Summary

This report deals with the basis idea and method of the structural design of interlocking block pavement in Japan. Two method has been built up through trial pavings, follow-up surveys on roads in actual service, foreign survey reports, reports analysis and so on. We hereby report mainly cur basic idea on the design and construction of the automotive road pavement.

1 Introduction

Fifteen or sixteen years have passed since interlocking concrete blocks were introduced to Japan, and pavement construction utilizing them during fiscal 1989 amounted to approximately six million square meters. Interlocking concrete block pavement, however, has been applied chiefly for pedestrian use, with their employment for roadway surfaces amounting to only about ten percent of the total. This is ascribed mainly to a lack of standards established by organizations in the public sector, in spite of the fact there has been a mounting need for such technical standards so as to cope with demands that are expected to increase during coming years.

In 1987 the Interlocking Concrete Block Pavement Research Committee, as operating within the Public Works Research Center in 1985, compiled a group of "Essentials" relating to the design and construction of interlocking concrete block pavement for pedestrian traffic, such as sidewalks, plazas and bicycle routes; and in 1990 the Committee carried it a step further by assembling a similar set of essentials pertaining to the design and construction of interlocking concrete block pavement for motor vehicle use.

At this conference a report will be made on essential, but mainly on those established in 1990 for roadway design and construction. The structural design method treated derives from follow-up surveys on the service-ability of experimental pavement and roads actually in use, reports on research conducted at home and abroad, theoretical analyses and the like. The Essentials comprise seven chapters, "Introduction," "Structural Design," "Plane Design," "Materials," "Execution of Construction Work," "Quality Control and Completed Amount Control" and
"Maintenance," plus an appendix. The traffic volume on which structural
design is based, as covered in the report, amounts to fewer than 1,000
one-way daily traffic volume of heavy vehicles (49 KN equivalent wheel
load applications \( N \): one million.) The design method of heavier vehicles
remains to be surveyed and studied further.

2 Structural design of interlocking concrete block pavement

The CBR-\( T_A \) design method, which thus far has been used for asphalt
pavement, has been applied in the Essentials for the design and
construction of pavement using interlocking concrete blocks (the volume
on roadway). In other words, the thickness and composition of pavement
are determined mainly using the road classification by traffic volume, the
design CBR of subgrade soil, target value for \( T_A \) and total thickness \( H \),
and conversion coefficient.

2.1 Classification of roadways by traffic flow volume

A pavement standard should be determined from classification (listed in
Table-1) on the basis of the estimation of one-way daily traffic volume
of heavy vehicles in the fifth year of operation.

Table 1 Classification of roadways by traffic flow volume

<table>
<thead>
<tr>
<th>Classification of roadways by traffic flow volume</th>
<th>Traffic volume of heavy vehicle (wheel/day • direction)</th>
<th>( N^{(\text{Note 1})} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (Roadways not intended for heavy vehicles) ( ^{(\text{Note 1})} )</td>
<td></td>
<td>7,000</td>
</tr>
<tr>
<td>II (Roadways intended for heavy vehicles)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Less than 100</td>
<td>30,000</td>
</tr>
<tr>
<td>A</td>
<td>100 to less than 250</td>
<td>150,000</td>
</tr>
<tr>
<td>B</td>
<td>250 to less than 1,000</td>
<td>1,000,000</td>
</tr>
</tbody>
</table>

Note 1: Roadways for pedestrians and vehicles of max. 4 ton in loadage (Ex. shopping streets,
community roads, and roads in a housing complex)
2.2 Target value for \( T_A \) and total thickness \( H \)

The following formulas are used for structural design:

\[
H = 28.0 N^{0.1} / CBR^{0.5} \quad (1)
\]

\[
T_A = 3.84 N^{0.16} / CBR^{0.2} \quad (2)
\]

Where \( H \) = Thickness of pavement (cm)

\( T_A \) = Design thickness necessary for the total pavement thickness using hot asphalt mix for surface and binder course.

\( N \) = Total number of wheel load application throughout the design period (10 years) converted to the number of 5 ton wheel load applications (wheel/direction)

The thickness of each layer of pavement and materials are found by the following formulas:

\[
T_A' = a_1 T_1 + a_2 T_2 + \ldots + a_n T_n \geq T_A \quad (3)
\]

\[
H' = T_1 + T_2 + \ldots + T_n \geq 0.8 H \quad (4)
\]

where \( a_1, a_2, \ldots a_n \): conversion coefficient shown in Table 2

\( T_1, T_2, \ldots T_n \): thickness of each layer (cm)

Table 2: Conversion Coefficient for the Calculation of \( T_A \)

<table>
<thead>
<tr>
<th>Pavement Course</th>
<th>Method and Material of Construction</th>
<th>Conditions</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface &amp; binder course</td>
<td>Hot asphalt mix for surface and binder course</td>
<td>Interlocking block</td>
<td>1.00</td>
</tr>
<tr>
<td>Base</td>
<td>Bituminous stabilization</td>
<td>Hot-mixed stability: 3.4N or more Cold-mixed stability: 2.5N or more</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>Cement stabilization</td>
<td>Unconfined compression strength (7 days): 3 N/mm²</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>Lime stabilization</td>
<td>Unconfined compression strength (10 days): 1 N/mm²</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>Crushed stone for mechanical stabilization</td>
<td>Modified CBR value: 80 or more</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Slag for mechanical stabilization</td>
<td>Modified CBR value: 80 or more</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>Hydraulic slag</td>
<td>Unconfined compression strength (14 days): 1 N/mm²</td>
<td>0.55</td>
</tr>
<tr>
<td>Subbase</td>
<td>Crushed Run, slag sand, etc.</td>
<td>Modified CBR value: 30 or more 20 to 30</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Cement stabilization</td>
<td>Unconfined compression strength (7 days): 1 N/mm²</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Lime stabilization</td>
<td>Unconfined compression strength (10 days): 0.7 N/mm²</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Conversion coefficients listed in Table 2 indicate the ratio of the thickness of pavement by each method and material of construction to the thickness of hot asphalt mix for the binder and the surface sources corresponding to the thickness of each material. The standard depth of sand cushion (two centimeters) is included in the calculation of the total thickness \( H \), but not in the computation of \( T_A \).

2.3 Comparison with design standards of other countries

Design standards for roadway are used in Australia, the United States, the United Kingdom, South Africa and so forth; and, in every case, standard base thickness is sought taking into consideration traffic conditions and the CBR of subgrade soil.

In order to compare Japanese design methods with the design standards of other countries, \( T_A \) is sought, as shown in Figure 1, by making traffic

Figure 1 Design standards for roadway \( T_A \) of other countries
conditions CBR 4%, dividing the amount of traffic into L traffic, A traffic and B traffic, finding the standard base course thickness on the ground of design methods, and, moreover, correcting materials for use as base as applied in each country by the conversion coefficient of Japan. As seen in the figure, pavement structuring in Japan lies on the safer side when comparing the classification of A and B traffic, while almost the same results are obtained in the classification of L traffic.

3 Examination of experimental pavement

3.1 First survey

3.1.1 Comparison with asphalt pavement

As a means to assess the structure of interlocking concrete block pavement and examine the effects the pattern of block laying has on such pavement, a survey was conducted by constructing experimental pavement at the pavement driving experimental station of the Ministry of Construction’s Public Works Research Institute. As shown in the cross section of pavement in Figure 2, interlocking concrete blocks were laid on a granular base course in two patterns (herringbone bond and stretcher bond), and dense graded asphalt concrete and course-graded asphalt concrete were laid on the same granular base course. The survey focused on changes in road surface properties as caused by having a ratio-controlled test vehicle run upon it 80,000 times (number of equivalent 49 KN wheel load basis: 150,000 to 190,000 wheels).

Each time the vehicle traveled the number of preset runs, the road surface properties were gauged in terms of deflection measurement with a Benkelman beam, depth of rutting, damage to blocks, and the degree to which blocks had shifted from their original position.

As indicated in Table 3, rutting and damage to the two divisions of interlocking concrete block pavement (in the instance of asphalt, the cracking ratio are greater than inflicted on asphalt. In particular, rutting introduced to the interlocking concrete block pavement became as deep as 28 millimeters after 10,000 runs by the vehicle and 40 millimeters after 80,000, more than three times those measured in the asphalt, making it clear that the pavement had reached the limit of its serviceability.
Next, the cross section profile of each layer of pavement was measured by digging trenches where the larger rutting had been made in each division as a means to certain the causes of rutting. This confirmed that deformations in the road surface had been caused not by changes in the sand cushion and the subgrade soil but by changes within the granular base course and sub-base course. From this it was concluded that, in order to secure a degree of serviceability equal to that of asphalt pavement, it will be necessary to increase the stiffness of the base course and, for the second survey, that experimental pavement should be constructed using a stabilized base.

3.1.2. Effects the pattern of laying blocks has on pavement

The relationship between the two kinds of patterns for laying blocks (herringbone bond and stretcher bond) and the degree to which blocks shifted from their original position after a predetermined number of test runs is shown in Figure 3.

The degree to which blocks moved from their original position in the stretcher bond pattern is approximately twice that of herringbone bond, indicating that the latter is a more effective method for laying blocks in terms of pavement for roads.

In view of the survey results, herringbone bond was adopted as the more viable block-laying pattern, and it was expressed in the Essentials for pavement design and construction set forth by the Committee in 1990.

3.2. Second survey: experimental pavement using a stabilized base
As shown in Figure 4, experimental pavement was constructed by laying interlocking concrete blocks on both cement-stabilized and asphalt-stabilized bases. The number of runs made by test vehicles was limited to 80,000, and the survey was conducted focusing on the same items as treated in the first survey. The herringbone pattern was used in both classes of pavement.

Table 4 shows the outcome of the survey. Better results were obtained in all the points surveyed than when the granular base was used.

Table 4 Test Results

<table>
<thead>
<tr>
<th>Section</th>
<th>Test Items</th>
<th>Number of Runs (×10^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B' Section</td>
<td>Damage (%)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Deflection (mm)</td>
<td>0.501</td>
</tr>
<tr>
<td></td>
<td>Depth of Rutting (mm)</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>Distance of Moving (mm)</td>
<td>0</td>
</tr>
<tr>
<td>C' Section</td>
<td>Damage (%)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Deflection (mm)</td>
<td>0.623</td>
</tr>
<tr>
<td></td>
<td>Depth of Rutting (mm)</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>Distance of Moving (mm)</td>
<td>0</td>
</tr>
</tbody>
</table>

In particular, rutting made in the B' and C' types of pavement measured only ten or eleven millimeters, making them less than those made in the asphalt pavement that had been laid for comparison purposes in the first survey. Moreover, when the survey on test runs continued in the B' division of pavement, with its asphalt-stabilized base, rutting made were as shallow as fourteen millimeters after 240,000 runs (converted to the number of 49 KN wheel load applications: 478,641 wheels).

It follows from the results specified above that a method of increasing stability using cement or asphalt should be used for the base course, as in the case of A traffic and heavier, and this has been incorporated in the Essentials set forth by the Committee in 1990.

3.3. Third survey: examination of damage to blocks with spacer ribs

Traffic will cause deformation on the surface of road pavement, such as rounded angles of blocks owing to their rubbing against one another, unless joint width is provided between them. This phenomenon was confirmed in both first and second surveys, and it was decided that, in order to preclude this problem, blocks having spacer ribs on their lateral faces, as shown in Figure 5 (called blocks with spacer ribs), be used and an examination of the effects be made.

The relationship between the number of test vehicles runs and the rate of damage to blocks is shown in Figure 6, and it has been confirmed that, by
using blocks with spacer ribs, the required width of a joing (standard: three millimeters) is secured and, as a result, the rate of damage can be reduced to one fifth.

As seen by the foregoing, it becomes highly desirable that blocks with spacer ribs be utilized for road pavement, and this is reflected in the 1990 Essentials prescribed by the Committee.

![Fig.5 Block with spacer ribs](image)

**Fig.5 Block with spacer ribs**

![Fig.6 Relationship between the number of runs and the rate of damage](image)

**Fig.6 Relationship between the number of runs and the rate of damage**

4 Conclusion

The Essentials set forth by the Committee as regards the design and construction of interlocking concrete block pavement include the following major points.

(1) When laying interlocking concrete block pavement, the design method of flexible pavement which has seen successful use in Japan, should be applied.

(2) The conversion coefficient of interlocking concrete blocks equals that of asphalt mixture, and the thickness of sand cushion should be disregarded.

(3) Rectangular blocks with a thickness of eighty millimeters should be used, and the herringbone bond pattern in principle will be adopted.

(4) It is desirable to utilize block spacer-ribs in order to keep a certain joing width and preclude the rubbing of blocks against each other.

(5) When more than a hundred heavy vehicles per day pass in one direction, cement-stabilized or asphalt-stabilized base will be used for the base course.

(6) The bending strength of ordinary blocks will be or more.
Bibliography


3  ANZAKI, Hiroshi, YANAGIDA, Tsutomu, YAGINUMA, Hiroshi: "Durability Evaluation of Interlocking Blocks" (1991) 19th Japan Road Congress

4  ANZAKI, Hiroshi, YANAGIDA, Tsutomu, NISHI, Junji: "Influences to Serviceability of Interlocking Concrete Block Pavement for Roads Affected by Shapes of Interlocking Blocks and Roadway Patterns." (1991) 19th Japan Road Congress

5  ROLLINGS, Raymond S.: "Corps of Engineers Design Method for Concrete Block Pavement," Second International Conference on Concrete Block Paving, 1984

6  KNAPTON, J.: "The Structural Design and Performance of Concrete Block Roads," Third International Conference on Concrete Pavement Design and Rehabilitation, 1985

7  SHACKEL, B.: "Evaluation, Design and Application of Concrete Block Pavement," Third International Conference on Concrete Pavement Design and Rehabilitation, 1985