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ON THE SERVICEABILITY OF CONCRETE BLOCK PAVEMENTS USED ON STREETS AND BUS BAYS

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SUMMARY

The application of concrete blocks to street pavements in Japan is extending from light traffic to heavy traffic roadways. Structural design for these pavements is based on the identical technique to the CBR design method being in use for flexible pavements in the country. This design method uses subgrade CBR and traffic volume (number of equivalent 49 kN wheel loads) as parameters and is also being used for concrete block pavements on the basis of various test results such as deflection test, etc.

In the present study, a follow-up survey was made of the serviceability of the concrete block pavements constructed on a street classified as light traffic and on a bus bay classified as heavy traffic.

In the follow-up survey, the amount of deflection and it's radius of curvature were measured for the structural evaluation of the concrete block pavement. As a result, the amount of deflection under the standard 49 kN wheel load was less than 0.5 mm, the permissible deflection for a conventional asphalt pavement, which means that the concrete block pavement has a high bearing capacity.

For the street, the noise characteristic and skid resistance of the concrete block pavement were investigated. In addition, a consciousness survey was taken to the residents living in the area, the results of which are partly shown here.

For the bus bay, the progress of permanent deformation (rutting) was examined, in addition to structural evaluation. The permanent deformation caused in the pavement surface could not be located visually, therefore the concrete block pavement was found to be suitable for use on roadways with static loads such as bus bays.

1. OUTLINE OF TEST PAVING

1.1 Pavement structures

The street selected for test is an ordinary local city street where there is no distinction between footway and roadway. The test pavement is 90 m in length and 6 m in average width. The subgrade of the test section was a soft ground of 1.5 in design CBR. Therefore, the top portion, 35 cm in thickness, of the existing subgrade was substituted by a lime stabilized material (modified CBR >20) to obtain a design CBR of 4, and a pavement structure shown in Fig. 1 (a) was adopted.

On the other hand, the test pavement of the bus bay is 55 m in length and 3.5 m in width. The bus bay has a traffic volume of more than 500 large vehicles per day, including the number of arriving and departing buses and through traffic. The subgrade of the test pavement was a soft subsoil of about 1.0 in design CBR. Therefore, the top portion, 40 cm in thickness, of the existing subgrade was stabilized with Portland cement to obtain a design CBR of 3, and a pavement structure shown in Fig. 1 (b) was adopted. The asphalt pavement being in service before the adoption of concrete block pavement underwent a severe flow fracture in the high temperature season of summer, so maintenance and repairs were needed every year.

The shape and pattern of concrete blocks used are as shown in Fig. 2

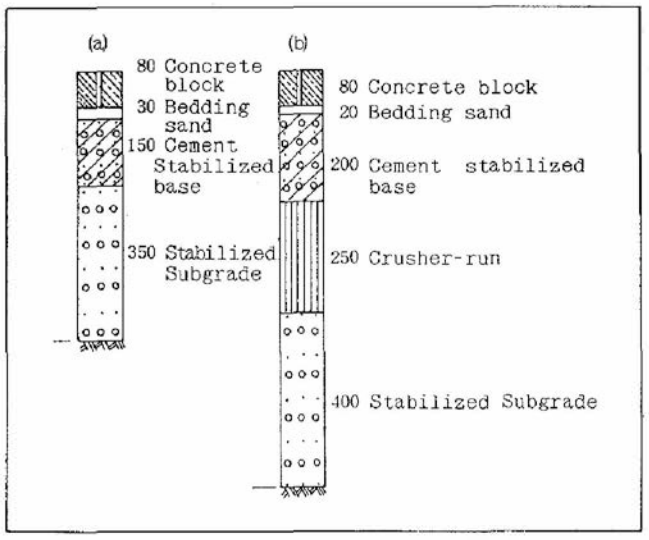

Fig. 1 Pavement structure

and herringbone bond was adopted as a laying pattern.

1.2 Materials

The properties of paving materials used are as shown in Table 1.

Table 1 Properties of Paving materials used

Course	Street	Bus bay
Surface course	Concrete block Compressive strength 718 MN/m²	
Base	Cement stabilized base Max Size = 40 mm PI ≦ 9 UCS ≧ 2.9 MN/m² Cement 6% added	
Subbase	—	Crusher Max Size = 40 mm PI ≦ 6 Modified CBR ≧ 30 %

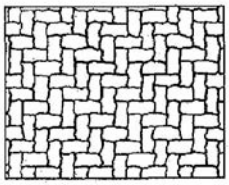

Fig. 2 Laying pattern

2. STREET PAVEMENT

2.1 Structural evaluation

For structural evaluation, the amount of deflection and it's radius of curvature were measured four months after placing in service. As shown in Fig. 3, the amount of deflection and it's radius of curvature are indices of the deflection bowl of the pavement surface under wheel load.

The average deflection under standard 49 kN wheel load had a small value of 0.31 mm as shown in Table 2, which was less than 0.5 mm, the standard deflection of ordinary asphalt pavement under heavy traffic. On the other hand, the radius of curvature was large, 120 m on an average.

One of the author, prof. Miura proposed a method of estimating the elastic moduli of each course, in the case of dividing pavement into two

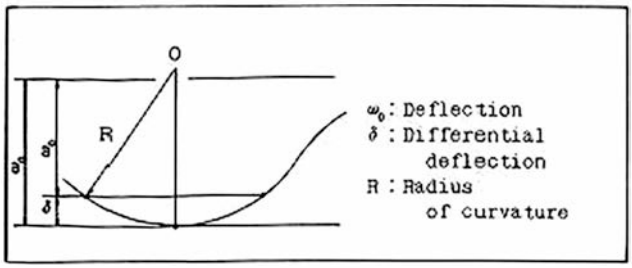

Fig. 3 Relation between deflection and radius of curvature

Table 2 Measured values of defecrion and rudius of curvature

	Deflection (㎜)	Differential deflection(㎜)	Rudius of curvature(m)
Surfase course	0.311	0.075	120
(49kN wheel load)	(0.110)	(0.029)	(58)

Note : Enclosed in paretheses are standard deviations.

courses, from deflection and radius of curvature[1]. The results of estimating the elastic modulus of the surface concrete blocks by using this method are given in Table 3. The elastic modulus of the block course is estimated at about 4,300 MN/m^2. Considering the 3 cm thick bedding sand course as a part of the surface course, the average elastic modulus of the surface course is about 1,650 MN/cm^2. From this result, it can be seen that the deformation on the surface occurs chiefly due to the presence of the bedding sand course. By substituting these values in equation (1) proposed by Takeshita[2], the coefficient of relative strength to the asphalt mixture for surface course can be determined. The value thus obtained is about 1.05 for the surface course including the bedding sand course and about 1.63 for the concrete block course.

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

where,

a = coefficient of relative strength

E = elastic modulus of various materials (kgf/cm^2)

Now, two years after being put in service, this pavement maintains a high serviceability (Plate 1).

Table 3 Elastic moduli of block surface course

Course	Concrete block	Concrete block - Bedding sand
Elastic modulus	4,330	1,650
(MN/m^2)	(1,860)	(720)

Note : Enclosed in paretheses are standard deviations.

2.2 Noise characteristics

In the application to streets, traffic noise becomes an important point. Fig. 4 shows a comparison of the noise levels between concrete block pavement, asphalt pavement and concrete pavement. The noise level of the concrete block pavement is similar to or slightly lower than that of the other pavements for a dry surface and considerably lower for a wet surface. Especially at a vehicle speed of 40 km/h in the wet condition, the noise level of the block pavement is about 8 dB(A) lower than that of the concrete pavement and about 10 dB(A) lower than that of the asphalt pavement.

Fig. 5 shows the results of conducting a 1/3 octave band analysis. For the dry surface, there is little difference in the sound pressure level in the octave band between the different types of pavements, while for the wet surface the concrete block pavement exhibits a considerably low level in the high frequency region (over 1 kHz). This



Plate 1 General view of street pavement

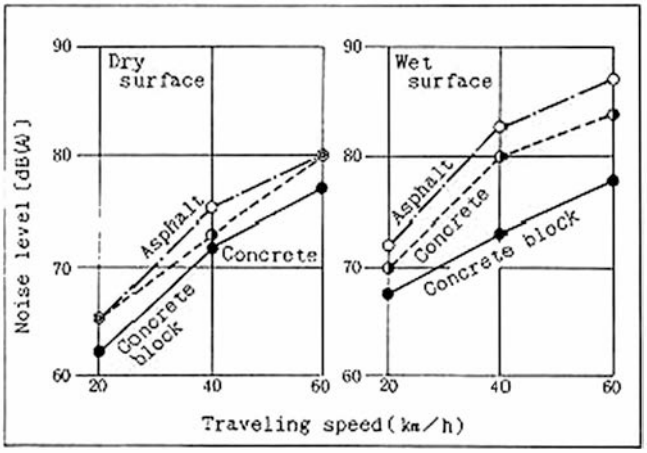

Fig. 4 Relation between traveling speed and noise level

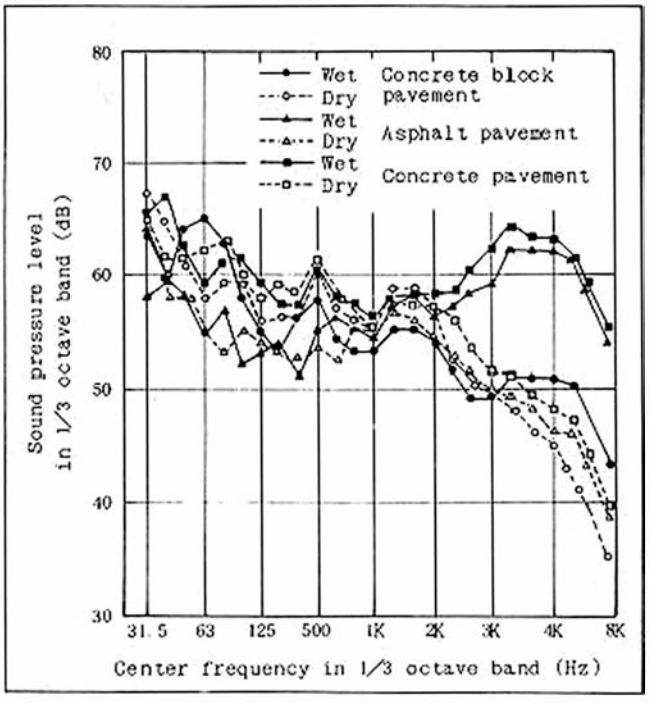

Fig. 5 Frequency components of each pavement

characteristic is observed irrespective of the vehicle speed. Therefore, it has become clear that the above-mentioned low noise level of the concrete block pavement in the wet condition is attributable to this reduction in sound pressure level in the high frequency region. With

the concrete block pavement, rain water flows out or permeates through the joints, so less water stays on the surface than with the other pavements. Therefore, the noise occurred from forced draining of surface water by tires decreases, which seems to contribute much to the reduction in sound pressure level in the high frequency region. This decrease in surface water has the merit of not only decreasing the noise level but also improving the driving property of vehicles.

2.3 Skid resistance

Skid resistance was investigated on the concrete block pavement and the asphalt pavement which were placed in service simultaneously. Tests were made using a portable skid resistance tester and following the method specified in ASTM. The results are given in Fig. 6. The skid resistance of the block pavement was at the same level as that of the asphalt pavement at the start of service but showed a slight decrease in the sixth month of service. Though its skid resistance was then low compared with that of the asphalt pavement, the concrete block pavement did not exhibit any further decrease and maintained a value similar to or higher than that of the asphalt pavement after the lapse of one year. This result agrees with the reports by S. Lekso[3] and Mavin[4].

In evaluating the skid resistance of the concrete block pavement, it is necessary to investigate the influence of the joints which are a special characteristic of this pavement. The above result is no more than the skid resistance of individual concrete blocks. Taking into consideration the influence of the joints, the skid resistance for traveling vehicles would show a higher value.

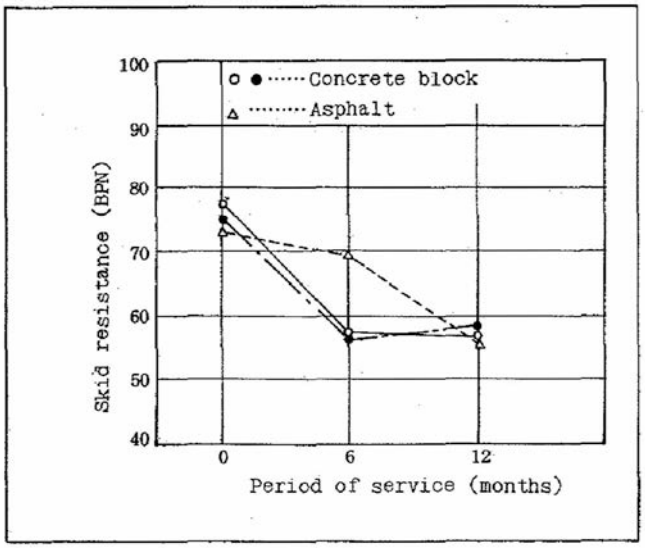

Fig. 6 Measured values of skid resistance

2.4 Consciousness survey of users

Six months after the start of service, a consciousness survey concerning the concrete block pavement was taken of the residents living in the area (188 persons including 78 women) and taxi drivers (120 persons).

Fig. 7 shows the results of the consciousness survey taken of the residents in the vicinity of the road laid with this pavement. It was pointed out by 81% of the residents that puddles would not form. Concerning noise and vibration, more than 80% answered "Unchanged", but the answers "Quiet" and "Decreased vibration" both showed a higher rate than the negative answers. Concerning walking comfort, more than 50% of the residents answered "Better" than ordinary pavements and it was only 16% that answered "Bad". The results of the survey taken of the taxi drivers are as shown in Fig. 8. Concerning riding comfort, 46% of the drivers answered "Good" and 41% "Unchanged", which substantiated that the joints constitute no obstacle to driving. Concerning the joints which are distinctive characteristic of this pavement, the answer "Indifferent" or "Not monotonous, so interesting" amounted to 76%. Perhaps reflecting this result, the answer "Inclined to speed down" amounted to 41%, while the answer "Inclined to speed up" was from only one of 120 persons. Thus a very interesting result was obtained for the street pavement.

Further, to the question of suitability as pavements in the urban area, 64% answered "Better" than the conventional asphalt pavement and it was only 15% that gave a negative answer "Unsuitable".

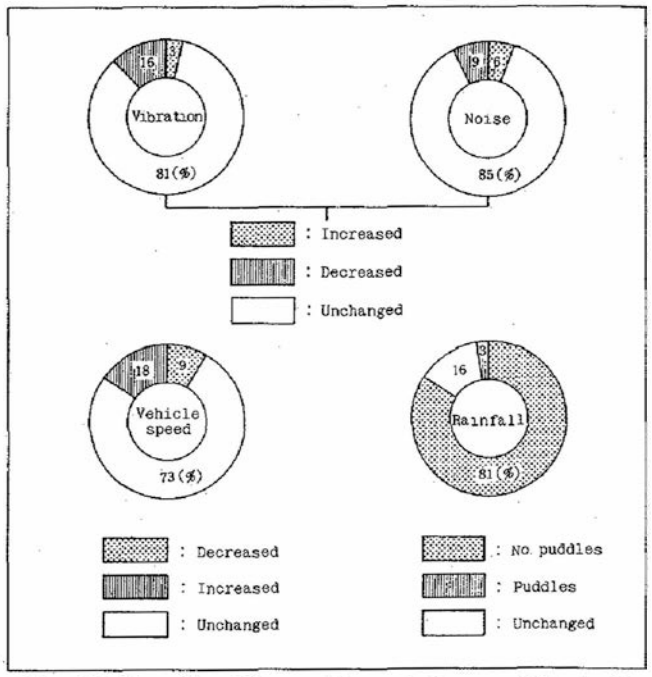

Fig. 7 Results of questionnairing residents in the vicinity of the road

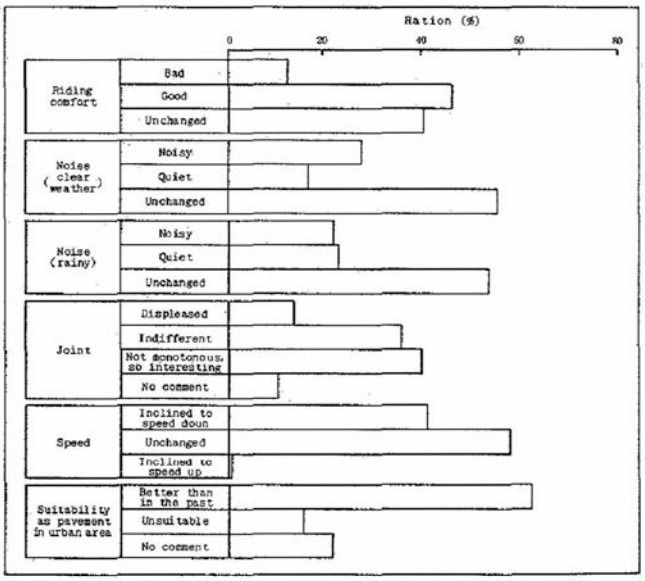

Fig. 8 Results of questionnairing taxi drivers

3. BUS BAY PAVEMENT

3.1 Structural evaluation

Structural evaluation was conducted by measuring the amount of deflection and its radius of curvature as the case of the street pavement. Measurements were made at the start of service, at the lapse of six months and one year.

Fig. 9 shows changes in deflection and differential deflection under the standard 49 kN wheel load (see Fig. 3). The amount of deflection decreased to about 0.4 mm, about 33% of that at the time of construction, by the sixth month of service and has maintained this value since then. This decrease in deflection is attributed to the increased effect of load distribution due to the progress of interlocking of concrete blocks under traffic and also to the increased strength of the cement

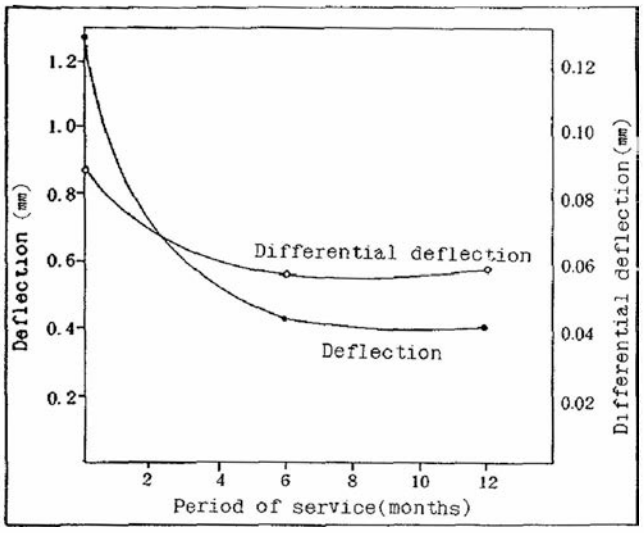

Fig. 9 Changes in deflection and differential deflection

stabilized base and the lime stabilized subgrade due to curing. Manifestation of these effects ended by the sixth month of service and the block pavement has been in a stable service condition since then. The differential deflection that is sensitive to the interlocking mechanism of blocks showed the same tendency as the amount of deflection.

The elastic modulus of the concrete block surface course estimated from deflection and radius of curvature has maintained a high value of about 3,900 MN/m^2 since the sixth month of service. Therefore the concrete block surface course can secure mechanically sufficient durability as a bus bay pavement.

3-2. Permanent deformation of surface

Although the deformational properties of concrete block pavement is similar to that of the asphalt pavement. A mechanical behavior of the concrete block pavement does not depend on temperature. This is quite dissimilar to the asphalt pavement. The surface temperature of the asphalt pavement rises above 55°C at its peak in Japan and then the stiffness of the asphalt mixture is about 300 MN/m^2 or lower. Thus, in the high temperature season, the resistance to flow fracture of the asphalt pavement decreases extremely. Figure 10 shows changes in the profile of the transverse direction. The amount of deformation after the lapse of one year is only about 3 mm maximum. The ordinary deformational failure patterns of the bus bay paved with asphalt are large rutting, conical cave, and waving while with the block pavement such damage is not observed. Now, 16 months after being put in service, the concrete block pavement maintains a high serviceability without exhibiting any such deformation which can be noticed visually. Thus the concrete block pavement can be said to be suitable for use on roadways with static loads such as bus bays.

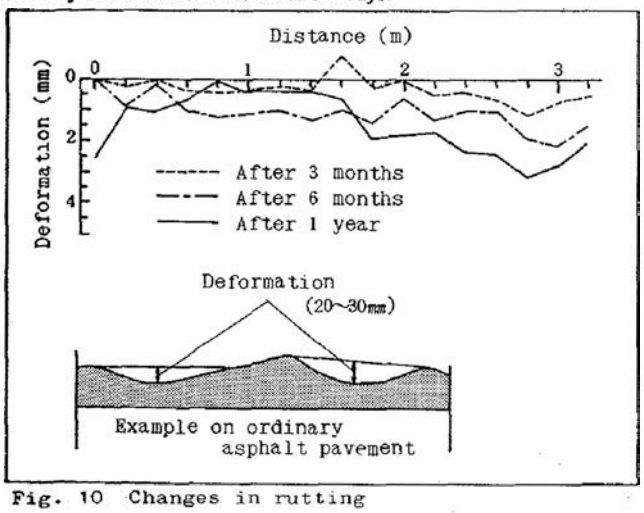

Fig. 10 Changes in rutting

4. SERVICEABILITY EVALUATION

Pavements always undergo external effects such as traffic load, weather conditions, etc., and their serviceability decreases with increasing period of service and finally reaches such a level at which smooth and safe traffic cannot be ensured. To prevent this, it is necessary to perform maintenance and repairs at a suitable time based on a fixed standard for judgement. What performs an important part as this standard for judgement is serviceability evaluation. In this evaluation, serviceability has to be related to surface performance and evaluated objectively and quantitatively.

From this point of view, the relation between the surface performance of the concrete block pavement and its serviceability is currently being investigated. The following are taken as performance parameters:

1) Depth of rutting
2) Longitudinal profile
3) Difference in level between blocks, or number of damaged blocks

The author et al. intend to conduct a follow-up survey concerning these parameters and, at the same time, to make a general evaluation of serviceability and thereby analyze the relation between surface performance and serviceability. And they will finally establish a serviceability evaluation formula of the following form:

$$H = 10 - a_1 D^{b_1} - a_2 \sigma^{b_2} - a_3 c^{b_3}$$

where,

H = general rating of serviceability (taking the value at the start of service as 10)
D = depth of rutting (mm)
σ = slope variance (mm)
c = difference in level between blocks (mm), or number of damaged blocks (%)

Assuming the relation between each parameter and the general rating of serviceability is as shown in Fig. 11, the performance parameters can

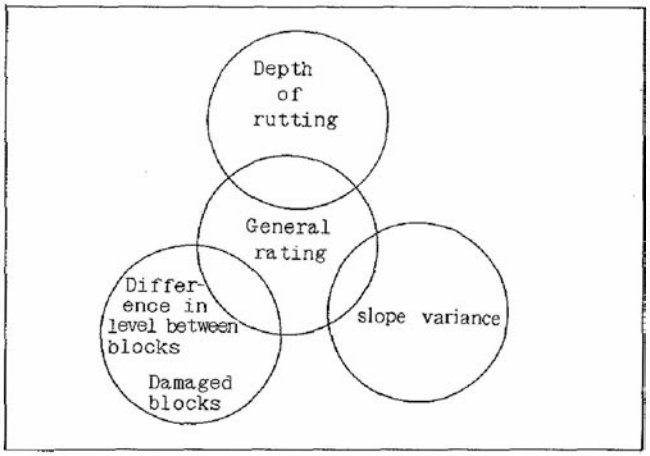

Fig. 11 Relation between general rating and surface quality parformance

be considered independent of each other. Therefore, the author et al. are thinking of establishing as a simple practicable method of evaluation by investigating also evaluation formulas based on two parameters or one parameter.

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