INTERLOCKING BLOCK PAVEMENTS FOR THE CONTAINER TERMINAL AT THE PORT OF KAWASAKI

H. Umeda, T. Ogihara, T. Sano, H. Yaginuma
Kawasaki-shi Ports and Harbors Bureau, Kawasaki-shi, Japan
Toa Construction Co. Ltd., Tokyo, Japan
Interlocking Block Pavement Technology Association, Tokyo, Japan

Summary
Container terminal construction in Higashi-ogishima Area of Kawasaki-shi is carried on aiming to open in April, 1996. It has been decided that interlocking blocks are going to be adopted as the paving material for this container terminal. Unfortunately though,since there are few application examples to port areas in Japan as compared to other countries, a riding test by 32-ton dump trucks was carried out to verify appropriateness of the design method and to evaluate durability of heavy duty pavements. Moreover, in order to improve efficiency and laborsaving of construction,mechanical laying was introduced and its effect has been confirmed. This paper covers applicability of interlocking block pavement to heavy duty pavement areas and mechanical laying.
Keywords; automated guided vehicle, concrete block pavement, mechanical laying, heavy duty pavements, riding test, container terminal

1. Introduction

The port of Kawasaki located in the northwest of Tokyo Bay developed as part of the Keihin industrial area and plays a role as one of the most important general ports in Japan. Container terminal construction is now being carried out in a section of this Higashi-ogishima area(Civil Port Island) intended to be opened in April, 1996. Interlocking blocks(hereafter called"ILB") have been adopted for the heavy duty pavement area in designing the terminal(700m long berth x 2, 14-15m water depth, 245,000 sq.m. yard area).

Although ILB pavement is frequently used in foreign countries for such heavy duty areas as airports and ports, there are only several such examples reported in Japan. Furthermore, there is no authorized standard design method for heavy duty application and the laying is only done manually at the moment. Under these circumstances, in order to verify appropriateness of the design method and to evaluate durability against heavy load for adopting ILB pavement, a riding test was implemented and the mechanical laying method was confirmed.

This paper covers ILB pavement applicability to heavy duty areas and the effect of the mechanical laying based on these test results.

2. Design of Test Pavement

2.1 If the paving material is not correctly selected for the container terminal, it will cause varied defects after service which not only hinder stevedoring but bring about maintenance and repair costs greatly lowering efficiencies of terminal operation. Such materials as asphalt, concrete and ILB can be nominated as a paving material for port areas, but ILB pavement was adopted after examining and discussing the actual situations including other countries.

This is because ILB pavement does not show any flow deformation at high temperature in the summer time as seen for asphalt pavement and because it has such advantages that it can adjust itself to a certain extent to differential settling below the subgrade, that repairing is simple and that it can immediately be presented to service after construction. Although ILB has only about 20 years history in Japan, its recent usage is expanding to walkways,parks,plazas and general traffic roads as a landscape material.

2.2 Design Condition of Test Pavement

(1)Traffic

1)Load condition of the vehicle in question:the wheel load of the automated guided vehicle(hereafter called"AGV")is 4.4 ton unloaded and 14.6 ton loaded.

2)Traffic volume:the annual traffic volume of loaded and unloaded AGV is 115,000-268,000

(2)Subgrade

1)Conventional subgrade design CBR=0.8%

2)Subgrade improved layer CBR=20%(cement used)

3)Improved subgrade thickness=120 cm

(3)Shape and laying pattern of ILB

1)The shape and thickness of ILB was determined to be Uni type as shown in Fig.2 considering actual usage for airports and ports in foreign countries as well as in Japan.

2)The laying pattern was determined to be herringbone

bond movement of which is less and load dispersion effect of which is excellent.

2.3 Structural Design

There is no authorized structural design method established in Japan yet when ILB is to be used for heavy duty areas like a port area. Therefore, the design method of the British Ports Association was applied after modifying it to adjust to our requirements. The main design principle is as follows;

(1)Design principle

This design method takes it for granted that breakage of ILB for heavy duty use is attributable to huge compressive stress at the subgrade surface or huge tensile stress at the base layer and determines the thickness of each layer by comparing strain which is calculated at the boundary of each layer which is equivalently conversed with respective allowable strain. Examples of the design flow and chart are shown in Fig.4-6.

(2)Pavement Structure

The ILB pavement structure determined by the aforementioned method is shown in Fig.7 and the asphalt pavement to compare serviceability is shown in Fig.8.

3. Interlocking Block Pavement Construction

3.1 Construction of Basecourse

Lean concrete forming the basecourse of ILB pavement was to be compressed concrete(RCCP) taking into consideration workability and early opening to the traffic. Its mix is shown in Table 1.

3.2 Laying of ILB

Both conventional manual laying and mechanical laying for ILB installation were done. The following is the explanation.

(1) Installation of cushion sand

There were two ways carried out for cushion sand carried by an excavator, the one was that it was roughly leveled and finished evenly by a rake as usual after slightly compressed once by a vibration roller and the other was to be finished evenly by asphalt finisher(Photo 2).

(2) Laying of ILB

Carrying and laying of ILB were done by imported cramping machine(Photo 3) and by domestic-made vacuum machine(Photo 4). As either machine can lay 36 blocks/cycle(0.9 sq.m) at a time, it enabled 4-5 workmen to lay 200 sq.m/day enhancing laying efficiency as compared with manual laying. Either machine, however, can work only for preliminarily arranged patterns like herringbone bond, therefore, in order to further enhance efficiency and labor saving, improvement of the machines and establishment of a system which is accommodated to varied patterns are indispensable.

(3) Compression

A 4-ton vibration roller was used for compressing ILB in order to bring up better compression effect. In such a case, however, when thickness differences exist between blocks, steel wheels hit the sides of the blocks directly and caused a lot of edge breakage. Therefore, when a vibration roller is used for compression, the steel wheels should be covered with rubber.

(4) Joint filling

Joint filling was carried out by manual sweeping with brooms after roughly leveled by a cramping machine with a special attachment. Because big labor is required for large construction sites, development of a specialty machine for joint filling

without relying on manual labor is necessary.
Under these circumstances, we see that ILB mechanical laying has just begun and we yet need to cope with development of economical laying machines and research on organization of construction machines in order to further improve efficiency and labor saving.

4. Riding Test

4.1 Construction Scope of the Riding Test

The riding test course to examine serviceability comparison of ILB and asphalt pavements was made in a part of the container terminal. It is a rectangular driving course with the width of 5-15m and 450m round and 2,122 sq.m of ILB and 925 sq.m of asphalt pavements were constructed.

4.2. Method of the Riding Test

A 32-ton dump truck whose wheel load was adjusted by mounted crushed stone to make it equal to AGV's designed wheel load(14.6 ton) was used for the riding test. Since AGV runs on the same line by remote controlling, the truck was made run on the same line 22,000 times at average speed of 20km/h to the counterclockwise direction. The test items, measuring points, frequency and checkup points to compare serviceability of ILB and asphalt pavements are shown in Fig.9.

4.3 Result of the Riding Test

(1)Benkelman Beam deflection

Deflection on the ILB and asphalt pavements is shown in Fig.10. According to this, deflection on the ILB pavement under 14.6 ton converges more or less to a constant value after 5,000 times riding. On the other hand, the value of the asphalt pavement shows a smaller value than the ILB pavement except for 20,000 times riding. Asphalt pavement deflection which was measured in winter may be reversed in summer when the temperature on the road surface gets high.

(2)Joint width

According to the joint width measuring result as shown in Table 2, although the joint width from pavement completion to the 22,000th riding seems to be almost constant falling on between 3.55-3.60mm evaluated in average of all the lanes, it tends to be a bit bigger than the standard joint width(3.0mm) provided by Interlocking Block Pavement Technology Association. Furthermore, in comparison between manual laying(No.1,2) and mechanical laying(No.3-5), although the joint width seems to be bigger in mechanical laying, it tends to be less deviating. That can mean that mechanical laying by unit gives better joint width balance and joint line.

(3)Block movement

As shown in Fig.11, the movement of blocks tends to decrease gradually in line with riding. Therefore, joint widths were measured in such respective lane locations where block movement was prominently recognized in order to confirm influence of block movement to the joint width. The result is shown in Table 3. The widest joint was 5.1mm and the average 3.59mm even in the lane 1 where the biggest movement of blocks of 15.0mm was observed. This means that as block movement is dispersed within fluctuation of each joint width, the joint width will not become extremely wide and joint line changes only a little.

(4)Transverse unevenness

It came to be known from the transverse unevenness result as shown in Table 4 that evenness( ) of ILB pavement at the completion time and at the 22,000th riding time increases in the

order of AF of IWP, manual laying of BWP and manual laying of IWP. This seems to mean that using an asphalt finisher contributes to improvement of evenness. These values comply with the value of within =5.0mm which is a finished block shape control standard set forth in the Interlocking Block Pavement Design and Construction Manual(for roadway).
Furthermore, the reason that the evenness value of asphalt is bigger is because its measuring direction and construction direction were different and why the values do not change a lot is likely because of the influence of winter(temperature) and less riding times.

(5)Rutting depth

The deformation property of ILB pavement seems to be rather prominent in the beginning of its service, but when interlocking between blocks gets stronger and cushion sand gets stabilized in the course of service, the property tends to converge to a certain value. The data shown in Fig.13 also shows the similar trend after 10,000 times riding and rutting attributes to compressive deformation of cushion sand.
On the other hand, deformation of asphalt pavement is approximately 2.0mm, which is rather small. This is maybe because the riding test measuring was done in winter when asphalt viscosity is high and it is less deformable. It is necessary to test in the mid summer when road surface temperature goes up to about 60 C in order to evaluate asphalt deformation.

(6)Breakage of block

According to conventional research 4), block breakage takes place in the beginning of service and it tends to drop by virtue of stabilization of joint sand and cushion sand as traffic load increases. The similar trend is seen at this test site from Fig.5, that is, broken blocks(149 blocks) at the 10,000th riding have reached 80% of the number at the 22,000th riding(185 blocks).
Approximately 75% of chip-off blocks at the 22,000th riding showed slight chip-off in the corners and in the sides(Fig.14). Except for slightly cracked 2 blocks(Fig.15), the chip-off itself doesn't hinder vehicle traffic at all.

5. Conclusion

Durability of ILB pavement against heavy load was studied applying the design method by British Ports Association to the structural design of ILB pavement. As a result, it has been confirmed that ILB pavement shows stabilizing tendency from over the 10,000th riding as reported in both foreign and domestic literature 5) and the durability evaluation against heavy duty areas has been also confirmed.
Furthermore, in comparison with the asphalt pavement, since there is no flow deformation seen in ILB pavement as seen in asphalt pavement associated to the temperature change, ILB has better serviceability than asphalt in a long run. In order to expand ILB pavement to airports, ports and harbors in the future, there still remain a lot of issues to be discussed like quality of cushion and joint sand, establishment of long term serviceability and maintenance and more effective mechanical laying.
A number of the valuable data obtained from the riding test this time should be quite helpful for the future technology of terminal pavement. Last but not least, we would like to express our deepest gratitude to Runway Research Office of Ministry of Transport's Port and Harbor Research Institute, Japan Port and

Harbor Consultant Co.,Ltd, Towa Consultants Co.,Ltd. and many others for their precious advice and instruction in connection with the riding test and construction implemented this time.

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Table 1 Indicated Mix of RCCP

Maximum size (mm)	Water cement ratio (%)	Fine aggregate (%)	Unit density (kg/m³)				
			water	cement	fine aggregate	coarse aggregate	additive
20	40.0	43.0	100	250	874	1,202	2.50

Note:1) preliminary strength:(age 28 days)
2) additive: AE water reducing agent (Pozzolis No.70, quadruple dilution)

Table 2 Joint Width

Lane	Data volume	Riding times	Maximum	Minimum	Average	Standard deviation
1	32	At completion	4.89	1.30	3.27	1.09
		22,000	4.99	0.94	3.21	1.22
2	96	22,000	4.99	0.92	3.43	0.98
			4.99	1.33	3.52	1.08
3	54	22,000	4.99	2.45	3.87	0.68
			4.97	1.63	3.97	0.82
4	32	22,000	4.91	2.08	3.52	0.76
			4.95	2.23	3.50	0.70
5	31	22,000	4.93	2.59	3.68	0.65
			4.95	2.24	3.72	0.82
Total	245	22,000	4.99	0.92	3.55	
			4.95	0.94	3.60	

Table 3 Joint Width at the Point of Movement

Lane NO	Maximum movement of block (mm)	Joint width of 20 adjacent blocks			
		Maximum	Minimum	Average	Standard deviation
1	15	5.10	2.05	3.59	0.93
2	11	5.62	1.00	3.13	1.13
3	14.5	4.16	1.62	2.86	0.77
4	6.5	4.87	1.36	3.03	0.95
5	3	4.51	0.10	2.71	0.88
Average		5.62	0.10	3.06	

Table 4 Evenness

Pavement	Part		At completion	5,000 times	10,000 times	20,000 times	22,000 times
ILB pavement	IWP	Manual laying	3.13	2.40	3.80	2.93	3.43
		AF	2.11	3.31	2.52	1.87	1.71
	BWP		2.57	2.69	2.78	2.92	2.84
Asphalt pavement	OWP		3.64	3.15	3.73	3.76	3.57
	BWP		4.02	4.00	4.04	4.09	4.06

Note:AF means Asphalt Finisher
IWP:Inside Wheel Passing Part
BWP:Central Part between Wheels
OWP:Outside Wheel Passing Part

Table 5 Block Breakage Inspection Result

Inspection Time	Location / Checkup Point / Breakage Style	A Tangent (number)	B Tangent (number)	C Tangent (number)	Sub Total (number)	Curve (number)	Total (number)
At Completion	Chip-off	0	0	0	0	0	0
	proportion(%)	0	0	0	0	0	0
	Cracked	0	0	0	0	0	0
	proportion(%)	0	0	0	0	0	0
5,000th	Chip-off	3	9	17	29	26	55
	proportion(%)	0.15	0.45	0.85	0.48	1.30	0.69
	Cracked	0	0	0	0	0	0
	proportion(%)	0	0	0	0	0	0
10,000th	Cracked	18	25	49	92	57	149
	proportion(%)	0.9	1.25	2.45	1.53	2.85	1.86
	Chip-off	1	1	0	2	0	2
	proportion(%)	0.05	0.05	0	0.03	0	0.02
20,000th	Chip-off	23	33	55	111	68	179
	proportion(%)	1.15	1.65	2.75	1.85	3.40	2.24
	Cracked	1	1	0	2	0	2
	proportion(%)	0.05	0.05	0	0.03	0	0.02
22,000th	Chip-off	24	33	58	115	70	185
	proportion(%)	1.2	1.65	2.90	1.92	3.50	2.31
	Chip-off	4	11	3	18	27	45
	proportion(%)	0.2	0.55	0.15	0.30	1.40	0.56
	Cracked	1	1	0	2	0	2
	proportion(%)	0.05	0.05	0	0.03	0	0.02

Note:1. 2,000 blocks each for tangent and curve parts were picked up to calculate the proportion.
2. The upper column shows the total chip-off number(slight and heavy) and the lower heavy in the chip-off data at the 22,000th riding.

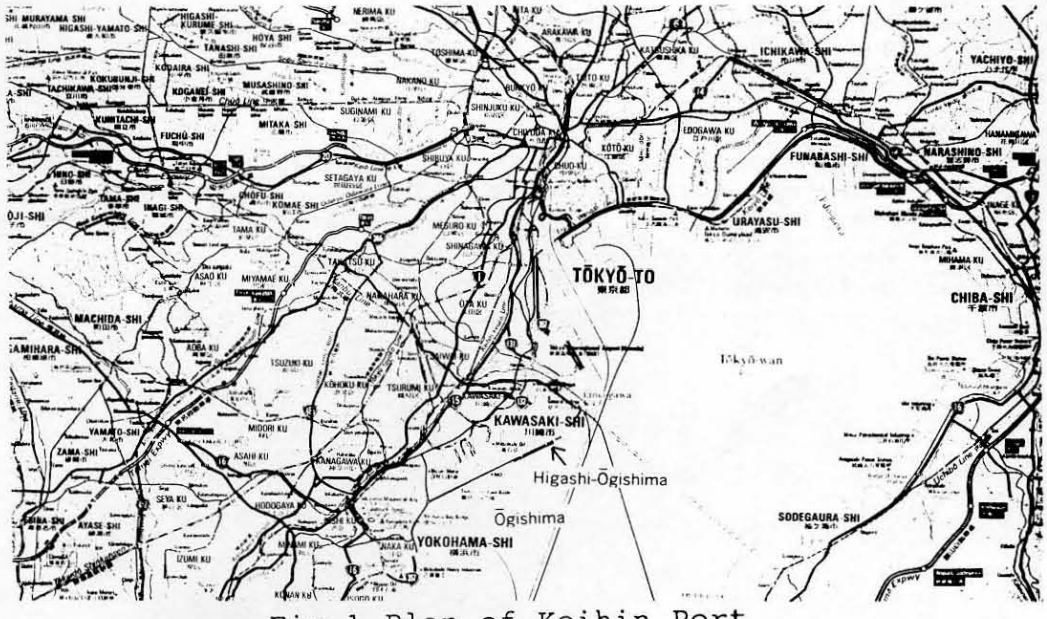


Fig.1 Plan of Keihin Port

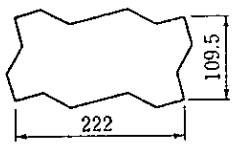


Fig.2 Shape of Uni Normal

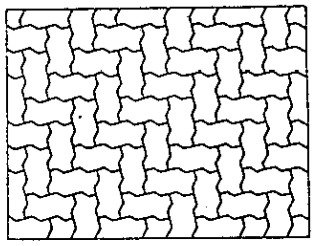
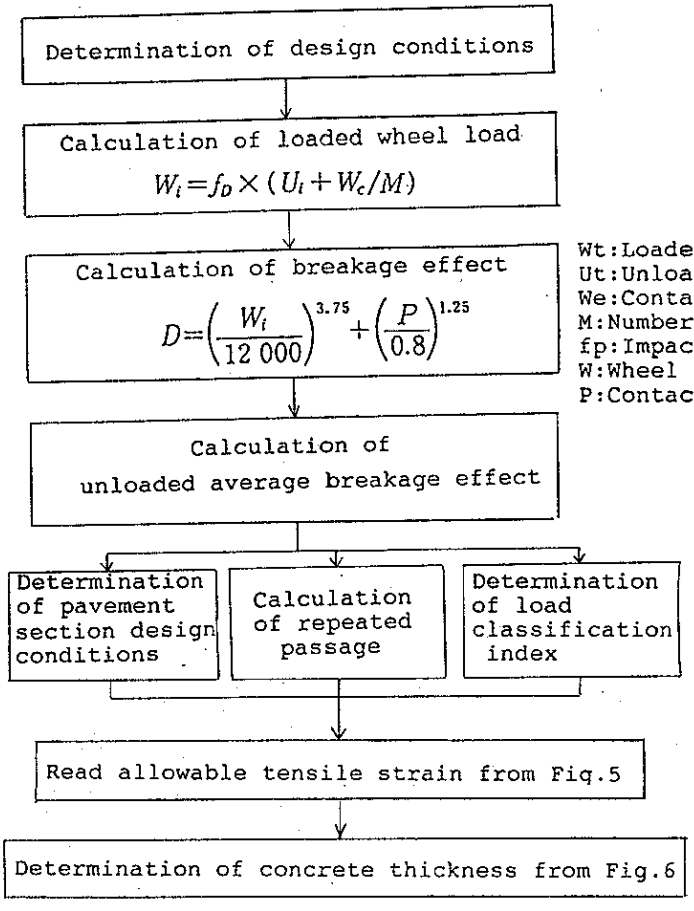


Fig.3 Herringbone Bond Pattern



Wt:Loaded wheel load(Kg)
Ut:Unloaded wheel load(Kg)
We:Container load
M:Number of wheel
fp:Impact coefficient
W:Wheel load(Kg)
P:Contact pressure of tire(N/sq.mm)

Fig.4 Design Flow

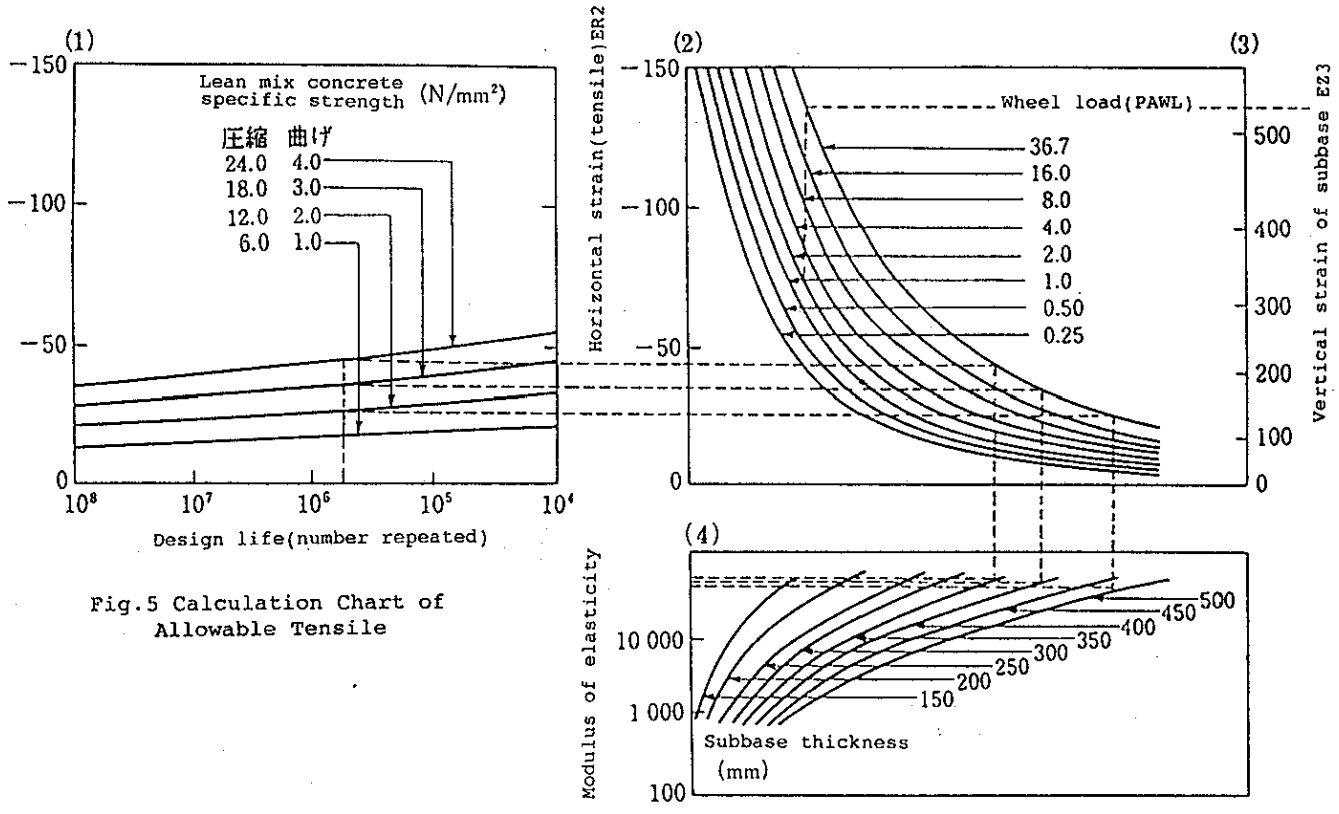


Fig.5 Calculation Chart of Allowable Tensile

Fig.6 Lean Concrete Plate Thickness Calculation Chart

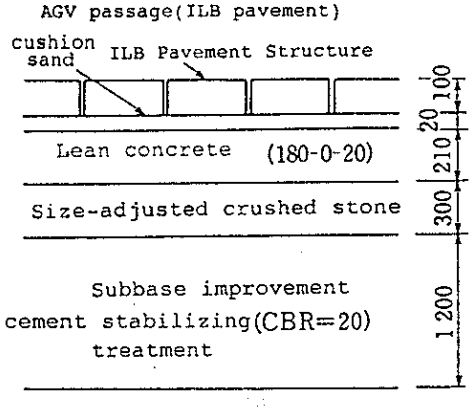


Fig.7 ILB Pavement Structure

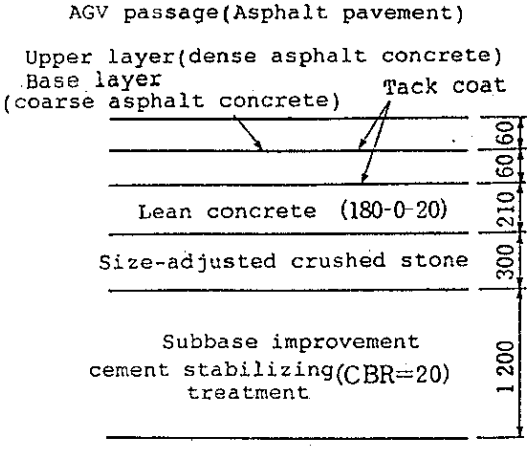


Fig.8 Asphalt Pavement Structure

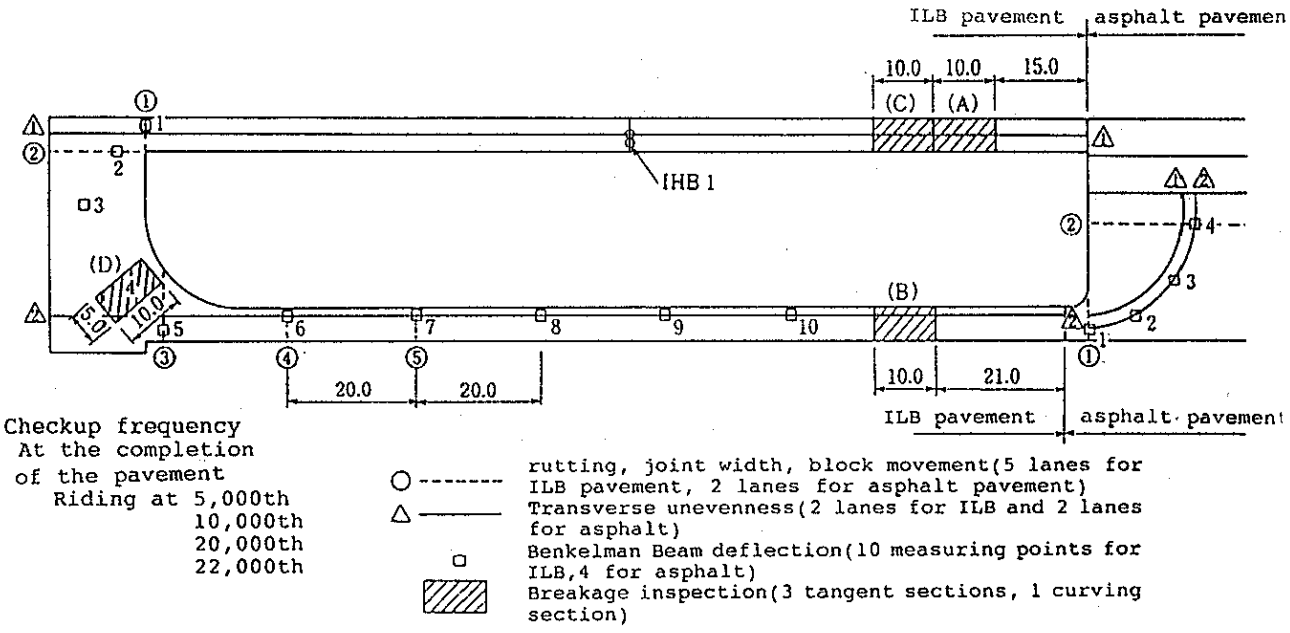


Fig. 9 Examination Points Location

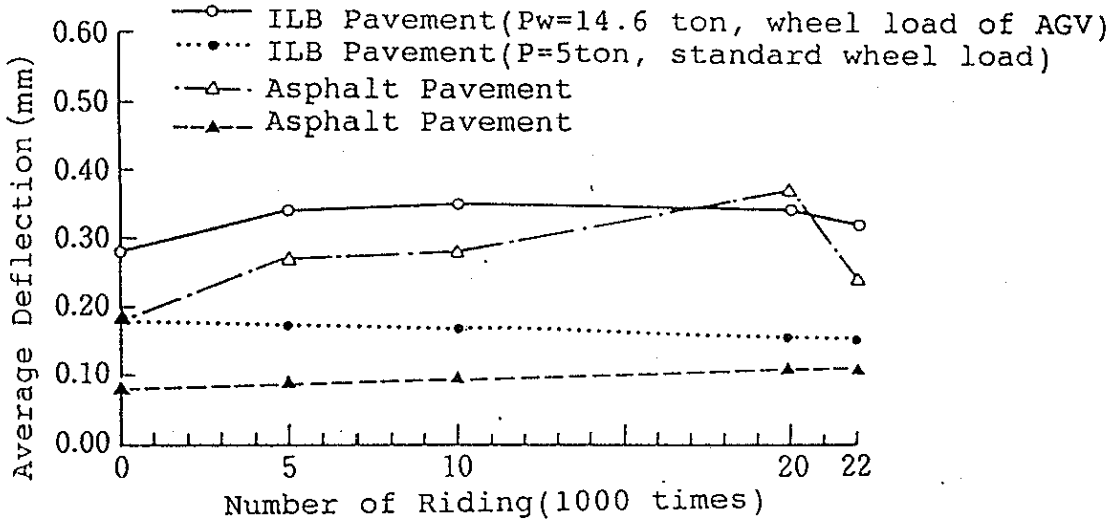


Fig. 10 Deflection on the Pavements

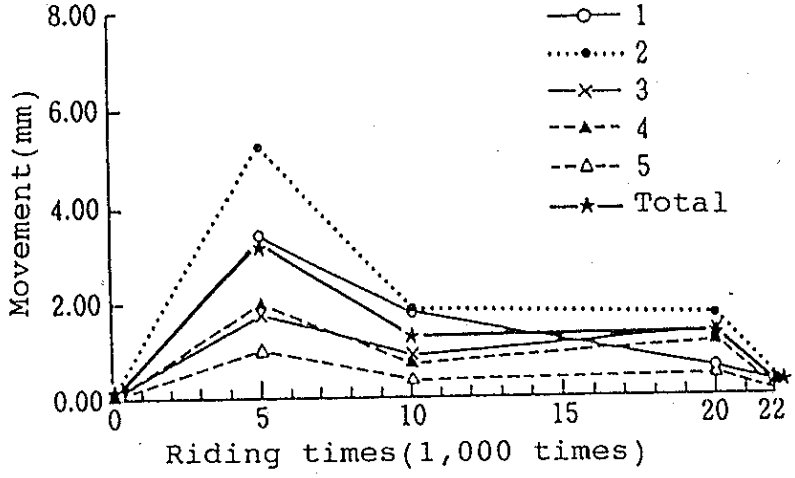


Fig.11 Block Movement(Progression)

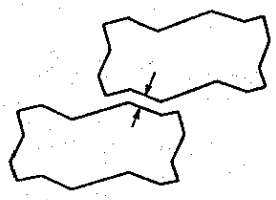


Fig.12 Joint Width
Measuring Point

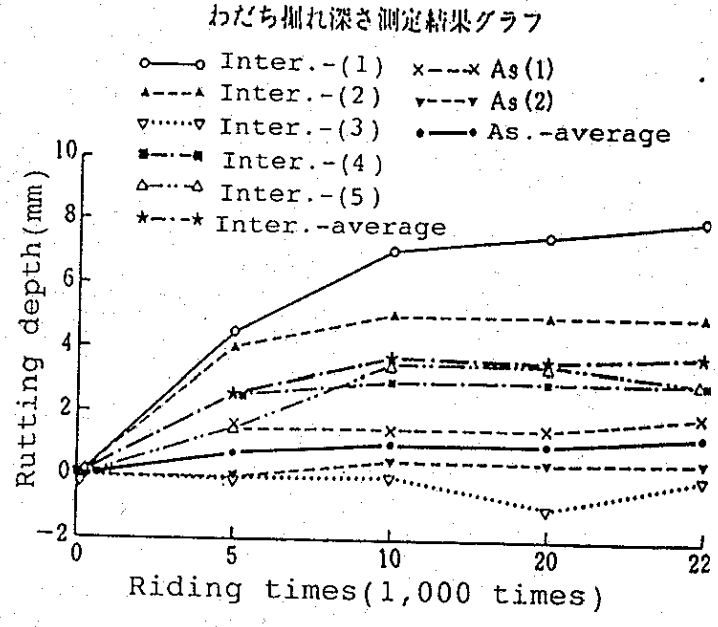


Fig.13 Rutting Depth



Fig. 14 Block Cracking

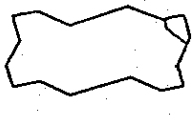


Fig. 15 Block chip-off



Photo 1 Construction of RCCP



Photo 2 Sand Spreading by Asphalt Finisher



Photo 3 Cramp Type Laying Machine



Photo 4 Vacuum Type Laying Machine



Photo 5 Compression by Vibration Roller



Photo 6 Riding Test by a 32-ton Dump Truck



Photo 7 Benkelman Beam Deflection Test



Photo 8 Container Terminal,
Port of Kawasaki(March 1995)