STRUCTURAL EVALUATION OF ILB PAVEMENT FOR ROADWAYS

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ABSTRACT

Applications of InterLocking Block (ILB) pavements for roadways are still few, and available reports on the results of ILB pavement investigations on actual roads are quite few. This paper is a summary of the investigation results on actual roads and begins with the description of the structural evaluation of ILB pavement on the basis of a test pavement constructed on a roadway.
The test pavement was constructed over a length of 160 m in Shirako Town, Chiba Prefecture. It was formed of eight sections differing in ILB material for the surface course and in material and construction method for the base and subbase courses.
Next, referring to an ILB pavement that has been in service for 18 years after construction in Atami City, Shizuoka, Prefecture, the paper describes the structural evaluations of this pavement in the state four months after construction and in the present state, from the viewpoint of long-term serviceability.
As a result of evaluating the ILB pavement based on the results of surface deflection measurement, it was confirmed that the pavement structure was sufficiently safe and that the 18-years-old ILB pavement would be sufficiently serviceable in the future as well.

1. INTRODUCTION

ILB pavements are highly rigid cement concrete pavements, but are structurally similar to flexible pavements because the joints deform as hinges. At present, therefore, ILB pavements are designed according to the asphalt pavement design method. [1]

With the cooperation of Chiba Prefecture and Shirako Town, a test ILB pavement was constructed in Shirako Town, and an opportunity of investigating the pavement from the structural viewpoint was obtained.

Before the construction of the test pavement, a structural evaluation by FWD (Falling Weight Deflectometer) of the existing road and an investigation of the properties of the existing subgrade soil were conducted as preliminary investigations.

After the construction, the surface deflection of the test pavement was investigated by FWD from time to time, i.e., right after construction and after the lapse of three months, six months and one year after construction.

Lastly, taking as an example the 18-years-old ILB pavement in Atami City, a structural evaluation was made of the pavement in the state four months after construction and in the present state, based on the results of surface deflection measurement by Benkelman beam. This paper summarizes the obtained investigation results.

2. PRELIMINARY INVESTIGATIONS

2.1 Investigation by FWD of The existing road

The pavement structure of the existing road was investigated by FWD. Table 1 shows the maximum value, minimum value and standard deviation of deflections at the loading center out of the surface deflections obtained from the results of investigation by FWD. The maximum value of surface deflection is about 1.5 mm, and the average plus standard deviation is about 1.1 mm though a little different between the left and right lanes. Considering that this road belongs to A-traffic in the traffic classification and that the target limit of deflection is about 0.9 mm, it was found that there exist not a few sections in which the bearing capacity of the pavement is insufficient.

Table 1 Investigation Results of Surface

	Deflection (D0) mm			
	Max	Min	Ave	S. D※
Right Side (B)	1.523	0.266	0.797	0.32
Left Side (A)	1.421	0.235	0.666	0.287

※ Standard Deviation

Table 2 Properties of Subgrade

Water Content (%)		40.3
Wet Density (g/cm^3)		1.664
Dry Density (g/cm^3)		1.186
CBR (3-67) (%)		2.5
Percent Passing By Mass	2.0^{mm}	98.1
	0.425^{mm}	95.5
	0.075^{mm}	22.5

CBR Value : (3L-67B)

2.2 Investigation of The Subgrade Soil and Subgrade Stabilization

2.2.1 Mix Design of The Stabilized Subgrade Layer

Table 2 shows the properties of the subgrade soil in the test pavement area. The natural moisture content of the subgrade soil is about 40%, and the CBR value of the disturbed sample is 2.5. Using these values, a mix design was made for subgrade stabilization with cement.

Figure 1 shows the relation between the CBR value of the stabilized subgrade soil and the amount of added cement. The CBR value increased proportionally with the amount of added cement. The amounts of added cement corresponding to the aimed values of CBR 20 and CBR 30 were found to be 42.5 kg/m^3 and 66.0 kg/m^3, respectively. In the actual field construction, however, a percentage increase in the amount of cement is practiced. For this test pavement, it was decided to increase the amount of added cement by 20% of that obtained in the laboratory test, use 51.0 kg/m^3 of cement for the section of CBR 20 and 79.2 kg/m^3 for the section of CBR 30 and make the stabilized subgrade soil (SSL) 30 cm thick.

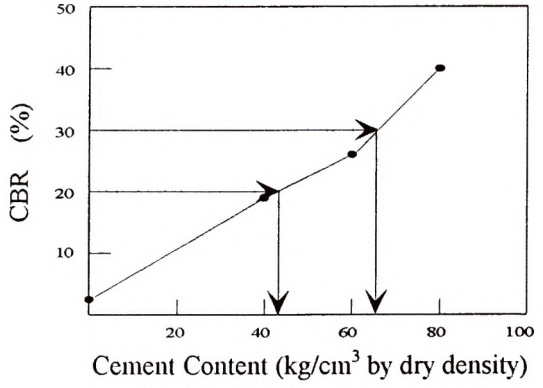

Figure 1 Relation between Amount of Added Cement and CBR

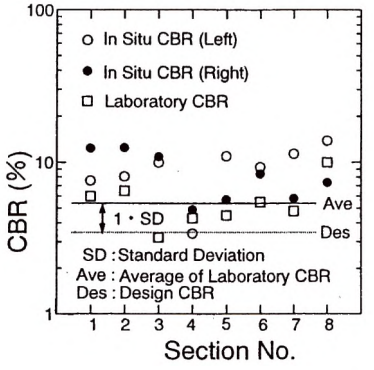

Figure 2 Investigation Results of Subgrade CBR

2.2.2 CBR of The Subgrade Soil

CBR tests of the subgrade soil were carried out before the construction of the test pavement. First, an in-situ CBR test was performed. Then, a laboratory soaked CBR test was done using an undisturbed sample. In the in-situ CBR test, measurements were made on both sides of the road. In the laboratory CBR test, measurements were made on the undisturbed sample taken from the center of the road.

Figure 2 shows the CBR values of the subgrade soil by construction section. The mean CBR value in-situ was 8.9, and the standard deviation was 3.0. The mean value of laboratory soaked CBR test value of the undisturbed sample was 5.6, and the standard deviation was 2.1. In designing the test pavement, the laboratory soaked CBR test value was adopted as the design CBR value for the sections, and the design CBR value was determined as CBR 3. The design CBR value for the section in which to provide an SSL thickness of 30 cm was determined as CBR 6 by calculating the mean CBR (CBRm) value by Equation (1), taking the CBR value of the SSL as CBR 20. [2]

$$CBR_m = \left(\frac{30 \cdot CBR_s^{\frac{1}{3}} + 70 \cdot CBR_d^{\frac{1}{3}}}{100} \right) \tag{1}$$

where CBR_s=CBR value of SSL
CBR_d=design CBR value of subgrade

3. PAVEMENT STRUCTURE

The traffic volume used in the pavement design was determined as A-traffic in the traffic classification, based on the past results in this area and the traffic investigation results obtained right before construction.

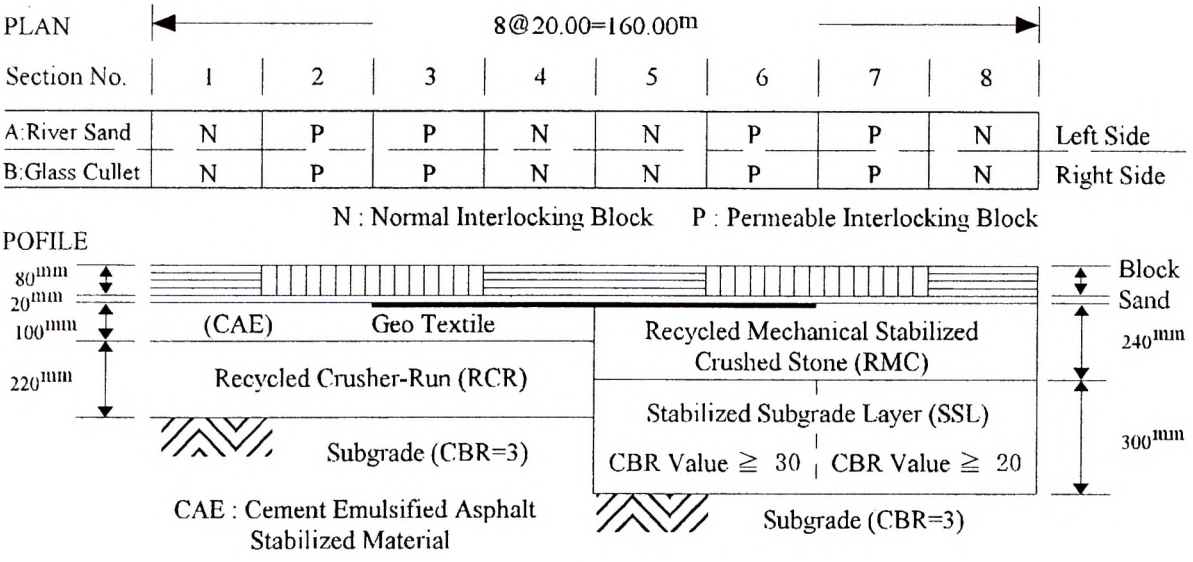

Figure 3 Test Pavement Structure

Figure 3 shows the cross sections of the test pavement which were determined based on the traffic volume and the design CBR value in accordance with the Manual for Design and Construction of Asphalt Pavement.

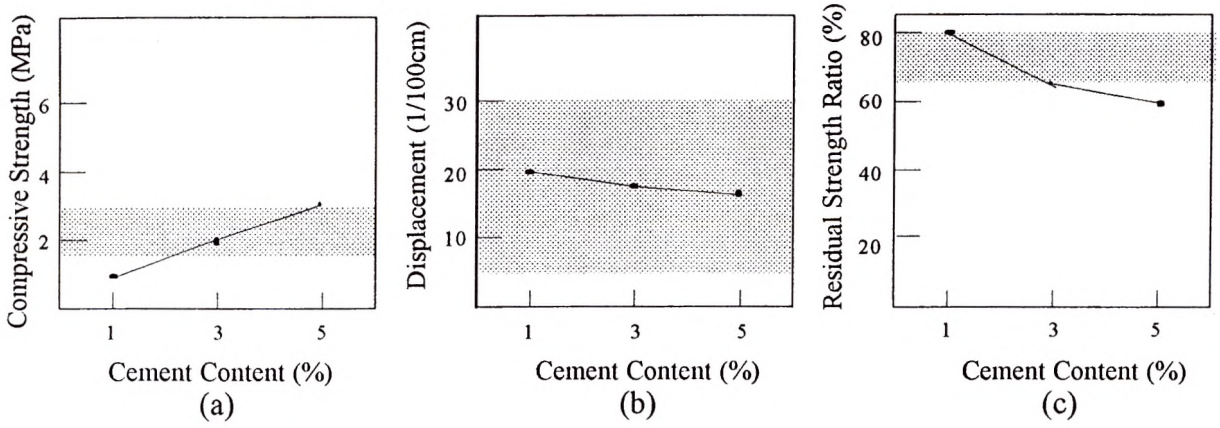

Figure 4 CAE Test Results

The test pavement was formed of eight different sections by using two kinds of surface course ILB materials: ordinary (non-porous) and porous, two kinds of base course materials: cement asphalt emulsion stabilized material (CAE) and recycled, mechanically stabilized crushed stone (RMC), and two kinds of subbase course materials/construction methods: recycled crusher-run (RCR) and SSL (two sections that use CBR 20 and CBR 30, respectively, as the aimed CBR value of the SSL; thickness of stabilized layer: 30 cm). The length of one construction section of the test pavement was 20 m, and the overall length was 160 m.

Table 3 shows the properties of RMC and RCR. Figure 4 shows the CAE test results obtained by the test method. [3]

Table 3 Properties of Base Materials

			RMC	RCR
Specific Gravity under Surface-dry			2.51	2.41
Water Absorption (%)			2.92	1.74
Abrasion Loss (%)			21.3	30.2
Consistency (%)		LL	NP	NP
		PL	NP	NP
		PI	NP	NP
Optimum Moisture Content			6.7	10.4
Maximum Dry Density (g/cm^3)			2.07	1.74
CBR Value	Layers-Number Blows	3L-17B	68	29
		3L-42B	120	61
		3L-92B	174	97
Modified CBR Value※			102	70
Percent Passing by Mass		53.0^{mm}	100	100
		37.5^{mm}	100	99
		19.0^{mm}	78	68
		4.75^{mm}	48	17
		2.36^{mm}	37	10
		0.40^{mm}	18	-
		0.075^{mm}	4	-

※ Degree of Compaction 95%

4. STRUCTURAL EVALUATION OF TEST PAVEMENT

4.1 Evaluation by Surface Deflection at The Loading Center Point

The investigation of the test pavement structure conducted continuously after opening to traffic was surface deflection measurement by FWD.

Figure 5 shows changes with time of the surface deflection (D0) at the loading center point out of the surface deflections measured by FWD. D0 decreases proportionally with time. This decrease in surface deflection is considered attributable to the fact that the effect of load distribution in the surface course increased with the progress of interlocking of ILBs.

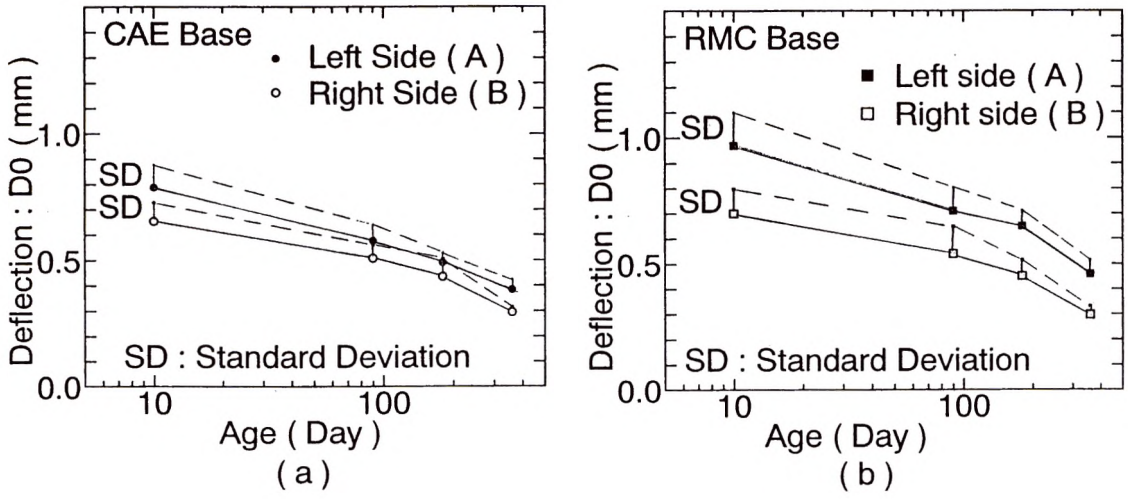

Figure 5 Changes with Time of Surface Deflection

Considering the changes in D0 by the difference between base course materials, the D0 value of the pavement using CAE for the base course is smaller than that of the pavement using RMC for the base course. Therefore, stabilizing the base course is considered to strengthen the interlocking of the surface course ILBs, resulting in smaller surface deflection.

Equation (2) calculates the traffic volume in terms of 5-ton (49kN) load by determining the relation between limiting value of deflection and traffic volume on the condition that the relation between initial deflection and pavement life, indicated by the TRRL, and the limiting values of deflection indicated by the AI be satisfied. [4][5][6] Table 4 shows the limiting values of deflection by traffic classification. By investigating the deflections given here in comparison with those obtained by the present investigation, the test pavement structure is assumed to be capable of accommodating not only A-traffic but B-traffic as well.

Table 4 Limiting Values of Deflection

Traffic Classification	L	A	B	C	D
N ($\times 10^4$)	3	15	100	700	3500
Limiting Values of Deflection (mm)	1.3	0.88	0.56	0.35	0.24

N : Number of Equivalent 5-ton (49kN) Wheel Loads

$$\log W = 1.19 - 0.24 \log N \qquad (2)$$

where W=limiting value of deflection (mm)
N=Number of equivalent 5-ton (49kN) wheel loads

4.2 Evaluation by Elastic Modulus of The Pavement Forming Layers

An attempt was made to evaluate the pavement structure by estimating the elastic modulus of the pavement forming layers by the trial calculation (back calculation) method, based on the results of surface deflection measurement by FWD.

The method of estimating elastic modulus by back calculation is as follows. First, the deflection at a reference point on the road surface is calculated by stress analysis, based on the multilayer elasticity theory, assuming the elastic modulus of each layer of the pavement forming layers from the known thickness and Poisson's ratio of the layer. Next, the

calculated value of deflection is compared with the value of deflection at the reference point on the road surface, measured by FWD. If the calculated value agrees with the measured value, the assumed elastic modulus is taken as the estimated value. If not, the elastic modulus of each layer is corrected and the same calculation is repeated until both values agree or the difference between them is within the specified range.

With this estimation method, good results have been obtained in the past. The method is considered capable of estimating elastic modulus with three or four repetitions if employed by an experienced engineer.

The elastic modulus of each layer calculated by the method is the so-called "apparent elastic modulus" which takes into account the effects of the adjacent layers, assuming the pavement as a multilayer elastic body. Therefore, it must be distinguished from the elastic modulus as a material constant, but is called here simply "elastic modulus" because there is not any other appropriate term.

Figure 6 shows changes with time of the elastic modulus of each layer. The elastic modulus of each layer increases proportionally with the number of days elapsed. In the figure, the values of elastic modulus are shown by kind of base course. The elastic modulus of the surface course ILBs in the case of using CAE for the base course is greater than that of the surface course ILBs in the case of using RMC for the base course. Presumably, the reason for it is that due to the presence of a stabilized layer on the base course the surface course ILBs placed above the base course exhibited stronger interlocking and was therefore rated as greater in elastic modulus. Moreover, this can be understood by considering the elastic modulus of CAE which is nearly equal to the elastic modulus of the surface course ILBs.

Considering the subbase course, the elastic modulus of RCR and of SSL progress in the same way and no significant difference is observed between them. Thus, it becomes clear that the SSL when evaluated based on surface deflection is rated as nearly equivalent to RCR. It is considered necessary to contrive to strengthen the pavement structure by stabilizing the subgrade.

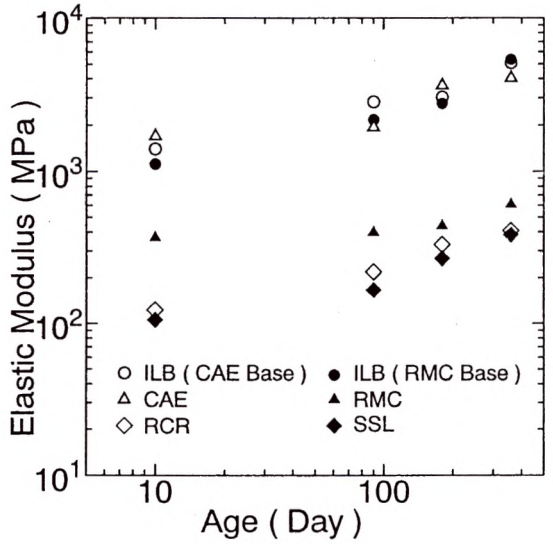

Figure 6 Changes with Time of Elastic Modulus

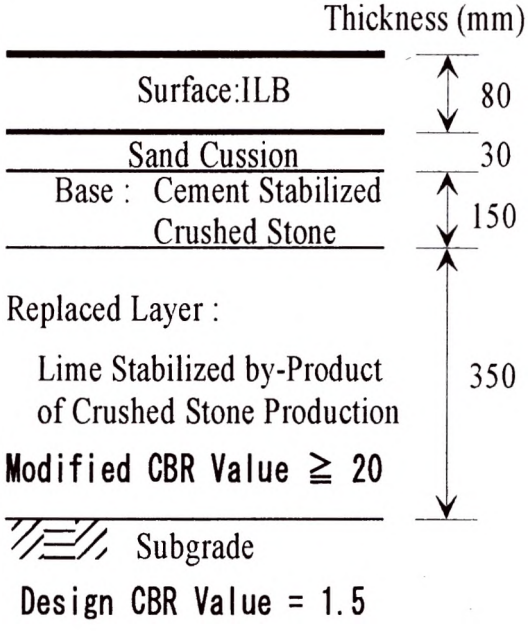

Figure 7 Cross Section of ILB Pavement (in Atami City)

5. STRUCTURAL EVALUATION OF ILB PAVEMENT 18 YEARS AFTER CONSTRUCTION

5.1 Outline at The Time of Construction

The ILB pavement was constructed on a relatively low traffic volume street with no demarcation between sidewalk and roadway, in the area of Hama-cho, Atami City (Hama-cho - Kaiwada Route), with an overall length of 90 m.

The subgrade soil on the site was weak with a design CBR value of 1.5, so it was necessary to stabilize or replace part of the subgrade. As the roads in this area had many underground facilities such as gas, water and hot-spring pipes, it was decided to replace part of the upper part of the existing subgrade with a lime stabilized fine powder of crushed stone (by-product of crushed stone production, modified CBR value $\geqq$ 20).

In designing the pavement structure, the design CBR value of the subgrade was determined as CBR 4 by reducing the CBR value for a thickness of 20 cm in the lower part of the replaced layer to the average of this value and the CBR value of the existing subgrade and calculating the mean CBR (CBRm) value by Equation (3). The cross sections of the pavement shown in Figure 7 were selected based on the design traffic volume, aiming at a cumulative number of more than 100,000 wheels in terms of 5-ton (49kN) load.

$$CBR_m = \left[\frac{(35-20)\cdot CBR_r^{\frac{1}{3}} + 20\cdot CBR_{r,d}^{\frac{1}{3}} + 65\cdot CBR_d^{\frac{1}{3}}}{100} \right]^{\frac{1}{3}} \tag{3}$$

where CBR_r=modified CBR value of lime stabilized fine powder of crushed stone
CBR_d=design CBR value of subgrade
$CBR_{r,d}=(CBR_r+CBR_d)/2$

The ILB pavement has been in service for 18 years after its construction in 1982, but is still capable of sufficiently withstanding the service conditions. It had the opportunity of being investigated for surface deflection in November 1999.

5.2 Structural Evaluation of The Pavement by Benkelman Beam

5.2.1 Evaluation Four Months after Construction

A two-layer structural evaluation of the pavement was made based on the surface deflection and radius of curvature, measured by Benkelman beam, four months after construction. The method for two-layer structural evaluation is as follows. First, the surface deflection and radius of curvature at the loading center point are measured by an improved type of Benkeleman beam with a curvature meter. Next, the pavement is temporarily divided into two layers, and the pavement structure is evaluated by estimating the elastic modulus of the first and second layers from the known thickness and Poisson's ratio of the respective layers. The method is simple. [7] Afterward, an attempt was made to expand the method to three-layer structural evaluation. [8]

5.2.2 Evaluation 18 Years after Construction

The pavement structure was evaluated based on the surface deflection profile measured by Benkeleman beam. The surface deflection profile was recorded using a device that is

capable of measuring the surface deflection and movement of wheel load concurrently and continuously at short intervals (in units of several millimeters).

The method of evaluating pavement structure is as follows. First, reference points (usually 10 points) are selected from the measured surface deflection curve and the surface deflections at these points are recorded. Next, the deflections at the reference points are calculated by stress analysis, based on the multilayer elastic theory, assuming the elastic modulus of each layer of the pavement forming layers from the known thickness and Poisson's ratio of the respective layers. If the calculated values do not agree with the measured values, the elastic modulus of each layer is corrected and the same calculation is repeated until both values agree or the difference between them is within the specified range. Thus, the pavement structure is evaluated by estimating its elastic modulus.

This method is the same as the generally known "back calculation" method, and the structural evaluation based on the elastic modulus of the pavement forming layers is common. In this paper, however, the pavement was evaluated as a two-layer structure for comparison with the structural evaluation made four months after construction.

Table 5 shows the elastic modulus and standard deviation of the surface course ILBs after the lapse of four months and 18 years after construction. The elastic modulus of the surface course ILBs was investigated separately for two ILB layers, one formed of only ILBs and one including a sand cushion layer. As a result, both layers were found to be great in the elastic modulus after 18 years. The elastic modulus of the ILB layer including the sand cushion layer is about 2200Mpa still at present, 18 years after construction. Therefore, the ILBs are confirmed to have properties equivalent to those of hot asphalt mix at normal temperature.

Table 5 Elastic Modulus

Layer		ILB	ILB + SC
Thickness (cm)		8	11
Elastic Modulus (MPa)	In 1982	4420	1680
		(1900)※	(743)※
	In 1999	5350	2210
		(880)※	(341)※

( )※Standard Deviation
SC : Sand Cushion

Moreover, the following can be said, judging from the fact that the surface deflections under 5-ton (49kN) wheel loads in the state four months after construction and in the present state - 18 years after construction - are about 0.3 mm:

(1) The ILBs interlock sufficiently under traffic load after opening to traffic, contributing to greater effect of load distribution.
(2) Due to the "plate" effect of the cement stabilized base, the deformation of the ILB layer is reduced, so the elastic modulus is rated as greater.
(3) The effect of replacing the subgrade with lime stabilized material acts organically to strengthen the pavement structure.

This ILB pavement is of the structure in which a cement stabilized layer is provided in the base course and a lime stabilized material is used as the subgrade replacement material. When constructing ILB pavements, it would be important to strengthen the pavement structure by means of mechanical stabilization and to reduce the deformation of ILBs by forming the base as a "plate" structure.

6. CONCLUSION

The test pavement constructed in Shirako Town, Chiba Prefecture, and the pavement that has

been in service for 18 years after its construction in Atami City are ILB pavements in which stabilized layers are provided. The investigation results are summarized as follows:

(1) The ILB pavements designed according to the asphalt pavement design method are found structurally safe as a result of the structural evaluation based on surface deflection.
(2) The surface deflection decreases with time, and the ILB pavement structure becomes stronger with time.
(3) Not only the one-year-old test ILB pavement but also the 18-years-old ILB pavement will be sufficiently serviceable in the future as well.
(4) The SSL stabilized with cement is confirmed to have properties equivalent to those of RCR.
(5) The subgrade replacement material stabilized with a by-product of crushed stone production is effective in strengthening the pavement structure.
(6) By using a stabilized material for the base course, the deformation of ILBs is reduced and the elastic modulus is rated as greater.

7. ACKNOWLEDGEMENT

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