FUNCTIONAL DEGRADATION AND RECOVERY METHODS OF INTERLOCKING BLOCK PAVEMENTS

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ABSTRACT

Interlocking block pavements are well established as a common method for paving sidewalks and roads. These types of pavements provide various options such as color tone and texture to match the location, and so they have become widely used in Japan, mainly in urban areas where people gather such as at parks, station fronts, shopping streets.

After interlocking block pavements have been in service for a while, degradation in functions such as permeability, together with fading and dirt start to occur. These cannot be recovered with general cleaning methods including the use of detergents.

For this reason, use of an ultra-high-pressure water jet, which is used for grinding and cleaning concrete surfaces, was attracting attention. Indoor experiments were performed, by varying the water pressure and discharge rate, to assess the improvement effect on permeability, fading, and dirt. A series of indoor experiments revealed that permeability, fading, dirt, etc. are recovered almost to the original level of the pavements.

Based on the results, field trials were performed on an actual road. These trials showed that the initially expected damages on cushion sand, crushed stone base course and joint sand, were almost non-existent, and the functions were restored equivalent to the results of the indoor experiments.

The results of both the indoor experiments and field trials confirmed that the surface treatment method, which uses an ultra-high-pressure water jet, is suitable for recovering the functions of block type pavements, and particularly ILB pavements.

1. INTRODUCTION

In interlocking block (hereafter referred to as ILB) pavements, which are one type of block pavements, materials of various color tone, chroma, texture, and shape are chosen and applied according to the location of use. ILB pavements are generally used in sidewalks and roads, except those subject to heavy traffic, and most are used for landscaping shopping streets, station fronts, squares and parks, etc. Since problems such as loss of aesthetic appearance due to dirt and fading, and loss of permeability and skid resistance have occurred in service, effective measures for recovering such functions have become necessary.

In order to develop recovery methods without replacing with new ILB's for such functionally degraded ILB pavements in service, a series of indoor experiments and field trials on actual sidewalks and roads were performed. The results confirmed that ultra-high-pressure water jet

(hereafter referred to as surface treatment method) is an efficient method of restoring ILB pavements.

2. OUTLINE OF THE SURFACE TREATMENT METHOD

In the surface treatment method, an ultra-high-pressure water jet (250 MPa maximum) using a small quantity of water (approximately 27 ℓ/min) is applied to the surface of the ILB pavements. By removing several microns to several millimeters from the surface with this force, it is possible to recover and improve the original functions of the surface (color, brightness, skid resistance and permeability).

The arrangement of equipment for the surface treatment method is shown in Figure 1, and the specifications for the main equipment are listed in Table 1.

2.1 Characteristics of the Surface Treatment Method

The characteristics of the surface treatment method are as follows:
· Treatment depending on the strength of the surface
· One-pass application with a series of equipment arranged in a line
· Shorter work period than conventional manual methods

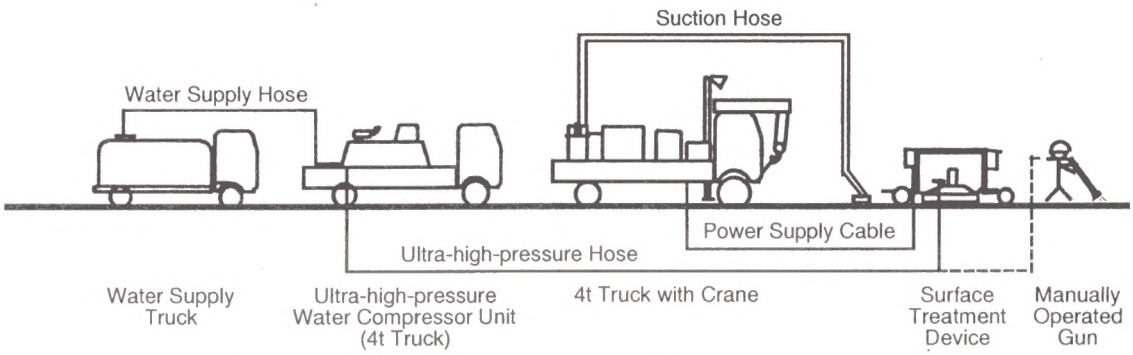

Figure 1 Equipment Arrangement for Surface Treatment Method

Table 1 Specifications for Main Equipment of Surface Treatment Method

Specifications for Ultra-high-pressure Water Compressor Unit			
Item	Type No.1	Type No.2	Type No.3
Type	Oil Hydraulic	Oil Hydraulic	Plunger Pump
Power Source	4t Truck Engine PTO	20PS Engine	130PS Engine
Water Pressure (MPa)	196 (MAX)	245 (MAX)	147 (MAX)
Discharge Rate (l/min)	10.0	27.0	33.0
Operating Mass (kg)	6,600	4,000	1,800

Specifications of Surface Treatment Device		
Item	OJE-95	OJM-97
Outer Dimensions	2,070 × 1,130 × 1,300	5,100 × 1,600 × 2,020
Drive Method	Electric Motor (with rotation control and indicator)	Oil Hydraulic Motor (with rotation control and indicator)
Drive Speed (m/min)	0 ~ 10	0 ~ 5
Treatment Width (mm)	1,000	1,000
Nozzle Unit Drive Method	Electric Motor (with rotation control and indicator)	Oil Hydraulic Motor (with rotation control and indicator)
Operating Mass (kg)	500	4,000

· Application with only a small quantity of water
· Minimum influence on working and surrounding environments

2.2 Applicable Surfaces for the Surface Treatment Method

The places where the surface treatment method can be applied are as follows:
· Concrete pavements
1) Increasing of skid resistance
2) Scrubbed finishing
3) Removing of attached debris and degraded portions

· Asphalt pavements and landscape pavements
1) Surface treatment (lighten color)
2) Recovery of surface functions (refresh)
3) Removing of attached debris

2.3 Selection of the Surface Treatment Method

When comparing methods for recovering various functions of ILB pavements, the water jet technology, which can correct micro level unevenness, has attracted attention for its ability to treat a surface depending on its strength without damaging the blocks.

Water jet technology can be categorized into 'high-pressure, high-volume water' and 'ultra-high-pressure, low-volume water' type systems. The former system is used for breaking concrete.

Since granular materials are used in ILB pavements such as cushion sand in the upper layer, crushed stone for the base and sand for the joints, the ultra-high-pressure, low-volume water system was chosen, because with the other system, the granular materials can be washed away and the pavement itself can be damaged

3. BASIC EXPERIMENTS

After categorizing the typical causes of functional degradation, and taking samples of various ILB pavements from actual sites, experiments for the surface treatment method were performed for various water pressures and speed of application conditions.

The results are shown in Table 2.

The results of the experiments showed the following.
1) In permeable ILB's, the skid resistance and permeability are recovered in addition to the recovery of the color tone. The coefficients of permeability are recovered almost to the original level by removal of the clogged debris.
2) The dirt from garbage and other factors can be removed, and the color tone is recovered substantially.
3) Chewing gum can be sufficiently removed, but the application method (pressure, speed, and additional operation) needs to be considered.
4) The permeability and color tone are recovered by the ultra-high-pressure water jet. The ultra-high-pressure water from a small diameter nozzle seems to be effective for restoring permeability, because of the smaller void of the ILB than that of drainage pavements.

Table 2 Factors of Functional Degradation and Experiment Results

Classification	Causes	Color at Construction Time	Years in Service	Conditions of Application: Water Pressure (MPa)	Conditions of Application: Application Speed (m/min)	Test Results: Visual Observation	Test Results: ΔE	Test Results: Skid Resistance: Before Water Jet Application	Test Results: Skid Resistance: After Water Jet Application	Test Results: Skid Resistance: Difference	Test Results: Permeability Test (cm/sec): Before Water Jet Application	Test Results: Permeability Test (cm/sec): After Water Jet Application
Permeability	Clogging	Orange	8 to 10 years	75	600	From visual observation, only a slight influence on block surfaces could be observed under all water jet application conditions	10.0	53	63	10	Not Measurable	4.3×10^{-2}
				75	600		8.9	57	63	6		3.2×10^{-2}
				75	400		9.9	47	60	13		4.6×10^{-2}
				75	400		8.1	52	59	7		1.4×10^{-2}
Dirt	Oil Stain	Gray	8 to 10 years	100	600		1.2	59	59	0		
				75	600		2.9	59	61	2		
				100	400		2.5	59	59	0		
				75	400		2.1	74	79	5		
				150	400		2.5	71	74	3		
	Garbage	Red	8 to 10 years	100	600		9.3					
				75	600		8.0					
				100	400		7.0					
				75	400		6.2					
				150	400		8.1					
	Others	Red	8 to 10 years	100	600		5.8					
				75	600		6.6					
				100	400		4.5					
				75	400		4.6					
Fade	Weathering	Gray	14 years	75	600		2.4					
				100	600		1.2					
				100	400		0.7					
				75	400		0.7					
				150	400		0.5					

4. FIELD TRIALS ON INTERLOCKING BLOCK PAVEMENTS

4.1 Outline of the Field Trials

From the results of the experiments in the previous section, field trials on ILB pavements were performed. The outline of the field trials is shown in Table 3, and the state of the field trials is shown in Photo 1.

4.2 Evaluation Methods

(1) Influence on Joint Sand
Since the loss of joint sand may occur with the ultra-high-pressure water jet, the loss was confirmed as follows.

Table 3 Outline of the Field Trials on ILB Pavements

	ILB Pavements (Sidewalk)		ILB Pavements (Road)
	Existing Section	Replaced Section	
Type of ILB	Shot blast finish, Green system		Shot blast finish, Red system
Area Applied	$168m^2$	$185m^2$	$142m^2$
Period of Application	Constructed in 1991, 6 years have elapsed		
ILB Surface Condition	Dirt and chewing gum attached in service, together with observed fading		
Surface Treatment Method	Grinding and cleaning system: Water pressure 50 MPa, Application speed 3.0 m/min Manually operated gun: Water pressure 50 MPa		



Photo 1 Field Trials

1) The depth of joint sand loss was measured at one location on the road and two locations on the sidewalk. For each location, the depths were measured with a digital caliper, at 20 to 25 randomly chosen spots.

2) The lost joint sand was replaced by grade 5 silica sand at two locations on the road and one location on the sidewalk. The joint sand loss was estimated from the refilled volume and area.

(2) Influence on Cushion Sand, Base Course and Subgrade

Since the ultra-high-pressure water jet may cause the loss of interlocking between the ILB's due to the loss of joint sand, the shift of cushion sand by penetrated water, and the loss of bearing capacity on the base course and subgrade, causing the loss of surface smoothness, the levels of these influences were measured as follows:

1) Measurement of Deflections

The deflections of the ILB pavements were measured with a handy FWD (falling weight deflectometer) [1], in which a free-falling weight is dropped from a certain height to apply an impact force on the surface of pavements. The measurements were performed at two locations on the sidewalk, at five points for each location, and on three occasions at the same point, namely, before, immediately after and seven days after the water jet application.

2) Measurement of Surface Roughness

The surface roughness of the ILB pavements was measured along the cross section with the leveling chord method, as indicated in the Pavement Tests Manual [2]. The measurements were performed along five transverse lines at two sidewalk locations. The vertical distances between the leveling chord and the surface of ILB pavements were measured at each point shown in Figure 2.

(3) Measurement of Coloring and Color Difference

The coloring and color difference were measured before and after the water jet application on various kinds of ILB pavements, using a coloring and color difference meter. The coloring and color difference are indicated according to the L* a* b* indication system specified in

'JIS Z 8730 Color Specification - Color Differences of Non-luminous Object Colors'.

Color difference is indicated color based on the position in the 'L. a. b' color solid, as shown in Figure 3, with 'L' as the height (indicating the lightness index), 'a' as left/right position, and 'b' as front/rear position in the coordinates (indicating the chromaticness index).
The method for evaluating of color difference is as follows.

· The differences in each of the components before and after the water jet application are calculated according to the following formula to obtain ΔE, which is evaluated according to the standard for color differences of fabrics by The Color Science Association of Japan shown in Table 4.

$$\Delta L = L_1 - L_2, \Delta a = a_1 - a_2, \Delta b = b_1 - b_2 \qquad (1)$$

$$\Delta E = \left((\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2\right)^{1/2} \qquad (2)$$

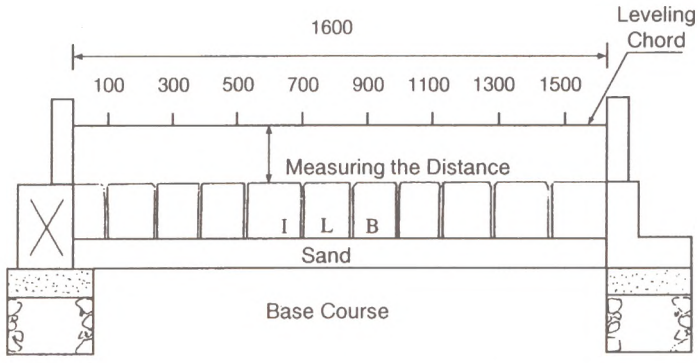

Figure 2 Measurement of Surface Roughness with the Leveling Chord Method

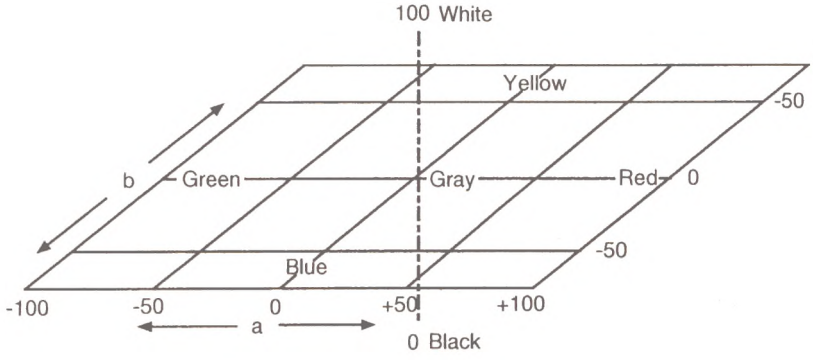

Figure 3 The L.a.b Color Solid

Table 4 Evaluation of Color

Evaluation of Color Difference	ΔE
Trace	0 ~ 0.5
Slight	0.5 ~ 1.5
Noticeable	1.5 ~ 3.0
Appreciable	3.0 ~ 6.0
Much	6.0 ~ 12.0
Very Much	Above 12.0

· The lightness indexes before and after the water jet application and their differences are evaluated on the graphs as shown in Figure 7.
· The coloring by combining 'a' and 'b' before and after the water jet application is evaluated on the graphs as shown in Figure 8.

4.3 Results of the Field Trials

(1) Influence on Joint Sand
Figure 4 shows the depth of joint sand loss measured with a caliper at one location of the road intersection and two locations of the sidewalk.

The depth of joint sand loss is 15.9 to 18.5 mm in average, which will not cause any trouble on the ILB pavements, because this is considerably less than the thickness of the block (t=80 mm).

(2) Influence on Cushion Sand, Base Coarse and Subgrade
Figure 5 shows the results of deflections measured with the handy FWD at each point on the sidewalk, while Figure 6 shows the surface roughness measured by the leveling chord method.

Since the deflections are almost the same before and after the water jet application and the increase in the surface roughness is small before and after the water jet application, it is considered that there is little influence on the cushion sand, base course and subgrade.

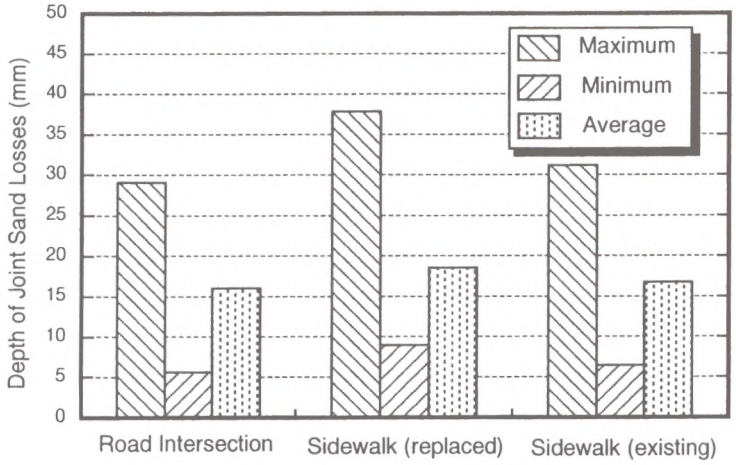

Figure 4 Depth of Joint Sand Losses

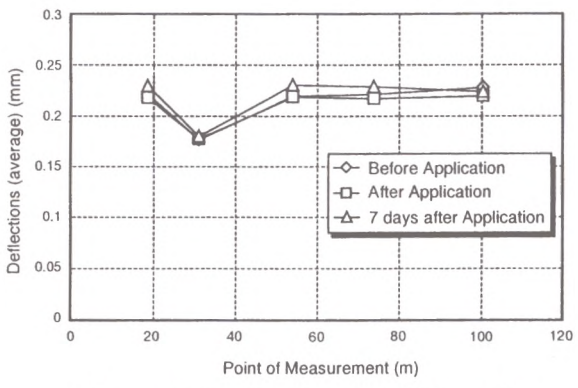

Figure 5 Deflections at Sidewalk (existing)

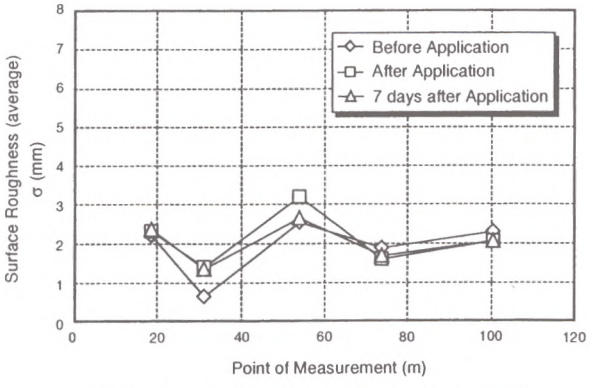

Figure 6 Surface Roughness at Sidewalk (existing)

(3) Recovery of Coloring
The lightness index and the chromaticness index before and after the water jet application measured at each point with a coloring and color difference meter, and the color difference (ΔE) obtained from these indexes, are shown in Table 5, and Figures 7 and 8.

Table 5 Color Difference (Average Value) before and after Application

Location	Color	Before Application			After Application			ΔE
		L	a	b	L	a	b	
Road (in front of park)	Red System	32.23	3.69	-0.84	37.13	6.64	-1.36	5.92
Sidewalk (existing)	Green System	31.93	-0.10	0.10	38.75	-0.72	-0.50	7.26
Road (near playground)	Red System	29.67	1.99	2.09	35.37	4.43	3.64	6.40
Sidewalk (replaced)	Green System	31.10	-1.26	2.52	37.11	-3.04	4.25	6.64

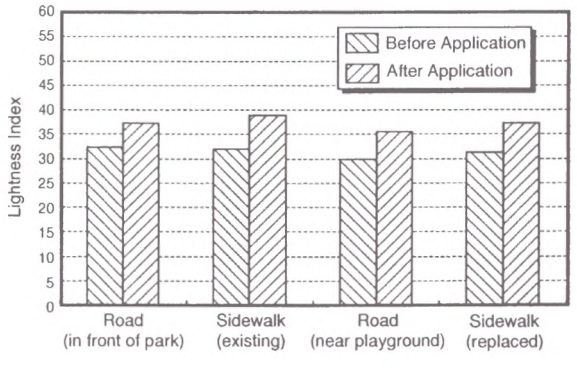

Figure 7 Lightness Index before and after Application

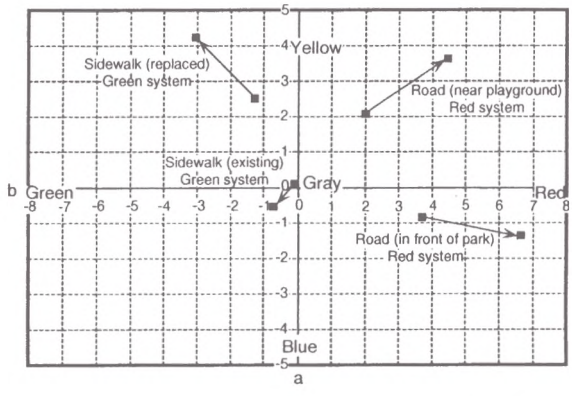

Figure 8 Color, before and after Application

The level of recovery of tone and color evaluated from visual observation or by a coloring and color difference meter, showed color differences (ΔE) of 4.62 to 8.11 for the red system, and 5.50 to 9.77 for the green system. Referring to the standard for fabrics by The Color Science Association of Japan, these values are classified as 'appreciably different' or 'much different', which shows that the recovery is sufficient.

5. FIELD TRIALS ON TILE PAVEMENTS

5.1 Outline of the Field Trials

The outline of the field trials on tile pavements is shown in Table 6.

(1) Application Method of Water Jet
1) Mechanical Application
The tiles were cleaned with the ultra-high-pressure water jet using the equipment arrangement shown in the previous section, by adjusting the water pressure and volume. The cleaning water and removed debris were collected by the suction collector device, and the

Table 6 Outline of Field Trials on Tile Pavements

	Section A	Section B
Area Applied	800 m^2	600 m^2
Type of Tile	3 Types: White, Gray, Dark Green Colors	3 Types: White, Gray (small), Gray (large) Colors

upper clear water after precipitation and separation was drained. Application standards are 98 to 157 MPa for water pressure, 10 to 16 ℓ for volume of water, and 2.5 to 3.5 m/min for speed of application.

2) Manual Application
Basically, mechanical application was performed wherever possible. However, other locations where mechanical application was not possible were treated with a manually operated gun.

The tiles were cleaned with the manual gun using the equipment arrangement shown in the previous section, by adjusting the water pressure and volume. Application standards are 74 to 118 MPa for water pressure and 6 ℓ for volume of water.

5.2 Results of the Field Trials at Section A

Since the results of the field trials at Section B are almost the same to those at Section A, only the results at Section A is shown for the typical ones.

(1) Visual Observation
The visual observation results of the cleaning on the road surface are shown below.
- The dirt on natural stone tiles was removed cleanly.
- Attached chewing gum was manually removed with a scraper, and then the water jet was applied. Hard old gum could be removed, but soft new gum could not be fully removed.
- Mortar joints had no damage at all, but some damages appeared on the elastite used in expansion joints.

(2) Measurement of Coloring and Color Difference
Table 7 shows the results of ΔE obtained from the measurements of the coloring and color difference meter. The results show the following:
- The ΔE values of the gray and deep green color tiles are classified as 'appreciably different'

Table 7 Table of ΔE Values

Section	ΔE		
	White	Gray	Deep Green
R 3	3.43	1.08	4.08
R 3 '	8.95	7.51	2.87
R 2	13.94	9.50	8.40
R 2 '	9.53	5.15	9.55
R 1	2.59	1.01	6.12
L 1	4.91	4.02	1.25
Average	7.23	4.71	5.38

Table 8 Losses of Mortar Joint Filler

Condition	No. of Data	Average Value (mm)
Before Application	40	1.71
After Application	40	1.82
Losses of Mortar Joint Filler (mm)	1.82 - 1.71 = 0.11	

according to Table 4, and the ΔE values of the white color tiles as 'much different', and therefore the cleaning with the surface treatment method is sufficiently effective.
- From the a. b color solid chart for each tile, the individual colors after the water jet application shift toward the primary colors.

(3) Losses of Mortar Joints
The losses of mortar joints are shown in Table 8. There is almost no damage to the mortar joints.

6. CONCLUSIONS

Experiments and field trials for functional recovery of ILB pavements and field trials on tile pavements were performed with the surface treatment method. The following results were obtained.

The field trials on ILB pavements showed almost no influence on joint sand and little influence on cushion sand, base course and subgrade, based on the comparison of deflection and surface roughness between before and after the water jet application. Referring to the standard for fabrics of The Color Science Association of Japan, the color differences (ΔE) for both the red system ILB and green system ILB could be categorized as 'appreciably different' or 'much different', which shows that the recovery of color is sufficient.

In the field trials on tile pavements, visual observations indicated that the dirt on natural stone tiles was removed, and that hard old chewing gum could also be removed. Some damages were observed in the elastite in expansion joints, but there were almost no damage to mortar joints. The colors of the gray and deep green tiles were categorized as 'appreciably different', and the white tiles as 'much different', which shows that cleaning with the surface treatment method is sufficiently effective.

These results confirmed that the surface treatment method, which uses an ultra-high-pressure water jet, is suitable for recovering the functions of block type pavements, and particularly ILB pavements.

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REFERENCES

1. Kasahara A., et al. (1991), Development of a Handy Falling Weight Deflectometer, Proceedings of 19th Japan Road Congress, pp.314-315
2. Japan Road Association, 1977, Pavement Tests Manual