LOAD TRANSFER EFFICIENCY IN INTERLOCKING BLOCK PAVEMENTS WITH JOINT AND BEDDING SAND

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SUMMARY

Interlocking block (IL block) pavement is constructed by a dry laying method in which sand is used for the leveling course and joints. In recent years, the most commonly used blocks have been those 60 mm or greater in thickness, whether tile or natural stone. There is a growing tendency to place such material on bedding sand layer over the granular base course, as is done with concrete flag pavement. Dry laying methods are economically superior to wet laying methods, which use material such as mortar, because 1) skilled workers are not needed, 2) products can be reused, and 3) the construction period can be reduced. Because of these numerous advantages, dry laying methods will be increasingly used for block pavements in the future.

IL blocks were introduced to Japan about 30 years ago. However, little research has been conducted on the sand used for bedding and joints in the dry laying method. It is necessary to clarify how the bedding sand quality and grading relates to the load transfer efficiency and to the performance of IL block pavements. It is also important to fully understand how joint sand transfers loads. To examine these, the authors constructed test pavements for the measurement of deflection using a handy falling weight deflectometer (HFWD), and of longitudinal and transverse profiles.

Test pavements were made with bedding sand of different quality. Performance of the pavement was observed for 5 years. It was confirmed that the load transfer efficiency (load transferred to an IL block by the sand filled around the block) of IL block pavement varies according to the bedding sand quality. It was also found that

some kinds of bedding sand greatly reduce pavement surface deformation, movement and damage to IL blocks, and changes in joint width. Moreover, a high correlation was found between the load transfer efficiency of IL block pavements and pavement surface deformation.

To understand differences in the efficiency of load transfer of joint sand, test pavements with different joint structures were made on sidewalks. It was made clear that sand is the most suitable joint material for IL block pavement and that, in the method that uses butt joints without sand filled between the blocks or rubber attached to the side of the block, the coefficient of load transfer efficiency was 30 to 40 % lower than that with sand-filled joints.

1. INTRODUCTION

The Japan Interlocking Block Pavement Engineering Association (JIPEA) has performed field studies and questionnaire surveys[1)] on pavement damage caused by the Great Hanshin-Awaji Earthquake (the Kobe Earthquake) of January 17, 1995, including on recovery from such damage. These found that 84% of the blocks in block pavements damaged in that earthquake were reused and that dry-laying installation, which uses joint sand and bedding sand without mortar, is more suitable for places with frequent earthquakes, such as Japan, than wet-laying installation, which uses mortar.

Permeable pavements have come to be used not just on walkways but also on roadways, to reduce the burden on rivers and sewage systems from localized torrential downpours. In some cases, IL blocks are being used in permeable and drainage pavements.

Block pavements have found increasingly broad application and they are often installed by dry laying. However, few studies on IL block pavements have addressed the relation between bedding sand quality and load transfer efficiency, and between bedding sand quality and in-service performance of the pavement surface. (Load transfer efficiency here is defined as a ratio of deflection near the joint on a loaded block to deflection near the joint on a non-loaded block.) When these pavements are used as permeable or drainage pavement or in pavements on steep slopes, there are concerns that water seepage may cause the pavement surface condition to deteriorate, reducing the bearing capacity or causing the sand to shift. Some products use rubber attached to the sides of the blocks in place of joint sand. There are also sand-free installation methods that use narrow joints. Such pavements often have problems after they enter service. It is important to clarify how the bedding sand quality affects the load transfer efficiency and the pavement surface condition, and to clarify the behavior of the joint sand. This paper reports on the above issues, based on measurements of pavement surface condition and deflection taken using a HFWD at a test pavement.

2. EFFECTS OF BEDDING SAND QUALITY ON LOAD TRANSFER EFFICIENCY

2.1 Test pavement

To examine how differences in bedding sand quality affect the surface conditions and load transfer efficiency of IL block pavements, a test pavement was installed and studied during a 5-year service period.

The test installation was done at an asphalt mixture plant that has traffic of 50 to 100 dump trucks per day and where the gradient is steep (8%). This gradient had raised concerns about seepage water from the joint causing movement of bedding sand and reducing the bearing capacity. The IL block pavement is 3 m wide and 10 m long. It was laid on an existing asphalt pavement that acts as the base course. The test pavement specifications are given in Table 1.

Natural sea sand and coated sand were used in the test pavement installation. The coated sand is made specifically for block pavements using natural sea sand as the base material. It is made by mixing the natural sea sand with an asphalt binder, a special admixture. The mixing ratio of the binder varies between 1.0-3.0% depending on the water absorption rate of the base sand. This sand can be applied cold, allowing application with the same method as conventional bedding sand. It is produced in asphalt plants, which ensures a consistent quality and continuous supply. Since the sand particles are coated with asphalt and a special admixture, the sand is more resistant to the effects of water than is natural sand.

The two types of bedding sand were laid side by side longitudinally, on a 3-m-wide pavement. The sand specifications are given in Table 2 and Figure 1. The joint sand is the same as the bedding sand. It has been confirmed that to prevent the loss of joint sand, the joints should be filled with materials that are as similar as possible to conventional bedding sand[2)].

The table shows that both natural sea sand and coated sand satisfy JIPEA specifications[3)]. The coated sand has been greatly improved in terms of resistance to pulverization by applying a coating of asphalt and a special admixture to the base material (natural sea sand). As shown in Figure 1, there is no difference in grading between the natural sea sand and the coated sand.

Table 1. Test pavement specifications

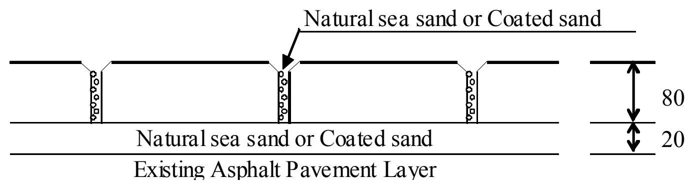
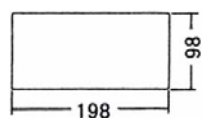
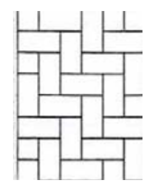
Section	A	B
Bedding sand	Natural sea sand	Coated sand
Joint sand	Natural sea sand	Coated sand
Width (m)	1.5	1.5
Length (m)	10.0	10.0
Pavement structure (mm)		
IL block dimensions (mm) and laying pattern	 	

Table 2. Quality of bedding sand

Item	Natural sea sand	Coated sand	JIPEA standard
Maximum size (mm)	2.36	2.36	4.75 or less
Fineness modulus	2.49	2.49	1.5 - 5.5
75μm sieve passing rate (%)	0.89	0.06	5 or less
Resistance to pulverization (%) (change in 75μm sieve passing rate before/after impact compaction test)	0.86	0.10	1 or less

2.2 Test method

The bedding sands were compared by measuring the deflection, rutting, movement and damage rate of the block, and the joint width. Deflection was measured by positioning an HFWD such that the center of the loading plate (D_0) was on the block's longitudinal axis and a sensor (D_1) was on the adjoining non-loaded block's longitudinal axis (Figure 2). The distance between the two sensors was set at 200 mm. Deflections were measured for IL blocks laid under two conditions: 1) no compaction of bedding sand either directly or by compaction of laid blocks, and no filling with joint sand; and 2) compaction of bedding sand only by compaction of laid blocks, and filling with joint sand. The second condition reproduces the condition of a road that is ready to enter service. The deflection values were expected to reveal how joint sand use or non-use and the degree of bedding sand compaction affect the load transfer efficiency. Furthermore, the measurement of defection was performed not just on the IL block, but also on the existing asphalt pavement, which acts as the base course for the block pavement.

Rutting, block movement and joint width were measured along the line that connects D_0 and D_1 in Figure 2.

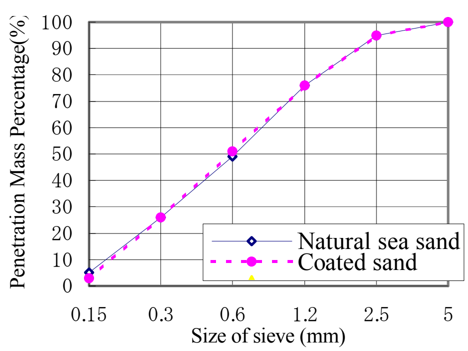


Figure 1. Particle size curves for two types of bedding sand

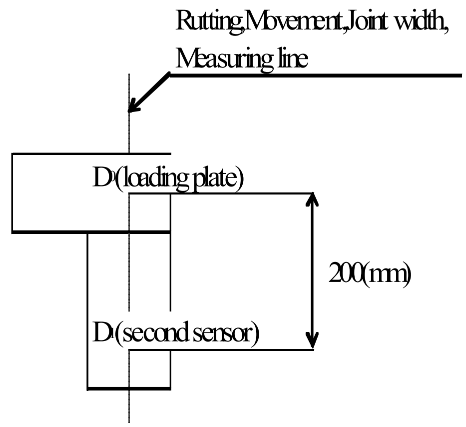


Figure 2. Locations of deflection measurement

2.3 Test Results

2.3.1 Load transfer efficiency

To determine the load transfer efficiency, we first use Equation (1) to calculate the radius of deflection curvature from the distance between D_0 and D_1 and the difference in the deflections at D_0 and D_1.

$$R = L^2 / 2\times(D_0 - D_1) \quad (1)$$

Where R: radius of deflection curvature (m)
L: distance between D_0 and D_1 (mm)
D_0-D_1: deflection at D_0 - deflection at D_1 (mm)

In a measurement using an FWD with a 49-kN load, the soundness of an asphalt pavement was assessed according to the difference in deflection between D_0 (deflection at the center of the loading plate) and D_{20} (deflection 20 cm from the center of the loading plate). The greater is a pavement's radius of deflection curvature, the greater is its ability to transfer the load to the surface course.

2.3.2 Deflection and radius of deflection curvature

The deflection measured on existing asphalt pavement that is used as the base course was 0.012-0.015 mm at D_0 and 0.009-0.010 mm at $D_{0\text{-}20}$. There was no considerable difference in between deflection values measured at D_0 and $D_{0\text{-}20}$. The bearing capacities at the two sections are uniform below the base course.

Figure 3 plots the deflection of IL block against time in service. The deflections (D_0) of IL block before the bedding sand was compacted are roughly the same for the natural sea sand section (0.258 mm) as for the coated sand section (0.240 mm). The deflection values at D_0 were compared after compaction: 0.193 mm for natural sea sand and 0.140 mm for coated sand. There is a considerable difference between the two values. This shows that filling with special joint sand followed by compaction affords greater stability than filling with natural sea sand followed by compaction. This is because the horizontal compressive forces produced by positive dilatancy of coated sand used as joint sand act between the blocks to transfer the load to adjoining blocks. And the dilatancy of coated sand is greater than that of natural sea sand. It must be mentioned that the increase in deflection after 6 months in service is attributed to the saturation of bedding sand from rainfall that started the day before measurement.

Figure 4 plots radius of deflection curvature against time in service. The radius of deflection curvature is greater with coated sand than with natural sea sand. The radius of deflection curvature with both natural seas sand and coated sand tends to increase with time in service, except at 6 months in service, at which time the values show the effects of rainfall. This figure also shows that the radius of deflection curvature of coated sand is about 1.1 to 1.3 times that of natural sea sand. It is therefore thought that the coated sand is superior to natural sea sand in terms of joint filling and compaction performances. Furthermore, joint sand and bedding sand become more stable with repeated traffic loadings, and the interlocking between blocks becomes stronger.

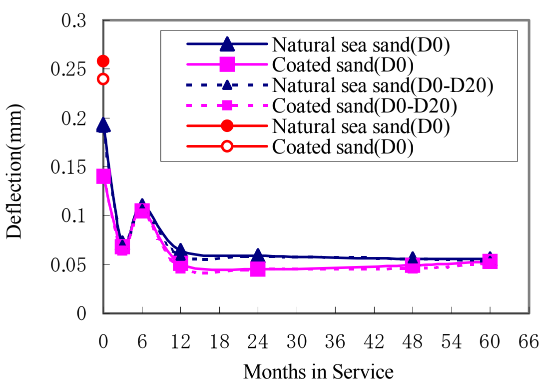


Figure 3. Changes in deflection (D_0,D_0-D_{20})

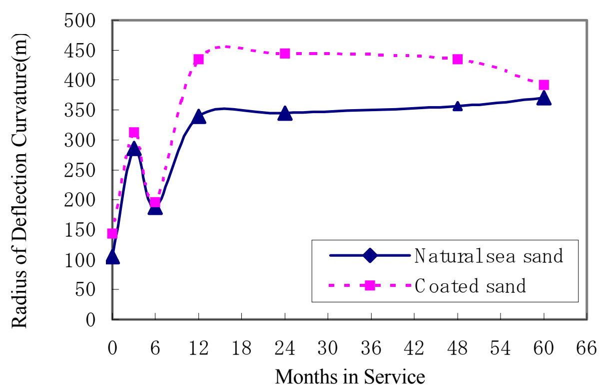


Figure 4. Changes in radius of deflection curvature

2.3.3 Rutting, movement, damage rate and joint width

Figure 5 plots depth of rutting against time in service. The pavement rutting depth increases steeply in the first 3 months and plateaus at 6 months after construction for both natural sea sand pavement and the coated sand pavement. The high degree of rutting that occurs in the first 3 months is attributed to insufficient compaction during construction that results from the use of a dedicated block compactor. To prevent deformation of the pavement surface at the initial stage of service, it is necessary to perform compaction with heavy rollers. The reasons the pavement rutting depth plateaus at 6 months after construction are the survey's timing of June, the rainiest season in Japan, and increases in the deformation of the bedding sand layer under the wheel paths because of seepage water from joints. The rutting depth for the coated sand also peaks at 6 months after construction and decreases thereafter. This is because water seepage from joints decreases with the passage of time after pavement installation, and bedding sand and joint sand both become stable because coated sand is used. If the base course is impermeable, a bedding sand layer should be installed with drainage. From 3 months to 5 years in service, the rutting on the coated sand pavement is about 2.1 to 2.8 mm less than that on the natural sea sand pavement. This shows that the coated sand can mitigate rutting.

Figure 6 plots block movement against time in service. At 2 years, the block movement for the coated sand pavement is less than for the natural sea sand pavement. At 5 years, the average movement is 1.53 mm with coated sand. This is approximately half of that for the joint filled with natural sea sand (2.9 mm). The figure suggests that the joints are out of alignment.

Figure 7 plots the damage rate of the blocks against time in service. At 5 years, the blocks show high damage rates regardless of the sand type: 29.5% for coated sand, and 28.5% for natural sea sand. This is because pebbles brought into the plant by dump trucks scattered over the blocks, and it is thought that these caused the block corners to chip when traveling vehicles concentrated stress at the edges of the blocks by exerting load on the pebbles. In the figure, the combined rate of heavy and light damage after 5 years is the same regardless of block type, but the heavy damage that requires replacement of the blocks laid with coated sand tends to be less than half of that for those laid with natural sea sand.

Figure 8 plots the widths of transverse joints and longitudinal joints against time in service. The figure indicates that at 6 months in service, the transverse joint widths tend to be smaller with coated sand than with natural sea sand. In contrast, at 2 years in service and onward, longitudinal joint widths are small and show little fluctuation, nor do they differ much according to the type of sand.

These results confirm that differences in the quality of bedding sand affect not only the load transfer efficiency of IL block pavements, but also the degree of rutting, block movement, heavy damage, and changes in joint width.

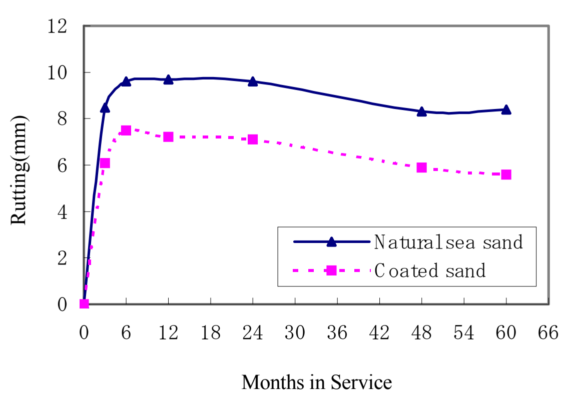


Figure 5. Changes in rutting

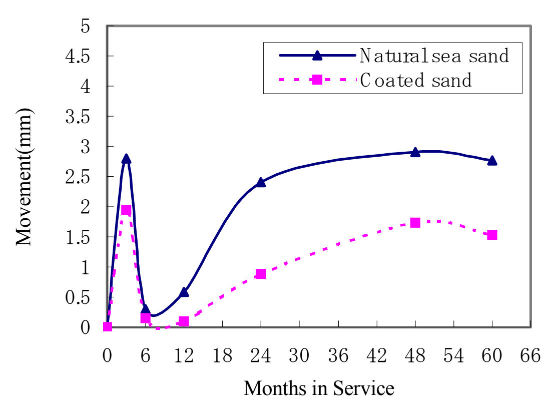


Figure 6. Changes in movement

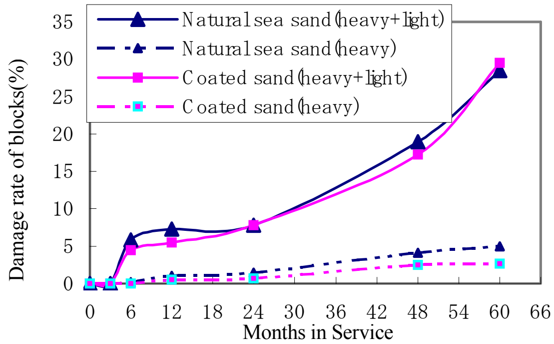


Figure 7. Changes in damage rate of blocks

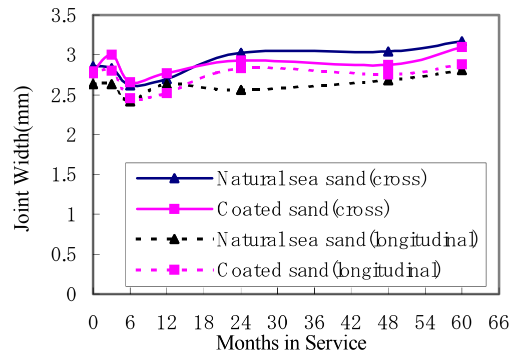


Figure 8. Changes in joint width

2.3.4 Correlation of variance among factors

Table 3 shows the correlation of variance among degree of movement, damage rate, joint width, rutting, radius of deflection curvature and other factors. The data at 6 months in service are excluded, because rainfall caused large fluctuations in deflection at that time. The correlation coefficient indicates a correlation of 0.72 between radius of deflection curvature and depth of rutting. It is thought that there is a strong correlation between them. This clarifies that bedding sand with high load transfer efficiency can afford reductions in block pavement rutting and that load transfer efficiency strongly correlates with the depth of rutting. Correlations were also found between 1) movement of blocks and transverse joint width, 2) movement of blocks and depth of rutting, and 3) joint width and block damage rate of blocks.

Table 3. Correlation Matrix

Item	Radius of deflection curvature	Movement	Joint width (transverse)	Joint width (longitudinal)	Damage rate of blocks	Rutting
Radius of deflection curvature	1.000					
Movement	0.411	1.000				
Joint width(transverse)	0.266	0.632*	1.000			
Joint width(longitudinal)	0.137	0.049	0.506	1.000		
Damage rate of blocks	0.543	0.440	0.688*	0.469	1.000	
Rutting	0.721**	0.681*	0.217	-0.217	0.320	1.000

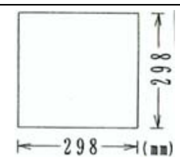
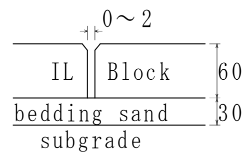
**significant at 1% *significant at 5%

3. EFFECTS OF DIFFERENCES IN JOINT MATERIAL ON LOAD TRANSFER EFFICIENCY

3.1 Outline of the test pavement

To test how different joint materials affect the load transfer efficiency, a test pavement was constructed and deflections of the block pavement were measured using an HFWD. As the test pavement, 298 × 298 × 60 mm blocks (Table 4), which are increasingly being used for pedestrian roads, were laid. Three types of joints were used: conventional joints (2 mm wide; with joint sand), butt joints (minimum width; without joint sand), and rubber joints (cushioned by 2-mm-thick rubber tape attached to the sides of blocks; without joint sand).

Table 4. Outline of Test Pavement

Test section	Block dimensions	Laying pattern	Joint structure	Joint width (mm)	Pavement structure (mm)
1		Stack bond	Sand	2	
2			Butt	0	
3			Rubber	2	

3.2 Measurement and assessment of deflection

The deflection measurements made using the HFWD were done at the points shown in Figure 9 and according to the patterns shown in Figure 10, at five separate locations. Assessment of deflection was performed using the load transfer efficiency (E_{LT}) obtained from Equation (2). The nominal load transfer efficiency was calculated by the deflection of the pavement layers below the bedding sand layer, since the load transfer efficiency is defined by the deflection ratio.

$$\text{Load transfer efficiency } (E_{LT}) = D_1' / D_1 \qquad (2)$$

Where D_1: deflection near the joint on a loaded block

D_1': deflection near the joint on a non-loaded block

With this measurement method, when the blocks are uneven or when they have settled, it is not always possible to place a second sensor near the joint. Therefore, the measurement method shown in Figure 2 was used for assessing changes with time in service.

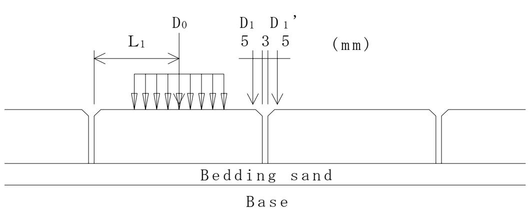


Figure 9. Sensor installation point

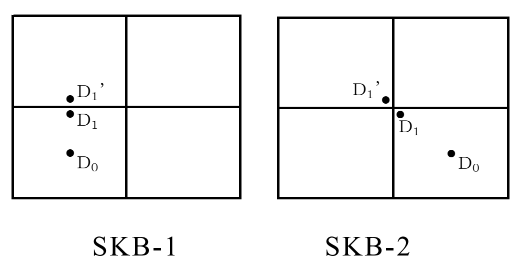


Figure 10. Deflection measurement

3.3 Measurement results

The measurements are shown in Table 5. The deflection directly below the loading plate (D_0) for pavement with sand joints averages 0.348 mm. Those for pavements with butt joints or rubber joints average 0.452 to 0.456 mm, which is about 1.3 times that for the sand joint pavement. Deflections at the edge or the corner of the loaded block (D_1) do not differ much for pavements with the different joint structures. However, deflections at the edge or the corner of adjoining non-loaded blocks (D_1') without sand (i.e., with butt joints or rubber joints) are about 30% to 40% of those with the sand joint. This is because with the butt joint and rubber joint, the deflections directly below the loading plate are large, whereas those at the edge of the adjoining non-loaded blocks (D_1') are extremely small.

Figure 11 compares the load transfer efficiencies of the three joint structures. The load transfer efficiencies of two blocks (SKB-1 and SKB-2 from Table 5), each of which uses butt joints and rubber joints, show low values about one-third those for the sand joint. This is because the horizontal compressive force produced by positive dilatancy, which acts between the blocks to transfer the load to adjoining IL blocks, does not occur with butt joints or rubber joints. And the load transfer efficiency is low; consequently, the interlocking effect between blocks is small. Therefore, interlocking cannot be expected in methods that either minimize joint width or use rubber joints in place of using sand. It is conceived that these types of joint, which are prone to unevenness and settlement of blocks after a long time in service, are unsuitable for use in block pavements.

Table 5. Results of Deflection Test

Joint structure	D_0 (mm)	SKB-1 (mm)		SKB-2 (mm)		Load transfer efficiency(D_1'/D_1)	
		D_1	D_1'	D_1	D_1'	SKB-1	SKB-2
Sand	0.348	0.337	0.227	0.265	0.109	0.67	0.42
Butt	0.456	0.378	0.071	0.282	0.044	0.19	0.16
Rubber	0.452	0.365	0.084	0.284	0.040	0.23	0.14

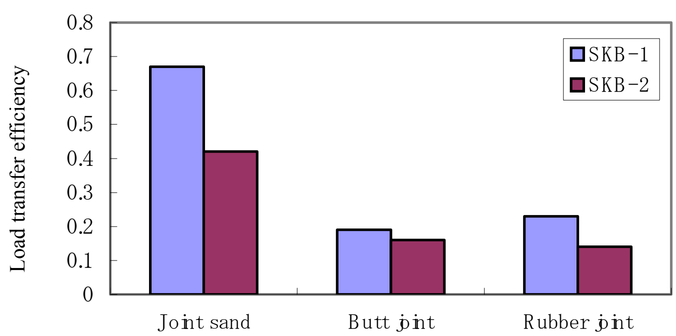


Figure 11. Comparison of load transfer efficiency

4. CONCLUSIONS

Because dry-laying installation of blocks has become more common and IL blocks are expected to achieve wider application, this study examined the load transfer efficiency of bedding sand and joint sand of block pavements. The findings are as follows:

1) Deformation of pavement surfaces can be reduced by using bedding sand made of material with greater load transfer efficiency. A strong correlation was confirmed

between load transfer efficiency of bedding sand and rutting.

2) Surface deterioration can be prevented by using bedding sand that is less prone to movement of sand particles and that is less prone to bearing capacity reduction when subjected to seepage water.
3) Butt joint installation, in which the joints are narrow and not filled with joint sand, and rubber joint installation, in which rubber tape is attached to the sides of blocks instead of joint sand, show low load transfer efficiencies that are about one-third those of conventional sand joints. Horizontal compressive forces between blocks occur in sand joints. Because positive dilatancy does not occur in butt and rubber joints, they are free of such dilatancy.
4) Butt joints and rubber joints are unsuitable for use in block pavements, because such joints make the pavement prone to unevenness and settlement after a long time in service.
5) Clarifying the behavior of joint sand has made it possible to prevent the unevenness and settlement of blocks that have been seen in permeable sidewalk pavements.

5. REFERENCES

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