EFFECTS OF BLOCK DIMENSION ON STRUCTURAL PERFORMANCE OF BLOCK PAVEMENT FOR ROADWAYS

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ABSTRUCT

In block pavement for roadways, only a block with a size of 10x20cm is usually used. However, block dimension and shape should be determined in terms of structural integrity and improvement of environmental scenery of road. The aim of this study is to examine the applicability of relatively large size blocks to roadway pavements based on the experimental results obtained by using a traffic load simulator which simulates moving wheel on pavement. In this study, the effects of size and thickness of block and type of base course on deflection and stress of pavement was investigated. Furthermore, the experimental results were confirmed by simulations using a finite element model.

1. INTRODUCTION

The block pavement which is supposed to improve scenery of road is widely used in open spaces, parks, sidewalks or light traffic roads. The blocks with a size of 10 by 10 cm to 60 by 60 cm are adopted from the viewpoint of surface design. For roadways, large size block has been used from the demand of improving environmental scenery of road these days. However, based on the experiential consideration on bearing capacity, only a block with a size of 10 by 20 cm is usually adopted for roadways. [1,2)]

The purpose of this study is to examine the applicability of large size block for roadways, since block pavement with the large size block is expected to have high bearing capacity. For this purpose, an accelerated loading experiment was carried out using a wheel load simulator. In the experiment, several block pavements with different size and thickness blocks were constructed. The effects of block dimension and base course type on structural performance of block pavement were investigated by measuring deflections, strains and amount of lift up of block. Furthermore, the experimental results were examined theoretically by finite element simulation.

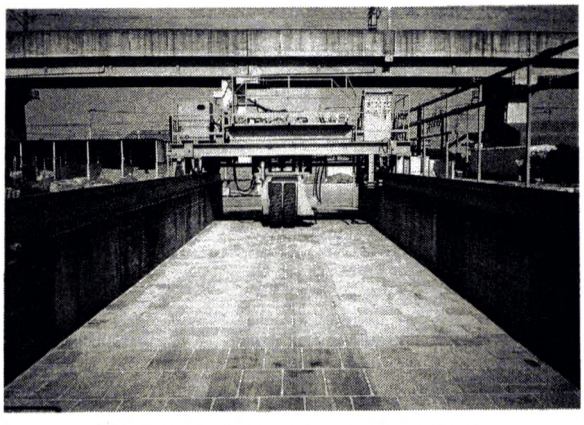
2. STRUCTURAL EVALUATION BY EXPERIMENT

In this chapter, the effects of block dimension and base course type on pavement performance were examined by measuring deflection, strain and amount of lift-up of block in test pavements under a wheel load.

2.1 Outline of Experiment

(1) Experiment Equipment

The experiment was performed using a road



Photograph 1 Road Simulator

simulator as shown in Photograph 1, which is able to create an repeated loading condition by moving a wheel load back and forth in a certain distance over the test pavements.

(2) Test Pavement Structures

Block sizes used in the experiment are shown in Table 1. The block length varied 10 to 60 cm, its width 20 to 60 cm and its thickness 8 to 12 cm. The laying pattern of block in the experiment was the stretcher-bond type. Three types of base course were constructed being made of an asphalt stabilized material and a crushed stone for mechanical stabilization with different thickness over a subgrade of design CBR=3. The base course reaction moduli (K-value or K30) were obtained by the plate loading test as 1.5N/mm^3, 2.0N/mm^3, and 2.5N/mm^3 for these type of base course, respectively. Thickness of a sand cushion layer was 2cm, and width of joint between blocks was 2mm as shown in Figure 1.

Table 1 Block Size Used in the Experiment

Length (cm)		Aspect Ratio	Area (cm^2)
Short Side	Long Side		
10	20	0.5	200
15	30	0.5	450
20	30	0.7	600
30	30	1.0	900
22.5	45	0.5	1013
30	45	0.7	1350
45	45	1.0	2025
30	60	0.5	1800
40	60	0.7	2400
60	60	1.0	3600

Note: Aspect ratio is defined as a ratio of the short side length to the long side length of a block

(3) Loading Condition

Double tires with a total width of 120 cm and a total amount of load of 5tf moved over the pavement along the centerline of the pavement with a lateral wandering range of 60cm. The maximum number of loading repetitions was 7000 times which is equivalent to the light traffic in the pavement design in Japan.

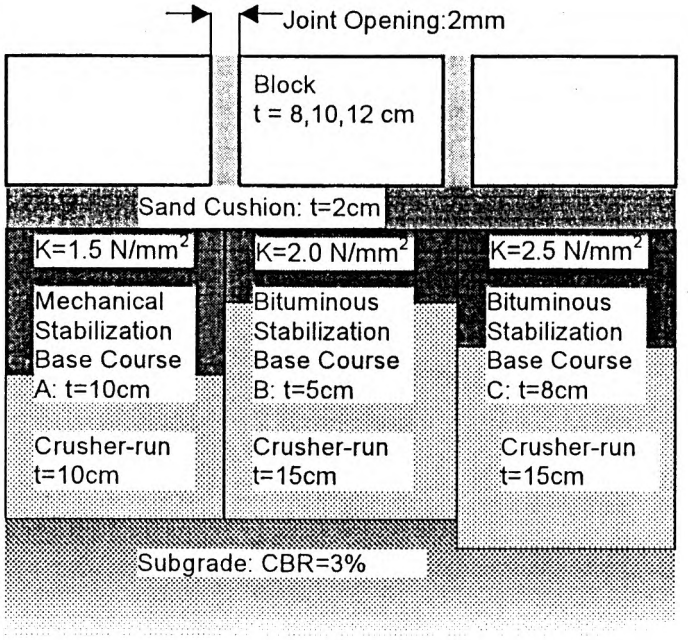


Figure 1 Pavement Structure

Table 2 Evaluation Items and Measuring Methods

Item	Measuring Method	Note
K-value on Base Course	Plate Loading Test	30cm Diameter Plate
Strain	Static Loading Test	Strain Gauge at Block Bottom, 7tf Wheel Load
Rut depth	Profilometer	Measured at 0, 100, 1000, and 7000 Repetitions with 5tf Wheel Load
Deflection	Benkelman Beam	
Lift up	Benkelman Beam	

(4) Measurement

Evaluation items and measuring methods are shown in Table 2 and Figure 2. Block pavement is required to avoid excessive lift up, faulting and unevenness due to the lack of the interlocking between the blocks during a design period. And the blocks should not break under the repeated loads. Therefore, at every certain load repetitions, we measured amounts of vertical movements at the opposite side of a block to the loading position (hereafter called as the lift up). The lift up was measured at the sides of the block in the traffic direction and in transverse direction as shown in Figure 2. Also, loading strains at the bottom surface of the block were measured. In this test, a load of 7 tf was statically applied at the center of the pavement From the measured strains, stresses of the block were estimated. The elastic moduli of concrete block used in the stress estimation were obtained from the laboratory test as 39.4 kN/mm^2 and 31.0 kN/mm^2 for the concrete block made by instant demolding and for the block made

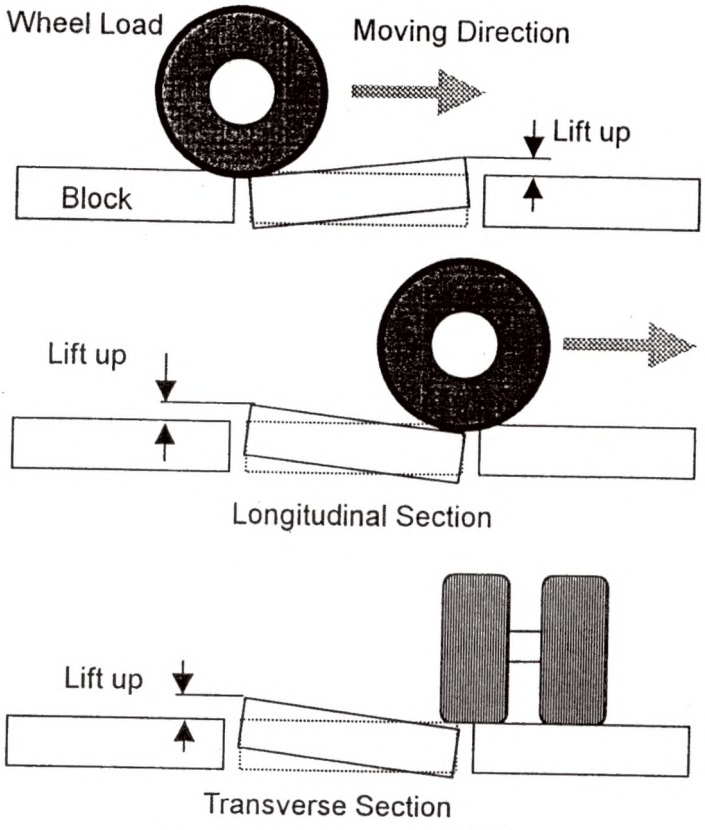


Figure 2 Measurement of Lift up

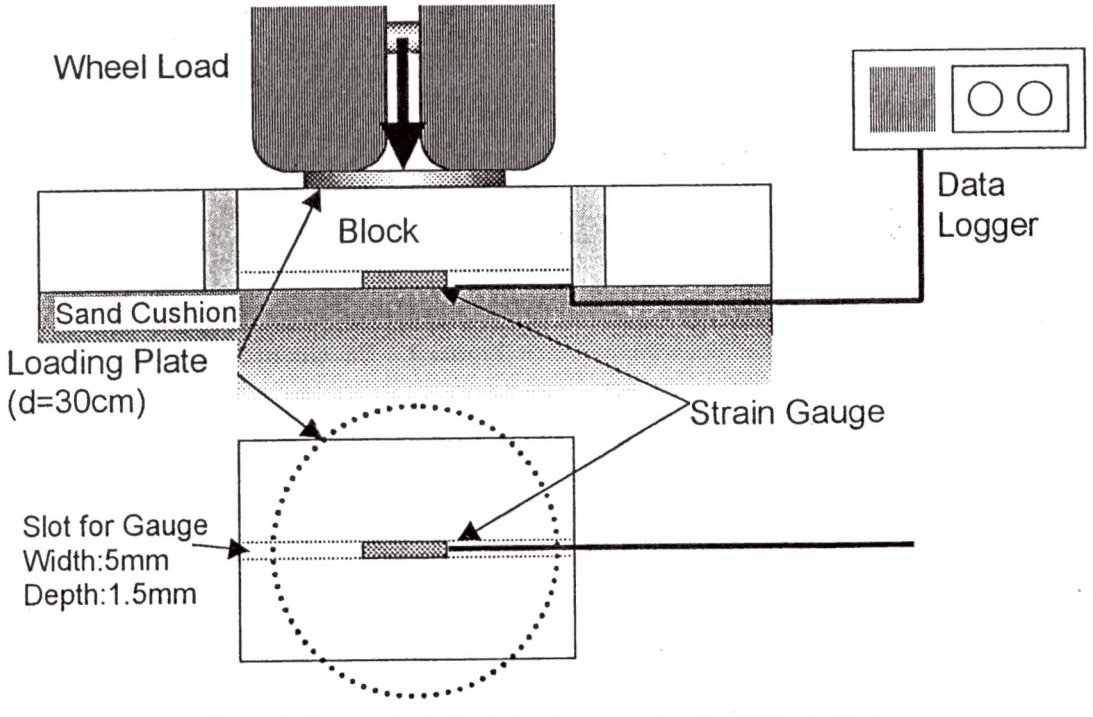


Figure 3 Strain Measurement under Static Loading

from casting concrete, respectively.

2.2 Experimental Results

Figure 4 shows the relationship between the number of load repetitions and the amounts of lift up and rutting. As the number of load repetition increased, the sand in the joints disappeared, resulting in pumping, and the amounts of rutting and lift up also increased. When K-value was 2.5 N/mm^3, amounts of rutting and lift up were very small.

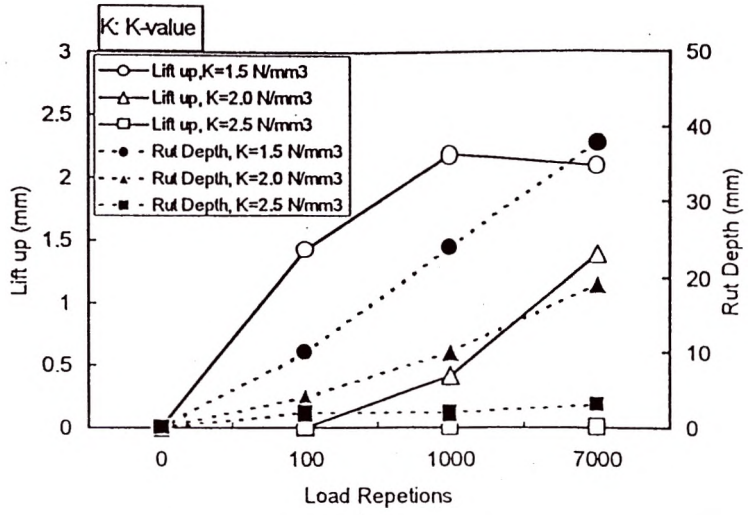


Figure 4 Relationship between the Number of Load Repetitions and Amounts of Lift up and Rut Depth (Block Size: 30cm by 45 cm, Block Thickness: 8cm)

Figure 5 shows the relationship between the K-value and the amount of lift up of a 30 by 45 cm size block at 7000 load repetitions. Increasing the thickness of the block from 8 to 12 cm and K-value from 1.5 to 2.5 N/mm^3 significantly reduced the lift up.

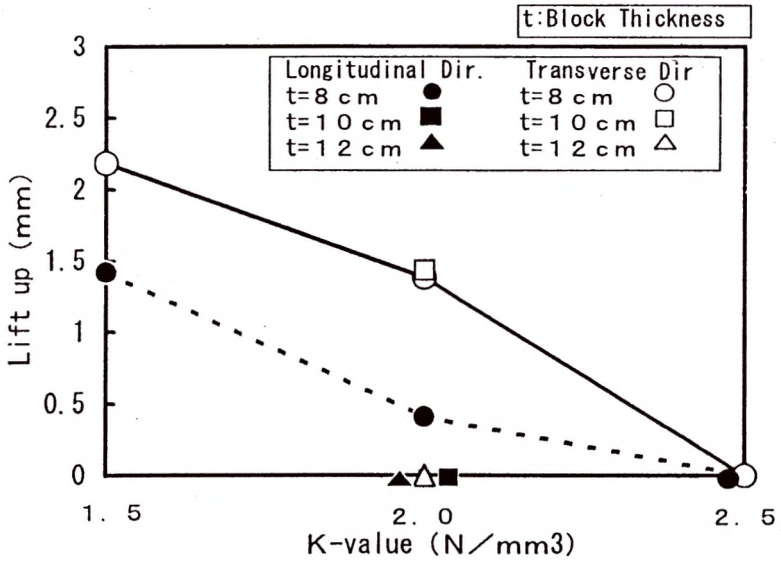


Figure 5 Relationship between K-value and Lift up (Block Size: 30cm by 45 cm, Block Thickness: 8cm)

Figure 6 shows the amounts of lift up of various block sizes and thicknesses with a K-value of 2.0 N/mm^3 at 7000 load repetitions. We can see the tendency where the amount of lift up increased as the block thickness decreased and the block size and aspect ratio increased. In the pavements using small blocks with a size of less than 30 cm, no lift up were observed.

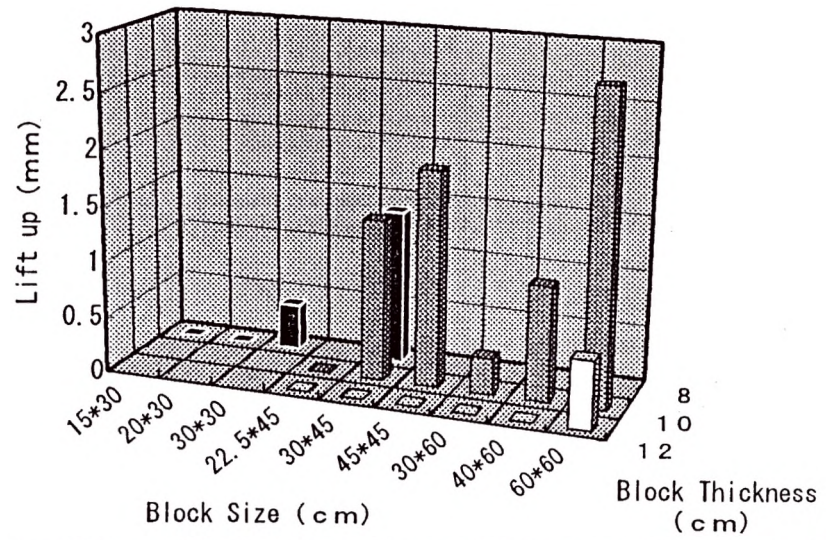


Figure 6 Amounts of Lift up of Various Block Sizes and Thicknesses (K-value = 2.0 N/mm³)

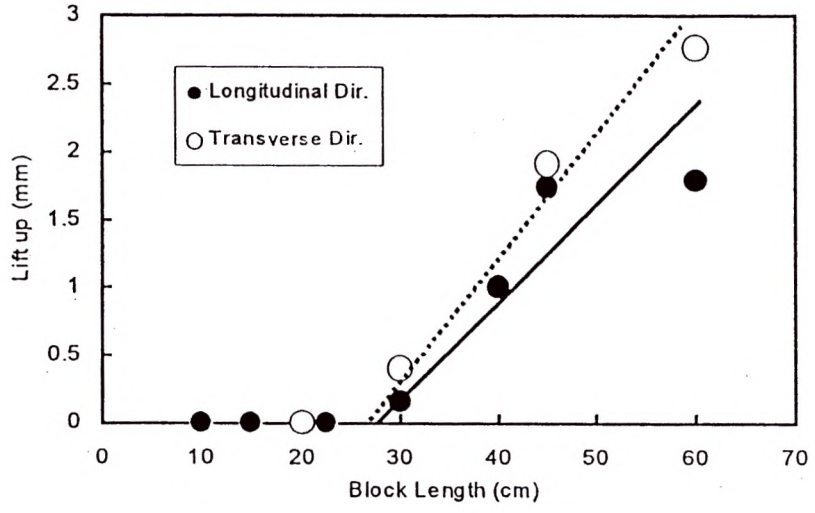


Figure 7 Relationship between Length of Block Edge and Lift up (7000 Load Repetitions, t= 8 to 12 cm, K=1.5 N/mm³)

Figure 7 shows the relationship between the amount of lift up and the block length with a K-value of 2.0 N/mm² at 7000 load repetitions. Increasing the block length increased the amount of lift up. When the block length was less than 30 cm and the block size was 10 by 20 cm, the lift up was not observed.

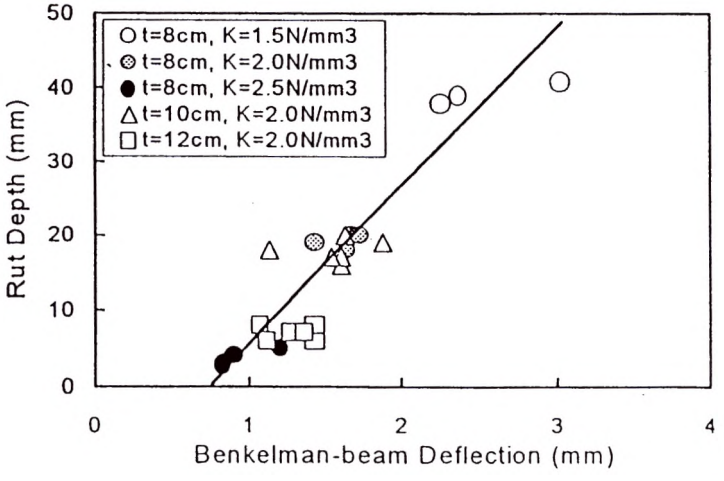


Figure 8 Relationship between Deflection and Lift up

Figure 8 shows a clear relationship between the amounts of rutting and Benkelman-beam deflection. As the

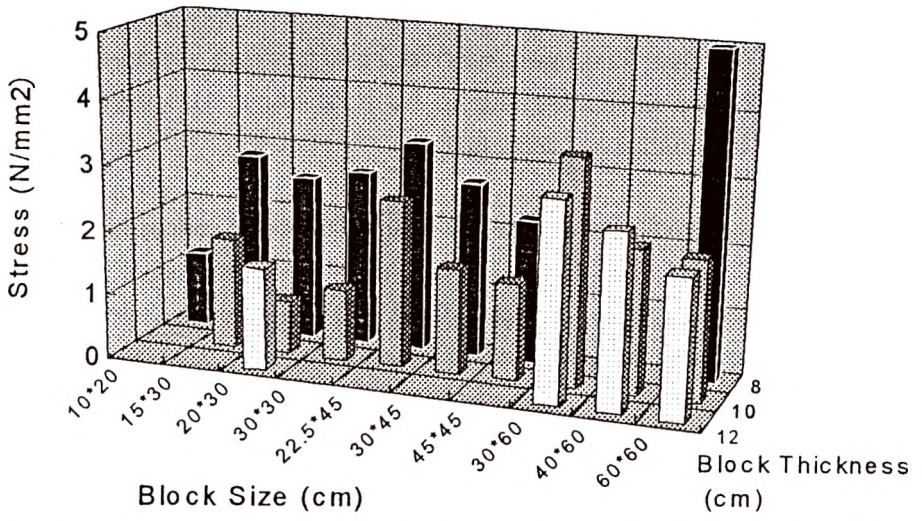


Figure 9 Loading Stresses at the Bottom Surface of Various Block Sizes and Thicknesses (Load = 5tf, K-value = 1.5 N/mm³)

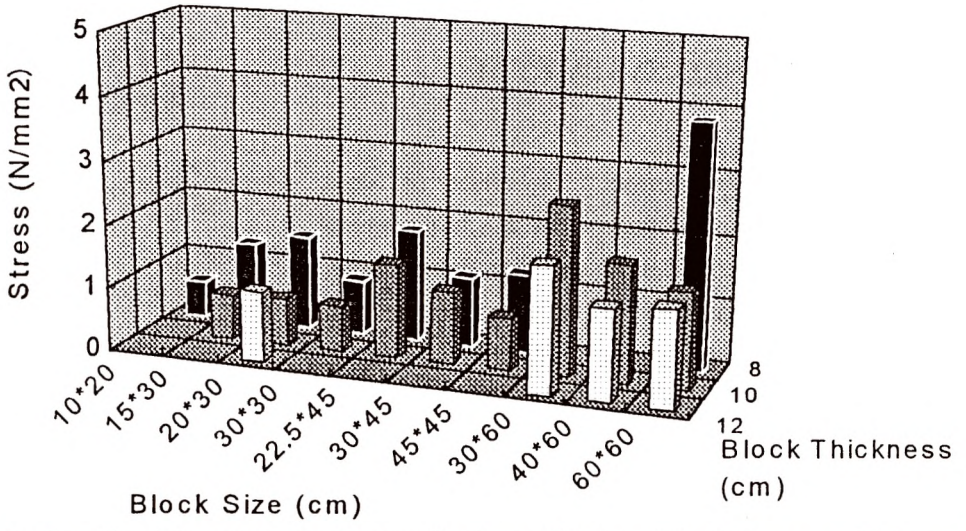


Figure 10 Loading Stresses at the Bottom Surface of Various Block Sizes and Thicknesses (Load = 5tf, K-value = 2.5 N/mm³)

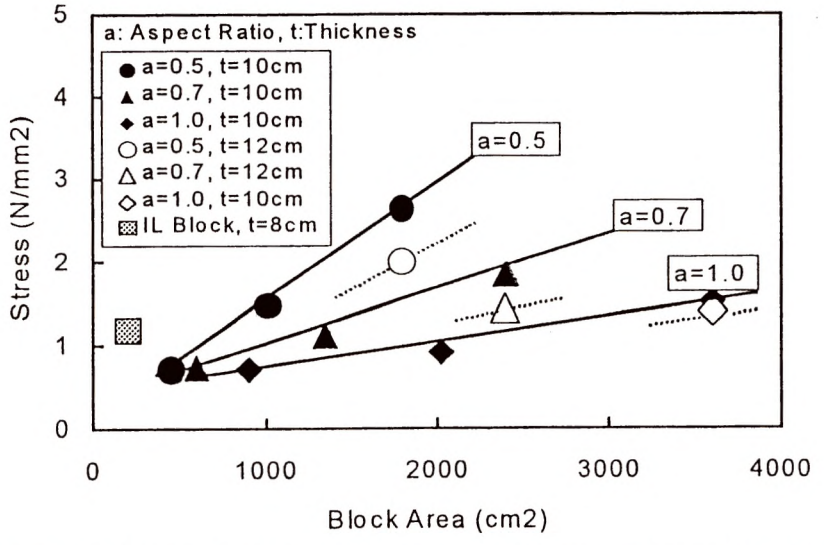


Figure 11 Relationship between Loading Stresses at the Bottom Surface and Block Surface Area (Load = 5tf, K-value = 2.5 N/mm³)

deflection decreased, the rutting also decreased. It can be seen that when deflection is less than 1.0 mm, very small rutting of less than 5 mm was observed. From the result, we can say that, in order to avoid excessive rutting, deflection should be limited to 1.0 in the design. Also, increasing the block thickness and K-value reduced both rutting and deflection.

Figures 9 and 10 show bending stresses at the bottom surface of various block sizes and thicknesses with K-values of 1.5 N/mm^3 and 2.5 N/mm^3, respectively, under the load of 5tf. The stresses decreased as K-value and the block thickness increased or the block edge length decreased. The stress reduction was also achieved by making the aspect ratio of the block close to 1.0.

Figure 11 shows the relationship between the block surface area and the block stress. If you want to limit the loading stress of 60 by 60 cm size block to the same level as that of the normal 10 by 20 cm size block, K-value of 2.5 N/mm^2 and the block thickness of 12 cm should be employed

3.THEORETICAL ANALYSYS BY F.E.M.

3.1 FEM model

In order to analytically examine the effect of block dimensions on stress and deflection of block pavement, FEM analysis was performed using the plate finite element model on Winkler foundation[3]. In this model, the joint between the blocks is modeled by a joint element with three springs: shear, bending and torsion, which represent the load transfer across the joint. Figure 12 shows an example of FEM mesh for a block pavement. Pavement area was

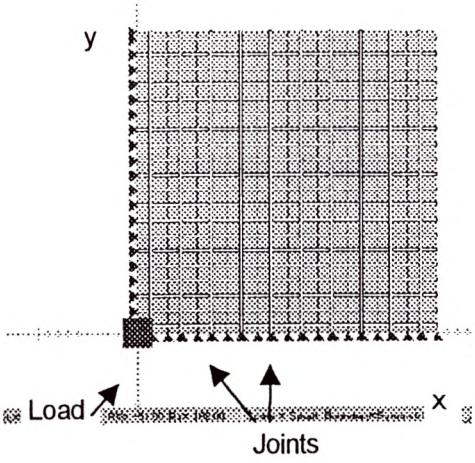


Figure 12 An Example of Mesh for a Block Pavement

Table 3 Determined Parameters

	Base Course A	Base Course B
K-value (N/mm^3)	1.5	3.0
Shear Spring Constant (N/mm^2)	10.0	
Bending Spring Constant (N/mm)	500.0	

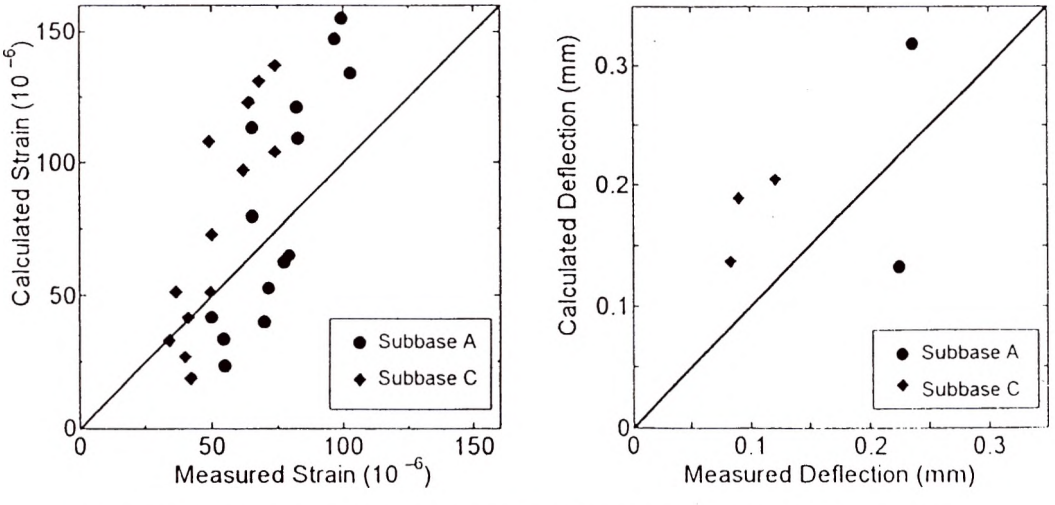


Figure 13 Comparisons between Measured and Computed Responses

assumed as 6m by 6m and a rectangular load was applied at the center of the area. The essential point to apply this model to block pavements is to determine the values of the spring constants as well as the modulus of subbase reaction (K-value). In this study, these values were determined by comparing computed strains and deflections with those measured in the experiment. The determined values are presented in Table 3.

Although, in reality, these values might be different if block dimension and laying pattern are different, the values of spring constants are assumed to be the same for all types of block pavements in this study. Other input data were assumed as follows: elastic modulus of block was 35 kN/mm^2 and Poisson ratio of block 0.2. Using the values, strains and deflections were computed by the FEM model and compared with the measured ones as shown in Figure 13. The computed strains are larger than the measured ones in the range of large strain. As for deflection, difference between computed and measured ones is more significant. These discrepancies might be caused by the measurement errors and the assumption of using the same spring constant for all types of block. In spite of these errors, we used these values in the following calculations. We thought that it was enough for qualitative examination on the effects of base course type and block dimension.

3.2 Effects of Design Parameters

Stress and deflection of block pavements are affected by block dimension and base course type. In this section, the effects of K-value, block thickness and shape on stress and deflection of block pavement were investigated based on the FEM simulations. All blocks used in the simulation had rectangular shape and their sizes were 15cm by 30cm, 20cm by 30cm, 30cm by 30cm, 30cm by 60cm, 40cm by 60cm and 60cm by 60cm. K-value varied as 1.0, 2.0, and 3.0 N/mm^3. Block thickness of 8, 10 and 12cm were used. A rectangular load of 7 tf was applied at the center of pavement with 6m by 6m area. Meshes for this simulation were the same as shown in Figure 12. Also, the values of the spring constants for joint in Table 3 were used. Maximum bending stress at the bottom of block and deflection was calculated by the FEM model.

Figure 14 shows effects of K-value on bending stress and deflection at the center of block pavement.

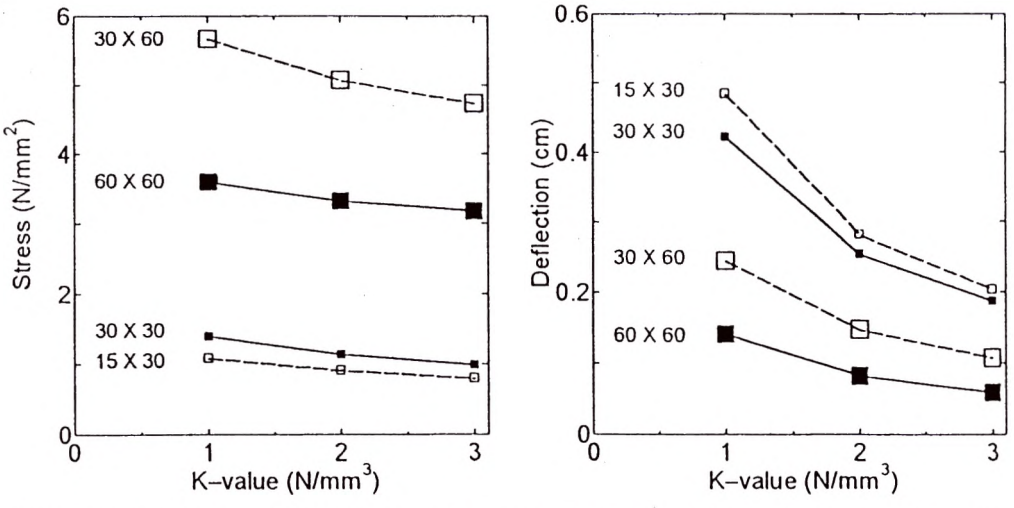


Figure 14 Effects of K-value on Stress and Deflection (Block Thickness=12cm)

The stress and the deflection decrease as K-value increases. The degree of decrease is more significant in the deflection than in the stress. From the results, it can be said that, in order to reduce the pavement deflection, strengthening base course is much effective measure. If the K-value is constant, the stress of large size block is much greater than that of small size block, whereas the deflection of large size block is much smaller than that of the small size block. Since the experimental results suggested that the deflection of more than 1.0mm leads to large lift up and rut depth, the deflection of small size block which exceeds 1.0 mm is not satisfactory for design alternative, even if the stress of the small block is much small.

3.3 Effect of thickness of block

Figure 15 shows effects of block thickness on stress and deflection. The block thickness has much effect on the stress, whereas it has very little effect on the pavement deflection. Thus, in order to reduce the stress of the block, increasing the block thickness may be a good measure.

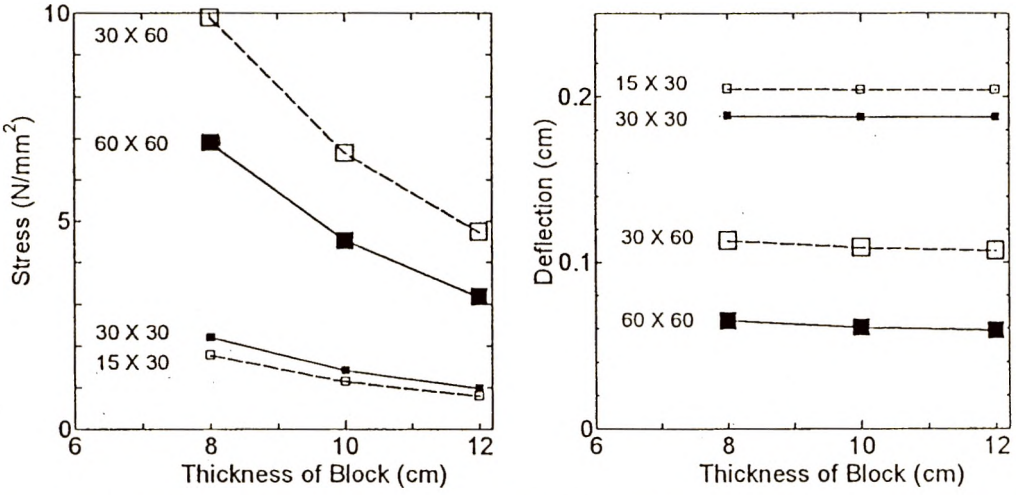


Figure 15 Effects of Block Thickness on Stress and Deflection (K-value=3.0 N/mm³)

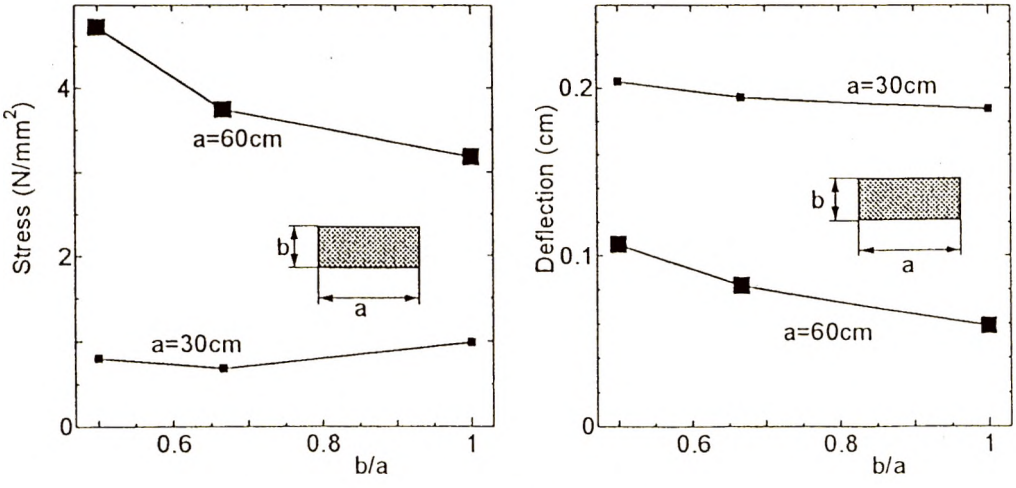


Figure 16 Effects of Aspect Ratio on Stress and Deflection (Block Thickness=12 cm, K-value=3.0 N/mm³)

Figure 16 shows effects of aspect ration of block on stress and deflection. In the case of small size block (a = 30 cm), the stress of the block with aspect ratio of 0.5 and 0.66 is a little less than that of 1.0. This is because the loaded area is larger than one block area and thus the amount of the load applied to the block is smaller than the total load. In case of large block (a = 60 cm), on other hand, the aspect ratio affects both the stress and the deflection. When the aspect ratio is 1.0 (square shape block), the stress and deflection become the smallest. This is corresponding with the results of the experiment. Again, the deflections of small size block are more than 1.0 mm for all range of the aspect ratio. Therefore, square block with large size might be the best choice for the design of the block pavement.

4. CONCLUSION

From the results of the experiment carried out on the test pavements in order to examine the structural performance of the block pavement, the following conclusions can be drawn:

1. In order to avoid excessive lift up and rut depth, increasing K-value of base course and block thickness is necessary. Moreover, a good road surface condition can be maintained by controlling the deflection to 0.5mm to 1.0mm.
2. In order to reduce the block stress at the bottom surface, it is effective to increase the K-value and the block thickness and to make the block square shape.
3. If the block stress with a large size is required to be limited to the same level as the normal block, it is needed to use a base course with a K-value of more than 2.5 N/mm^3 and a square shape block with the thickness of 12 cm or more.

From the results of FEM analysis of the block pavement, the following remarks can be made:

1. It is effective for reducing deflection and stress at the bottom surface to increase the K-value of base course.
2. Although it is effective to increase block thickness for reducing stress, it is rather small impact on deflection.
3. In the case of large size block, the aspect ratio of 1.0 (square block) is the best shape to reduce stress.
4. If it is required that deflection is limited to 1.0 mm or less as the experimental results suggested, a 60 by 60 cm size block with a thickness of 12 cm might be the best choice.

We constructed another similar type block pavements based on the results mentioned above and their performances have been observed. These pavements remains in very sound surface condition four years after the construction.

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