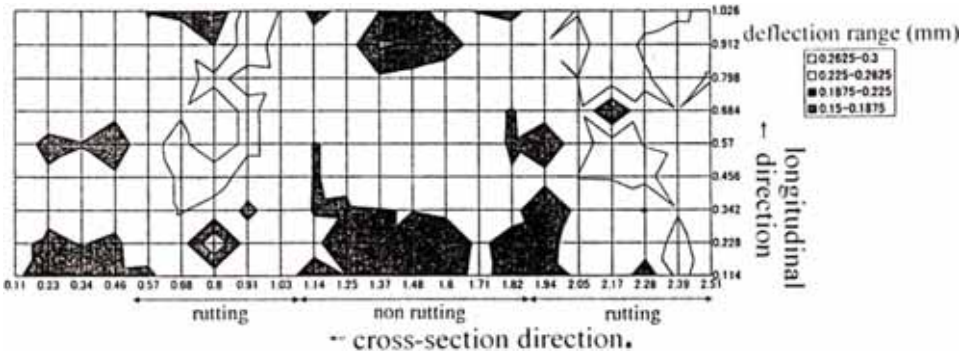

Figure 9 Three-dimensional graph of deflection (2)

Based on the above, it was established that deflection trends for rutted sections and those for non-rutted sections for rutting on IL block pavement caused by deformation of base course are reversed when the rutting results from the characteristics of the leveling layer. Reliability should be improved by accumulation of additional data.

4.4 Calculation of Deflection Ratio

Deflection was compared between IL block pavement of different structures as well as between undamaged and damaged pavement sections (with rutting, movement, etc.). A

sensor (D_0) was placed in the center of randomly chosen block while another sensor (D_1) was placed in the center of one of the six blocks surrounding that block. In a similar manner, with D_1 fixed, a third sensor (D_2) was placed in the center of one of the 12 blocks surrounding the six blocks, and a fourth sensor (D_3) was placed in the center of one of the 18 blocks surrounding the 12 blocks. These sensors measured deflection at each location (Figure 10).

The values of deflection at the sensor locations (D_0 to D_3) and the deflection ratio calculated by Equation (1) were obtained.

$$\text{Deflection ratio} = \frac{Dx}{Do} \times Do \qquad (1)$$

where, D_x is average value of deflection for D_1 to D_3 (mm) and D_0 is average value at D_0 (mm).

Table 2 Deflection measurement locations

name	location
D_0	deflection immediate beneath the loading point
D_1	deflection of six blocks around D_0
D_2	deflection of 12 blocks around D_1
D_3	deflection of 18 blocks around D_2

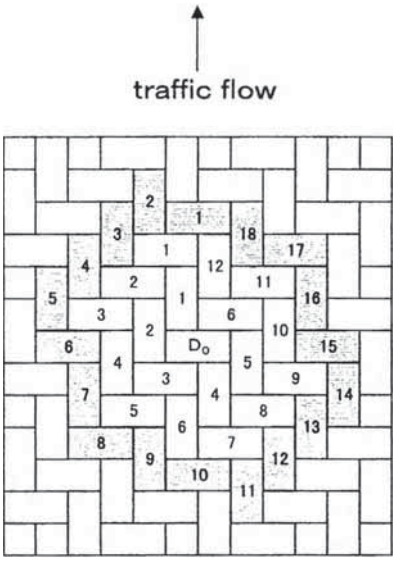

Figure 10 Deflection measurement locations

4.4.1 Deflection Comparison Between Different Pavement Structures

Figures 11 and 12 show the results of deflection measurement on IL blocks with granular base and cement treated base (CTB) that were laid on a roadway (traffic volume of large vehicles: 100 - 249 / day - direction).

As shown in these figures, the deflection on CTB was 0.043 mm which is less than half the deflection on the granular base course (D_0) of 0.103 mm. Also, the CTB had a higher deflection rate than the granular base course at every measurement location, and it had a lower rate of decline. This could indicate that IL block pavement with a rigid base course would achieve greater interlocking effect of the blocks under traffic load, which would yield greater load distribution.

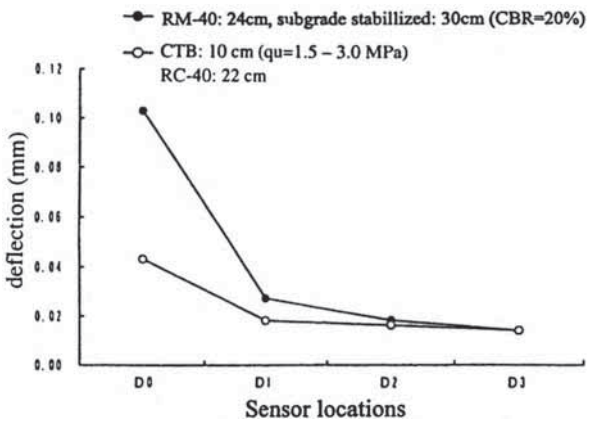

Figure 11 Deflection comparison

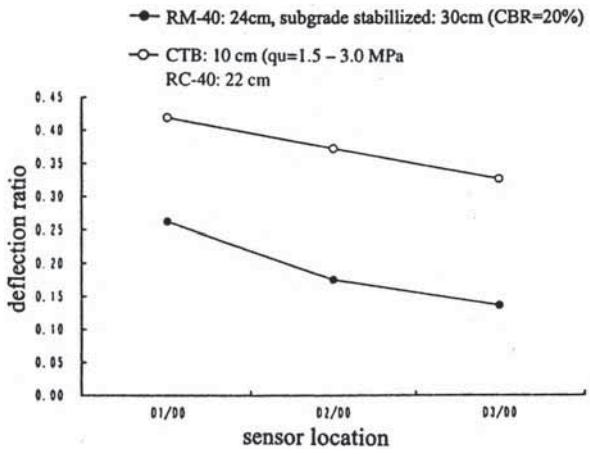

Figure 12 Comparison of deflection ratio

4.4.2 Comparison Between Damaged and Undamaged Sections

Figures 13 and 14 show the results of deflection measurement on IL block sections without rutting as well as on those with rutting, widened joints and the resultant partial loss of joint sand, for blocks laid at a bus bay (traffic volume of large vehicles: < 250 / day - direction). According to the figures, deflection of the damaged sections is 0.25 mm, which is 1.5 times the deflection measured on the undamaged sections (D_0) of 0.166 mm. In contrast, the deflection ratio measured on the undamaged sections is about 1.3 times that on the damaged sections. This may indicate a loss of bearing capacity of the pavement in the damaged sections. Load transfer through IL block pavement results from the propagation of horizontal force between the blocks through dilatancy of joint sand. The measurement results indicate that deflection ratio will decrease as rutting and joint width grow and joint sand is lost from use of the pavement.

5. WORK EXECUTION CONTROL OF IL BLOCK PAVEMENT

The Japan Interlocking Block Pavement Engineering Association, Inc. (JIPEA) is revising its roadway pavement manual. In the revised edition, the deflection value required to prevent the accumulated plastic deformation of base course will be set at 0.8 mm or less at the upper base course (a wheel load conversion of 50 KN) for roadways of traffic volume

class III (traffic volume of large vehicles: 250 / day - direction) or above.

In light of this, the HFWD deflection on the upper base course that would correspond to 0.8 mm deflection as measured by FWD was estimated, using an equation developed by Kasahara et al. to correlate HFWD measurements of asphalt pavements of different structure with FWD measurements of such pavements.

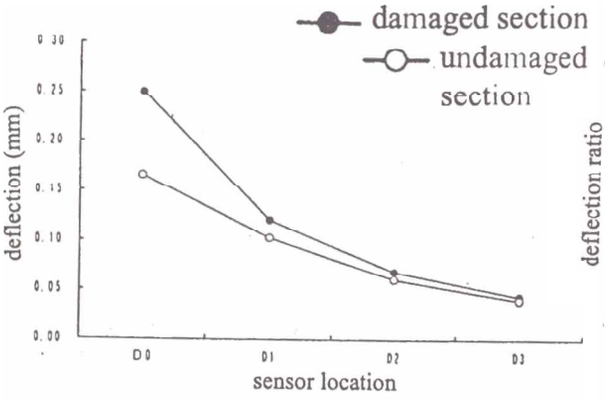

Figure 13 Deflection amount comparison

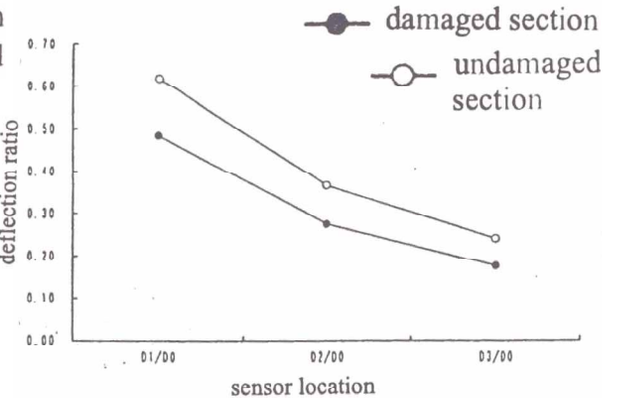

Figure 14 Deflection ratio comparison

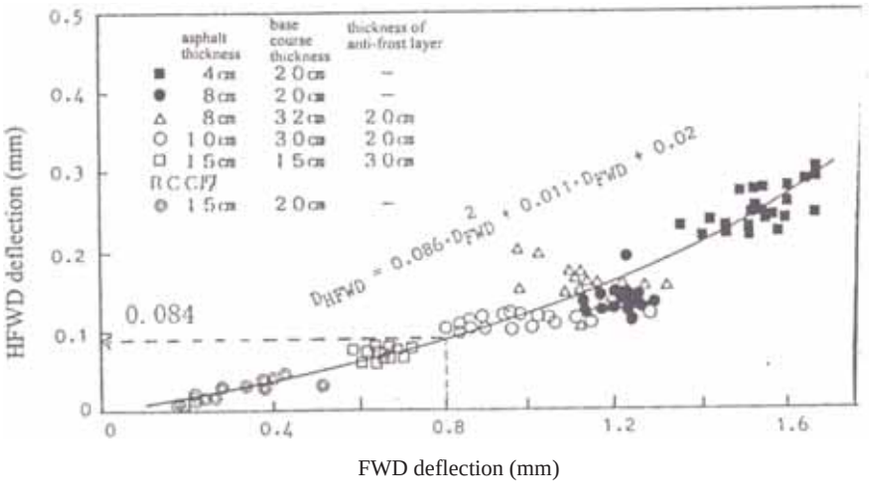

Figure 15 Correlation between FWD and HFWD deflection at wheel load of 50 KN

$$D_{HFWD} = 0.086 \times D_{FWD}^{2} + 0.011 \times D_{FWD} + 0.02 \qquad (2)$$

From Equation (2),

$$D_{11FWD} = 0.086 \times 0.8^2 + 0.011 \times 0.8 + 0.02$$

$$= 0.084 \text{ (mm)}$$

is obtained.

6. SUMMARY

The findings are summarized as follows.

(1) The deflection values measured by HFWD and by Benkelman beam have a linear approximation, with a high correlation coefficient of 0.93.

(2) It is possible to locate the boundary between pavement of different structures by observing profiles of measured deflection.

(3) In those sections of IL block pavement that have suffered damage including rutting, it is possible to identify the difference in damage of the pavement and of those layers of and below the base course in the transverse direction.

(4) Where IL block pavement has become rutted, bearing capacity differs transversely. In such places, rutted and non-rutted sections have reversed deflection patterns depending on the reason for the difference in bearing capacity.

(5) Deflection ratio is effective as a tool for comparing pavement of different structures as well as for comparing damaged and undamaged sections.

(6) For roadways of Traffic Volume Class III or above, the HFWD deflection on the upper base course that would correspond to deflection of 0.8 mm or less as measured by FWD (based on 50 KN) is 0.084 mm or less.

7. CONCLUSION

This study confirmed that HFWD is an effective tool for evaluating the bearing capacity of pavement material with multiple joints, such as IL block pavement, and that HFWD facilitates efficient management of work execution.

Reliability requires improvement by accumulation of additional data. In addition, confirmation will be made on joint sand, width of joint, effect of rolling compaction during construction, and other factors; and review will be made on the applicability of HFWD to decisions on the need for maintenance and repair.

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