PERFORMANCE OF CONCRETE BLOCK PAVEMENT ON LOW-VOLUME ROAD

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SUMMARY

The Association of Hokkaido Interlocking Block Manufacturers has published a guide to structural designs of interlocking block pavement in Hokkaido on low volume road, with one-way daily traffic volumes of less than 250 truck passages. To Investigate the adequacy of the structural design method, a test road was built as a part of the approach road to a landfill disposal site in Sapporo city. The traffic volume and the gross weight of trucks on the approach road were measured with a weigh bridge. Four different types of concrete block pavement structures were included in the test road. Deflection and rut depth measurements were made to evaluate the performance of the concrete block pavements. The total number of 50kN equivalent wheel load, was 1879 wheel passages for the test period. An equivalent elastic modulus of the concrete block layer which is the assumed modulus of a layer consisting of both the concrete block layer and sand bed was backcalculated from deflection data using a falling weight deflectometer (FWD). The estimated equivalent elastic modulus varied from 200 MPa to 570 MPa before service, and after. The loading of 1879 passages it varied from 330 MPa to 1010 Mpa. The moduli increased with the number of passages. The magnitude of the equivalent elastic modulus is corresponding to the elastic modulus of asphalt concrete at about 50°C. Therefore the load spreading capacity of concrete block layer, with sand bed is equivalent to the load spreading capacity of asphalt concrete at high temperatures.

Introduction

A wide range of design methods for concrete block pavements have been published, and may be divided into four categories : 1) Design by experience, 2) Adaptations of design procedures for conventional flexible pavements, 3) Empirical designs based on full-scale traffic test, 4) Mechanically based designs with design parameters determined by laboratory tests. A performance evaluation of concrete block pavements designed by the different methods is necessary to establish more objective design methods.

This study reports the performance of test sections of a concrete block pavement designed by a modification of commonly adopted Japanese design procedures for conventional flexible pavements [1] by measurements of deflection and rut depth. A permissible strain in a subgrade on rutting are calculated by BISAR [2] with backcaluclations of elastic modulus of each layer. The measured rut depth is compared with rutting criteria related to the permissible strain and a number of load repetitions.

Structural Design Method for Low Volume Road

Guide lines for the structural design for interlocking block pavements in Hokkaido on low volume road, with less than 250 one-way truck passages a day was published in 1988 by the Association of Hokkaido Interlocking Block Manufacturers [3]. The design method is based on the following assumptions :

1) The load spreading capacity of concrete block layers with sand bed is equivalent to the load spreading capacity of asphalt concrete [4,51.

2) The design thickness of the pavement [1] depends on the design GBR of the subgrade, GBR (%), and the number of 50kN equivalent wheel loads over a design period of 10 years, N.

3) The thickness of the anti-frost layer is the difference between the depth of frost penetration and the design thickness [6].

The structural design method is for low volume roads with less than 250 one-way daily truck passages. Low volume roads are classified by the traffic on the roads. Table-1 shows the classification of roads and the total 50kN equivalent wheel loadings for a design period of 10 years.

Table-1 Road classification by traffic volume

Road Classification	One-way Daily Traffic Volum of Commarcial Vehicles	Total Number of 50kN Equivalent wheel Load for 10 years of Design priod
A	100 to 250	150,000
LI	40 to 99	30,000
L2	15 to 39	7,000
L3	5 to 14	1,500
L4	less than 5	220

With this design method, the total thickness of the pavement, H (cm), and the required thickness of a full depth asphalt pavement, TA (cm), are calculated by equations 1 and 2 :

$$H = 28 \cdot N^{0.1} / GBR^{0.6} \qquad (1)$$

$$TA = 3.84 \cdot N^{0.16} / GBR^{0,3} \qquad (2)$$

The thickness of individual layers are determined by equation 3 :

$$TA = a1 \cdot T1 + a2 \cdot T2 + a3 \cdot T3 \qquad (3)$$

where,
the coefficients of relative strength are
a1=1 for concrete block layer with sand bed,
a2=0.35 for crushed stone with GBR above 80%,
a3=0•25 for crushed stone with GBR above 30%,
and the thicknesses of individual layers (cm) are
T1= thickness of concrete block plus sand bed,
T2= thickness of base,
T3= thickness of subbase.

The coefficients of relative strength, a1-a3, indicate the ratio of 1 cm thick pavement materials to the strength of 1 cm of asphalt concrete. The relative strengths are a modified Structure Number, SN, for pavement materials determinated by the AASHO road test.

Two different thicknesses of concrete blocks were used for the pavements. An 80 mm thick block was used for A, L1, and L2 class roads and a 60 mm thick block was paved for L3 and L4 class roads. The thickness of the sand bed was 30 mm. The base consists of crushed stone which GBR above 80%. The subbase is crushed stone with GBR above 30%. Table-2 shows examples of structural designs of concrete block pavements for different road classifications and design GBR of subgrade.

Table-2 Examples of concrete block pavement structure design

Road Classification		A	L1	L2	L3	L4
Thickness of Concrete Block		80	80	80	60	60
Thickness of Bed Sand		30	30	30	30	30
Design GBR of Subgrade (%)						
3	Thickness of Base	100	—	—	—	—
	Thickness of Subbase	250	300	200	200	150
4	Thickness of Subbase	350	250	150	150	100
6	Thickness of Subbase	300	200	100	100	100
8	Thickness of Subbase	250	150	100	100	100
12	Thickness of Subbase	100	100	100	100	100

Test Road

A test road was built as a part of the approach road to a landfill disposal site in Sapporo city in October 1989, to evaluate the performance of concrete block pavements designed by the method. The traffic volume and gross weight of trucks on the approach road were measured by a weigh bridge. The test road had four sections corresponding to road classifications A, L1, L2, and L3. The value of the CBR in the subgrade of the road was 3%. The lengths of the sections are 10 to 20 m. Each test section is as shown in Fig.-1. Fig.-2 shows the pavement structures of the test sections. The total number of 50kN equivalent wheel loads for the test period was 1879 passages.

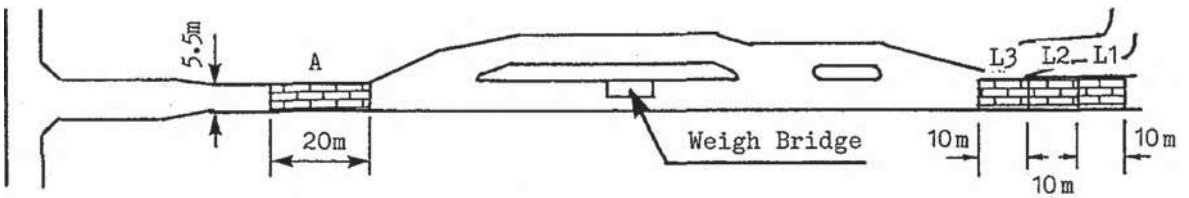


Fig.-1 Test section location

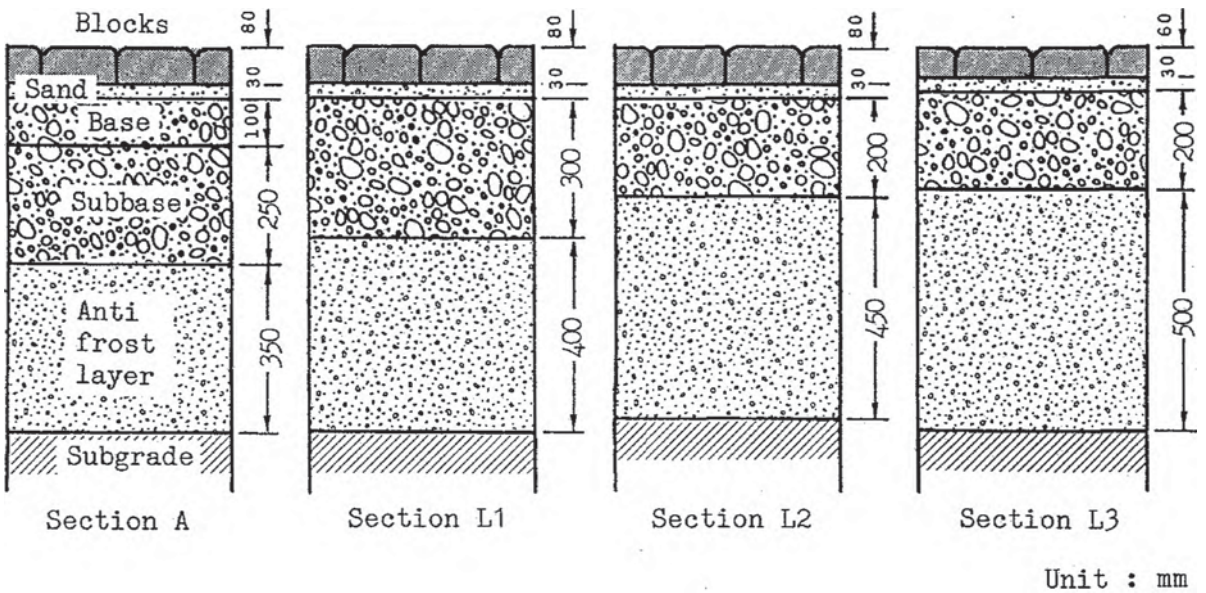


Fig.-2 Concrete block pavement structures

Deflection Measurements

Phonix type Falling Weight Deflectometer (FWD) was used for the deflection survey. The maximum loading capacity of the FWD is 50kN and the radius of the loading plate is 150mm. This instrument can measure deflections at the

center of the loading plate (DO) and also at points 300mm, 600mm, 900mm, 1200mm, and 2000mm from the center (D300, D600, D900, DI200, and D2000). The deflection measurements were carried out in November 1989 and April 1990. The mean values of twenty deflection tests and applied loads in each test section are shown in Table-3.

Surface deflections are strictly limited to usually less than 0.5 mm for both rigid concrete and asphalt pavements. This is to avoid load-associated cracking of the road surface. However, the surface of a concrete block pavement is forms sections by a network of joints, and this bind of pavement usually permits much lager deflections than conventional pavements. This means that the overall stiffness of a concrete block pavement can be lower than for a conventional pavement. Concrete block pavements may consistently be subjected to deflections of 2 mm or more under standard loads as shown in Table-3.

Table-3 Deflection data

	Test Sections							
	A		LI		L2		L3	
Date of Measurement	17 Nov… 1989	9 Apr. 1990	17 Nov. 1989	9 Apr. 1990	17 Nov. 1989	9 Apr. 1990	17 Nov. 1989	9 Apr. 1990
Load (kN)	45.55	49.18	48.42	45.71	48.62	49.16	39.61	49-04
0	1.872	1.681	1.788	1.809	1.870	1.617	1.935	1.622
300	0.965	1.006	0.931	0.933	0.986	0.830	0.945	0.859
600	0.575	0.572	0.489	0.465	0.520	0.455	0.475	0.464
900	0.516	0.511	0.348	0.337	0.357	0.327	0.326	0.342
1200	0.377	0.390	0.222	0.225	0.225	0.215	0.212	0.226
2000	0.219	0.226	0.121	0.132	0.137	0.128	0.119	0.121

Backcalculations

The method of estimating the in situ elastic modulus of the structural layer in concrete block pavements is as follows :

1) The pavement is stratified into three layers,the concrete block layer including sand bed, the granular base, and the subgrade including the anti-frost layer.

2) A theoretical deflection at 2000 mm from the center of the loading plate (62000) is obtained by BISAR for each assumed elastic modulus of the subgrade (E3).

3) The value of E3 can be estimated with the measured deflection (D2000) from the diagram of the relation between 62000 and E3 (Fig.-3). Lytton shows that the deflection far from the center of the loading plate depends directly on the elastic modulus of subgrade [7].

4) Since E3 is known, deflections at the center of the loading plate (60) and 300mm from the center (6300) are calculated by changing the equivalent elastic modulus of the concrete block layer (El), the assumed modulus of the layer consisting of both the concrete block layer and the sand bed, and the elastic modulus of the granular base (E2).

5) A diagram of curves of theoretical deflections with E1 and E2 as the parameters are prepared with 6300 on the abscissa and 60 - 6300 on the ordinate.
6) Plotting the co-ordinate of deflection data (D300, D0-D300) measured with the FWD in the diagram, yields El and E2 by interpolation (Fig.-4).

The elastic moduli estimated for each pavement layer by the method are shown in Table-4. The value of the equivalent elastic modulus of the concrete block layer including the sand bed lies between 200 MPa and 1010 MPa. These values are approximately equal to our results reported in the Proceedings of the Third International Conference on Concrete Block Paving [3]. Equivalent elastic moduli of concrete block layers range of about 250 MPa to 170,000 MPa have been reported [5]. The value of the equivalent elastic modulus of a concrete block layer depends on the treatment of the sand bed layer.

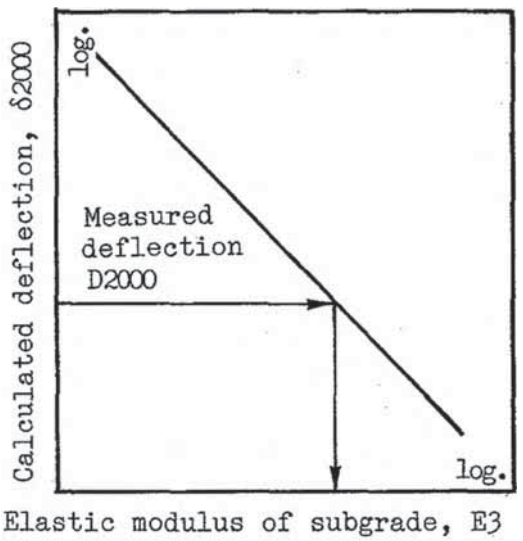


Fig.-3 Illustration of relationship between elastic modulus of subgrade and calculated deflection.

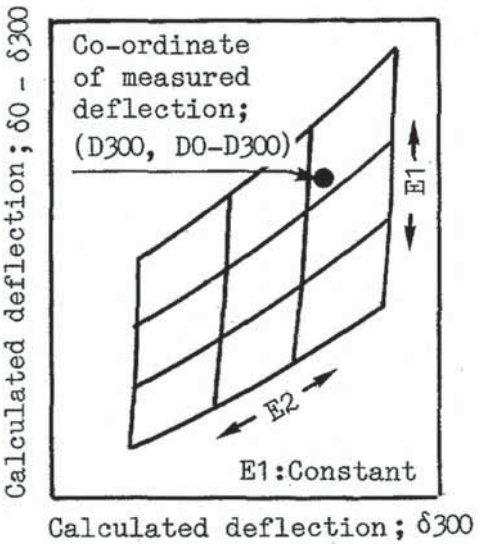


Fig.-4 Illustration of estimation method of E1 and E2.

Table-4 Estimated elastic moduli of each pavement structural layer

	Test Sections							
	A		L1		L2		L3	
Date of Measurement	17 Nov. 1989	9 Apr. 1990	17 Nov. 1989	9 Apr. 1990	17 Nov. 1989	9 Apr. 1990	17 Nov. 1989	9 Apr. 1990
El (MPa)	200	330	510	650	570	530	540	1010
E2 (MPa)	150	140	51	31	50	59	38	78
E3 (MPa)	27	30	45	44	46	50	34	50

Permanent Deformation

Like asphalt pavements, concrete block pavements exhibit permanent surface deformations or rutting under traffic. A rutting criterion is used to assess the performance of concrete block pavements. The terminal levels of rutting of asphalt pavements where maintenance is required ranges between from 13 mm for freeways, to 40 mm or more for low traffic volume roads. Similar rutting may be deemed acceptable for concrete block pavements and a terminal rut depth of 25 mm is suggested as the limit to serviceability of concrete block pavements in the structural design of interlocking block pavements in Hokkaido on low volume roads.

Measurements of rut depth on each test section were carried out by the profilemeter before service on the test road and after 1879 wheel passages. The traverse profiles of each test section are shown in Fig-5. Increasing thickness of the blocks /base/subbase normally reduces the rut depth caused by traffic.

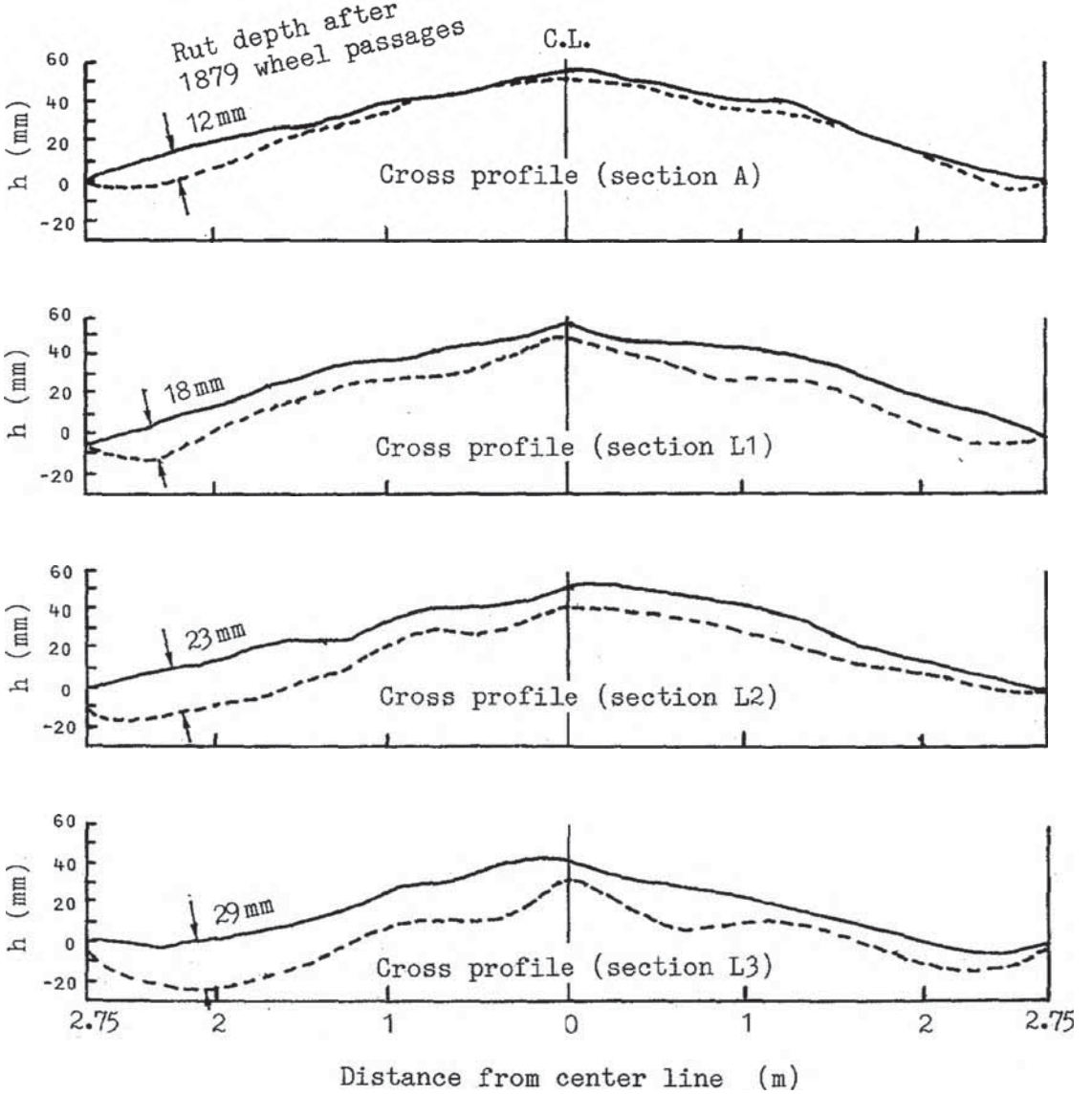


Fig.-5 Transvers profiles of test sections

Permissible Strain in Subgrade

A number of subgrade strain criteria relate to the amount of rutting for asphalt pavements. Fig.-6 shows a comparison of acceptable subgrade strains [8], The agreement is poor because of the very different terminal criteria used. Some of the terminal rut depths are shown in Fig.-6.

The vertical compressive strain generated at the top of a subgrade by a standard wheel load for each test section is calculated by BISAR. The calculations use the E1, E2, and E3 estimates for each test section based on deflection data measured 17 November 1989. The loading conditions of the standard wheel used here are : dual wheels each with loads of 25 kN, radius of contact area 132-5 mm, and distance between wheel centers 340 mm. Table-5 gives the calculated strains in the subgrade for the four test sections. The co-ordinate of the calculated strain and the number of load repetitions (1897 wheel passages) is plotted for each test section in Fig.-6. The co-ordinate of section L3 lies between the NAASRA and Asphalt Institute values. The other co-ordinates plot under the TRRL values. This indicates that subgrade strain criteria related to specific amounts of rutting of asphalt pavements are useful in the structural design of concrete block pavements.

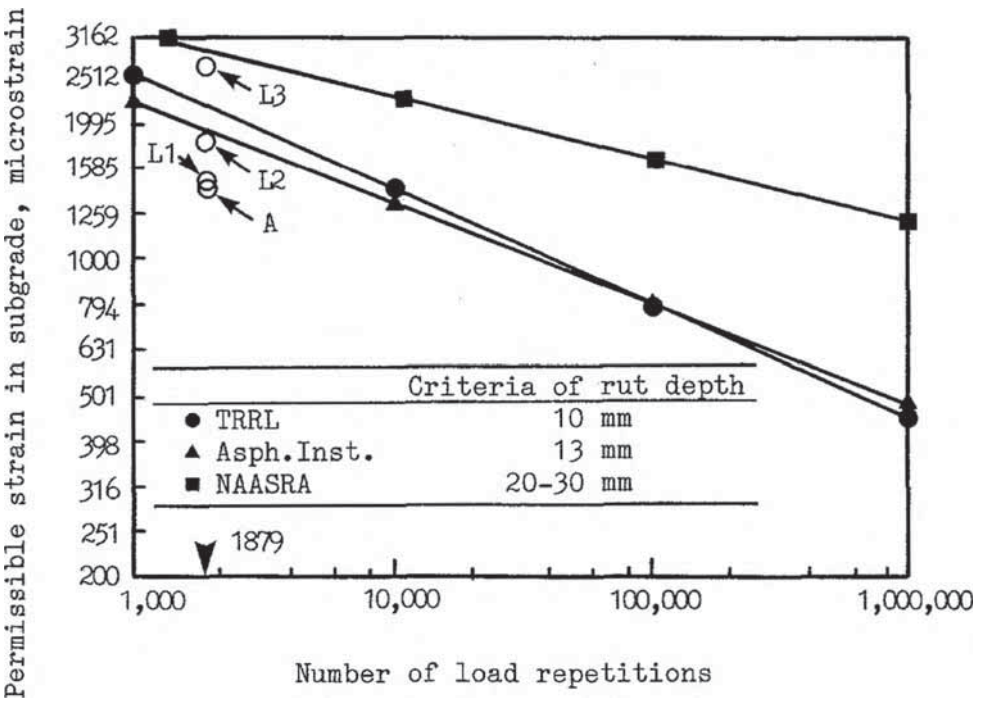


Fig.-6 Subgrade strain criteria. After Per Ullldtz [8]

Table-5 Estimated strain in subgrade

	Test Sections			
	A	L1	L2	L3
Strain (microstrain)	1420	1440	1790	2630

Conclusions

Measurements of deflections using FWD and rut depths were carried out on a low traffic volume test road with four types of concrete block pavements. The performance of the concrete block pavements was evaluated, and the major results of the study may be summarized as follows;

1) The equivalent elastic moduli of the concrete block layer which is the assumed modulus of the layer comprising both the concrete block layer and the sand bed layer is between 200 MPa and 1010 MPa.

2) The load spreading capacity of a concrete block layer with the sand bed is equivalent to the load spreading capacity of asphalt concrete at about 50 °C.

3) Subgrade strain criteria related to a certain amount of rutting for asphalt pavements is useful for the structural design of concrete block pavements.

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