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CASE STUDY FOR THE GOOD LONG-TERM SERVICEABILITY OF INTERLOCKING BLOCK PAVEMENT

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Note: The following is the notation used in this paper: (.) for decimals and ( ) for thousands.

Summary

Interlocking pavers were introduced to Japan in 1974 and have since been widely applied mainly to pedestrian roads such as walkways, parks as well as to roadways and container yards. Recent annual pavement areas are approximately 5 million m^2 and the accumulated total areas of the pavement in Japan amount to 180 million m^2. Although the development of pavers has been remarkable, some distress, particularly in roadways, has come to be revealed, if a design/construction was inappropriate. Considering the further improvement of durability and appropriate maintenance for the pavers, it is important to understand the factors affecting the sound long term serviceability through investigation. Therefore, the investigation for the serviceability was conducted in Japan looking at both 18 and 27 years old interlocking pavers laid at the station bus terminal and in-service carriageway, respectively.

The results revealed that, for the pavers at the station bus terminal, the distress such as breakage, joint expansion and rutting was found in some parts though, it was confirmed that the state which does not need to conduct repair works has been kept even after 18 years in service, if followed Japanese maintenance standard. The reasons for keeping the performance were mainly due to the used block and paving pattern which were suitable for the traffic condition, sound bearing capacity of base course, and appropriate thickness of bedding sand. Also, it was confirmed that the sound state has been kept even at the 27 years old in-service carriageway, as similar results were obtained.

1. INTRODUCTION

Interlocking pavers were introduced to Japan and have since been widely applied mainly to pedestrian roads such as walk side, park as well as to roadways and container yards. Recent annual pavement areas are approximately 5 million m^2 and the accumulated total areas of the pavement in Japan amount to 180 million m^2.

The development of pavers has thusly been remarkable. As pavers develop widely, some breakages particularly in roadways have come to be revealed various kinds of damage if a design/construction was inappropriate. Under this circumstance, we need to investigate the interlocking pavers with long-term sound serviceability and grasp the factor enough in order for correspondence to durability improvement of the interlocking block pavement and appropriate maintenance.

Thus, the investigation of serviceability was conducted at the two in-situ locations (the bus terminal around the train station that was built 18 years ago and the roadway that was built 27 years ago). This paper reports those findings of investigation.

2. INVESTIGATION FOR LONG-TERM SERVICEABILITY OF THE BUS TERMINAL

2.1 Location

The investigation was performed at the bus terminal around the train station in Tokyo that was built in December 1990. The pavement was wavy pattern rectangular interlocking (IL) block of thickness 80 mm (111*225 mm) that was laid in a herringbone bond pattern 90°.

As shown in Figure 1, bitumen stabilization was used for base course and the design of traffic volume was N5 (number of commercial heavy vehicle 250~1000 /day-direction). The design CBR of subgrade was 3%. The road surface condition of IL block pavement was comparatively sound at the sections from near the terminal entrance to cornering region of taxi bay and bus stop as shown in Figure 2 and Figure 3. However, rutting occurred partially in the cornering region of taxi bay and bus stop, and a spout of joint sand and bedding sand due to the settlement and pumping was observed as shown in Figure 4 and Figure 5.

2.2 Summary of investigation

2.2.1 Location and items of investigation

The investigation was performed on October 2008, about 18 years after the construction. In consideration of an action form of traffic load as shown in Table 1, the investigation sites were selected to bus/taxi roadway and bus/taxi station at each sound

region and damaged region as described previously.

The items of investigation were 1) rutting depth, 2) faulting between blocks, 3) rate of block breakage, 4) joint width, 5) road roughness (crossing long), 6) skid resistance, 7) bearing capacity, and 8) thickness and quality of bedding sand.

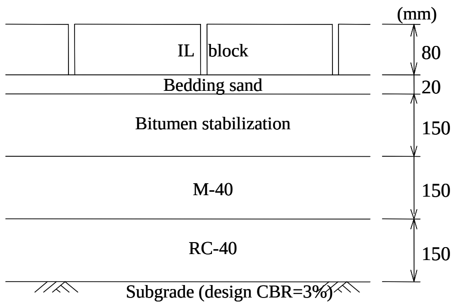

Figure 1. Pavement structure

All investigation was performed along two survey lines each in the transverse directions. Exceptionally, the rate of block breakage was investigated at entire survey region.

In addition, roughness and bearing capacity at specific point were measured along the one survey line at the sound region of bus/taxi roadway and bus station. At damaged region, they were measured at two locations along the same (one) survey line in and out bus station. Similarly, skid resistance was measured at one location along the one survey lines. Thickness of bedding sand was measured at the same survey locations as roughness and bearing capacity. The quality of bedding sand was measured at each location of damaged and sound section.

Figure 2. Sound condition at entrance and corner.

Figure 3. Sound condition at bus station.

Figure 4. Rutting near taxi bay.

Figure 5. Damaged area at part of bus station.

Table 1. Survey section and location

SECTION	ROADWAY OF BUS AND TAXI		BUS STATION	
Condition and section	DAMAGED	SOUND	DAMAGED	SOUND
	Near taxi bay	Between entrance and cornering	Inside & outside bus station	Near bus station

2.2.2 Method of investigation

Each investigation followed the method determined by Japan Interlocking Block Pavement Engineering Association [JIPEA, 2008]. In other words, the depth of rutting was investigated by measuring the transverse shape of the road surface with 20cm interval by a leveling string method. The faulting between blocks and joint width were measured by slide calipers. The rate of damage was calculated using the results of visual survey and Equation 1. The sliding resistance, BPN, was measured by a portable skid register tester. Roughness was measured by the vertical inequality scale developed by JIPEA. Bearing capacity was evaluated using the deflection measured by handy falling weight deflectometor (HFWD) of IL block surface and bitumen stabilized base course. Deflections of IL block surface were measured in order to identify the performance of pavement load distribution. The deflection at block D0, directly below the loading plate was measured. Then the deflections (Dx) at the centers of six adjoining blocks were measured with a second sensor. The ratio of deflection was calculated from Eq.2.

$$Rate\ of\ damage\ (\%) = \frac{Number\ of\ dameged\ block}{Total\ number\ of\ dameged\ block} \times 100 \qquad \textbf{(1)}$$

$$Ratio\ of\ deflection = \frac{D_x}{D_0} \qquad \textbf{(2)}$$

Thickness of bedding sand was measured by ruler. To evaluate the quality, % of passing 75μm sieve and pulverization resistance was measured by conducting the sieve tests specified in JIS A 1102 and pulverization resistance according to JIPEA-TM-2.

2.3 Results of investigation

2.3.1 Joint width and faulting between blocks

Table 2 indicates the result of investigation for joint width and faulting between blocks at the sound and damaged section at both bus stop and near taxi bay. As seen in the table, only outer bus stop of damaged section-2 has the width whose mean value exceeds 4 mm. As for joint width, the number of results exceeding 5mm that is JIPEA maintenance standard [JIPEA, 2007] is shown in the table, and its ratio was the about 11%. As for faulting between blocks, the results exceeding JIPEA maintenance standard value of 5 mm are minor at both sound and damaged sections. Its rate was the about 3%. Hence, the conditions of both joint width and faulting between blocks were excellent.

2.3.2 Roughness

Figure 2 indicates the mean value of measured roughness. It can be seen that roughness at taxi bay in the damaged section is deteriorated due to the effect of rutting. However, all results are less than the JIPEA maintenance standard of 5 mm. Therefore, the roughness was sound condition.

Table 2. Results of joint width and faulting between blocks (mean value).

SECTION		BUS STATION						NEAR TAXI BAY			
CONDITION		DAMAGED 1		DAMAGED 2		SOUND		DAMAGED		SOUND	
SURVEY LINE NO.		Inside bus station	Outside bus station	Inside bus station	Outside bus station	1	2	1	2	1	2
Joint width	Mean value (mm)	3.1	3.6	4.0	4.6	2.6	2.8	2.9	2.4	2.7	1.6
	# of data > 5mm	1	3	2	9	0	0	3	3	3	0
Faulting between blocks	Mean value (mm)	2.3	2.2	2.3	2.5	1.4	1.5	2.3	1.8	1.1	1.2
	# of data > 5mm	1	0	0	2	0	0	2	2	0	0

Note: # of data indicates "Number of data"

2.3.3 Rate of block breakage

Results from the investigation of block breakage are shown in Figure 3. The rate of block breakage at bus station of damaged section was more than 20%, which is JIPEA maintenance standard value. Otherwise, the rates of block breakage at other sections were less than JIPEA standard criteria.

There exists 11.3% of minor broken edges and 5.5% of major broken edges. No major breakage was observed. Overall, it was sound condition.

2.3.4 Rutting depth

The mean rutting depth of the bus station in the sound and damaged section were 2.6 mm and 12.6 mm respectively. As well, rutting of taxi bay in the sound and damaged section were 17.9 mm and 5.5 mm respectively. The largest depth was 17.9 mm at the taxi bay in the damaged section. Including this section, all sections satisfied the JIPEA maintenance standard value (i.e., less than 30 mm). Thus, the condition of rutting depth was roughly sound.

2.3.5 Bearing capacity

Figure 4 indicates the ratios of deflection measured at IL block surface, and Figure 5 shows the modulus of deflection measured at base course by HFWD. In the Figure 4, it can be seen that some ratios of deflection are large in the damaged section. However overall, the ratios of deflection in the sound section are larger than those of damaged section. In Figure 5, all modulus of deflection of base course are larger than JIPEA standard criteria (upper N4 in normal roadway and upper 730 MN/m^2), except the one from the taxi bay of damaged section. Based on the modulus of deflection, although the load transfer efficiency varies due to the effect of joint width, the bearing capacity was strong enough.

2.3.6 Skid resistance

BPN indicated an almost equal value in both the sound section and the damaged section in the vicinity of the taxi bay and the bus station. Except the damaged section in the taxi bay, BPN was about 56, which is below the JIPEA maintenance standard specification BPN 60. However, because the speed of running in the vehicle is low in the bus terminal, it can be said the value of unquestionable.

2.3.7 Depth of bedding sand

The mean thickness of bedding sand of the bus station in the sound section and damaged section were 29 mm and 23 mm respectively. It can be said that the bedding sand of consolidation deformation caused the larger rutting in the damaged section than that of in the sound section.

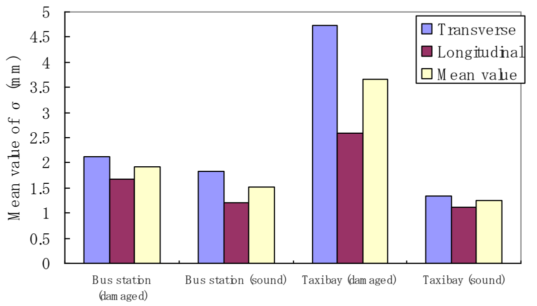

Figure 6. Results of roughness σ.

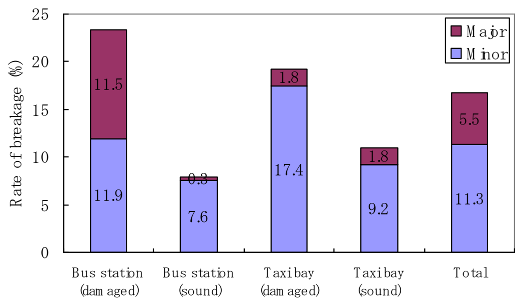

Figure 7. Results of rate of block breakage.

Thickness of the sound section was a little thicker than 20 mm of the design thickness though, the thickness kept excellently constant.

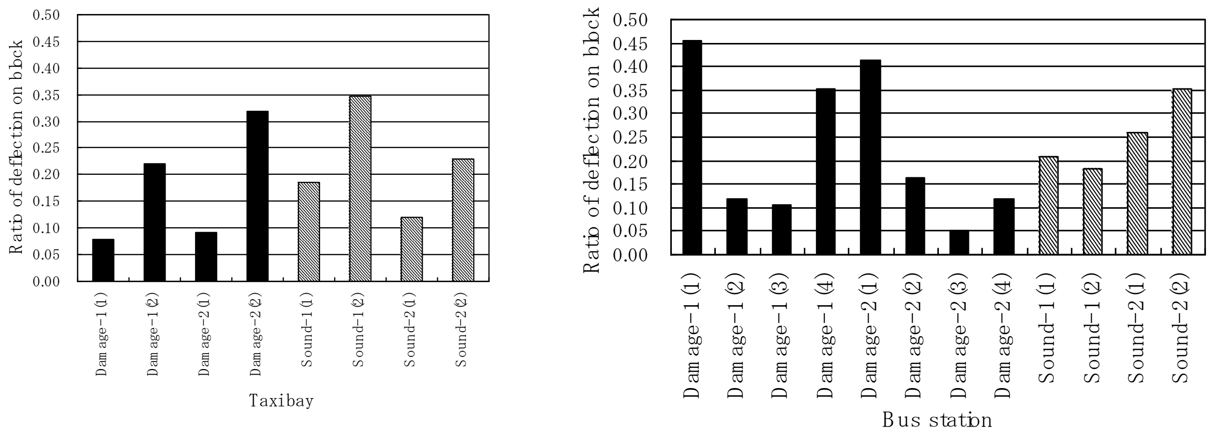

Figure 8. Results of ratio of deflection of block.

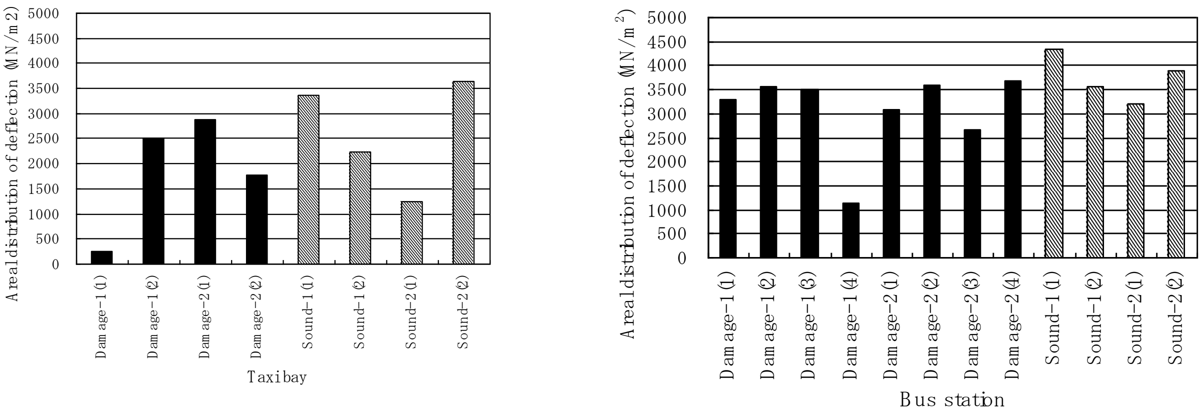

Figure 9. Results of modulus of deflection of base course.

2.3.8 Quality of bedding sand

Table 3 shows that the percentage passing the 75 µm sieve of the in-situ bedding sand in both sections are highly larger than JIPEA standard value of 5%. The value of damaged section is larger than that of sound section. Moreover, all the resistances of pulverization were larger than JIPEA standard value, which was less than 1%. Because the quality of bedding sand against the resistance of pulverization was poor, the pulverization was remarkable in the damaged section.

2.3.9 Evaluation of serviceability by MCI

The rate of block breakage *C* and the mean rutting depth *D* in the entire survey section were 16.9% and 9.6 mm respectively. Then, with these data, the Maintenance Control Index (MCI_0) which is used to evaluate the serviceability in Japan was calculated from equation (3).

$$MCI_0 = 10 - 1.51C^{0.3} - 0.30D^{0.7} \quad \textbf{(3)}$$

As a result, MCI_0 became the value of 5.0 and the rank of C according to the evaluation division in the Table 4. According to the maintenance standard in Japan, this result is evaluated that no rehabilitation was required even after 18 years serviceability. Even though the quantity of bedding sand was poor, the used block and paving pattern were suitable for a traffic condition. As a result, because the used block, paving pattern, strong enough bearing capacity, and thickness of bedding sand were suitable for the traffic condition, IL block pavement has sustained the long-term serviceability.

Table 3. Results of quality of bedding sand.

SECTION		% PASSING THE 75MM SIEVE	RESISTANCE OF PULVERIZATION (%)
Taxi bay	**Damaged**	18.4	3.9
	Sound	14.6	3.5
Bus station	**Damaged**	13.9	4.1
	Sound	11.6	2.9

Table 4. Evaluation for MCI measurement

RANK	COMMENT	POINT
A	No defect (good)	10
B	Some defects, but it seems good	8
C	Many defects, but do not need to repair	6
D	Need maintenance a little	4
E	Need large scale repair	2

3. INVESTIGATION FOR LONG-TERM SERVICEABILITY OF ROADWAY

3.1 Location

Investigation was conducted at the roadway in shopping street that was built on March 1981 in the city of Osaka. The pavement was wavy rectangular IL block (111*225mm) with thickness 80mm that was laid in a 45°herringbone bond pattern. As shown in Figure 6, three different types of pavement were employed for investigation. The design of traffic volume was N3 (number of commercial heavy vehicle less than 100/day-direction), and the design CBR of subgrade was 4%. According to the current design standard, the pavement design of site B and C are currently lack of enough T_A.

The surface conditions of IL block pavement at three sites are shown in Figure 6. In a whole are of 642 m^2 at site A and B, there were repair marks in about 250 m^2 repaired by new material. This was due to the restoration construction (water service and drainage), but not the repair with the pavement distress. As long as visual survey, there was no significant damage. The surface condition was excellent.

3.2 Summary of investigation

3.2.1 Items and method of investigation

Investigation was conducted on November 2008, about 27 years after the construction. Items and method for investigation were the same as the above-mentioned bus terminal investigation. Bearing capacity measured by handy FWD was executed at IL block surface. The quality of bedding sand was not investigated.

3.2.2 Location

Investigation was not carried out at the above-mentioned repaired spots in the A and B site, but carried out at non-repaired spots. Each investigation item was measured along the 2 survey lines in transverse direction.

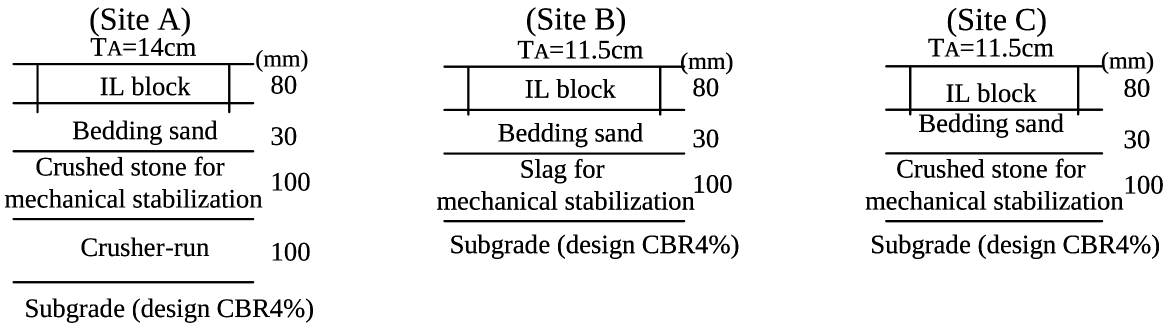

Figure 6. Pavement cross section.

Site A **Site B** **Site C**

Figure 7. Surface condition (27 years serviceability).

3.3 Results of investigation

3.3.1 Joint width and faulting between blocks

Table 5 indicates the measurement results of both joint width and faulting between blocks. As for joint width, the number of results exceeding the JIPEA maintenance standard value of 5 mm is only 1.5 %. As for faulting between blocks, the number of results exceeding the JIPEA maintenance standard value of 5 mm is only one at B site. Hence, the condition of both joint width and faulting between blocks are excellent.

3.3.2 Roughness

Results of the mean value of roughness are shown in Figure 7. As shown in this figure, the minimum value occurred in site A whose base course thickness is thick. All results satisfy the JIPEA maintenance standard value of 5 mm. Thus, as long as roughness, the condition was excellent.

3.3.3 Rate of block breakage

Results of rate of block breakage are shown in Figure 8. As shown in this figure, all results satisfy the JIPEA maintenance standard value 20%. The damages are only minor broken edges. Thus, as long as the rate of block breakage, the condition is excellent.

3.3.4 Rutting depth

The rutting depth at A, B, and C site are 5.2 mm, 14 mm, and 12 mm respectively. All results satisfy the JIPEA maintenance standard value of 30 mm. Therefore, as long as the rutting depth, the condition are excellent.

3.3.5 Bearing capacity

Figure 9 indicates the result of the ratio of deflection of block surface measured by handy FWD. As shown in this figure, all ratio of deflection in 3 sites are almost all the same. Hence the effect of load distribution by IL block is excellent. Additionally, by comparing with the above-mentioned results in bus terminal, these ratios of deflection are larger than those of above-mentioned. Hence, the effects of load distribution are larger.

3.3.6 Skid resistance

BPN are almost all the same among three sites and close to the JIPEA maintenance standard value of 60. Therefore, the skid resistance is in sound condition.

Table 5. Results of joint width, faulting between blocks, MCI, and rank

SITE		A			B			C		
SURVEY LINE NO.		1	2	ALL	1	2	ALL	1	2	ALL
Joint width	Mean value (mm)	2.8	2.8	2.7	3.4	2.8	3.1	2.8	2.8	2.8
	# of data > 5mm	0	0	0	3	0	3	1	1	2
Faulting between blocks	Mean value (mm)	0.7	1.2	0.9	0.8	1.0	1.0	1.1	0.6	0.8
	# of data > 5mm	0	0	0	0	1	1	0	0	0
MCI0		7.3			6.5			6.2		
Rank		B			B			B		

Note: # of data indicates "Number of data"

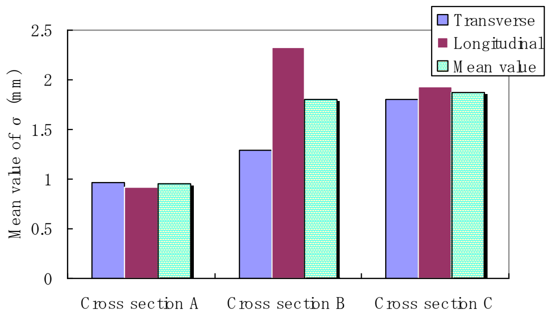

Figure 7. Results of roughness σ

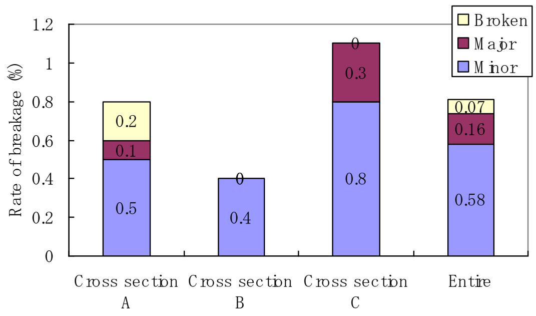

Figure 8. Results of rate of block breakage

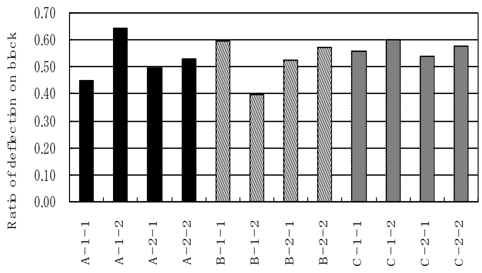

Figure 9. Results of ratio of deflection of block.

3.3.7 Evaluation of serviceability by MCI

The maintenance control index (MCI0) calculated by ratio of block breakage and the mean rutting depth at each site is shown in Table 5. The evaluation ranks are B (Some defects, but it seems good) in all sites. Therefore, it can be said that no rehabilitation is required even after 27 years serviceability. As well as the results of above-mentioned bus terminal case (18 years serviceability), because the used block, paving pattern, strong enough bearing capacity, and thickness of bedding sand were suitable for the traffic condition, IL block pavement has sustained the long-term serviceability.

4. SUMMARY

Followings are the findings.

4.1 Result of the investigation of bus terminal around the station after 18 years serviceability.

- The joint width between blocks, faulting, roughness, ratio of block brokerage, and rutting depth that were individual evaluation items of the road performance satisfied the maintenance standard value of JIPEA in all surveyed sites. The skid resistances were a little lower than the maintenance standard value in all surveyed sites. However, because the speed of running in the vehicle was low in the bus terminal, it could be said the value of unquestionable.
- The modulus of deflection of base course near the taxi bay where the rutting was observed did not satisfy the JIPEA maintenance standard value. However, other 7 sites significantly satisfied the standard value. Overall, this site had strong enough bearing capacity. Additionally, even though the bedding sand consisted of lower quality of pulverization than the current standard value, the thickness was in excellent condition.
- Based on the comprehensive evaluation of serviceability according to Japanese maintenance standard, the maintenance control index, MCI_0, was 5.0 and the condition was “Many defects, but do not need to repair” after 18 years serviceability. When the IL block was paved, the standard for the resistance of pulverization for bedding sand was not established. Thus, the quality of bedding sand did not satisfy the JIPEA quality criteria. However, because the used block, paving pattern, strong enough bearing capacity, and thickness of bedding sand were suitable for the traffic condition, IL block pavement has sustained the long-term serviceability.

4.2 Results of investigation of the roadway after 27 years serviceability

- The joint width between blocks, faulting, roughness, ratio of block brokerage, and rutting depth of all different three types sites satisfied the maintenance standard value of JIPEA. Moreover, based on the ratios of deflection of block surface measured by handy FWD, the effects of load distribution were excellent.
- Based on the comprehensive evaluation of serviceability according to Japanese maintenance standard, the maintenance control index, MCI_0, were between 6 and 8, and the condition was “Some defects, but it seems good” after 27 years serviceability. As well as the case of bus terminal around the station, because the used block, paving pattern, strong enough bearing capacity, and thickness of bedding sand were suitable for the traffic condition, IL block pavement has sustained the long-term serviceability.

5. REFERENCES

Japan Interlocking Block Pavement Engineering Association (2008), Interlocking Block Pavement Engineering Maintenance Rehabilitation Guidelines.

Japan Interlocking Block Pavement Engineering Association (2007), Interlocking Block Pavement Engineering Design and Build Guidelines.