REPORT ON THE SURVEY AND REPAIR OF INTERLOCKING BLOCKS USED FOR TEN YEARS AT HEAVY-TRAFFIC BUS TERMINAL

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ABSTRACT

There are a limited number of applications of interlocking blocks for sites subject to heavy commercial traffic in Japan. This study investigated an interlocking block pavement used for 10 years at a major heavy-traffic bus terminal. The interlocking block pavement had been subjected to heavy traffic of about 550 large route buses operating daily. Furthermore, traffic conditions were severe, with frequent braking, stopping, starting, movement and cornering of buses causing extensive damage. The ten years of service had thus caused severe deterioration in the pavement, including certain types of damage specific to interlocking blocks such as local settlement, faulting and breakage (corner breakage) of the blocks and the consolidation or lateral migration of bedding sand.

This paper describes the results of a pavement investigation , which was performed to identify the cause of damage to the pavement used for 10 years at the heavy-traffic major bus terminal, and reports on the repair method (improvement work) that was subsequently adopted.

1. INTRODUCTION

Ikebukuro Station is one of the busiest railway stations situated in the heart of an entertainment district of central Tokyo, surrounded by many popular facilities. The major bus terminal on the west side of the station had been paved with interlocking blocks (hereafter, “block pavement”) in May 1990.

Because of the heavy traffic at the terminal, where about 550 large route buses operate daily, the pavement was becoming severely damaged by the braking, stopping, starting, movement and cornering of buses over the years. Some types of damage specific to the block pavement were observed, such as local settlement, faulting and breakage (corner breakage) of blocks and the consolidation and lateral migration of bedding sand. To identify the causes, a pavement investigation was carried out in August 2000, at which time the pavement had been in service for ten years. Based on the results, a suitable repair method was proposed and implemented , and the pavement was back in service in September 2002.

This paper describes the results of the investigation and test pits excavated to identify the causes of the distress and reports on the repair method (improvement work) that was subsequently adopted.

Proceedings of the 7th International Conference on Concrete Block Paving (PAVE AFRICA 2003) 12th – 15th October 2003
ISBN Number: 0-958-46091-4 Sun City, South Africa
Proceedings produced by: Document Transformation Technologies Conference Organised by: Conference Planners

2. PAVEMENT OUTLINE

2.1 Pavement configuration

The original configuration of the pavement is shown in Fig. 1. The characteristic features were the use of 15-cm thick concrete slab as the base and dry mixed mortar (sand mixed with cement in the ratio of 3 to 1 by weight) as the bedding sand.

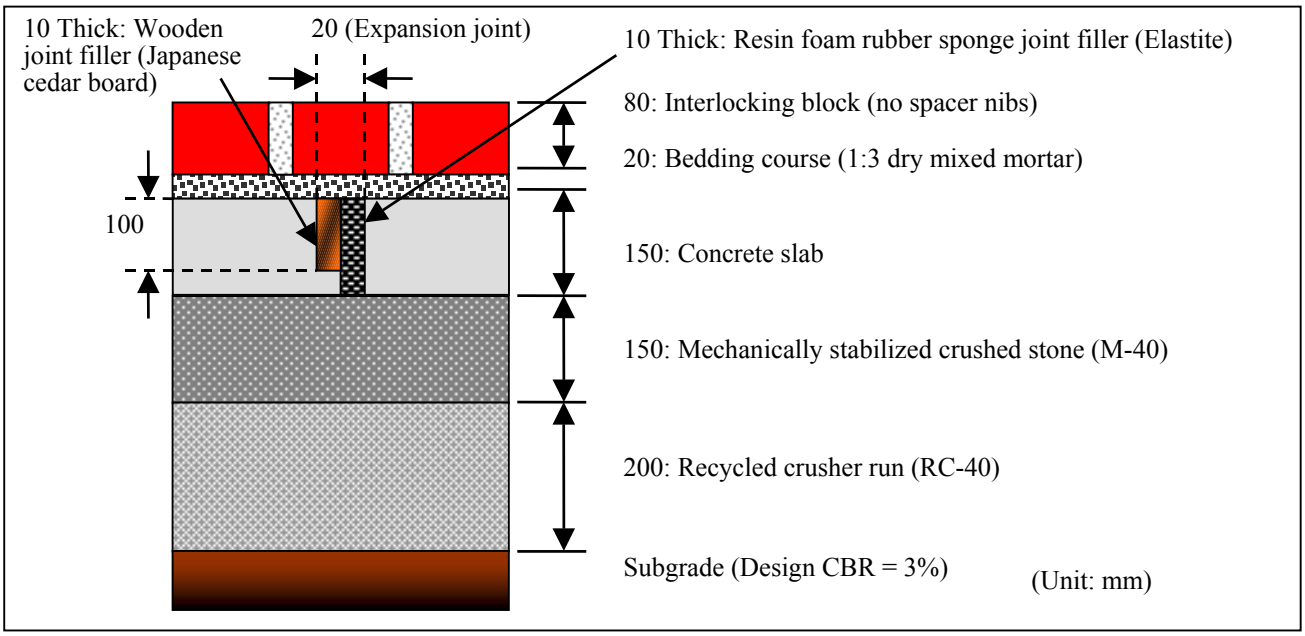


Figure 1. Pavement Configuration.

2.2 Shape and dimensions of the blocks and their laying pattern

The original shape and dimensions of the blocks and their laying pattern are shown in Figs. 2 and 3, respectively. Each block had a wavy-sided rectangular shape and had no spacer nibs. The laying pattern was the 90-degree herringbone bond.

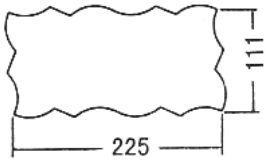


Figure 2. Block shape and dimensions (unit: mm) (Wavy-sided rectangular, no spacer nibs)

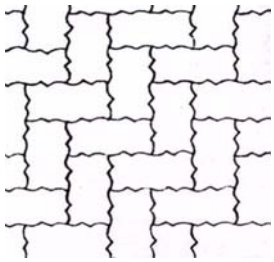


Figure 3. Laying pattern. (90-degree herringbone bond)

2.3 Traffic volume and accumulated number of equivalent 5-ton wheel loads

The area of block pavement at the bus terminal was about 1,260 m^2. As shown in the schematic drawing of Fig. 4, the terminal had 7 bus bays (bus stops) used by 554 buses in each direction per day on average, giving a total annual traffic volume of 202,210 buses in each direction. Because the passenger occupancy of buses (two-axle type) departing from the terminal was about 50%, the number of equivalent 49 kN wheel loads was calculated to be 1,741,028 (in the exit area); the terminal was thus identified as Class "C" (49 kN wheel loads/direction/10 years: 1,000,000 to 7,000,000) under the traffic classification of Japan.

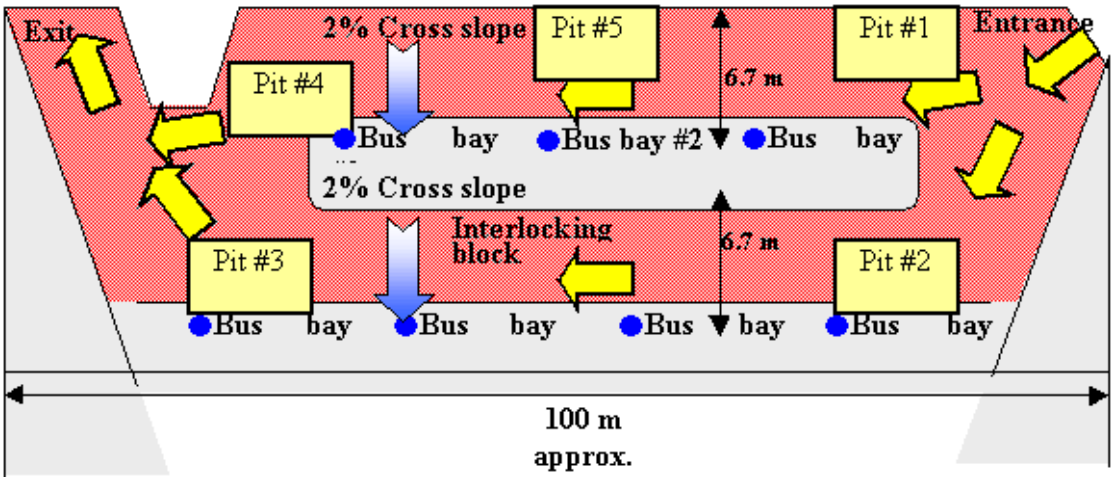


Figure 4. Schematic drawing of the bus terminal.

2.4 Damage types and locations

The distress to the pavement was broadly categorized into the following five types: (i) block breakage (corner breakage), (ii) loss of joint sand, (iii) joint widening (block migration), (iv) bumpy ride caused by faulting, and (v) local settlement. The various types of distress did not occur independently but also in combination in some areas. The distress was concentrated at the following five locations: (i) the lower side of the cross slopes (2%), (ii) bus stop areas, (iii) locations frequently affected by the movement and cornering of buses, (iv) the entrance and exit areas, and (v) locations above the expansion joints of the concrete slabs.

3. IDENTIFICATION OF DAMAGE CAUSES THROUGH PAVEMENT EXCAVATION SURVEY

3.1 Locations covered in pavement excavation survey

To maintain the smooth operation of buses and passenger safety, the test pits were excavated at the five locations shown in Fig. 4. Each test pit was 1 m^2 (1 m x 1 m). The test pits excavated in bus operation areas, that is Pits #1 to #4, were excavated from the surface through the concrete down to the subgrade. Pit #1 showed extensive damage to the blocks immediately above the expansion joints of the concrete slabs. Pits #2 and #3 also showed damage to the blocks while at Pit #4 the blocks were in a sound condition. Because the surface at Pit #5 in the non-operational area was in good condition, the excavation survey was performed in order to sample the bedding sand only.

3.2 Survey items

The pavement excavation survey covered the nine items listed in Table 1 below, consisting of various measurements taken during the pavement excavation, the sampling of specimens, laboratory tests on the specimens and a series of analysis using multi-layer elastic theory.

Table 1. Items Surveyed for Identifying Damage Causes.

Category	Survey Item	Evaluation Method
1	Measurement of the cross-sectional profile of each pavement layer	Deformation measurement by the string method
2	Quality evaluation of the blocks	Flexural strength test
3	Quality evaluation of the sand used in the bedding course	(i) Sieve analysis (Maximum particle size, fineness modulus) (ii) Decantation test (Amount of materials passing through the 75-μm sieve)

		(iii) Pulverization resistance test

Table 1. continued

Category	Survey Item	Evaluation Method
4	Quality evaluation of the concrete slab	Compressive strength test by core sampling
5	Identification of joint structure of the concrete slab	Measurement and by sketching
6	Quality evaluation of base materials	(i) Plasticity index (ii) Modified CBR test * (iii) Water content (iv) Sieve test (Particle distribution)
7	Quality evaluation of subsoil	CBR test
8	Deflection measurement using the handy falling weight deflectometer	Measurement using the handy falling weight deflectometer
9	Estimation of deflection of pavement surface	Analysis according to the multi-layer elastic theory (Elastic Layer System Analysis)

* Due to the inadequate volume of the samples, it was decided to use the CBR test instead of the modified CBR test.

4. RESULTS OF SURVEY

Among the items surveyed for identifying the causes of damage listed in Table 1, the following items directly related to the causes will be explained in a later section.

4.1 Cross-sectional profile of each pavement layer

The cross-sectional profiles of each pavement layer at Pits #1 to #4 were measured by the string method, for the bedding course, concrete slab, base and subgrade. After the blocks had been removed, a leveling string was stretched from the right edge to the left edge (transverse direction) at the center of the excavated area. The difference in level between the string and each pavement layer was measured.

Figure 5 shows the cross-sectional profile of each pavement layer in Pit #1, which represents the overall measurement results. Compared with the flat surface of the concrete slab, other layers experienced greater surface irregularity. However, because these layers under the concrete slab were in reasonably good condition, the focus was placed on the cross-sectional profiles of the concrete slab and bedding course. Figure 6 shows the deformation of the bedding course in Pit #1. Note that similar tendencies were observed in Pits #2 and #3 in terms of the cross-sectional profile of each layer and bedding course deformation.

The results of cross-section measurement of each layer are summarized as follows:

(i) The irregularity level of the bedding sand surface was about 10 mm; the block pavement had experienced a similar degree of irregularity before the excavation.
(ii) Considering result (i) and the fact that the concrete slab surface was still reasonably flat, the irregularity of the block pavement surface was assumed to have followed the deformation of the bedding course.
(iii) The bedding course tended to be thicker than the design thickness of 20 mm.
(iv) Away from the cross-section measurement points, several locations in the same pit had lost most of the bedding sand, with blocks lying directly on the concrete slab.

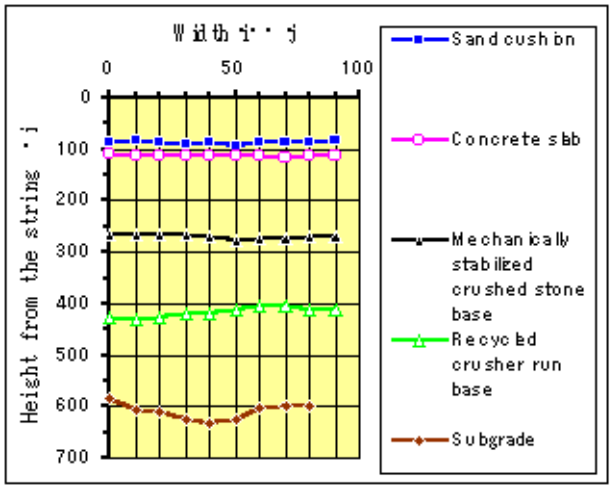


Figure 5. Cross-sectional profile of each pavement Layer in Pit #1

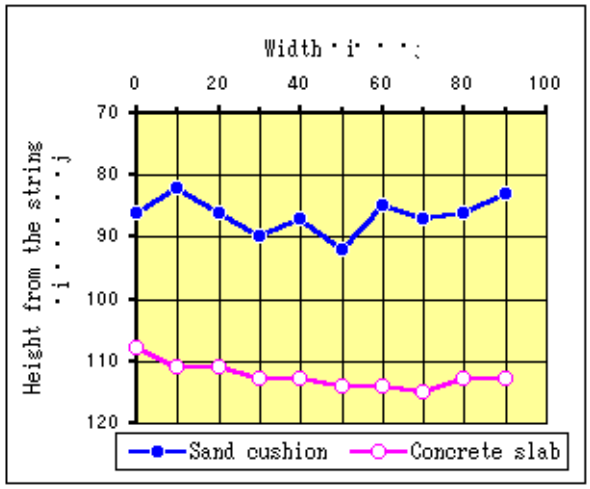


Figure 6. Deformation of bedding course in Pit #1

4.2 Quality of bedding sand

Table 2 shows the results of evaluation tests on the bedding sand. The quality of the bedding sand of the block pavement can be summarized as follows and is compared with the test results for the sand in Pit #5 which was not trafficked, as well as the quality criteria for bedding sand specified in the Design and Construction Manual [1)] of the Japan Interlocking Block Pavement Engineering Association (JIPEA), which is also included in Table 2.

(i) The dry mixed mortar in the bedding course was found to be non-homogeneous, with segregation of cement and sand.

(ii) According to the results of evaluation tests on Pit #5, the bedding sand did not satisfy the required value for resistance to pulverization.

(iii) The sand in Pits #1 to #3 was considered to have been pulverized, as a larger amount of materials passed through the 75-μm sieve in the decantation test than that obtained from Pit 4 or Pit 5. This appears to have been due to the heavy traffic loads coupled with water ingress as these pits are located on the lower side of the pavement cross fall where surface water collects. It is postulated that the reason for the higher level of pulverization resistance of the sand in Pit #2 was that the sand had already undergone some pulverization at the time of sampling due to the 10 years of service, and thus showed less pulverization in the subsequent evaluation test.

(iv) Pit #4 was in good condition even though it was in the bus operation area, and thus the sand was found to be of better quality than that in other sections in the evaluation test.

Table 2. Results of Evaluation Tests on Bedding sand and JIPEA Quality Criteria.

Evaluation Item	Section #1	Section #2	Section #3	Section #4	Section #5	JIPEA Quality Criteria
Maximum particle size (mm)	2.5	2.5	1.2	2.5	2.5	4.75 or less
Amount of material passing through 75-μm sieve (%)	8.8	11.1	11.0	3.4	3.9	5.0 or less
Fineness modulus	2.30	1.75	1.61	2.32	2.28	1.5 to 5.5
Pulverization resistance (%) *	2.9	0.1	1.9	0.2	1.5	1.0 or less

* The post-compaction-test increase in the amount of material passing through the 75-μm sieve was 1% or less.

4.3 Joint structure of concrete slab

As shown in Fig. 1, the joints in the concrete slab were 20-mm thick expansion joints, which consisted of a wooden joint filler (Japanese cedar board) of 10-mm thickness and 100-mm height and a resin foam rubber sponge joint filler (Elastite) of 10-mm thickness and 150-mm height. These expansion joints were placed at intervals of 4 m and had been designed to expand in the transverse direction, and no tie bars or dowel bars had been installed. Note that reinforcing bars (round steel bars of 6-mm diameter) had been placed at the bottom of the rectangular slabs.

4.4 Deflection measurement with handy falling weight deflectometer

Table 3 shows the deflection of each pavement layer in the vicinity of Pit #4, which was measured during the pre-excavation investigation (D_0), and the surface elastic modulus of each layer was obtained by Equation A based on these deflection measurements D_0. The surface elastic modulus of each layer was estimated to be 800 MN/m^2 for the blocks, 3,714 MN/m^2 for the base course (concrete slab) and 99 MN/m^2 for the subbase. Considering the relationship between the surface elastic modulus of the subgrade (488 kgf/cm^2) and 100 CBR, the subbase was expected to have a CBR value of 3% or greater.

Table 3. Deflection of each pavement layer measured with handy falling weight deflectometer and surface elastic modulus

Location	Blocks	Base course (Concrete slab)	Subbase (Mechanically stabilized crushed stone)	Subgrade
Deflection (D_0)	0.065 mm	0.014 mm	0.526 mm	1.087 mm
Surface elastic modulus (E)	8,162 kgf/cm^2	37,896 kgf/cm^2	1,009 kgf/cm^2	488 kgf/cm^2
	800 MN/m^2	3,714 MN/m^2	99 MN/m^2	48 MN/m^2

$$\delta = 2\,(1-\mu^2)p \cdot a/E \cdots\cdots\cdots\

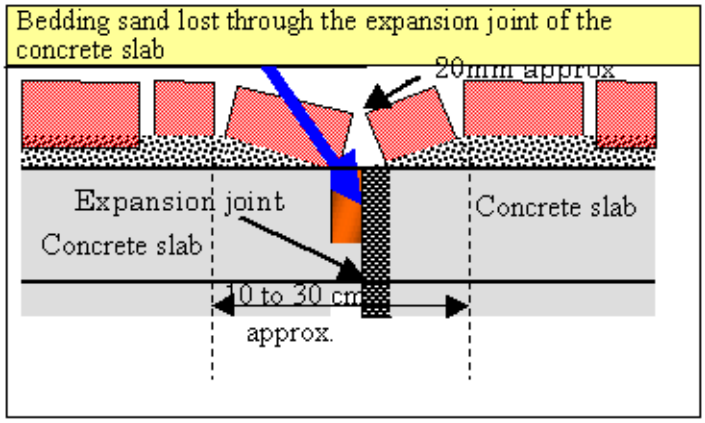


Figure 9. Loss of Bedding Sand.

It was confirmed that all the distress was related to the bedding sand. The loss of joint sand was also a common problem. This would have resulted in water ingress through the joints with the resulting saturation of the bedding sand and its migration and deformation.

4.6 Miscellaneous evaluation tests

The average flexural strength of the blocks and the average compressive strength of the concrete slab were found to be 8.2 MPa and 54.0 MPa, respectively, which can be regarded as good results in view of the required strength levels.

5. IDENTIFICATION OF CAUSES OF DISTRESS

The results of the pavement excavation survey indicated that the distress in the pavement was primarily "functional damage", with the impact limited to the bedding sand and blocks.

This type of damage is characteristic of block pavement, and the possible causes are as follows:

(i) The blocks had adequate flexural strength but the joint sand had not formed a competent seal to prevent moisture ingress. The presence of spacer ribs in new blocks, coupled with improved specifications for joint sand to prevent water ingress will improve the situation.

(ii) The braking, stopping, starting and movement of buses as well as the lateral shear force generated by cornering caused lateral migration of blocks, widening of joints and further loss of joint sand, thereby causing the blocks to break by striking each other (corner breakage). This could be prevented by constructing competent edge restraints to the pavement.

(iii) The bedding course suffered multiple damage, including sand pulverization and consolidation, local settlement and lateral migration of the bedding course itself. The causes of these damages were: the use of dry mixed mortar and sand with inadequate pulverization resistance, aggravated by water ingress through the joints.

(iv) The excess bedding course thickness that had been adopted to offset the inadequate thickness of the concrete slab also further compounded the problem.

(v) The poor drainage at the bottom of the pavement cross fall caused all water that penetrated into the bedding sand to remain in the pavement structure and promoted lateral migration and pulverization of the bedding sand.

(vi) Because the concrete slab had expansion joints without tie bars or dowel bars, it was prone to vertical movement when buses ran on the pavement. This created gaps in the expansion joints, through which the bedding sand penetrated. The bedding sand in the regions around the gaps was thus lost, causing the block pavement to undergo settlement alongside the expansion joints in the concrete slab.

6. REPAIR METHOD (IMPROVEMENT WORK)

6.1 Outline of improvement work

Improvement work was performed based on the results of the pavement investigation. The bedding sand and blocks were replaced, and the existing concrete slabs, base and subgrade were reused. The work was designed and executed according to the Design and Construction Manual of JIPEA. The pavement configuration for the improvement work is shown in Fig. 10.

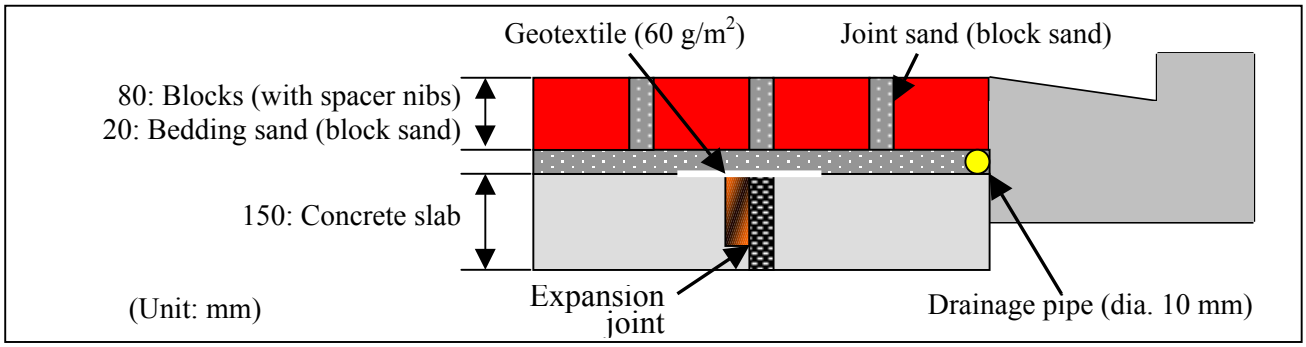


Figure 10. Pavement configuration adopted in the improvement work.

The key features of the work were as follows:

(i) Penetration of rainwater through block joints and its retention in the bedding course would cause the bedding sand to lose its bearing capacity and migrate in the lateral direction, resulting in failure of the block pavement. Therefore, an improved specification block that includes spacer nibs, coupled with an improved specification for the joint sand to prevent water ingress and geotextile-wrapped drainage pipes were installed inside the bedding sand alongside the gutters to drain away any water that does get into the bedding sand. The existing gutters were also effectively used.

(ii) As shown in Fig. 11, the blocks were laid at a 45-degree herringbone bond pattern in order to minimize the risk of blocks being moved by the traffic at the exit area. The pavement ends were finished with dedicated end blocks.

(iii) The survey results showed that the settlement along the concrete slab expansion joints had been caused by the loss of bedding sand through the joints. As a countermeasure, geotextile (60 g/m^2) was installed with the width of 50 cm across the expansion joints.

(iv) As shown in Fig. 12, reinforced cast-in-place concrete was used as the edge restraint at the boundary between the block pavement and the existing asphalt pavement to provide a configuration that would withstand the bus traffic.

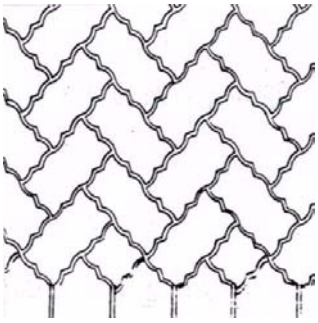


Figure 11. Laying Pattern Adopted in the Improvement work

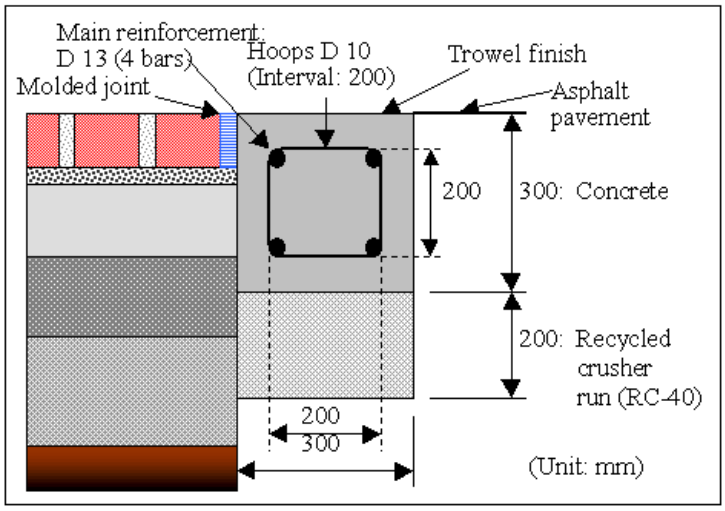


Figure 12. Edge Restraint Configuration.

6.2 Bedding sand and joint sand

It was confirmed in driving tests performed by the Public Works Research Institute of the Ministry of Construction (currently, an independent administrative entity) [2] that block paved roadways may experience fatal damage such as settlement-caused rutting and lateral migration of blocks, due to sand particle pulverization caused by repeated traffic loads. This phenomenon was also confirmed in the present excavation survey of the pavement. To prevent this, JIPEA specified the pulverization resistance of bedding sand to be 1% or less in its Design and Construction Manual based on resistance evaluation tests performed at the Public Works Research Institute [3]. Considering these, the bedding and joint sand characteristics were determined in the following manner:

(i) Bedding sand consisting of asphalt coated particles ("block sand") was used as the bedding sand and joint sand. This selection was made based on the test results shown in Fig. 13. The particle distributions of the block sand (fineness modulus = 2.49) are shown in Fig. 14.

(ii) As shown in Fig. 13, the pulverization resistance of block sand and natural sand were both 1.0% or less after 67 times of compaction as required by JIPEA. The pulverization resistance of the natural sand tended to increase in proportion to the increase in the number of times of compaction; it reached 6.21% at 500 times of compaction, while the pulverization resistance of the block sand was 1.03% at the same number of times of compaction. This result shows that the coating of sand particles significantly improved the pulverization resistance.

(iii) Use of a material with a higher pulverization resistance was considered essential because the pulverization of bedding sand will be accelerated under the severe traffic conditions of the bus terminal. The block sand was also used as the joint sand.

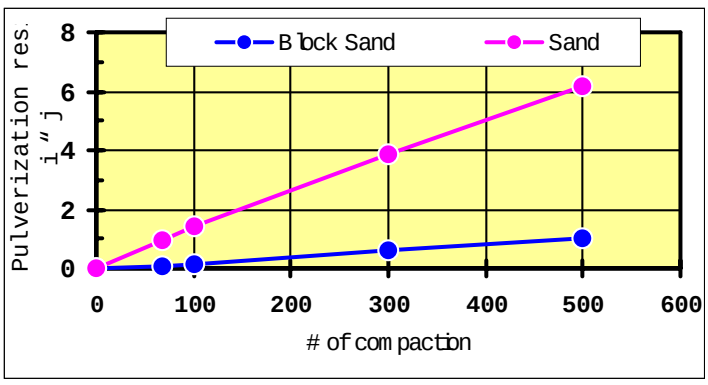


Figure 13. Comparison of pulverization resistance of bedding course

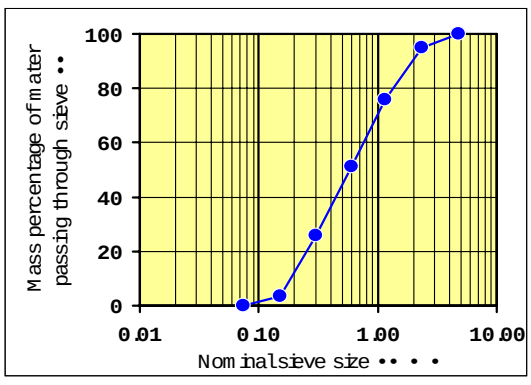


Figure 14. Particle distributions of the block sand.

6.3 Block laying and rolling compaction

Blocks were laid manually at the average daily rate of 115 m^2 during limited nighttime hours after daytime bus operations had finished. For the initial rolling compaction of the block pavement, compactors conventionally designed exclusively for initial compaction were used. Then, according to the Manual of JIPEA, combined vibration rollers (total weight of 34.3 kN) and pneumatic tire rollers (total weight of 201 kN) were used for the secondary rolling compaction and finishing compaction, respectively.

7. CONCLUDING REMARKS

In Japan, block pavement has mainly been applied to pedestrian areas for its aesthetic properties. However, now that performance-based requirements are becoming the key principles, it is essential to develop of block pavement having new functional merits for more practical applications such as the bus terminal pavement reported here, and to establish the reliability of block pavement and promote its application to roadways.

8. REFERENCES

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A BRIEF RESUME OF MINORU HATA

Engaged in research and development of interlocking block for 20 years since he entered Taiheiyo Cement Corporation.

Engaged mainly in evaluation of interlocking block applied to motorways, development of composite interlocking block using tile and natural stone, development of high strength permeable interlocking block for motorways and development of water retentive interlocking block..