DEVELOPEMENT OF A STANDARD FOR BLOCK DIMENSIONS FOR USE UNDER JAPANESE CONDITIONS

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ABSTRACT

Although almost 30 years has passed since the introduction of the IL block into Japan, no technical standards have been established for its shapes or dimensions. The reason is that little basic research has been conducted on its dimensions and interlocking effects. This paper describes a study of the effects of block dimension on bearing capacity as a means of developing a standard for block dimensions for adoption in Japan. The study involved the measurement of the deflection of IL blocks using the handy falling-weight deflectometer (HFWD), a portable FWD developed in Japan in 1993.

It was found that the relationship between IL block dimension and interlocking effect was related to the total side area divided by the top area and on the load transfer efficiency (E_{LT}). Also, it was possible to produce objective indices of load transfer efficiency of rectangular and non-rectangular blocks. The identification of block dimensions whose values of load transfer efficiency were equal led to the development of a relationship between block shape and bearing capacity.

As a result of this study, Standards for IL block dimensions for use in Japan are proposed for various traffic loads.

1. INTRODUCTION

The manufacturing technology of interlocking blocks (IL blocks) was introduced into Japan from West Germany in 1974. Since then the use of IL block pavement has become widespread, primarily in pedestrian paths. It is also employed where heavy loads act, such as on roadways and at airports and harbors. As of 2001, the annual installation area of IL blocks was 8 million m^2, and the total area in service exceeded 100 million m^2. Almost 30 years has passed since the introduction of the IL block, but no technical standards have been established for its shapes or dimensions in Japan. The reason is that little basic research has been conducted on its dimensions and interlocking effects.

This paper describes a study involving the measurement of the deflection of IL blocks using the handy falling-weight deflectometer[1)] (HFWD), a portable FWD developed in Japan in 1993. The HFWD is used to assess the bearing capacity of asphalt pavement[2)] and the strength of the soil subbase for railways. This study examined an issue fundamental to IL block design: the effects of block dimension on bearing capacity. Based on this, standardization of the block dimensions was studied.

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2. DESCRIPTION OF HFWD

The HFWD is a proven, portable diagnostic percussion device. Technicians often carry it in the field to obtain information on pavement.

HFWD has the following features:

- Its weight of only 22 kg makes it easy to carry.
- It takes only 1 second for it to measure one point, enabling the user to gather large volumes of data in a short time.
- Measurement of base course deflection is possible by removing only one block (100 mm x 200 mm).
- Measurement can be taken in relatively restricted spaces.
- It is possible to examine the degree of compaction of subgrade and base course material in the field.

The device consists of a falling weight and a measuring section. Measurement is made by free fall of an 8-kg weight, which imparts an impact load of 2.9 kN to 4.9 kN to the pavement. The device is capable of simultaneously measuring the deflection at two points, one immediately beneath the impact and where the measured deflection will be larger than 0.01mm.

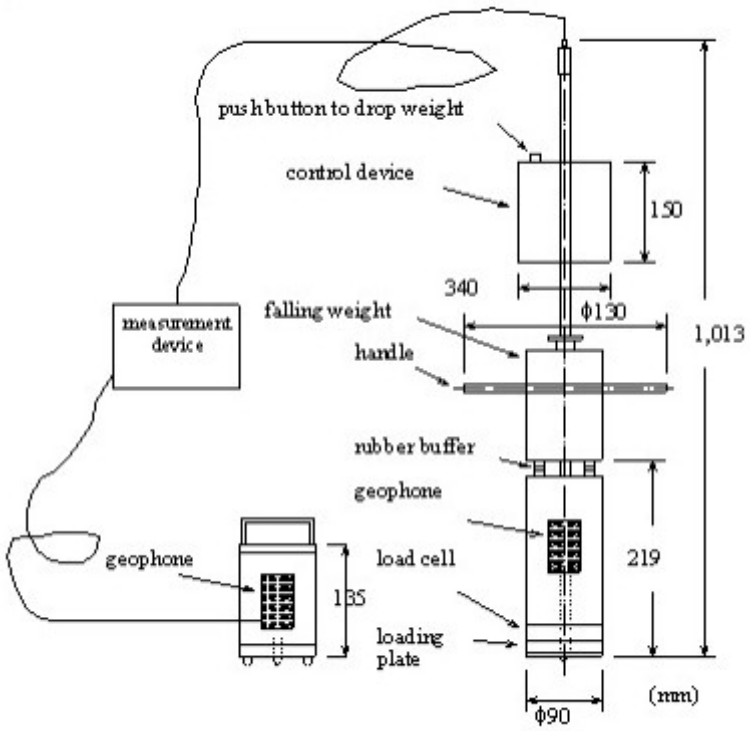


Figure 1. External view of HFWD.

Table 1. Specifications of HFWD.

Total weight	22 kg
Weight	8 kg
Loading plate diameter	90 mm
Max. drop height	800 mm
Loading period	5-30 msec
Load	0-5.0 kN
Deflection measurement range	0-2 mm
Deflection resolution	0.002 mm

A schematic drawing of the HFWD is shown in Figure 1, whilst Table 1 shows the related specification.

3. IL BLOCK DIMENSION SPECIFICATIONS

According to Design and Construction Manual for Interlocking Block Pavement[3)] of the Japan Interlocking Block Pavement Engineering Association (July 2000), an IL block pavement is defined in Japan as a "pavement in which small concrete blocks are placed on bedding sand such that they interlock, with joint sand in between." However, this definition does not clearly specify shape or dimension. Houben[4)] reported that, by 1984, specifications and standards for block dimensions had been established in 15 countries. Parameters addressed included block dimensions (length, width, thickness), top area, ratio of thickness to length, and ratio of length to width. Table 2 shows that 15 countries specify standard dimensions, with 13 countries clearly specifying the dimensions. Also, 7 countries, about half the number of the countries listed in the Table, specify top area or ratio of dimensions, in addition to dimensions.

Table 2. Specifications or recommendations for concrete blocks.

Specification	Number of countries	Countries
Dimensions	6	Canada, Finland, Germany, Israel, The Netherlands, USA
Top areas	1	Australia
Dimensions ratio	1	Austria
Dimensions and top areas	4	Belgium, Denmark, Italy, Norway
Dimensions and dimensions ratio	3	France, New Zealand, United Kingdom

Table 3 depicts the standard dimensions in the U.S., Germany, and the U.K. The U.S., in ASTM[5)], specifies the standard for top area and the standard ratio of length to width. Germany, in Der Einsatz von Betonplastersteinen in der Dundesrepublik Deutschland-planung, Bemessung, Einbau, Abnahme[6)], provides different standard aspect ratios for concrete blocks and plates. The British standard[7)] specifies the standard ratio of length to width, aspect ratio, and width more strictly than the United States and Germany and rules out blocks with very small dimensions.

Table 3. Standard dimensions of IL block in the U.S., Germany, and the U.K.

Countries	Specified or Recommended
USA	Exposed face area less than or equal to 0.065 m^2 Aspect ratio≤4.0
Germany	Aspect ratio≤4.0
United Kingdom	Length and width shall not exceed 250 mm Aspect ratio≤5.0 Width shall be not less than 50 mm at a distance of 50 mm from any edge

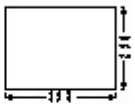
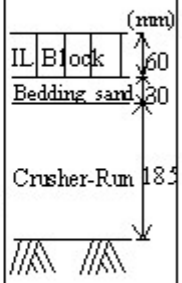
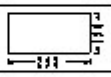
IL blocks in Japan are polygonal, e.g., rectangular, square, hexagonal, octagonal. They are rectangular or non-rectangular (Figure 2). Non-rectangular ones are generally used for roadways.

4. DETAILS OF STUDY

Five test pavements, each with rectangular and non-rectangular blocks of different dimensions, were installed at a factory in Iwamizawa, Hokkaido, for assessment of the effects of block dimensions on bearing capacity. Deflection was measured using the HFWD.

Table 4 presents details of the tested pavements. Stretcher bond (STB) and herringbone bond (HBB) are the most common installation patterns for IL block in Japan. Pavements No. 4 and No. 5, whose block dimensions are small, tend to be laid in STB or HBB patterns. Pavements No. 1 through No. 3, whose dimensions exceed those of the remaining two types, tend to be installed in STB pattern.

Table 4. Details of test pavements.

Pavement No	Laying pattern	Shape of IL block	Dimensions (mm)			Lateral total areas / Top surface areas	aspect ratio	Joint	Pavement structure
			Length	Width	Thickness				
1	Strecher bond (STB)		398	298	60	0.70	6.63	Sand	
2	〃		298	198		1.01	4.97		
3	〃		198	148		1.42	3.30		
4	Herring bone bond (HBB)		198	98		1.83	3.30		
5	〃		222	109.5		1.71	3.70		

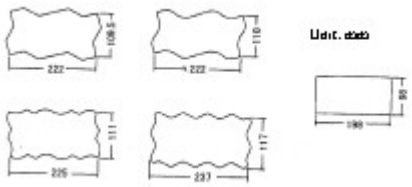


Figure 2. Common shapes of blocks installed on roadways.

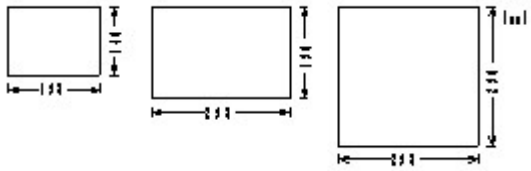
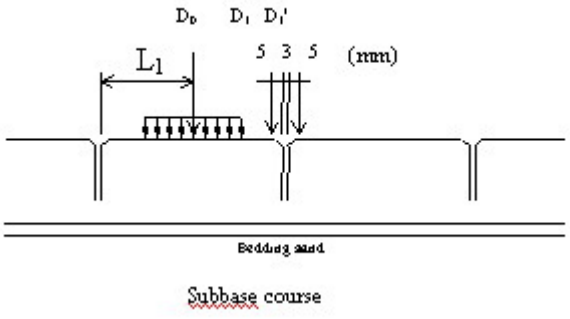


Figure 3. Shape of rectangular block.



D_0: Deflection at the center of the block
D_1: Deflection near the corner of joint and corner of intersection of the loaded block
D_1': Deflection near the corner of joint and corner of intersection of the block adjoining the loaded block
L_1: Distance from the center of loading plate to the corner of joint or corner of intersection (99 to 247 mm, depending on block shape)

Figure 4. Sensor installation points.

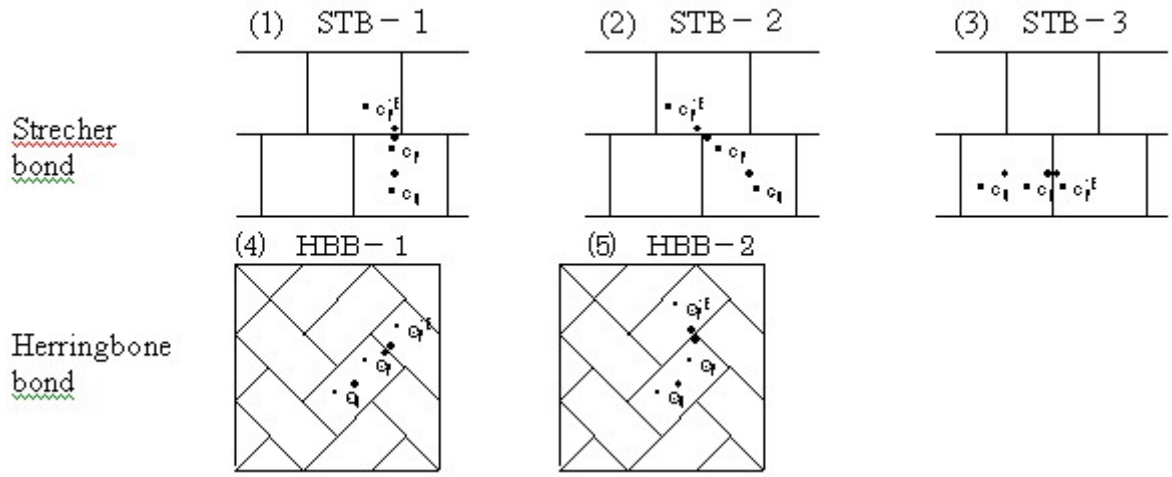


Figure 5. Pattern of deflection measurement.

4.1 Deflection Measurement Method

Figure 4 shows the deflection measurement method, which uses HFWD. The HFWD loading plate is placed at the center of the loaded block. A second sensor is placed near the joint of the same block to measure deflection there. Then the second sensor is moved to a location near the joint of an adjoining block, which is not loaded. The interlocking effect was assessed based on the ratio of deflections near the joint of the loaded block (D_1) and the deflection near the joint of the adjoining block (D_1') (Equation (1)). The closer this ratio is to 1, the greater the interlocking effect, because this means that the deflections of adjoining blocks are approximately equal. This ratio is defined as "load transfer efficiency", an index describing the relationship between block dimension and bearing capacity. Measurements were made at these three points for each block type, with the joint sand pre-compacted.

$$\text{Load transfer efficiency} = D_1/D_1' \quad (1)$$

where,

D_1: defection near the joint of the loaded block (mm), and
D_1': defection near the joint of the adjoining non-loaded block (mm)

The second sensor was installed near the corner of joint and corner of intersection in five patterns (Figure 5).

4.2 Effect of Block Dimension on Bearing Capacity

Table 5 shows load transfer efficiency calculated from the average deflection of each block type measured by the HFWD, whilst. Figure 6 compares the calculated load transfer efficiency with the ratio of the total side area divided by the top area. The pavements are indicated by number. The Figure shows that there is a good correlation between the corner of joint load transfer efficiency, and the ratio of total side area to top area. Analysis of variance of corner of joint load transfer efficiency yields a significance level of 1%. The coefficient of determination (R^2) is high and equals or exceeds 0.9. When the block is small in dimension, the number of joints is large. By placing sand in the joint and compacting it, blocks are settled and stabilized. As a result, positive dilatancy, which induces an increase in the volume of the joint sand, promotes compressive forces between the blocks in the horizontal direction. This, in turn, effectively distributes the load to adjoining blocks.

Table 5. Load transfer efficiency of IL blocks.

Pavement N_0	Dimensions for concrete block (mm)	Ratio of total side area to top area	Measurement pattern	Corner of joint load transfer efficiency	Measurement pattern	Corner of intersection load transfer efficiency
1	298x398	0.70	STB-1	0.25	STB-2	0.13
2	198x298	1.01	STB-1	0.36	STB-2	0.31
3	148x198	1.42	STB-3	0.60	STB-2	0.53
4	98x198	1.83	HBB-1	0.66	HBB-2	0.79
5	109.5x222	1.71	HBB-1	0.59	HBB-2	0.65

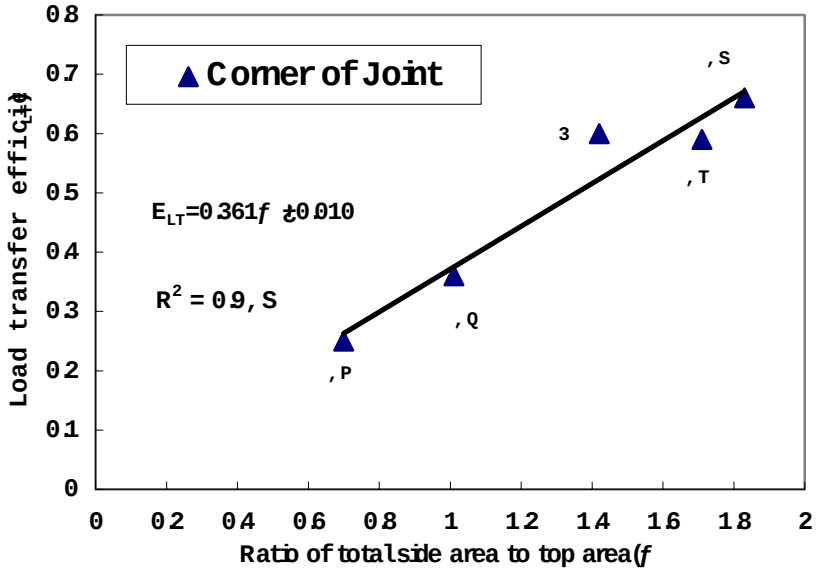


Figure 6. Load transfer efficiency of IL block.

5. STANDARDIZATION OF BLOCK DIMENSIONSES

The corner of joint load transfer efficiency can be calculated from the area ratio α: the ratio of total side area to top area. This calculation is approximated by the linear equation in Figure 6:

$$E_{LT} = 0.361\alpha + 0.010 \quad (2)$$

where,

E_{LT}: corner of joint load transfer efficiency, and
α: area ratio: the ratio of total side area to top area.

Equation (3) is used to calculate the block dimension for an arbitrary value of E_{LT}, that is obtained using Equation (2):

$$\alpha = (E_{LT}-0.010) / 0.361 \quad (3)$$

The area ratio, α, can also be calculated from Equation (4):

$$\alpha = (2 \cdot h \cdot L + 2 \cdot \beta \cdot h \cdot L)/(\beta \cdot L^2) \quad (4)$$

$(0<\beta\leq 1)$

where,

h: thickness,
L: length of the longer side, and
βL: length of the shorter side.

As in the Standards of the U.S. and Germany, Equation (5) defines the aspect ratio, r, as the length of the longer side divided by the thickness:

$$r = L/h \tag{5}$$

where,

r: aspect ratio.

Equation (5) can be transformed as follows:

$$L = r \cdot h \tag{6}$$

Substituting Equation (6) into Equation (4) yields Equation (7):

$$\alpha = 2h(1+\beta)/\beta \cdot h \cdot r \tag{7}$$

Solving Equation (7) for β yields Equation (8):

$$\beta = (-2)/(2-\alpha \cdot r) \quad (0<\beta \leq 1) \tag{8}$$

According to Figure 6, the mean corner of joint load transfer efficiency is 0.5, and its greatest value is 0.66. Tables 6 and 7 show values of IL block dimension calculated from the mean and greatest values of load transfer efficiency that were obtained using Equations (3) and (8).

β is defined to be greater than 0 and less than or equal to 1. Therefore, the value of r that corresponds to $\beta = 1$ is computed first. When β is equal to 1, the value of r is the smallest. In addition to this smallest value, other values were assigned to r for computation of the parameters in the Table. For the assignment, r was set at increments of 0.5 from 2.50 to 5.00. When r is greater than 5.0, the block dimension decreases due to an increase in thickness, and the length of the longer side increases.

Blocks having the dimensions shown in Tables 6 and 7 have the same load transfer efficiency values. This means that the bearing capacity is equal for all the block dimensions in the Tables.

Table 6. Block dimensions when corner of joint load transfer efficiency is 0.5.

Length to thickness ratio (r)	Width ratio (β)	Thickness of blocks(mm)				
		40	50	60	80	100
2.94	1.000	118x118	147x147	176x176	235x235	294x294
3.00	0.962	120x115	150x144	180x173	240x231	300x289
3.50	0.725	140x102	175x127	210x152	280x203	350x254
4.00	0.581	160x93	200x116	240x139	320x186	400x232
4.50	0.485	180x87	225x109	270x131	360x175	450x218
5.00	0.417	200x83	250x104	300x125	400x167	500x209

Table 7. Block dimension when corner of joint load transfer efficiency is 0.66.

Length to thickness ratio (r)	Width ratio (β)	Thickness of blocks(mm)				
		40	50	60	80	100
2.22	1.000	89x89	111x111	133x133	178x178	222x222
2.50	0.800	100x80	125x100	150x120	200x160	250x200
3.00	0.588	120x71	150x88	180x106	240x141	300x176
3.50	0.465	140x65	175x81	210x98	280x130	350x163
4.00	0.385	160x62	200x77	240x92	320x123	400x154
5.00	0.286	200x57	250x72	300x86	400x114	500x143

Table 8. Standard block dimensions of other countries (Corner of joint load transfer efficiency : 0.5 to 0.66).

Country	Thickness of blocks(mm)			
	50	60	80	100
USA	200x (77 - 116)	240x (92 - 139)	320x (123 - 186)	400x (154 - 162)
Germany	200x (77 - 116)	240x (92 - 139)	320x (123 - 186)	400x (154 - 232)
United Kingdom	250x (72 - 104)	250x (91 - 136)	250x (138 - 222)	250x (200 - 250)

Table 9. Maximum block dimensions (Corner of Joint Load Transfer Efficiency: 0.5 to 0.66).

Classification (E_{LT})	Thickness of blocks (mm)			
	50	60	80	100
Light traffic (0.5)	200x116	240x139	250x222	250x250
Heavy traffic (0.66)	200x77	240x92	250x138	250x200

Where the corner of joint load transfer efficiency does not need to be great (e.g., where settlement of IL blocks is small, such as on sidewalks and roads used by light vehicles), relatively large IL blocks should be installed. Table 6 shows the limits of the dimensions. Where the corner of joint load transfer efficiency needs to be large (e.g., roadways and large-vehicle yards where the load is high), relatively small IL blocks should be installed, such as those in Table 7.

Block dimensions were calculated based on corner of joint load transfer efficiencies of 0.5 to 0.66, according to the standards of three countries: Germany, the U.S., and the U.K. (Table 3). The German Standard calls for the ratio of the longer side of the IL block to its thickness, r, to be 4 or below. The American Standard calls for r to be less than or equal to 4, and exposed face area to be less than or equal to 0.065 m^2. The British Standard calls for r to be less than or equal to 5, the side length to be less than or equal to 250 mm, and the width to be greater than or equal to 50 mm. The dimensions of IL blocks calculated according to these Standards are shown in Table 8.

Table 9 presents the recommended maximum IL block dimensions. These allow the length of the longer side to be at a minimum while still meeting the standards of the three countries and Japan (Table 8). The maximum dimensions according to the Japanese Standards are in shaded boxes. In Japan, the standard thickness is 60 mm for sidewalks and roads with light traffic, and 80 mm for roads accommodating heavy loads.

As a result of this study, the ideal dimensions of IL blocks for different traffic loads have been determined. This was achieved by considering the aspect ratio, as in the case of other countries, and the ratio of lateral total areas to top surface areas.

Load transfer efficiency was then compared between rectangular blocks and non-rectangular blocks. Pavement No. 5 in Table 4 is of non-rectangular blocks, and the ratio of lateral total areas to top surface areas is 1.71. For pavement of rectangular blocks, whose longer and shorter sides are equal, the value is 1.64, a difference of 0.07 from the non-rectangular blocks. If this difference is substituted into Equation (2) for conversion into load transfer efficiency, then a load transfer efficiency of 0.03 is obtained. The non-rectangular blocks are approximately 4% more efficient than the rectangular ones in terms of load transfer efficiency. This fact indicates that Equation (2) can produce values that serve as objective indices for comparison of load transfer efficiency of the two types.

6. CONCLUSIONS

In this paper, the effects of block dimension on bearing capacity, an issue fundamental to IL block design, has been examined. This examination was made for blocks of various shapes, with joint sand and bedding sand.

To test the deflection, a test pavement was installed, and an HFWD, a portable type of FWD, was used.

The main findings of the study were as follows.

- The relationship between IL block dimension and interlocking effect was found to be assessable based on the ratio of lateral total areas to top surface areas and on the corner of joint load transfer efficiency (E_{LT}). Also, it was found to be possible to produce objective indices of load transfer efficiency of the rectangular and non-rectangular blocks.
- Block dimensions whose values of load transfer efficiency are equal have been identified. This has led to clarification of relationship between block shape and bearing capacity.
- Standards for IL block dimensions for use in Japan are proposed for various traffic loads. These incorporate aspect ratio, as do the standards of other countries, and the combined the ratio of lateral total areas to top surface areas. Dimensions of 240 x 139 mm or smaller for a thickness of 60 mm, 250 x 138 mm or smaller for a thickness of 80 mm, and a length of the shorter side of 50 mm or shorter are proposed.
- The smaller the block dimension, the greater is the load transfer efficiency achieved by filling the joint with sand and compacting it. The load transfer efficiency is high in adjoining blocks due to their settlement and stabilization.
- The HFWD is an ideal apparatus for assessing the deflection characteristics of pavement when blocks of various shapes, such IL blocks, and joint and bedding sand are used.

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