STUDY ON HARDNESS OF BEDDING COURSE AFFECTING THE SURFACE PROPERTIES OF INTERLOCKING BLOCK PAVEMENT

AKIHIKO KARASAWA, CONCRETE PRODUCTS GROUP, CENTRAL RESEARCH LABORATORY, SAKURA, TAHEIYO CEMENT CORPORATION, 2-4-2 Daisaku, Sakura, Chiba 285-8655 Japan
TEL+81-43-498-3853 FAX +81 -43-498-3821 E-MAIL akihiko kam5av^(Nail«l>'o-<«nsL
HIDEYUKI YAMAGUCHI, GAI ART KUMAGAI CO, LTD.,TECHNICAL CENTER, NO. 1 RESEARCH DEPARTMENT, NO. 1 RESEARCH GROUP, 216-1 Yawara-mura, Tsukuba, Ibaragi 300-2445 Japan
TEL+81-297-52-4751 FAX+81-297-52-2579 E-MAIL gaeaake@ma. neweb. ne.in
SH1GEO SUDA INTERLOCKING BLOCK PAVEMENT ENGINEERING ASSOCIATION
1-13-5 Iwamotocho, Chiyoda-ku, Tokyo 101-0032 Japan
TEL+81-3-3851-3234 FAX+81-3-3851-3235 E-MAIL shigeo suclaC'laiheivo-cement.oo.ip

ABSTRACT

The authors implemented indoor riding tests assuming the conditions close to the actual vehicle travelling using a miniature pavement model and confirmed the influence of hardness of the bedding course on the surface properties of interlocking block pavement The authors demonstrated the optimum hardness of the bedding course and the mechanism of floating of block through analyzing the results of a series of tests.

1. INTRODUCTION

In recent years, applications to roadway pavement of B traffic category have been increasing as its excellent properties like landscape aspect, durability, flexibility to differential settlement and easiness for maintenance have been recognized.

There are problems of such functional damage as floating of block, shifting of joint and local settlement in some of the interlocking block pavement so far used for roadways and there are many domestic as well as overseas reports on the causes being such a secular change that sand used for the bedding course breaks into fines and is removed with rain water and load[l][2][3]. Under the circumstances of roads in Japan that there are more slopes and curves and annual rain fells double the average of the world as compared to foreign countries, it is absolutely necessary to use bedding materials which do not undergo a secular change in order to develop interlocking block pavement for roadways on a full scale.

On fee other hand, taking into consideration fee difficulty of getting cheap and good aggregate in urban areas, there are limits in coping wife roadway pavement only wife quality requirements of sand. The authors implemented indoor riding tests assuming fee conditions close to the actual vehicle travelling using a miniature pavement model in order to verify the influence of hardness of fee bedding course on fee surface properties of interlocking block pavement for the purpose of developing bedding materials which are better in serviceability compared to the bedding course where conventional quality sand is used and have obtained good results.

This paper reports on fee verified optimum hardness of the bedding course and mechanism of floating of block based on the analysis of the results of a series of tests.

2. OBSERVATIONS ON THE CONVENTIONAL STUDIES

Yaginuma and others report as follows on the results of investigations at the site where floating of block took place and the mechanism of its occurrence presumed therefrom[l].

(1) Joint sand is lost at e place where floating of block took place.

(2) Bedding sand was compacted very hard and the hardness of Proctor indentation resistance was approximately 140kgf/cm^2 or more.

(3) The thickness of the bedding course was 5~6 cm which is thicker than the design thickness(2 ~3cm).

(4) The silt fiactions(under 0.075 mm) in the compacted sand were in the range of 6~15.9%.

(5) It may be conceived from the aforementioned that when the bedding course is thick and sand used fix the bedding course contains more than 6% of silt fractions, floating of block takes place by gradual solidification of the bedding course by traffic loads and rain water permeated from joints and simultaneously by loss of joint sand around blocks.

At this point, Yaginuma and others pointed out that one of the causes is using sand containing more than 6% of silt fractions for the bedding course but subsequent studies made it clear that there are cases where silt fractions increase with sand particles broken into fines by traffic loads after a service even though the sand contains less silt fractions at the time of construction.

3. STUDY ON HARDNESS OF BEDDING COURSE AFFECTING THE SURFACE PROPERTIES OF INTERLOCKING BLOCK PAVEMENT

The authors started the study for the purpose of developing bedding materials which can restrain a change in fire bedding course over years but because hardness of the bedding course is presumed to be a factor of floating of block from tire aforementioned studies of Yaginuma and others, the indoor riding tests assuming the conditions close to fire actual vehicle travelling using a miniature pavement model in order to verify the influence of hardness of the bedding course on the surface properties of interlocking block pavement were implemented to begin with.

3.1 Outline of the Tests

(1) Testing Apparatus

The tests were carried out by diverting a spiked raveling tester for testing wear resistance of pavement materials. The mechanism of this tester is such that a spiked tire runs round on the specimen fixed on the rotating steel table.



Photo 1 Testing Apparatus

The tests were done in such a manner that 6 trapezoid-shaped steel molds were fixed on the steel table in which the bedding course and miniature blocks were installed and a normal tire ran round on the blocks. How the tests were done is shown in Photo 1.

(2) Specification of the Bedding Course

The specification of the bedding course tested is shown in Table 1. The specification of the bedding

course is classified roughly into 3 kinds which are plain sand, sand solidified with cement as a binder(hereinafter referred to as “cement type”) and sand solidified with asphalt emulsion as a binder(hereinafter referred to as “asphalt emulsion type). Preliminary tests were carried out for several asphalt emulsions which were picked up taking workability, durability and cost into consideration and finally selected were 3 kinds which are “PK-3” generally used for prime coating, high penetrating emulsion for prime coating and emulsion with rubber in for tack coating And normal Portland cement was added as an auxiliary in order to accelerate dissolution of the emulsion and to enhance durability of the solidified sand The results of quality tests for crushed sand used is shown in Table 2. The evaluation of hardness of the bedding course was conducted by the Proctor indentation resistance test which is used for measuring setting time of concrete and the CBR test. Preliminary tests were earned out for the additions of cement and asphalt emulsion so that the value of Proctor indentation resistance and CBR would moderately fluctuate. The conditions for the Proctor indentation test and CBR test are shown in Table 3. The relationship between the values of the Proctor indentation resistance and CBR of each bedding course is shown in Figure 1. The tests were done twice for the cement type and asphalt emulsion type due to numbers of specimens.

(3) Structure of Specimens and Test Conditions

The structure of specimens is shown in Figure 2. The test conditions are shown in Table 4,The bedding course was installed in thickness of 20 mm which is the standard thickness for roadways in the trapezoid-shaped steel mold with the bottom area of 0.21 m^2 [4], The blocks used are straight type of width x length x height=98 x 48 x 40 mm. The laying pattern was stretcher bond but unlike the usual laying direction, the blocks were laid so that direction of the longer side of block is to become parallel to that of the tire running to make the performance of block under load clearly visible. Neoprene rubber was attached on the outside of the block of the far end for fire same purpose. #5 silica sand was used for joint sand The speed of the rotating table was set at 5km/h and contact pressure of the tire was set at 0.55N/mm^2 The tire was made run traversing sideways at a fixed speed within the running area shown in Figure 2. While running 97mm/h of water which is equivalent to the rainfalls on the block was sprayed Cumulative 30,000 runs were performed. And acceleration added in the test onto the block by centrifugal force emulates gravitational acceleration of pavement having the grade of 180% (slope of 62).

(4) Items and Methods of Measurement

3 items shown in Table 5 were measured after finishing 30,000 runs.

Table 2 Results of the Quality Tests for Crushed Sand Used for the Bedding Course

Sand	Maximum Size	Specific gravity surface-dry	Water absorption	Solid volume percentage	Loss in washing
Crushed sand	2.5 mm	2.63	1.44%	66.8 %	4.3 %

Weight of passing sieves (%)						Fineness modulus (FM)
Nominal size of sieves (mm)						
5	2.5	1.2	0.6	0.3	0.15	
100	92	58	32	17	8	2.93

Table 1 Specification of the Bedding Course

No	Specimen Tests [1)]	Binders	Binder additions (oven-dry weight of sand x %)	Water quantity or auxiliaries	Proctor indentation resistance (N/mm^2)	CBR (%)
1	1,2	Plain sand	—	Ratio of water content 10% (optimum ratio of water content)	1.0	19.7
2	2	High penetrating asphalt emulsion for prime coating	12	Normal Portland cement weight of emulsion x 30%	2.2	58.4
3	1,2	Normal Portland cement	1	Mixture of sand with ratio of water content 10% and binder	11.6	87.6
4	1		2		14.0	118
5	2	"PK-3" asphalt emulsion for prime coating	8	Normal Portland cement weight of emulsion x 30%	16.5	103
6	2		12		30.0	172
7	1	Normal Portland cement	3	Mixture of sand with ratio of water content 10% and binder	35.0	175
8	2	Asphalt emulsion with rubber in for tack coating	16	Normal Portland cement weight of emulsion x 30%	39.7	89.8
9	1	Normal Portland cement	4	Mixture of sand with ratio of water content 10% and binder	54.9 [2)]	273
10	1		5		54.9 [2)]	474

1) 1 in the Tests means the first test, 2 second test and 1,2 commonly done in fte first and secmi tests.

2) The upper limit for Proctor indentation resistance is 54.9N/mm2

Table 3 Conditions for Proctor Indentation Resistance Test and CBR Test

		Test Coalitions
Proctor indentation resistance test	Cementtype	♦ The test is basically subjected to ASTM C 303"Setting Time Testing Method for Concrete by Indentation Resistance". ♦ The specimens were produced by filling and compacting the materials mixed under the same conditions as the bedding course for the indoor riding tests into a steel mold of width x length x height=100 x 200 x 40 mm and by curing for 7 days in a room at temperature of 20X3 and at humidity of 70%
	Asphalt emulsion type	♦ Basically the same as cement type but curing was for 7 days in a dryer at 60°C
CBR test	Cement type	♦ The test is basically subjected to CBR testing method ♦ The specimens were produced by compacting the materials mixed under the same conditions as the bedding course for the indoor riding tests and curing for 3 days at temperature of 20°C and at humidity of 70% then curing in water for 4 days.
	Asphalt emulsion type	♦ Basically the same as cement type but curing was for 7 days in a dryer at 60°Cand then 4 days in water

Table 4 Test Conditions

Items			Conditions
Bedding course	Mixing	Cement type	♦ Hovert mixer was used ♦ Plain sand was mixed for 30 seconds after water was added achieve optimum ratio of water content ♦ Cement type was mixed for 1 minute after cement was added
		Asphalt emulsion type	Oven-dry sand and emulsion was mixed for 30 seconds, then mixed for 1 minute after adding cement
	Raking		Compacted with trowel
	Curing	Cement type	Blocks laid, joint sand filled then cured for 7 days at temperature of 20˚C and at humidity of 60%
		Asphalt emulsion type	Blocks laid, joint sand filled then cured for 7 days in a dryer at 60˚C
Block	Shape		Straight N-N type, length x width x height = 98 x 48 x 40 mm
	Spacer nib		2 in the longer side, 1 in the shorter side(average joint width 2 mm)
	Laying pattern		Stretcher bond(the longer side parallel to tire running direction)
	Strength		Bending strength 4.9N/mm^2 or more
Joint sand			#5 Yamagata silica sand(maximum size 1.2 mm,specific gravity of saturated surface-dry 2.62, FM 2.06,water absorption 0.523%, solid volume percentage 62.6%, loss in washing 0.32%)
Rolling on block and filling of joint sand			Small vibrator was used
Load	Tire size		<j> 282 mm, width 63 mm
	Wheel load		100 kg
	Contact radius		2.39 cm
	Contact pressure		0.55 N/mm^2
Width of tire shifting			100 mm
Rotation speed of the table			5 km/h (maximum speed for joint sand not to pop out by rotation)
Temperature in the testing room			20˚C
Quantity of sprayed water			1201/h (97 mm/h if converted to rain fells on the block)
Numbers of riding			Cumulative 30,000 runs

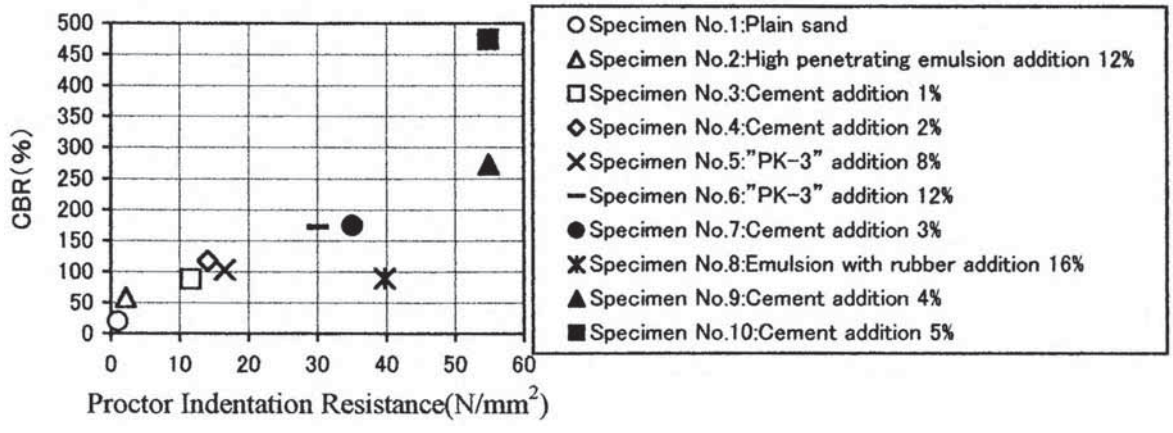

Figure 1 Relationship between Proctor Indentation Resistance and CBR of the Bedding Course

Table 5 Items and Methods of Measurement (First Test)

No.	Items of Measurement	Methods of Measurement	Position of Measurement
1	Deformation of block surface	By dial gage	At each measurement point (1-72) on tire measurement li 1-6 as shown in Figure 1
2	Deformation of bedding course surface	By dial gage	
3	Infiltration of joint sand into under block	By visual observation	–

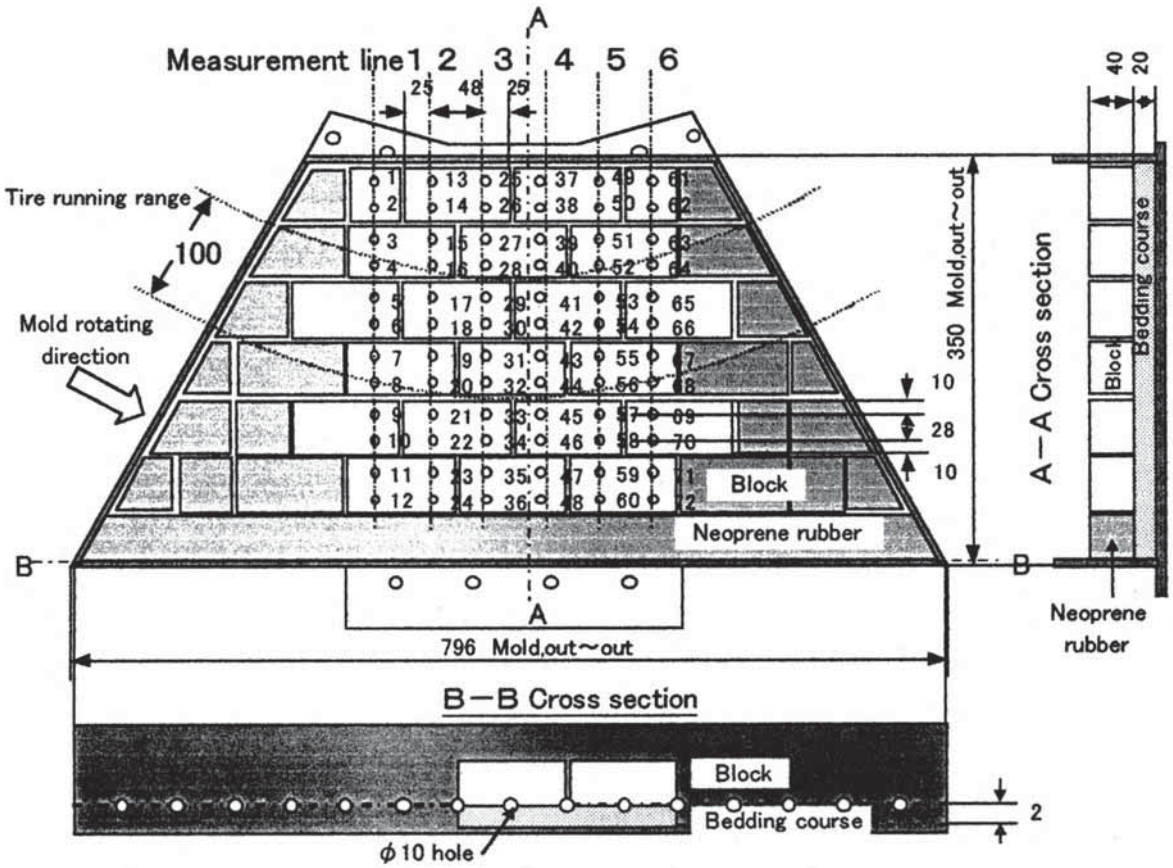

Figure 2 Structure of Specimens

3.2 Test Results

(1) Influence of Hardness of the Bedding Course on Settlement and Floating of Block

As one of the examples of deformation of the surface of block after 30,000 runs, the deformation of the surface of block using plain sand for the bedding course is shown in Figure 3. The maximum settlement was defined as the deformation at the point where the settlement was maximum compared to the height at the point before the runs. Adding to it, The deformation at the point where floating of block was maximum compared to the height at the point before the runs was defined as the maximum floating of block.

The relationship between Proctor indentation resistance and the maximum settlement of block(the average of the maximum settlements in all the measurement points) for each specimen is shown in Figure 4. It has been confirmed therefrom that settlement tends to be bigger in the bedding courses with Proctor indentation resistance of l.0N/mm^2 and 2.2N/mm^2 and small with more than

11.6N/mm^2.

The next shown in Figure 5 is the relationship between Proctor indentation resistance of toe bedding course and toe maximum floating ofblock(average of toe maximum floating values in all the lines). It has been confirmed therefrom that no floating of block was observed in the bedding course with Proctor indentation resistance of 11.6N/mm^2 and that Proctor indentation resistance more or less than 11.6N/mm^2 caused floating of block It has also been confirmed that there was no settlement of block nor floating of block in the bedding course with Proctor indentation resistance of 11.6N/mm^2 maintaining good surface conditions.

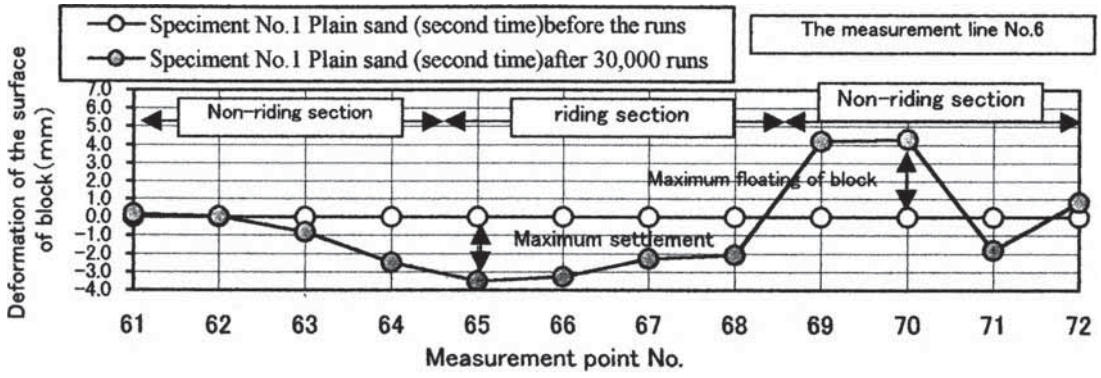

Figure 3 An example of Deformations of the Surface of Block after 30,000 Runs

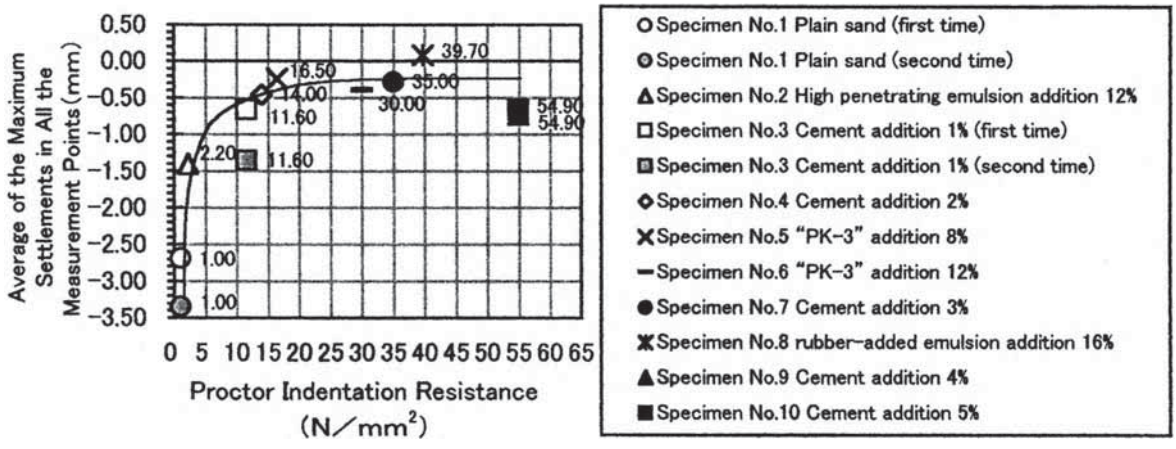

Figure 4 Relationship between Proctor Indentation Resistance and the Maximum Settlement of Block

(2) Cause of Settlement and Floating of Block

As a result of measuring deformation of the surface of the bedding course removing the blocks after 30,000 runs, the identical settlement and floating of block with the surface of block were observed in the bedding course with Proctor indentation resistance of l.0N/mm^2 and 2.2N/mm^2 On the contrary, there was no settlement nor

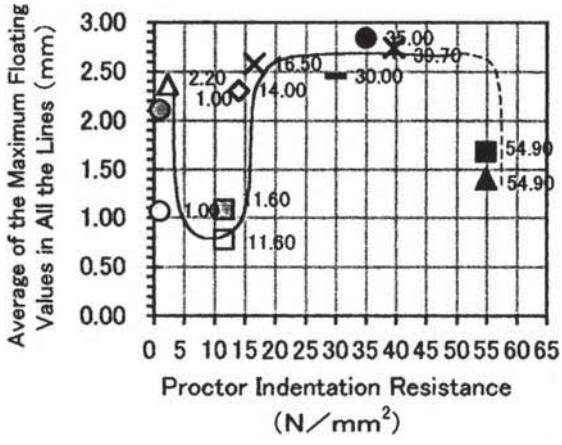

Figure 5 Relationship between Proctor Indentation Resistance and the Maximum Floating of Block

floating of block in the bedding course with Proctor indentation resistance of 11.6N/mm^2 or more. It is conceivable therefrom that settlement and floating of block were attributable to settlement and floating of the bedding course itself caused by progressive consolidation, movement and liquefacation of the bedding course due to load, spraying of water and centrifugal force.

The infiltration of joint sand into underblock in the first test(cement typejafter 30,000 runs is shown in Photo 2. There was no infiltration of joint sand into underblock in the bedding course with Proctor indentation resistance of 1. 0 N/mm^2 and 11.6N/mm^2 but on the contrary, much of joint sand infiltrated into underblock in the bedding course with Proctor indentation resistance of 14.0N/mm^2 or more. It is conceivable therefrom that blocks floated up by the infiltration of joint sand into the spaces between underblock and the bedding course as the deformation of the bedding course can not follow the performance of block even though deformation does not take place in the bedding course with Proctor indentation resistance of 14.0N/mm^2 or more.

The reason why the blocks on the bedding course with Proctor indentation resistance of 11,6N/mm^2 maintained good conditions was because there was no infiltration of joint sand into underblock as no deformation of the bedding course itself took place and the performance of the bedding course followed that of block. Althoug floating of block was small in the bedding course with Proctor indentation resistance of 54.9N/mm^2 as shown in Figure 5, it is conceivable to be due to the bedding course and the bottom of block coming into contact with each other thus less infiltration of joint sand. Floating of block, however, would possibly increase as joint sand would infiltrate if more runs are performed and the contact is failed.

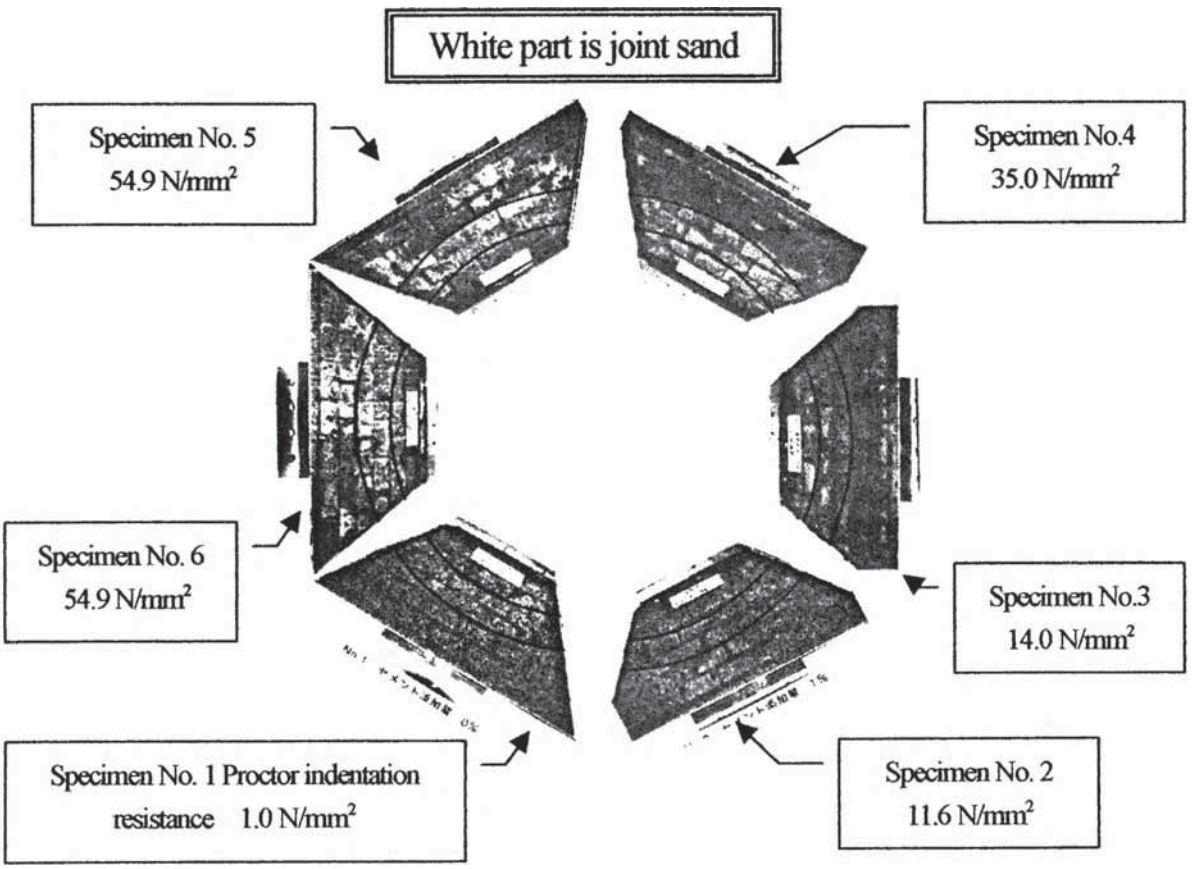

Photo 2 Conditions of the Bedding Course after 30,000 Runs (The First Test: Cement Type)

4. Mechanism of Floating of Block

From the analysis of the conventional studies and the results of the tests this time, the mechanism of floating of block is conceived as shown in Table 6.

Table 6 The Mechanism of Floating of Block

<table>
<tr><td rowspan="3">Step</td><td colspan="2">Sand Bedding
Silt Auction at construction</td><td rowspan="3">Joint sand</td><td rowspan="3">Block</td></tr>
<tr><td>Less than 6%</td><td>More than 6%</td></tr>
<tr><td>1</td><td>• Hardness around Proctor indentation
• Performs follow performance</td><td>NW for resistance ing block</td><td rowspan="2">Properly filled</td><td rowspan="2">• Blocks are in contact by spacer nibs
• Adjacent blocks perform sequentially
• High load distribution</td></tr>
<tr><td>2</td><td>Silt Auction increases to more than 6% by sand breaking into fines</td><td>⇩</td></tr>
<tr><td>3</td><td colspan="2">• Solidifies by consolidation by traffic load and ruin water
• Proctor indentation resistance increases than the proper range
• Unable to perform following block performance</td><td>• infiltrates into spaces between underblock and bedding course by rainfall and road slope
• Joint sand in side of block is lost</td><td>• Blocks independently perform
• Load distribution drops and concentration of stress occurs
⇔ Repetition</td></tr>
<tr><td>4</td><td colspan="4">Floating of Block Occurs</td></tr>
</table>

5. CONCLUSION

The items verified in the indoor riding tests assuming the conditions close to the actual vehicle travelling using a miniature pavement model with regard to influences of hardness of the bedding course on the surface properties of interlocking block pavement are summed up as follows;

(1) It is conceivable that deformation of the block surface can be restrained to a minimum and that such functional damages as floating of block and local settlement can be prevented by achieving the optimum hardness of the bedding course. The range X for the optimum hardness of the bedding course under the test conditions this time is supposed to be $2.2N/mm^2 < X < 14.0N/mm^2$(X includes $11.6N/mm^2$) for Proctor indentation resistance and $58.4\% < X < 118\%$(X includes 87.6%) for CBR.

(2) It is conceivable that in case of hardness of the bedding course being lower than the optimum range, floating of block and local settlement would occur pursuant to settlement and floating taking place in the bedding course itself by the progressive consolidation, movement and liquefacation of the bedding course depending on traffic load, grade of roads, weather conditions and drainage facilities.

(3) It is conceivable that in case of hardness of the bedding course being higher than the optimum range, floating of block would occur by infiltration of joint sand into the spaces between underblock and the bedding course as the performance of the bedding course can not follow that of block even though deformation does not take place in the bedding course.

(4) The evaluations of the tests this time were implemented for the cement and asphalt type bedding courses with different elasticity and it is conceivable that the surface properties of interlocking block pavement are influenced by hardness of the bedding course but not by elasticity of the bedding course as settlement of block and floating of block were identical if hardness of both bedding courses was identical.

6. FUTURE ISSUES FOR STUDYING

The following is the issues to be studied in the future based on the test results implemented this time.

(1) The specimens were fixed on the steel table in the tests done this time and rigidity under the bedding course is very high, which makes difference from the actual interlocking block pavement. Therefore, now, installing concrete base course with different rigidity, bituminous stabilized base course and mechanically stabilized crushed stone base course below the bedding course, similar tests as done this time are under study for influences of rigidity of the base course on the range of the optimum hardness of the bedding course. At the moment, it has been confirmed that the optimum hardness of the bedding course for each base course varies and soon the range of the optimum hardness of the bedding course will be made clear.

(2) In the tests this time, the thickness of the bedding course was set at 20 mm which is the standard thickness for roadways but more studies about influences of the thickness of the bedding course on the range of the optimum hardness of the bedding course are considered to be necessary.

(3) Good quality crushed sand was used in the tests this time but it is considered necessary to study about influences of the quality of sand on the range of the optimum hardness of the bedding course.

(4) It is presumed from the tests this time that load distribution effects of the block layer vary depending on hardness of the bedding course and it is considered necessary to express clearly the points in numerical value.

(5) It is considered from the tests this time that the bedding course with 1% cement addition among the canent types has the optimum hardness but since some sections were confirmed in the observation after 30,000 runs that they had returned to the plain sand state due to weakened consolidation , materials possible to maintain the optimum hardness for a long time should be studied Production methods and construction methods of such materials should also be studied.

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