STRUCTURAL DESIGN OF CONCRETE BLOCK PAVEMENTS BY CBR METHOD AND ITS EVALUATION

Yuji MIURA, Nihon University
Masayuki TAKAURA, Chichibu Cement Co., Ltd.
Tokihiro TSUDA, Chichibu Kenzai Hanbai Co., Ltd.

SUMMARY

Structural design of asphalt pavements in Japan is based on the CBR design method. The purpose of this paper is to study the applicability of the CBR method to the structural design of concrete block pavements.

Firstly, in order to elucidate the deformation behavior of the concrete block pavement and the stress distribution in the pavement structure under moving loads, full-scale test pavements were constructed.

Based on the deformation data, an analysis of two-layer structure was made by the elastic theory, and the block pavement was compared with a conventional asphalt pavement. And also the progress of permanent deformation (rutting) was investigated. As a result, it was confirmed that the deformation behavior of the block pavement was similar to that of the asphalt pavement.

Secondly, the coefficient of relative strength of block surface course material which was necessary for the CBR design method was determined, as a result of which it was found that this value was equal to or higher than that of asphalt mixture. And it was confirmed that the coefficient of relative strength of the block surface course was from 1.01 to 1.17, which nearly agreed with the result of B. Shackel's study.

Moreover, the influence of the thickness of bedding sand course on surface deformation and the influence of the shape and thickness of blocks on deformation behavior were investigated using a full-scale load simulator.

1. OUTLINE OF TEST PAVING

Full-scale test pavements were constructed with a view to clarifying the mechanical properties of the concrete block pavement and investigating the applicability of the CBR design method.

The study with test paving consisted of two steps. As a first step, test pavements having structures shown in Fig. 1 (a) were built to elucidate the mechanical properties of the concrete block pavement. Nextly, concrete block pavements and asphalt pavements having an identical base were built to compare their deformation characteristics.

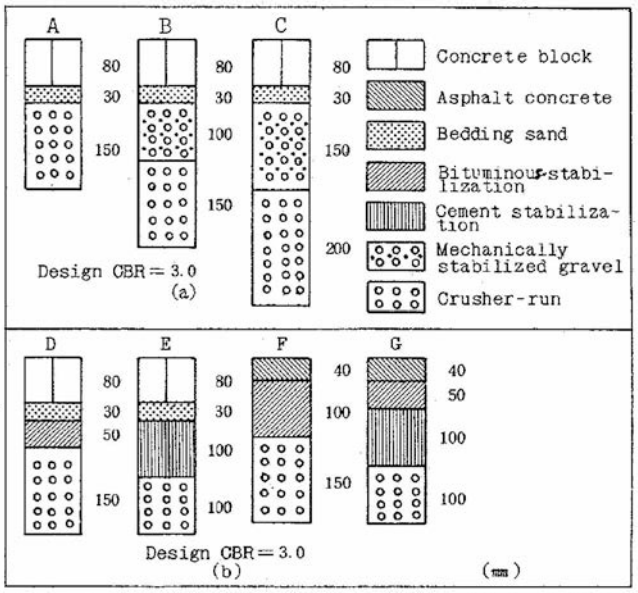

Fig. 1 Pavement structure used in test paving

Structural design of the block pavements was made based on the CBR method employed for asphalt pavements in Japan[1]. The design CBR of the base was taken as 3.0 and the coefficient of relative strength of the concrete block surface course to the asphalt surface course was conservatively taken as 1.0 referring to B. Shackel's study[2]. As a laying pattern of concrete blocks was adopted herringbone bond as shown in Fig. 2. The grading of sand used in the bedding sand is as shown in Table 1.

2. MECHANICAL PROPERTIES

2.1 Load distributing ability

Stresses in the pavement were measured in order to know the load distributing ability of the concrete block surface course. Tests were made for both static load and moving load.

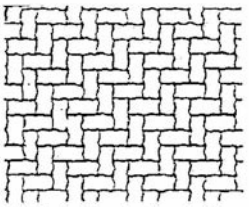

Fig. 2 Laying pattern

Table 1 Grading of sand used in bedding sand

Sieve size(mm)	Passing (%)
5	100
2.5	95
1.2	70
0.6	43
0.3	22
0.15	8
0.074	2

Fig. 3 gives the results of static load tests conducted using the plate bearing test method. The relation between loading stress and vertical stress ratio at top of the base is shown here. It is seen that the load distributing ability increases due to interlocking effect of the blocks with increasing load. This result well agrees with that of a series of static load tests made by J. Knapton[3]. Data slightly differ with laying patterns. At loading stresses over about 0.3 MN/m², herringbone bond gives a better result.

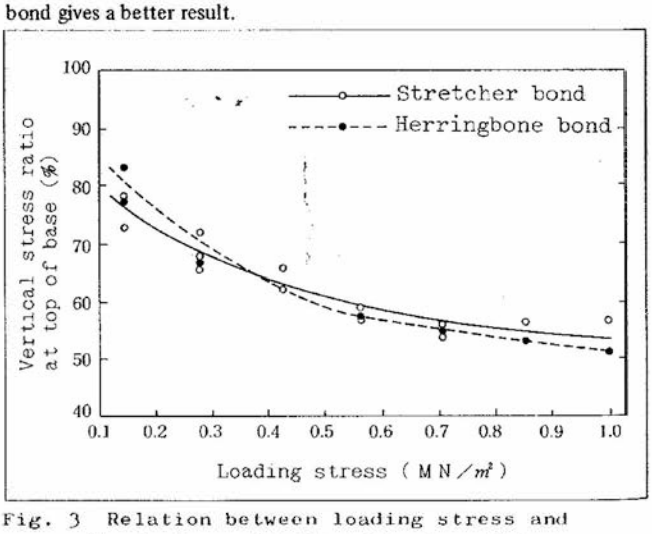

Fig. 3 Relation between loading stress and vertical stress developed on top of base

Fig. 4 shows the stress distribution occurring in the pavement structure under standard 49 kN wheel load. The stress developed at top of the base decreased to about 35% of the applied loads, so it was confirmed that the concrete block surface had a high load distributing ability for moving load, as well. Further, from theoretical stress distribution curve shown with the two-layer elastic modulus ratio (E_1/E_2) as a parameter, it was seen that the average value of E_1/E_2 was 33. Thus the load distributing ability of the concrete block pavement was found to be similar to that of the asphalt pavement.

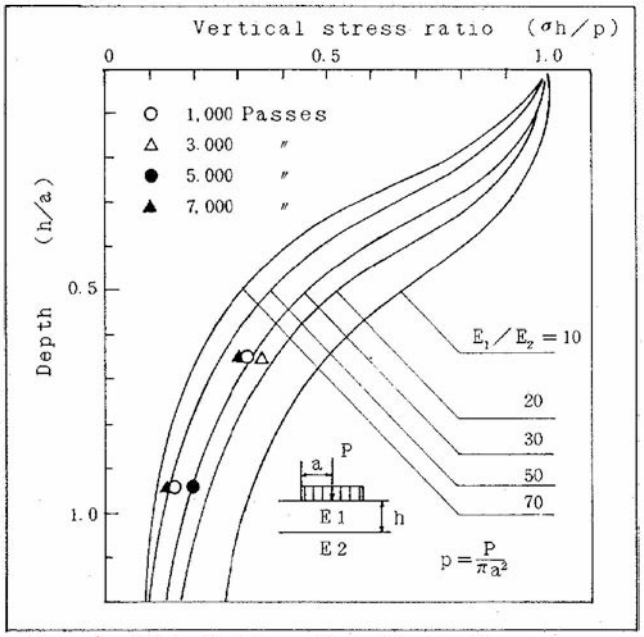

Fig. 4 Distribution of vertical stresses developed in pavement structure

2.2 Elastic modulus of concrete block surface course

The author, prof. Miura proposed a method of estimating the elastic moduli, the pavement as a two layer structure, from the amount of deflection and it's radius of curvature beneath the wheel load on the basis of the elastic theory[4]. The relation between deflection and radius of curvature is as shown in Fig. 5.

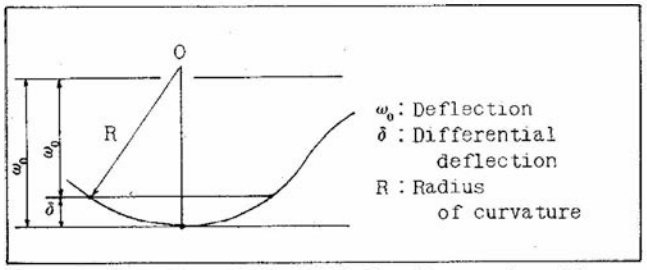

Fig. 5 Relation between deflection and radius of curvature

Table 2 shows the measured values of deflection and radius of curvature and the estimated values of elastic modulus of the block surface course, obtained from the test pavements. Though different in base structure, the elastic modulus was estimated about 1620 MN/m² on an average.

Table 2 Elastic moduli and coefficients of relative strength of concrete block course

Section	Deflection (mm)	Radius of curvature (m)	Elastic modulus (MN/m²)	Coefficient of relative strength
A	2.31	23	1 560	1.02
B	1.88	34	1 730	1.08
C	1.82	32	1 660	1.05
D	2.24	28	1 580	1.03
E	2.34	26	1 560	1.02

From the elastic modulus, the coefficient of relative strength was estimated using a method shown below. Takeshita[5] proposed the following relation between the coefficient of relative strength and the elastic modulus of various materials:

$$a = 0.00525 \cdot E^{0.46}/0.44 \qquad (1)$$

where,

a = coefficient of relative strength

E = elastic modulus of various materials (kgf/cm²)

The result of estimating the coefficient of relative strength by equation (1) is in the range of 1.02 to 1.08 as shown in Table 2, so the coefficient of relative strength of the block surface course can be evaluated to be equal to or higher than that of the asphalt surface course. Compared with the values of 1.1 to 1.5 according to B. Shackel's study[2], the values estimated by equation (1) are slightly

3. RUTTING

With increasing the period of service, rutting in the pavement surface increases until its service limit is reached.

Fig. 6 shows the relation between the depth of rutting and the number of 49 kN wheel loads applications. It is seen that after the passage of 1,000 wheels the relation between the two approximates to a straight line having a slope. The results of regression analysis are the equations shown in the figure.

In Japan, the allowable values of rutting are specified to be from 3 to 4 cm for ordinary roads with heavy traffic. For the block pavement, however, no such standard values are specified yet. Therefore, the author et al. employed the average of the above allowable values, 3.5 cm, to this pavement and estimated the number of wheels passed till the end of service life, using the equations given in Fig. 6. The results are shown in Table 3. Structural design method of the asphalt pavement in Japan is as shown in Appendix. The quality of the pavement structure is specified by the following equations 1):

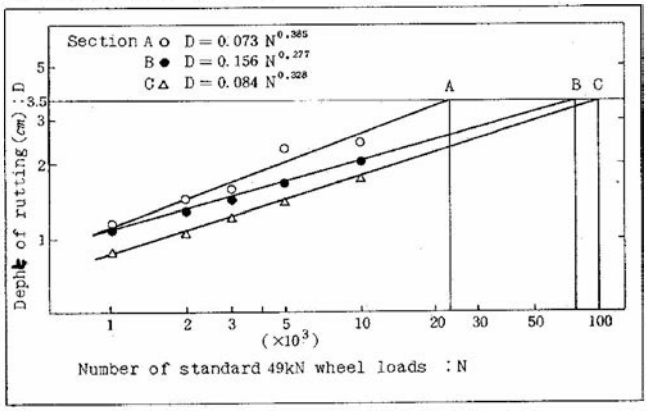

Fig. 6 Relation between depth of rutting and number of standard 49 kN wheel loads

$$T_A = \frac{3.84\ N^{0.16}}{CBR^{0.3}} \qquad (2)$$

$$T_A = a_1h_1 + a_2h_2 + \cdots + a_nh_n \qquad (3)$$

where,

T_A = design thickness, i.e. the required thickness of full-depth hot-mix asphalt pavement having an equivalent strength, (cm)

N = number of equivalent 49 kN wheel loads in one direction to be expected during the 10-year period following construction

a_n = coefficient of relative strength of each course constituting pavement

h_n = thickness of each course constituting pavement (cm)

The value of T_A can be estimated by substituting in equation (2) the design CBR value of 3.0 and the number of wheels passed until the allowable limit of rutting is reached. The values of coefficient of relative strength of each material used in the base are known (Table

4), so the coefficient of the block surface course can be calculated from TA estimated by equation (2), and equation (3). The results were shown in Table 3.

Table 3 Coefficients of relative strength estimated from allowable depth of rutting

Section	Number of wheels passed	TA(cm)	Coefficient of relative strength
A	23000	13.77	1.06
B	75000	16.64	1.17
C	87000	17.04	0.85
Average			1.02

Table 4 Coefficients of Relative Strength for Calculating T_A

Pavement Course	Method and Material of Construction Used	Conditions	Coefficient
Binder and Surface Courses	Hot asphalt mix for binder and surface courses		1.00
Base	Bituminous stabilization	-Hot-mixed Marshall stability:350kg or more	0.80
		-Cold-mixed Marshall stability:250kg or more	0.55
	Cement Stabilization	-Unconfined compressive strength(7 days):30kg/cm²	0.55
	Lime Stabilization	-Unconfined compressive strength(10 days):10kg/cm²	0.45
	Mechanically Stabilized Gravel and Slag	-Modified CBR:80 or more	0.35
	Hydraulic Mechanically Stabilized Slag	-Modified CBR:80 or more	0.55
	Penetration Macadam	-Unconfined compressive strength:(14 days):32kg/cm²	0.55
Subbase	Crusher-run, Slag,	-Modified CBR:30 or more.	0.25
	Sand etc	-Modified CBR:20 or more, less than 30	0.20
	Cement Stabiliza-tion	-Unconfined compressive Strength.(7 days):10kg/cm²	0.25
	Lime Stabilization	-Unconfined compressive Strength(10 days):7kg/cm²	0.25

On the other hand, Fig. 7 shows a comparison of the progress of rutting between the block pavement and the asphalt pavement. The pavement sections are designed so that sections D and F, and sections E and G, are equal in T_A when the coefficient of the block surface course is assumed to be 1.0.

Compared with the asphalt pavement, the block pavement exhibits relatively large deformation in the initial stages of service. This is attributed to unstable interlocking of blocks and to consolidation settlement of the bedding sand course under traffic. However, after the passage of 1,000 wheels when the blocks interlock stably each other and the bedding sand is stabilized, the rutting of the block surface progresses slowly and its rutting becomes smaller than that of the asphalt pavement. Note that measurements after the passage of 1,000 wheels were made at atmospheric temperatures around 30°C, at which rutting of the asphalt pavement exhibited a rapid progress.

The results of estimating the number of wheels passed till the end of service life, T_A and the coefficient from the allowable value of rutting (3.5 cm) following the foregoing method are shown in Table 5. The coefficient of the block pavement was 1.07 on an average, which value agreed with data given in Table 3. In Japan where the pavement surface temperature in summer exceeds 55°C, rutting is an important factor which affects serviceability. In terms of deformation behavior in the high temperature season, therefore, the concrete block pavement can be considered superior.

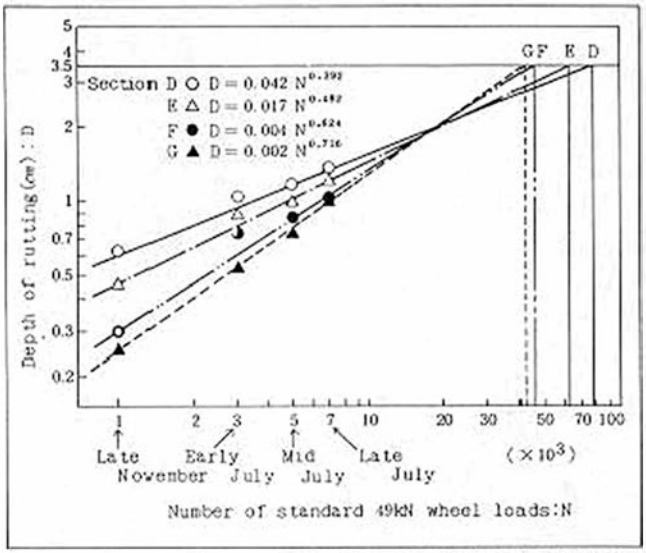

Fig. 7 Comparison of depth of rutting between concrete block pavement and asphalt pavement

Table 5 Comparison of coefficients of relative strength in high temperature season

Section	Number of wheels passed	TA(cm)	Coefficent of relative strength
D	77 700	16.73	1.12
E	63 300	16.59	1.02
F	46 300	15.40	0.91
G	42 500	15.20	0.80

4. DYNAMIC LOAD TESTS BY LOAD SIMULATOR

The full-scale load simulator shown in plate 1 has performance characteristics shown in Table 6. In the study using this load simulator, tests were made especially for comparison of the surface courses of different types of pavements. Hitherto the following items have been investigated:

(1) Influence of the thickness of bedding sand on surface deformation.
(2) Influence of the shape and thickness of blocks on deformation behavior.

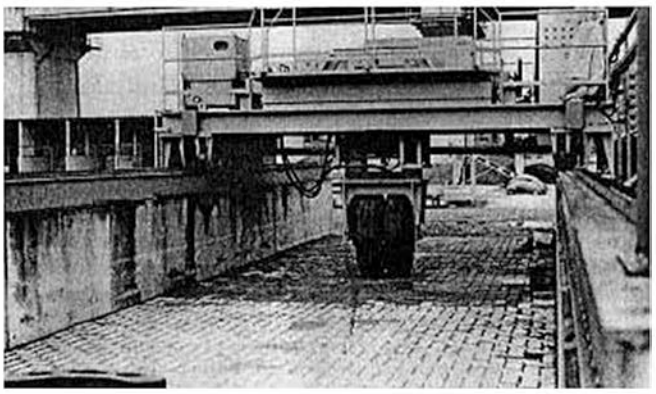

Plate 1 Wheel load simulator

4.1 Influence of the thickness of bedding sand

With conventional pavement structure, the upper course is built of more stronger material. With the concrete block pavement, a bedding sand which is structurally weak is provided between the block surface course and the base, so a relatively large deformation occurs in the bedding sand under traffic load. This deformation becomes a major cause

Table 6 Performance of load simulator

Item	Performance
Load applied	0–69kN
Traveling speed	5 Km/h
Width	4 m
Extension	16m

of rutting under repeated load.

Fig. 8 shows the relation between the progress of rutting and the number of 49 kN wheel loads, expressed in terms of the thickness of bedding sand. Adopted as the thickness of the sand course were 20, 40 and 60 mm. The thickness of sand course here means the thickness of compacted sand. The laying pattern of concrete blocks adopted here is the stretcher bond.

With 40 mm and 60 mm, the rates of progress of rutting were nearly the same although there was a slight difference in initial settlement. While in the case of 20 mm, both the depth of rutting and the rate of progress decreased largely.

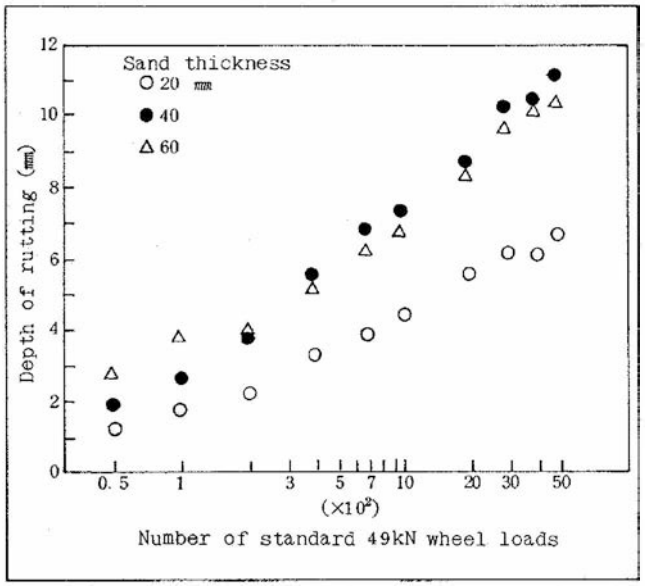

Fig. 8 Thickness of bedding sand and depth of rutting

On the other hand, the bedding sand is structurally a weak point. On the basis of the measured deflection and radius of curvature, the elastic modulus of the materials was estimated by F.E.M. The result is shown in Table 7. The elastic modulus of the bedding sand is 26 MN/m². And the modulus of the jointing sand shows a low value of 4 MN/m², so it can be seen that this is the major cause of the decrease in apparent elastic modulus of the concrete block surface course.

Thus the thickness of bedding sand is a factor which largely affects the serviceability of the concrete block pavement. B. Shackel proposed 20 mm as the thickness of bedding sand after rolling[6]. This was evidenced by the results of the present study.

Table 7 Elastic moduli of each material estimated by finite element method

	Concrete block	Jointing sand	Bedding sand	Base	Subbase	Subgrade
Elastic modulus (MN/m²)	17 600	4	26	88	79	70

4.2 Influence of the shape of blocks

To investigate the influence of the shape of blocks, tests were made to compare several types of concrete blocks shown in Fig. 9.

Fig. 10 shows the results of comparison of the progress of rutting between them. Compared with Types I and II, Type III exhibits a large ininial settlement and a high rate of progress of rutting. At the

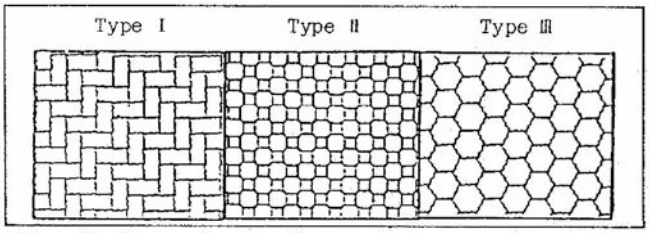

Fig. 9 Concrete blocks used for comparison of shape

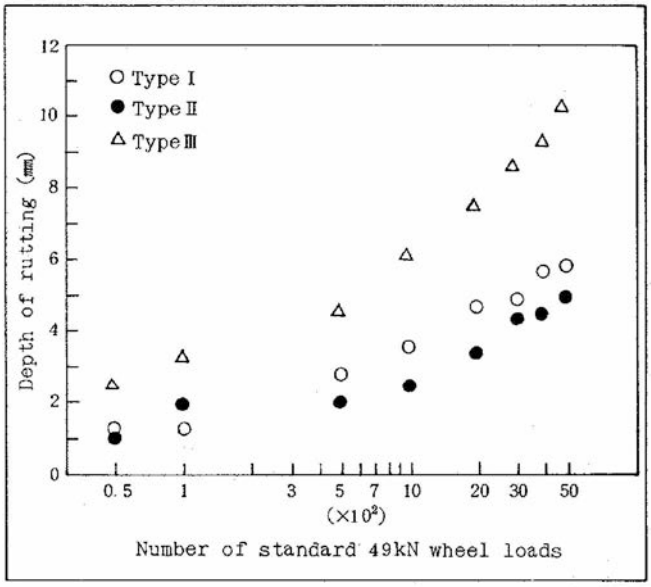

Fig. 10 Shape of block and depth of rtting

point of 5,000 wheel passes, the depth of rutting is about 4 mm larger than with Types I and II.

On the other hand, the values of deflection, radius of curvature and coefficient of bearing capacity (K-value) measured as factors indicating bearing capacity are given in Table 8. The results of a relative evaluation of Types II and III made taking the values of Type I as 1.0 are shown in parentheses.

Type II can be evaluated to be equivalent to Type I, but Type III is found to be obviously inferior in bearing capacity. The cause for this can be attributed to size rather than shape.

In structural design, therefore, the shape and size of blocks also become factors to be considered.

Table 8 Comparison of bearing capacities by shape of block

Shape of block	Deflection (mm)	Radius of curvature (m)	K-value (kg/cm³)	Average
Type I	1.08 (1.00)	34 (1.00)	55.8 (1.00)	(1.00)
Type II	1.14 (0.95)	36 (1.06)	52.5 (0.94)	(0.98)
Type III	1.35 (0.80)	25 (0.74)	47.3 (0.85)	(0.80)

Note: Enclosed in parentheses are values evaluated taking values of Type 1 as 1.0.

4.3 Influence of the thickness of blocks

Concerning the thickness of blocks, valuable research data have so far been reported by B. Shackel and others. In Japan, 60 mm thick blocks are mostly adopted for use in footway, while 80 mm thick blocks find main application in roads. At present, 100 mm thick blocks are not under mass production.

Fig. 11 shows the results of comparison of the progress of rutting between 60, 80 and 100 mm thick blocks, from which it can be seen that 60 mm thick blocks are somewhat higher than the others in the rate of progress of rutting. The difference between 60 mm and 80 mm is greater than that between 80 mm and 100 mm. A similar result is

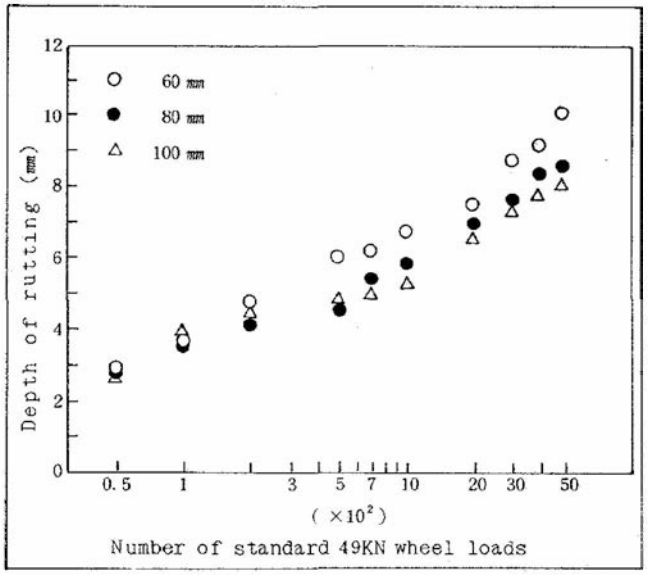

Fig. 11 Thickness of block and depth of rutting

reported by B. Shackel[6].

Further, to compare the bearing capacities of these blocks, their values of deflection, radius of curvature and coefficient of bearing capacity (K-value) were compared, the results of which are given in Table 9. The results of a relative evaluation of other blocks made taking the values of 80 mm thick blocks with proven bearing capacity as 1.0 are shown in parentheses. It can be seen that increase or decrease of 20 mm results in about 7% increase or decrease in bearing capacity. However, it is presumed that the thickness of blocks exerts a greater effect on the durability of individual blocks. Therefore, much more data must be accumulated and incorporated in structural design.

Table 9 Comparison of bearing capacities by thickness of block

Thick-ness of block	Deflection (mm)	Radius of curvature (m)	K-value (kg/cm³)	Average
60 mm	1.23 (0.94)	23 (0.85)	43.8 (1.01)	(0.93)
80 mm	1.16 (1.00)	27 (1.00)	43.2 (1.00)	(1.00)
100 mm	1.13 (1.03)	31 (1.15)	44.9 (1.04)	(1.07)

Note: Enclosed in parentheses are values evaluated taking 80 mm as 1.0.

5. CONCLUSIONS

In conclusion the main points of this paper may be summarized as follows:

(1) The load distributing ability of the concrete block surface course increases with increasing load, and the stress distribution in the pavement under 49 kN wheel load coincides with that of the asphalt pavement.

(2) The coefficient of relative strength of the concrete block surface course, estimated from its apparent elastic modulus, was in the range from 1.02 to 1.08 and, therefore, was evaluated to be equal to or higher than that of the asphalt surface course.

(3) Concerning the progress of rutting, the result of evaluation of the concrete block pavement was equal to or better than that of the asphalt pavement. It has become clear that the concrete block pavement is superior to the asphalt pavement in the deformation behavior especially in the high temperature season.

Based on the foregoing results, the structural design method for asphalt pavements can be applied for the time being until the structural design method for concrete block pavements is established.

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APPENDIX OUTLINE OF STRUCTURAL DESIGN IN JAPAN

The pavement sturcture is determined on the basis of subgrade CBR and the traffic volume of large vehicles (number of equivalent 49 kN wheel loads) by the following equations:

$$H = \frac{28.0\,N^{0.1}}{CBR^{0.6}} \qquad (4)$$

$$T_A = \frac{3.84\,N^{0.16}}{CBR^{0.3}} \qquad (5)$$

where,

H = pavement thickness (cm)

T_A = required thickness of full-depth hot-mix asphalt pavement having an equivalent strength (cm)

N = number of equivalent 49 kN wheel loads in one direction to be expected during the 10-year period following construction

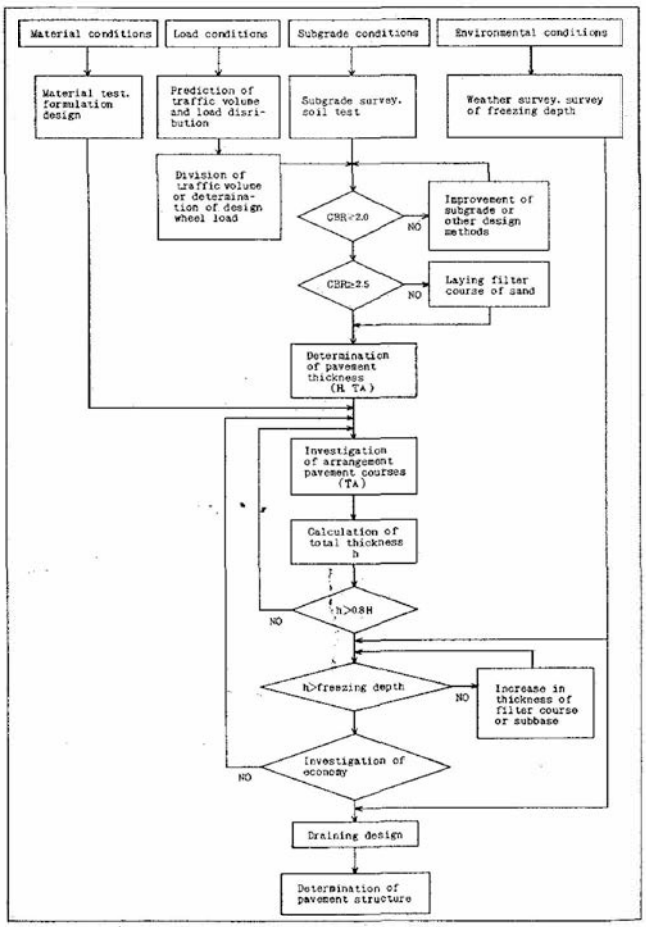

Fig. 12 Flow chart for designing pavement structure

T_A can be calculated from the thicknesses and coefficients of relative strength of the courses constituting the pavement as shown in equation (3). The materials and thicknesses of each course are determined so as to satisfy the values of H and T_A determined by equations (4) and (5). The sequence of structural design is as shown in Fig. 12. The coefficient of relative strength of the concrete block surface course has been conservatively taken as 1.0 based on the results of this study, and concrete block pavements are currently being designed using this tentative value.