STUDY ON BLOCK SHIFTING OF INTERLOCKING BLOCK PAVEMENT

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SUMMARY

The most common damage to interlocking (IL) block roadway pavements is horizontal shifting of blocks, according to surveys of such pavements. This phenomenon, whereby blocks are deflected in the direction of vehicle travel, causes the joints to widen. This can cause the pavement surface to become faulted or the blocks to break, which can eventually hinder vehicle and pedestrian traffic. Clarifying the cause of block shifting and developing countermeasures is important in raising confidence in the reliability of IL block pavements. The authors performed an excavation survey to obtain the basic data necessary to reveal why blocks shift. The survey was conducted at a roundabout in front of a train station in Saitama Prefecture where the phenomenon had occurred.

The excavation survey found the following reasons for shifting: 1) excessive loads from torsional and braking forces imposed by vehicles; 2) consolidation of bedding sand from use of bedding materials with insufficient pulverization resistance; 3) reduction of load transfer efficiency by loss of joint sand and/or increase of joint width; 4) insufficient drainage at the bedding layer; and 5) the use of a block type (rectangular) and laying pattern (stretcher bond) that is inappropriate for the traffic volume.

Based on the survey results, the mechanism of shifting was identified, and an installation method, including materials and laying pattern, that affords shifting resistance is proposed.

1. INTRODUCTION

A survey by the Japan Interlocking Block Pavement Engineering Association (JIPEA) has revealed that the shifting of blocks is the most common damage to roadways of IL block pavements. When the blocks are pushed horizontally, they shift in the direction of vehicle travel. This has widely occurred on roadways in shopping and residential areas where heavy vehicles do not travel, and on roadways with heavy traffic such as at bus stops, bus terminals, and intersections. Shifting can cause pavement surface faulting or block breakage, which eventually hinders the flow of vehicle and pedestrian traffic. Shifting can even detract from the roadside living environment by increasing “rattling” of passing vehicles.

Clarifying the cause of the horizontal shifting of blocks and devising countermeasures are important issues in raising confidence in the reliability of IL block pavements. The authors performed an excavation survey to obtain the basic data on why such shifting occurs. The survey was conducted at a roundabout in front of a train station in Saitama Prefecture where this phenomenon had been observed.

This paper reports on the findings from the excavation survey, investigates the mechanism whereby the blocks shift, and proposes a laying pattern, materials and installation method for IL block pavement that resists shifting.

2. SHIFTING OF IL BLOCKS IN JAPAN

Table 1. Surveyed Damage to IL Block Pavements

Location	No. of Cases	Damage					
		Horizontal shifting	Block breakage	Faulting	Rutting	Partial unequal settlement	Sinking of areas adjoining the road facilities
Retail area	9	2	5	7	2	3	1
General roadway	15	9	5	9	6	3	2
Bus lane	7	6	4	4	3	5	4
Bus stop	6	2	3	1	2	2	2
Bus bay	6	3	4	1	3	3	3
Intersectio	5	3	4	1	3	1	2
Total	48	25	25	23	19	17	14
Occurrence rate (%)	-	52	52	48	40	35	29

Table 1 shows the results from damage surveys performed by JIPEA in 2002 on IL block pavements at 48 locations. The most common damage types are shifting and breakage (each occurring at 52% of the damaged locations investigated; hereinafter: occurrence rate), followed by faulting (48%), rutting (40%), and partial unequal settlement (35%). The high occurrence rate for breakage is attributed to collisions between blocks caused by shifting, faulting and unequal settlement.

Not only does this damage hinder vehicle and pedestrian and traffic, the shifting of the blocks reduces the aesthetic appeal of the pavement surface. Notably, the shifting can trigger faulting that causes the blocks to loosen and eventually break. Clarifying the cause of block shifting and developing countermeasures are important issues. The authors performed an excavation survey to obtain the basic data necessary to reveal why shifting occurs.

3. EXCAVATION SURVEY

3.1 Location

The excavation survey was performed in Saitama Prefecture on pavement that had been installed in February 1997 at a railway station roundabout with traffic on two lanes in one direction. The pavement was straight rectangular IL block (198 x 98 mm) that was laid in a stretcher bond pattern (STB) on one section and a herringbone bond pattern (HBB) on the other section. The pavement had a relatively strong base course of stabilized cement (Figure 1).

The excavation survey found horizontal shifting of blocks at the pedestrian crossing and at bus stops

near the station terminal exit (Photo 1). Loosening, breakage and faulting of blocks were observed in those areas. The bedding sand layer was unable to drain the seepage water.

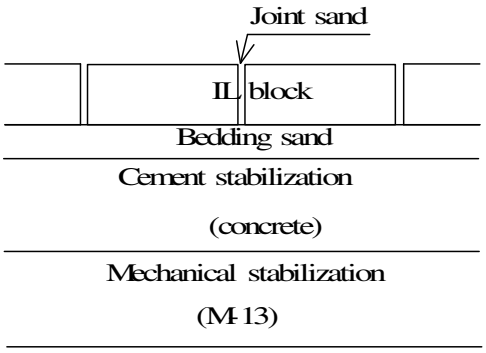


Figure 1. Structure of IL block pavement



Photo 1. Pavement with block that has shifted

3.2 Outline of the excavation survey

The excavation survey was performed in July 2003, which was six years and five months after construction. One damaged location and one sound location on each of two lanes was examined. The survey on sections laid with the STB was performed within an area of 1.5×2 m. That on sections laid with the HBB was performed within an area of 1.3×2.5 m. In these areas, measurements were performed along two survey lines each in the longitudinal and transverse directions. A top view of the survey site is shown in Figure 2.

A survey of 12-hour traffic volume was performed to estimate the daily traffic volume for the excavation survey. The shifting displacements were measured with a ruler and leveling string along each survey line. Visual inspections of damaged blocks were performed within the designated area of survey. The joint width and the reduction in depth of joint sand were measured using a caliper. Longitudinal and transverse profiles were measured at 20-cm intervals with a leveling string.

Measurement of deflection at the IL block surface was performed at the sections shown in Figure 3, to identify the horizontal distribution of deflection. The deflection of block D_0, directly below the loading plate, was measured. Then the defections (D_1) at the centers of six adjoining blocks were measured with a second sensor. The ratio of deflection was calculated from Equation (1).

$$\text{Ratio of deflection} = \frac{D_1}{D_0} \qquad (1)$$

To determine the bearing capacity of the base course and the layers below the base course, the deflection directly below loading plate (D_0) and deflections at points 20 cm from the loading plate (D_{20}) were measured. The D_{20} measurements were made at a position on the block equivalent to that on the D_0 block.

The physical properties of joint sand and bedding sand were measured by the sieve tests specified in JIS A 1102 and the decantation test specified in JIS A 1103. The bedding sand was tested for pulverization resistance according to JIPEA-TM-2. Flexural strength tests were performed on blocks according to JASS 7 M101.

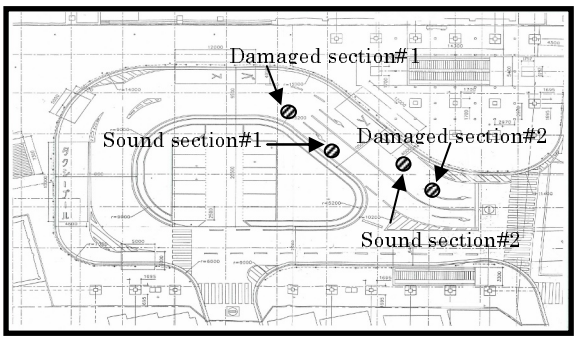
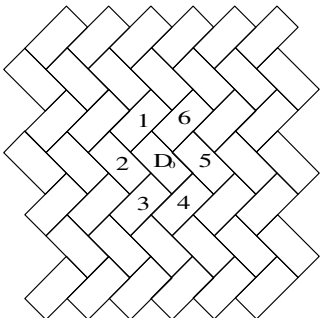


Figure 2. The surveyed sections



D_0: deflection directly below the loading plate

1 to 6: deflections at blocks adjoining the block with loading plate

Figure 3. Positions of deflection measurement with a handy falling weight deflectometer (HFWD)

4. SYRVEY RESULTS

4.1 Traffic volume

The traffic volume on the damaged section of lane 1 (right-turn lane) was about 110,000 wheel loads (cumulative 49 kN converted wheel loads per direction for 10 years). The traffic volume on the damaged section of lane 2 (left-turn lane) was about 150,000 wheel loads.

The traffic volume on the damaged section of lane 1 falls into category III (traffic volume of heavy vehicles = 100 to 250 vehicles per day direction) of the design traffic volume specified by *The Outline of the Design and Construction Manual for Interlocking Block Pavements*[1)] (JIPEA, July 2000, hereinafter: the manual).

The traffic volume on the damaged section of lane 2 falls into category IV (traffic volume of heavy vehicles = 250 to 1,000 vehicles per day · direction) of the manual. Both lanes are subjected to traffic by heavy vehicles.

The manual states that rectangular blocks laid in STB pattern should be installed on lanes with category II traffic volume (traffic volume of heavy vehicles < 100 vehicles per day · direction) or less. The STB laying pattern was not appropriate for either of the damaged locations, because the traffic volume of heavy vehicles in the roundabout exceeds 100 vehicles per day.

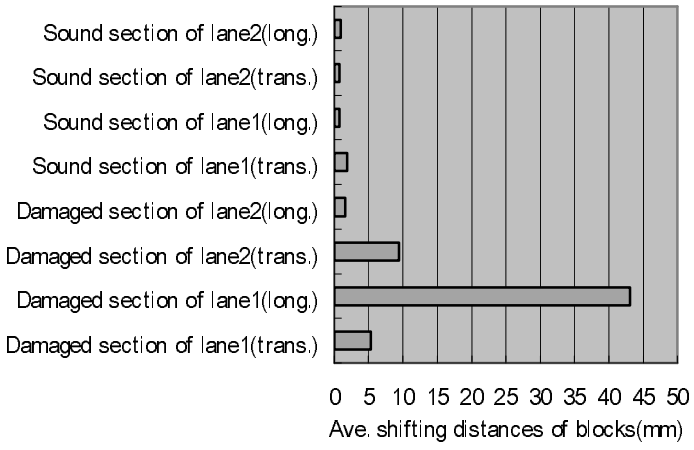


Figure 4. Shifting distances of blocks

4.2 Shifting distances

Figure 4 shows the shifting distances. At sound sections, the shifting distances at

each survey line are very small (0.7 to 1.8 mm). However, at the broken sections, the shifting distances show large values of 1.6 to 43 mm.

At the damaged section of lane 1, the transverse shifting distances are greater than the longitudinal shifting distances. However, at the damaged section of lane 2, the longitudinal shifting distances are greater. This is attributed to differences in loading patterns. The damaged section of lane 1 is at a curve, and the blocks are prone to transverse shifting from the effect of vehicles turning the curve. However, at the damaged section of lane 2, which is at the exit of the roundabout, the blocks are prone to shifting in the direction of vehicle travel, an effect from the braking force of vehicles. A shifting distance of 43 mm was measured at the damaged section of lane 1. This shifting distance (43mm) is almost half the width of this block (100 mm). It is estimated that the blocks no longer interlock.

Table 2. Breakage ratio

Section	Laying Pattern	No. of blocks			Breakage ratio (%)
		Sound	Broken edge	Total	
Damaged, lane 1	STB	69	31	100	31.0
	HBB	50	0	50	0
	(subtotal)	119	31	150	20.7
Sound, lane 1	STB	100	0	100	0
	HBB	50	0	50	0
	(subtotal)	150	0	150	0
Damaged, lane 2	HBB	147.5	15	162.5	9.2
Sound, lane 2	HBB	147	3	150	2.0
Total		563.5	49	612.5	8.0

4.3 Breakage of blocks

Results from the survey of block breakage are shown in Table 2. The breakages are all minor broken edges; there are no major breakages that could obstruct vehicle traffic or require replacement of the blocks. The breakage ratio is defined as the number of broken blocks expressed as a percentage of all blocks. The breakage ratio averages 1.0% in the sound section. The breakage ratio for the damaged section was 14.7%, more than ten times that for the sound section.

This high breakage ratio is attributed to the loss of joint sand, which was followed by the shifting and collision of blocks with other blocks, and breakage of the block edges. However, the 14.7% breakage rate was within the maintenance standard specified in the manual (less than 20%).

When block failure is compared according to laying pattern, the failure rate of the stretcher bond pattern tends to be higher than that of the herringbone bond pattern. This supports the view that the herringbone bond laying pattern is more durable than stretcher bond laying pattern.

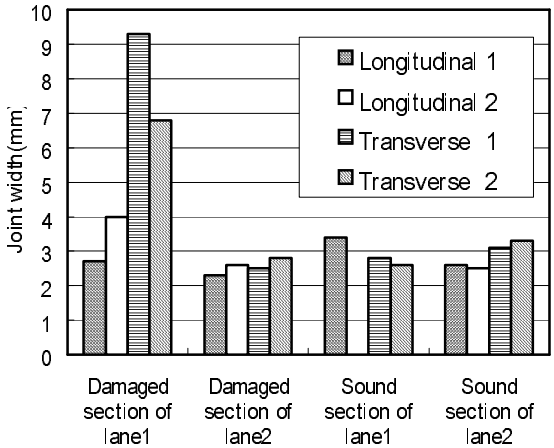


Figure 5. Joint width

4.4 Joint width

The joint widths are shown in Figure 5. Those at the sound sections are 2.5 to 3.4 mm. The widening of joints was not severe enough to cause breakage. However, the joint widths at the damaged sections are 2.3 to 9.3 mm, which shows great widening. Notably, at the damaged section in lane 1, there is great transverse widening of joints. The manual specifies joint width of less than 5 mm for road sections with design traffic volume of category III or over. The damaged section of lane 1 requires repair.

4.5 Depth of lost joint sand

Figure 6 shows the reduction in depths of joint sand. Those reductions in the sound section are less than 5 mm, which would not lead to failure. However, those in the failed section are 39 to 65 mm -- more than half of the 80-mm thickness of the block. It is assumed that the reduction in depth of joint sand caused the block to no longer interlock, which accelerated their shifting.

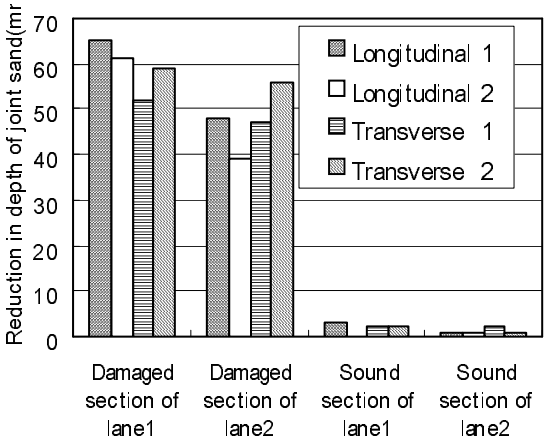


Figure 6. Reduction in depth of joint sand

4.6 Longitudinal and transverse profiles of pavements

Examples of the measured longitudinal and transverse profiles of the pavement cross sections are shown in Figures 7 and 8. At the base course, both the sound and the damaged sections are relatively even. The IL blocks and bedding sand in the sound section are even and smooth, whereas those in the damaged sections are uneven. There is a great reduction in the depth of joint sand at the damaged sections. It is estimated that the joint sand loss was caused when the joint sand infiltrated under the blocks, causing faulting.

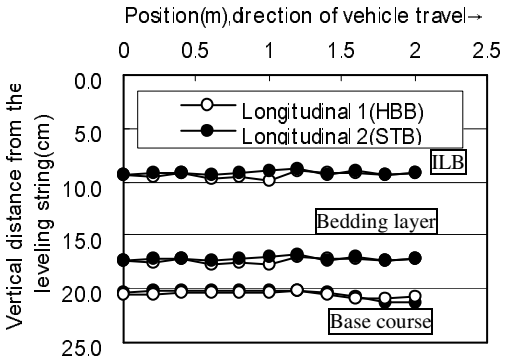


Figure 7. Longitudinal profile of the damaged section of lane 1

4.7 Deflection measured by HFWD

4.7.1 Deflection measured at the IL block surface

The deflections (D_0) measured by the HFWD at the IL block surface and the ratios of deflection (D_1 / D_0) are shown in Figure 9. The defections (D_0) measured at sound sections are 0.039 to 0.045 mm. The deflections (D_0) measured at damaged sections are 0.091 to 0.093 mm, about twice those at sound sections.

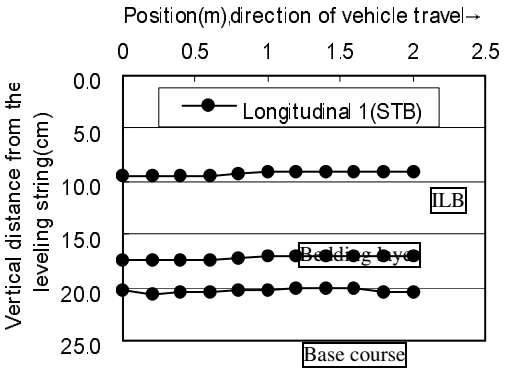


Figure 8. Longitudinal profile of sound section of lane 1

The areal distribution of deflection is compared between sections using the ratios of deflection. The ratios are 0.21 to 0.33 at sound sections versus 0.013 to 0.095 at damaged sections. The ratios at damaged sections are far less than those at sound sections. The load transfer efficiency at the damaged section is also far less than that at the sound section. When shifting occurs at block pavements, the interlocking that characterizes IL block pavement is weakened, and the load transfer efficiency tends to decline.

4.7.2 Deflection at the base course

Deflections (D_0) at the concrete slab surface of the base course were 0.010 to 0.015 mm at the sound section and 0.006 to 0.017 at the damaged section, and there were no differences between the two

sections. In the manual, the deflection at the base course for design traffic volume category III and above is specified as less than 0.8 mm (at 49 kN). This is equivalent to a deflection of less than 0.084 mm measured by HFWD. Therefore, the deflections at the sound and damaged sections satisfy the manual. The difference of deflections (D_0 - D_{20}) was 0.003 to 0.004 mm at the sound section, and 0.002 to 0.006 mm at the damaged section. Those values were roughly the same between the sections. It is therefore assumed that the reduced bearing capacity of the base course and below at the sound and damaged section is not the cause.

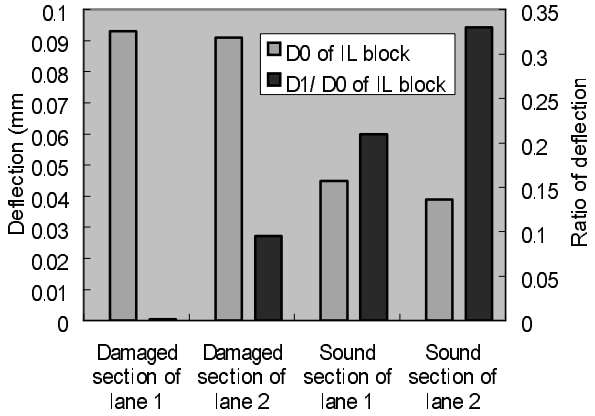


Figure 9. Deflection measured by HFWD at the IL block surface

4.8 Quality of bedding sand and joint sand

At the damaged section, a few clumps were found in some bedding sand and joint sand. The problem was more common in bedding sand. The results from the physical property test of the bedding and joint sand are shown in Table 3. Differences in the grading of bedding sand are seen

Table 3. Test results of bedding and joint sand

Item		Bedding sand			Joint sand		
		Damaged section	Sound section	JIPEA standard	Damaged section	Sound section	JIPEA standard
Max. particle size (mm)		2.36	4.75	4.75	2.36	2.36	2.36
Fineness modulus		2.3	2.9	1.5 - 5.5	2.3	1.4	—
Sand passing vol. 0.075 mm sieve (%)		17	4.5	< 5%	13	12	< 10%
Clumps		Yes	No	-	-	-	-
Pulverization resistance (%)	Compactions: 67	2.4		1	-	-	-
	Compactions: 300	8.6		1.0*	-	-	-

*tentative value specified by

between the sound and the damaged sections. Notably, test samples that passed the 0.075 mm sieve account for more than 17% of the total volume, which is far more than the quality standard value of less than 5% specified by the manual. Therefore, it is assumed that the bedding sand was prone to pulverization. At the excavation survey, consolidation of bedding sand through pulverization has been confirmed at the damaged sections.

To determine the quality of bedding sand, samples were gathered from portions that are thought to have not been subject to vehicle loads, and the samples were tested for their resistance to pulverization. The passing volume for 0.075 mm sieve was 2.4%, which does not satisfy the quality standard of less than 1% specified by the manual. For use on sections with a high traffic volume, the bedding sand should have passing volume for the 0.075 mm sieve after 300 times of compaction of less than 1%, but the test result was 8.6%. From this, it is assumed that material used at this site for bedding sand is prone to pulverization with increasing tampings, and has a low resistance to pulverization.

Differences in grading of joint sand were also found between the sound and damaged sections. The

passing volume for 0.075 mm sieve exceeded the manual's standard of 10%. Therefore, it is assumed that the joint sand material that was used at this site was also prone to pulverization.

4.9 Quality of IL blocks

Flexural strength tests were performed on two blocks sampled from the damaged section, which had severely broken edges. The tests found bending strengths of 9.7 MPa for one block and 10.0 MPa for the other, which satisfy the quality standard of more than 5 MPa specified by the manual. It was thought that the block edges were broken by block-on-block collisions that occurred as the blocks shifted horizontally, and not because of any lack of strength.

5. CONCLUSIONS

The excavation survey has revealed that horizontal shifting of blocks in IL block pavements is caused by "functional failure" (from insufficient pulverization resistance) of the bedding sand in the IL block layer, a layer that consists of the IL block and bedding sand. There was no structural failure caused by insufficient bearing capacity of the base course or the layers below the base course.

5.1 Causes of block shifting

Based on the survey, the causes of shifting blocks were assumed as follows. The shifting mechanism is outlined in Figure 10.

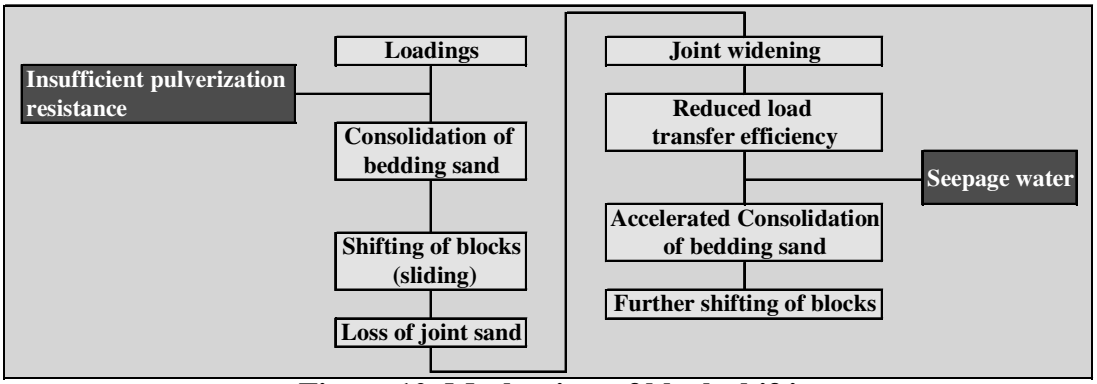


Figure 10. Mechanism of block shifting

1) When the bedding sand has insufficient resistance to pulverization, the traffic loading causes the sand to consolidate. Then, the blocks become prone to shift with the sliding movement that occurs at the layer between the IL block and bedding sand.
2) The shifting of blocks results in the loss of joint sand and the widening of joints. This reduces the load transfer efficiency of IL blocks. Furthermore, insufficient drainage at the bedding sand would make it difficult to drain the rainwater that seeps into the joints. This accelerates the consolidation of bedding sand, and further increases the shifting of blocks.
3) Torsional or braking forces from vehicles that are imposed on the IL blocks result in the shifting of blocks at curves or near pedestrian crossings at the exit of the roundabout.
4) Blocks for locations with heavy traffic should be those with wavy edges. Otherwise, the interlocking between blocks is insufficient and the blocks become prone to shifting.
5) The blocks should be laid in the herringbone bond pattern. Otherwise, they become prone to shifting.

5.2 Causes of loosening

The causes of block loosening, which accompanies of block shifting, are assumed as follows. The mechanism is outlined in Figure 11.

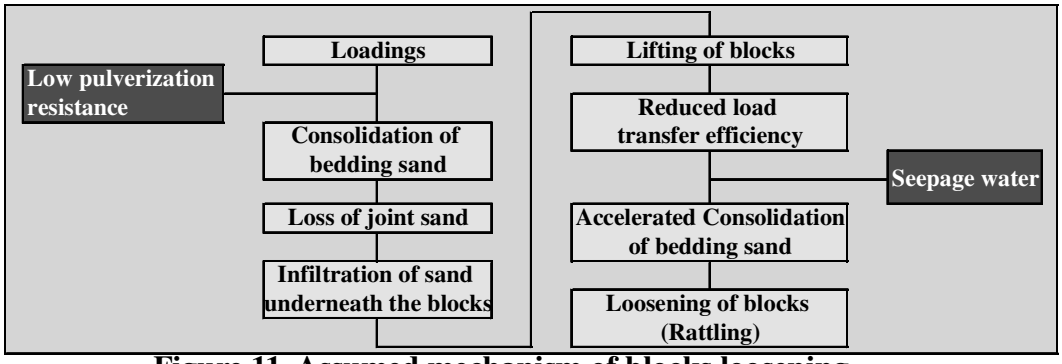


Figure 11. Assumed mechanism of blocks loosening

1) When the bedding sand has insufficient resistance to pulverization, the traffic loading causes the bedding sand to consolidate. This causes the joint sand that has infiltrated underneath the blocks to lift the block, which promotes sliding.
2) Then, torsional or braking forces from vehicles that are imposed on the IL blocks cause the blocks to loosen at curves or near pedestrian crossings at the exit of the roundabout.
3) With load transfer efficiency reduced by the lifting (loosening) of IL blocks and insufficient drainage at the bedding sand, the consolidation of bedding sand is accelerated, which further loosens the blocks.

6. ADDITIONAL OBSERVATIONS

Traffic volume surveys and excavation surveys were performed to clarify the causes of the horizontal shifting of blocks on IL block pavements installed at a roundabout in front of the train station in Asaka City. Shifting and loosening at this location were attributed to the following:

1) Insufficient drainage at the bedding sand and the use of sand with insufficient resistance to pulverization caused the bedding sand to consolidate by torsional and braking forces of vehicles.
2) The use of straight type blocks and stretcher bond laying patterns that were inappropriate for the locations with heavy traffic reduced the load transfer efficiency of the IL blocks.
3) These resulted in the loss of joint sand and the widening of joints, and then loosened the blocks before the pedestrian crossing at the exit section of the roundabout.

7. PROPOSALS FOR IMPROVING THE DURABILITY OF IL BLOCK PAVEMENTS

Based on the findings from this research, the authors propose the following measures to improve the durability of IL block pavements.

7.1 Structure of IL block pavements

1) Improve drainage

(1) Install collecting pipe in the bedding sand to drain rainwater that has seeped into and has been retained at the bedding sand.
(2) Include drainage holes in water catchments to drain water from the collecting pipe.

2) Secure bearing capacity of the base course and below.

7.2 Materials to be used

1) Bedding sand
(1) For bedding sand, use materials with high resistance to pulverization.
(2) At locations with traffic volumes that are greater than the Classification III design traffic volume, the tamping of samples for testing pulverization resistance should be increased from the current 67 times to more than 300 times. After tamping 300 times, the amount that passes the sieve test should be less than 1%. The materials that are to be used for bedding sand should satisfy this, and should be of higher quality than those specified in the current manual.

2) Blocks
At locations with traffic volumes that are greater than the Classification III design traffic volume, use wavy-sided IL blocks instead of straight-sided IL blocks.

7.3 Installation method

1) Laying pattern
At locations with traffic volumes that are greater than the Classification III design traffic volume, the blocks should be laid in accordance to the manual, with the herringbone bond pattern instead of the stretcher bond pattern.

2) Reinforcement with reinforcing plates
At locations where braking loads are imposed and where there are concerns over horizontal shifting of blocks, reinforcing plates such as those shown in Photo 2 should be installed for reinforcement between the blocks.

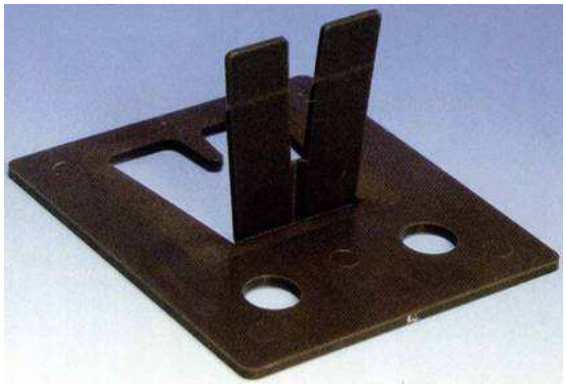


Photo 2. Reinforcement plate

8. REFERENCES

Japan Interlocking Block Pavement Engineering Association, 2000, “The Outline of the Design and Construction Manual for Interlocking Block Pavement”