IN-SERVICE CONDITION OF IL BLOCK PAVEMENT CONSTRUCTED AS A COUNTERMEASURE TO PLASTIC FLOW

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ABSTRACT

Roadway paved with interlocking (IL) block sometimes suffers functional damage due to loss of joint sand and fining of bedding sand. Thus the quality criteria of sand used for joint or bedding is critical for maintaining pavement function. Currently there are no data for performance of IL block used for a roadway section with heavy traffic load, or for cost comparison between IL block pavement and asphalt pavement. We conducted a laboratory test and confirmed that the defining of criteria for the grain shape and hardness of bedding sand is effective in preventing fining and deformation of such sand. Based on the laboratory tests, we constructed IL block pavement on a road section with heavy traffic load in Tomakomai, Hokkaido. This paper introduces an evaluation method and a quality criterion for bedding sand used in IL block pavement and for roadway. It also reports performance of IL block pavement applied as a countermeasure to asphalt flow rutting after three years in service, and cost comparison between IL block pavement and asphalt pavement.

1. INTRODUCTION

With application of IL blocks for roadway pavement, reports of functional distress such as loss of joint sand, rutting caused by subsidence attributed to bedding sand of inadequate quality, unevenness between blocks, and movement of blocks have increased throughout Japan. This distress not only spoils the block's appearance as a landscaping material; it also causes functional deterioration of the block and endangers pedestrian safety. Furthermore, when a vehicle passes the distressed point, noise and vibration attributed to the distress may affect the surrounding environment.

Therefore, attention was focused on grain shape and hardness, rather than just on grading which has been the conventional quality standard for bedding sand of roadway pavement. The relationship between grain shape and hardness and that between fining and deformation were examined by laboratory tests.

This paper introduces quality standards and evaluation methods for bedding sand and joint sand, which are regarded as important factors in the paving of roadway by IL block. Furthermore, this paper reports the performance of IL block used as a material for resisting plastic flow on a heavily trafficked road. The paper concludes with issues for future

examination.

2. SELECTION OF BEDDING SAND

2.1 Procedure for the Selection

We attempted to develop a method of selecting the sand most suitable for use as a cushion for roadway pavement, through laboratory tests. Six types of material that had been used as bedding sand for IL block pavement in and around Tomakomai were selected: five river sands (A, B, C, D and E) and one sea sand (F).

2.2 Test Method and Results

The test methods for bedding sand and their results follow.

2.2.1 Sieve Analysis Test

The sieve analysis test was carried out according to JIS (Japanese Industrial Standard) A 1102. All six of the bedding sands had continuous grading and were classified into three categories according to the cumulative mass percentage passing 600 /zm standard sieve: 80% or more, around 70% and 50% or less. Three sands (A, E and F) fell into the first category. One sand (B) fell into the second, and two sands (C and D) fell into the third. Their FM values were 1.5-1.9, 2.0 and 2.6-2.8. That 90% of cumulative mass percentage of sand D passed 2.36 mm standard sieve indicates it had a larger volume of coarse grain. It follows that sand D has little filling ability as joint sand.

2.2.2 Hardness of Bedding Sand

The hardness of bedding sand was tested by impact compaction test and crushing test. The impact compaction test was performed in accordance with JIS A 1210. Bedding sand in the state of natural water content was put into a mold ordinarily used for CBR test, and was punned 67 times per layer by 4.5-kg rammer. The hardness was evaluated from the grading difference between pre- and post-punning.
The crushing test was performed by making the grain size of bedding sand uniform (0.3-0.6 mm in diameter), leveling the bedding sand to a thickness of 2 cm in a Marshall mold, and punning it 100 times with 4.5-kg rammer. The hardness was evaluated from the grading difference between pre- and post-punning.

2.2.3 Dry Viscosity (DV) Test

The DV test that is ordinarily used to evaluate the grain shape of fine aggregate was used to evaluate the grain shape of each material. First the grain size of test sand was made uniform (0.6-0.3 mm diameter). The time required for 500 g or 680 cm^3 of sand to run through the instrument was measured. The measured value was used for evaluation of the

grain shape of each material.
Sand with the same grading (0.6-0.3 mm diameter) was tested (Table 1). Although the sand had the same mass or volume, and the same instrument was used, sand A and sand B had larger DV values than the other sands. In DV test, the grain shape could be evaluated by the conventional method in which the mass of test materials is kept the same (500 g).
The materials chosen for the deformation test were B, C and E, and F. In addition, a deformation test was made for #7 crushed stone, which has been used for construction in Germany.

Table 1 Results of laboratory test

type of cushion sand	sieve analysis		FM	percentage of mass passing through 75 μm sieve before/ after compaction test (%)		percentage of mass passing through 75 μm sieve before/ after crushing strength test (%)		DV test (sec.)		displacement (mm)	
	2.36 mm	600 mm		before	after	before	after	mass (g)	volume (cc)	dry	wet
River sand A	98.8	80.3	1.74	4.8	6.3	0	7.5	40”90	52”26	-	-
River sand B	96.8	67.5	2.04	4.6	6.0	0	7.7	39”58	52”57	10.65	11.07
River sand C	95.6	45.1	2.68	1.4	1.2	0	2.4	27”90	50”12	8.62	8.81
River sand D	90.0	45.5	2.74	1.3	1.5	0	2.0	25”81	49”66	-	-
River sand E	99.9	87.1	1.87	1.3	1.3	0	2.4	26”74	49”09	11.82	5.98
Sea sand F	97.4	85.3	1.54	0.7	1.3	0	1.0	24”30	48”09	6.54	4.66
#7 Crushed stone	4.8	-	-	-	-	0	5.1	-	-	10.05	-

2.2.4 Deformation Test of Sand

The deformation of sand was tested by the wheel tracking test that has been widely used for the design and quality control of asphalt mixture. The test piece was made with IL blocks of 3 cm in thickness and bedding sand of 2 cm in thickness (Figure 2). A wheel load of 688 N (70 kgf) was loaded along the center (B and C in Figure 2) of the test piece

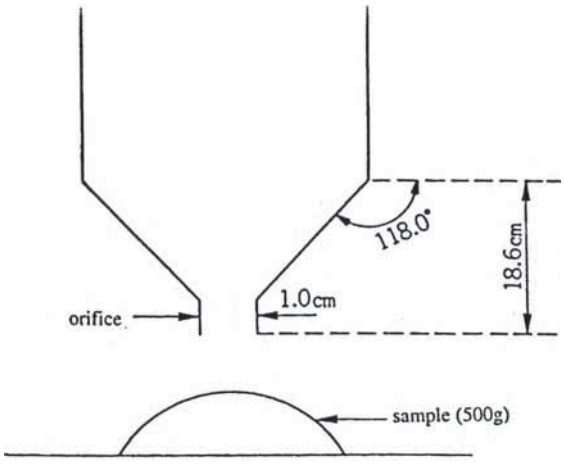
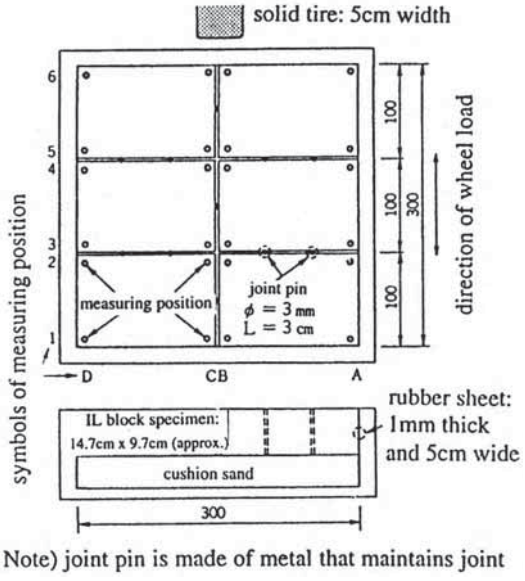


Figure 1 Scheme of Dry Viscosity Test



Note) joint pin is made of metal that maintains joint

Figure 2 Test Piece

1000 times each in dry state and wet state. Displacements along the center (B, C) and along both edges (A, D) of the test piece were measured after loading, and deformation was evaluated by adding the deformation along the center to that along the two edges. After 1,000 times of wheel loading, the materials were arranged in Table 1 in decreasing order of deformation. For dry condition, the order is F, C, #7 crushed stone, B, and E. For wet condition it is F, E, C, and B.

These four tests show that type F has the smallest DV value (24.30 sec), little change after grinding in the impact tests (the change in mass passing 75 μm standard sieve is 1%) and little deformation in the wheel tracking test. Accordingly, it was decided to use F as bedding sand for the heavily trafficked road in Tomakomai. Another reasons for using F as joint sand was that not only is its DV value small but 97.4% of mass passed 2.36 mm standard sieve.

Moreover, #7 crushed stone is considered unsuitable as bedding sand on heavily trafficked roads because of its greater susceptibility to grinding and deformation than that of F or C.

3. LAYING OF IL BLOCK PAVEMENT

IL block pavement was installed on a trunk road connecting the Tomakomai port ferry terminal to a national highway leading to Sapporo. Traffic volume survey of the route in 1997 found large commercial vehicles to account for 1,989 vehicles/day of the 6,024 vehicles/day in the left lane and 1,065 of the 3,208 vehicles/day in the right lane. Therefore, the road is classified as having class-C traffic volume (passage of 1,000 - 3,000 large commercial vehicles / day-direction).

The section between the viaduct and the intersection has two Sapporo-bound lanes. There is an additional lane from the approach to the intersection where National Highway 36 merges with the route, thereby making three lanes. Therefore, pavement on the approach to the intersection is exposed to the particularly severe conditions of a large number of vehicles stopping and starting on the section. On this route, anti-freezing pavement and wear-resistant pavement of dense-graded asphalt concrete were installed in 1994. However, plastic flow occurred and potholes appeared. Therefore, maintenance repairs such as cutting and overlay, and patching have been made yearly. Under these circumstances, IL blocks were installed on the ferry terminal side of the approach to the viaduct between 1996 and 1997.

A core sample of conventional pavement showed that the pavement structure of the approaches to the intersection differed from that of nearby sections. Therefore, to find the boundary between the two different pavement structures, deflection was measured by handy falling-weight deflectometer (HFWD) every 50 cm from 11 m to 19 m before the intersection (Figures 3(1) and 3(2)). Those deflections that ranged from 0.027 to 0.045 mm were measured between 11.0 and 14.5 m before the intersection. In contrast, those deflections that ranged from 0.083 to 0.158 mm were measured between 14.5 m and 19.0 m before the intersection, values that are three times those of the section between 11.0 m and 14.5 m before the intersection. Consequently, the boundary of the two different pavement structures is estimated to be 14.5 m before the intersection.

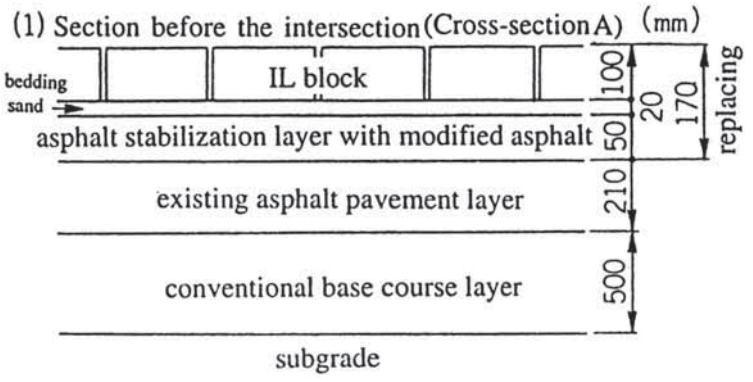


Figure 3 (1) Intersection Approach (Cross-section A)

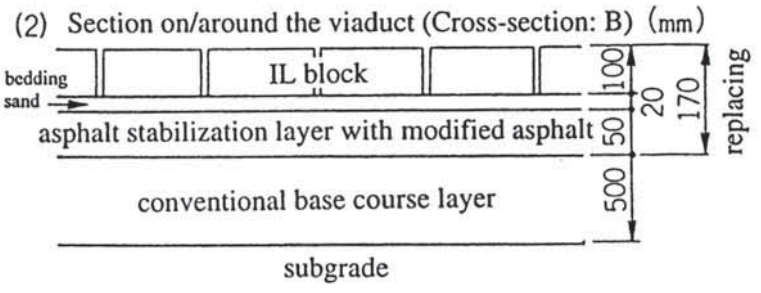


Figure 3 (2) Near Viaduct (Cross-section B)

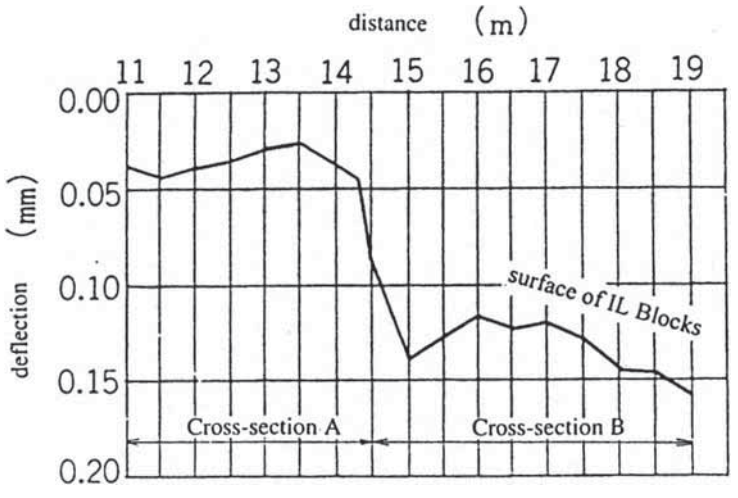


Figure 4 Cross-sectional Change of HFWD Deflection

4. FOLLOW-UP SURVEY

To observe the change in unevenness of IL block pavement since start of service, a follow-up survey was performed. The survey targeted the lane that had a great volume of large commercial vehicles traveling toward Sapporo from the ferry terminal.

4.1 Lateral Unevenness

The lateral unevenness of IL block pavement was measured at 10-cm intervals by laser profiler. The sharp fluctuations in Figures 5 and 6 are probably a consequence of the laser beam being emitted at the joint sand and the laser profiler not being able to discern the reflection. The lateral profile at the intersection approach where the original, remaining asphalt mixture layer is an average of 21 cm shows little rutting after two and a half years in service (Figure 5). In contrast, the lateral profile near the viaduct (cross-section B) shows that rutting due to thin thickness of the original asphalt pavement of 5 cm occurred in the center vehicle lane after a half year in service (Figure 6). After the survey, the unevenness progressed greatly and rutting depth reached between 10 mm and 20 mm. A cutting survey was made after 11 months in service.

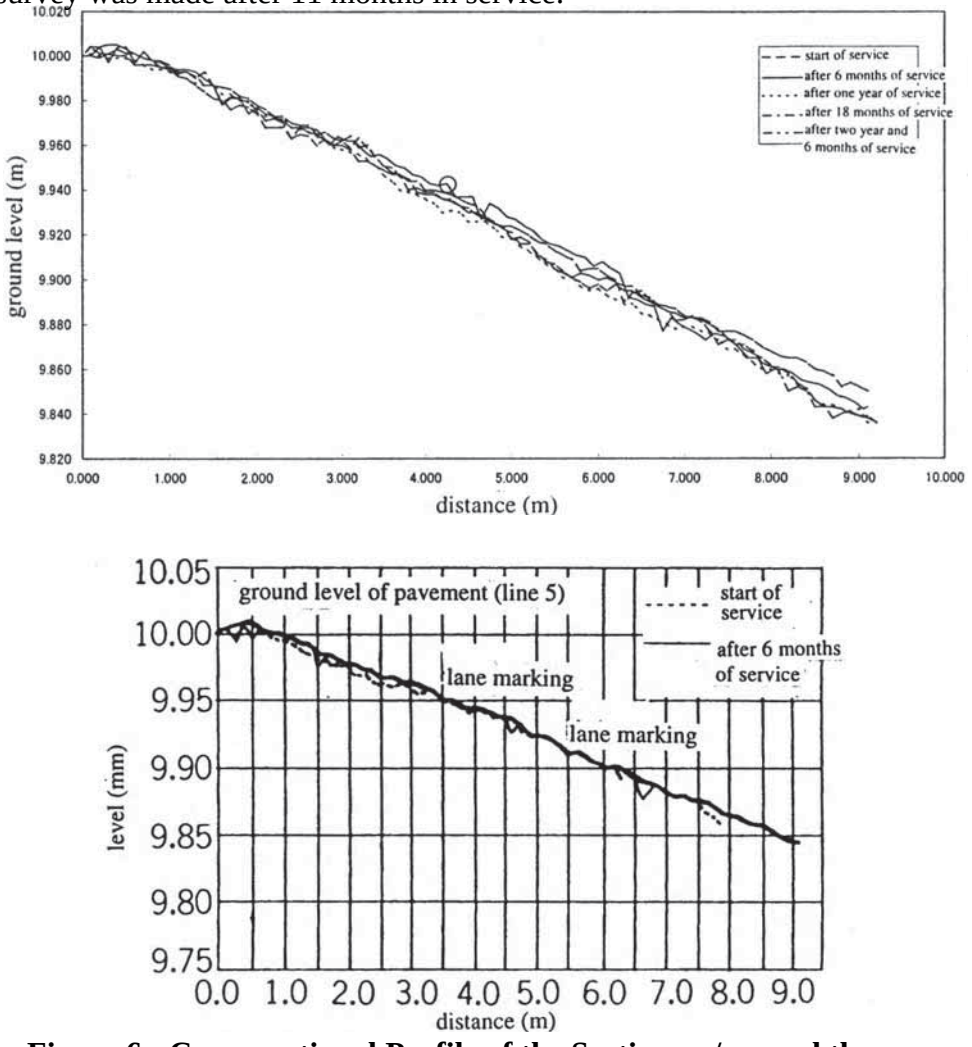


Figure 6 Cross-sectional Profile of the Section on/around the Viaduct after 6 Months of Service (B-B)

4.2 Deflection Measured by FWD

Figure 7 shows the variations in deflection of IL block in service. The deflections (D_o) are compared in terms of thickness of asphalt mixture layer. The section with 26 cm of asphalt mixture layer (cross-section A) showed a deflection of 0.11 mm after cumulative passage of 140 million large commercial vehicles on both shoulders and center of roadway. The section with 5 cm of asphalt mixture layer (cross-section B) showed a deflection of 0.8 - 0.9 mm, which is about 8 times as large as that of cross-section A. Also, trends of deflection of these sections A and B are largely different (Figure 8). It is considered that the sections with thin asphalt mixture layer have insufficient bearing capacity in the layer of base course and below it.

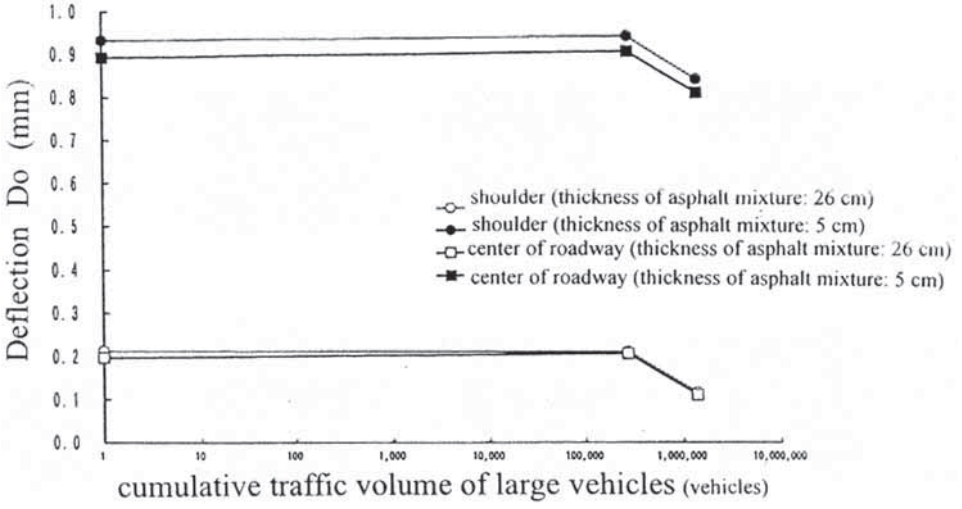


Figure 7 Changes in Deflection

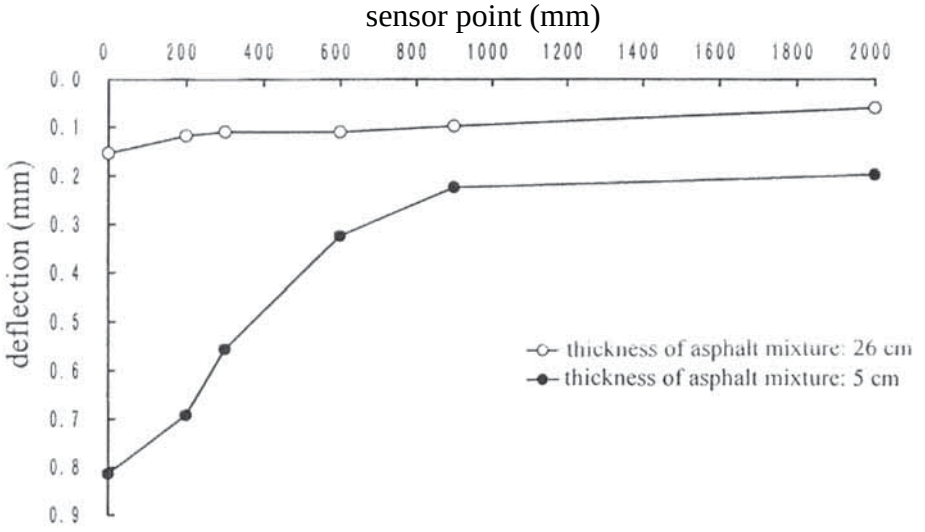


Figure 8 Comparison of Deflection Condition

5. CUTTING INVESTIGATION

The rutting of the IL pavement occurred for about 120 m between the viaduct and 15 m

before the intersection. The depth of rutting reached about 10 to 20 mm, and joint sand was lost where the rutting occurred, after 11 months in service or when the cumulative passage of large commercial vehicles reached 500,000 vehicles.
A cutting investigation was made to discover the cause of rutting on the center lane of the slope near the viaduct and on the flat part before the intersection where rutting was concentrated. Lateral profile was measured by leveling cord and deflection was measured by HFWD on the surface of IL blocks and asphalt stabilization layer, at 20-cm intervals.

5.1 Lateral Profile Measured by Leveling Cord

An example of the lateral profile measured by leveling cord makes it clear that the rutting of IL block is attributable to the deformation of the bedding sand and the asphalt stabilization layer (Figure 9). The reason the rutting occurred only in the center lane is that almost all large vehicles arc fully loaded and drive in the center lane where the number of lanes became three at the approach to the intersection with National Highway 36.

5.2 Deflection Measured by HFWD

Cross-sectional deflection was measured by HFWD at the surface of IL block and asphalt stabilization layer (Figure 10). Figure 10 shows that deflection of the rutted part exceeds that of the other part, for both IL block and asphalt stabilization layer. Accordingly, we found some fluctuations of bearing capacity in the lateral direction.
The rutting occurred from 15 m before the intersection to the viaduct. The point that corresponds to the boundary of two different pavement structures (14.5 m) was estimated from the longitudinal deflection (Figure 4). The above indicated that the rutted part corresponded to the part with thin pavement structure. The repeated deflection in this part exceeds that of the other part because of its thin asphalt mixture layer of 5 cm. Accordingly, the bedding sand and the asphalt stabilization layer were deformed, and rutting finally occurred.

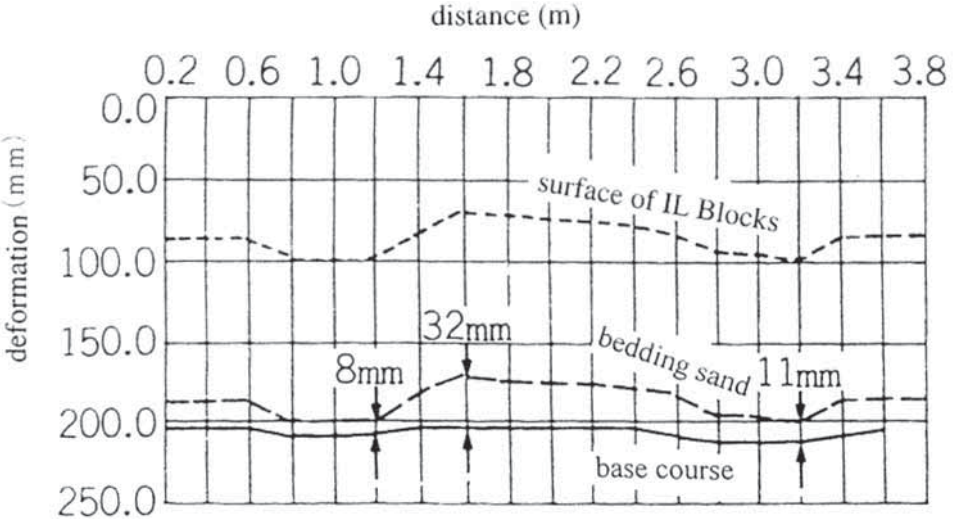


Figure 9 Cross-sectional Profile of Respective Pavement Layer

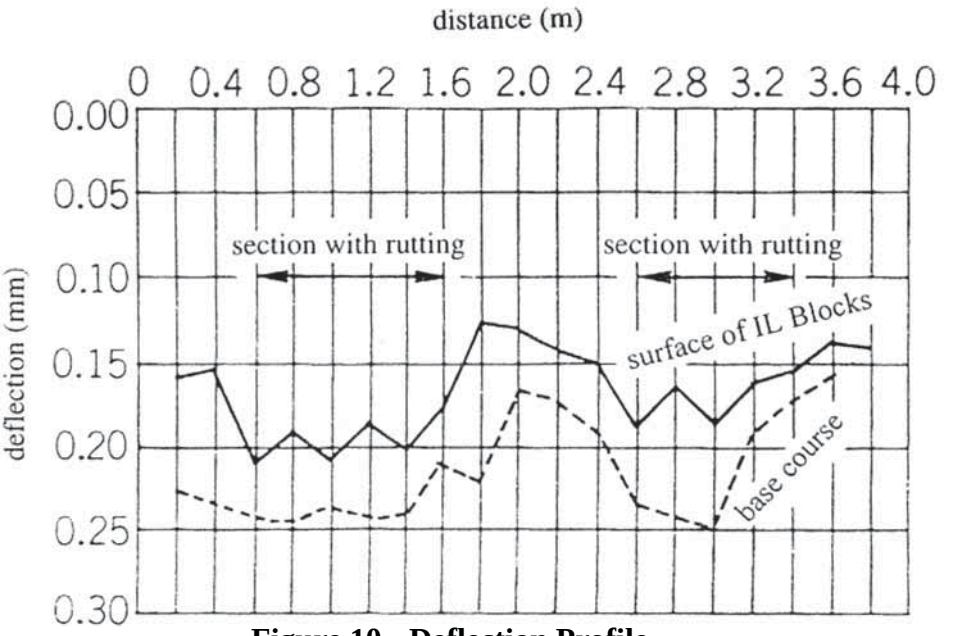


Figure 10 Deflection Profile

6. COMPARISON WITH ASPHALT PAVEMENT

6.1 Durability Comparison

The wearing of IL block was remarkable due to the heavy traffic of the researched route. In addition, loss of bedding sand and joint sand was observed. However, the situation is stable today and there is no need for repair.
Whereas conventional dense-graded asphalt mixture concrete pavement required annual maintenance work such as cutting and overlay, IL block pavement performs better and greatly decreases the maintenance work.

6.2 Ice and Snow Control

The City of Tomakomai takes various countermeasures to skidding on winter roads. IL block is one of such measure, and it is installed around the city. Because IL block has many more joints than do other methods and has a rough surface, its skid resistance coefficient exceeds that of other pavements. It is an effective solution because of its ease of maintenance and high durability.

6.3 Cost Comparison

Table 2 Cost Comparison

Structure	Fine graded GAs Cause graded GAs Asphalt stabilization	IL Block sand
Thickness	t = 4cm t = 5cm X 2 t = 3 cm	t =10 cm t = 2 cm Asphalt stabilization: t = 2 cm
Cost	approx. 4,000 yen/m^2	approx 8,800 yen/ m^2

The unit costs of IL block pavement and asphalt pavement are compared (Table 2). Although asphalt pavement costs half of what IL bock pavement costs, it requires winter anti-skidding measures at intersection with longitudinal gradient, such as that discussed in this paper. In contrast, IL block pavement does not require skid resistance measures because it has joints and the block surface is rough in texture. In light of this, we can consider that their initial cost may be the same.

7. CONCLUSIONS

The results of the laboratory tests and the follow-up survey are summarized as follows.

(1) Deformation attributed to fining of the bedding sand can be mitigated to a certain degree by including specifications for hardness and grain shape in addition to the specification for grading, which has been the quality standard of bedding sand for roadway pavement.

(2) The grain shape of bedding sand can be evaluated by DV test, and the hardness of bedding sand can be evaluated by crushing test.

(3) Regarding a proposed specification for quality of bedding sand, the laboratory tests suggest that it should be about 25 seconds for DV value and 1 % or less for difference between the mass percentage passing 75 /rm standard sieve pre- and post-punning in the crushing test.

(4) Even if a quality specification for bedding sand is included, rutting due to subsidence will occur where the asphalt mixture layer in the base course is thin, such as near the viaduct. This is because that part will suffer from strong repeated deflection due to insufficient bearing capacity.

(5) The IL block can function suitably as a plastic flow resistant pavement by preventing deformation caused by the fining of bedding sand.

(6) IL block pavement is superior to asphalt pavement in durability, even under severe traffic load. It is effective as a countermeasure to skidding in winter, and it is easy to maintain.

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