EVALUATION METHOD FOR JOINT LOAD TRANSFER EFFICIENCY IN CONCRETE PAVEMENTS

Kazuyuki KAWAMURA
Civil Engineering Research Institute, Hokkaido Development Bureau

Shinichi NAKAGAWA
Civil Engineering Research Institute, Hokkaido Development Bureau

Tatsuo NISHIZAWA
Department of Civil Engineering, Ishikawa National College of Technology

Atsushi KASAHARA
Department of Civil Engineering, Hokkaido Institute of Technology

INTRODUCTION

In concrete pavement, to reduce the stress which occurs in concrete slabs by allowing movement of the concrete slabs such as expansion, shrinkage and warping, various types of joints are installed. These joints become structural weak points. In most cases, the failure of concrete pavement advances from joints. The joints must act as the structure by which the load is transmitted between loaded slabs and unloaded slabs. Therefore, primarily dowels have been used. There is a large influence by load transfer on the service performance of concrete pavement.

However in the joints of RCCP, sawn joints have generally been used. The capability of load transfer in these sawn joints is dependent on the width of the crack opening.

With concrete pavement containing RCCP, it is important to establish a technique to evaluate reasonably the capability of load transfer. So far, the capability of load transfer has been evaluated by the difference of deflection in both loaded slabs and unloaded slabs. However, it can be said that the load transfer efficiency does not represent directly the mechanical behavior of joints. Therefore, when the behavior of joints is mechanically evaluated, it is necessary to introduce a mechanical model that properly simulates joint behavier.

This study was conducted to develop a mechanical model properly simulating joints. The following investigations were conducted ;

1. Construction of a test road for RCCP
2. Measurement of deflection by FWD at joints
3. Calculation of load transfer efficiency using deflection
4. Proposal of shear spring model
5. Determination of the coefficient of shear spring by backcalculation from FWD deflections
6. Stress calculation near joint edges using shear spring model

KIKONAI TEST ROAD

The Kikonai test road was built on a national highway in Hokkaido in July 1989 and opened in October. As shown in Fig. 1, the town on Kikonai, where the test road was built, is located in the southern part of Hokkaido, where the maximum freezing depth is about 900 mm and maximum freezing index is about 400℃•days. The amount of traffic load was measured with a portable axle load meter after the service. Consequently, the number of equivalent 49 kN wheel loads per day was about 800.

For this test road, both plain concrete pavement (PCP) and RCCP were built. Design bending strength of concrete was 4.4 MPa in both cases. The results of bending strength tests at the 28 days by using the cut-out specimens are shown in Table 1. The bending strength of roller compacted concrete is about 6.5 MPa and the bending strength of plain concrete is about 4.4 MPa, both of which almost fulfilled the bending strength of design criteria.

Table 1. RESULTS OF BEARING STRENGTH TEST AT THE AGE OF 28 DAYS

	Bending Strength [MPa]			
	Each Test Peace			Average
RCC	6.9	6.8	5.9	6.5
PC	4.3	4.5	4.3	4.4

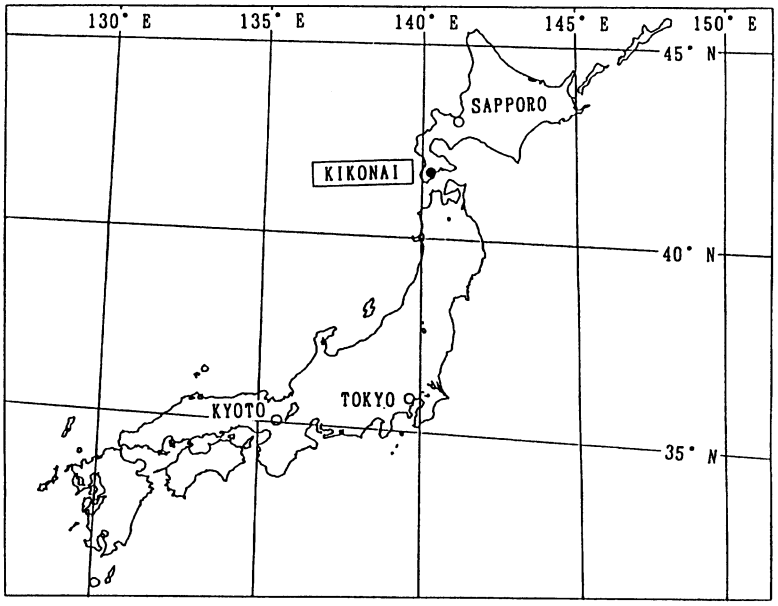


Fig 1. LOCATION OF TEST ROAD

Length and joint spacing of the test road are shown in Fig. 2. Both the pavement structures are the same, as shown in Fig. 3. Both the pavement structures have a 300-mm anti-frost layer.

The main purpose of this test road was to determine the load transfer at the joint of RCCP. For RCCP, both sawn joints and dowel joints were installed. For the PCP, dowel joints were used.

Sawn joints were made in RCCP by cutting a groove with a depth of 70 mm and a width of 8 mm from the top of a concrete slab. At this joint, a crack occurs in the lower portion of the concrete slab below the cut groove after construction. After the crack occurs, the transfer of shear force will occur only by the interlocking of aggregates on the surface of cracks. Dowel bars used in the dowel joints in RCCP are 700 mm long and 28 mm in diameter, and asphalt is coated to 350 mm of dowel bar. For installation of dowel bars in RCCP, the concrete pavement was built with two layers, each being 140 mm thick.

Construction of dowel joints in PCP is the same as that of RCCP. Joint spacing is generally 10 m, but even 15 m is occasionally adopted for RCCP. Details of each joint construction are shown in Fig. 4 and Fig. 5.

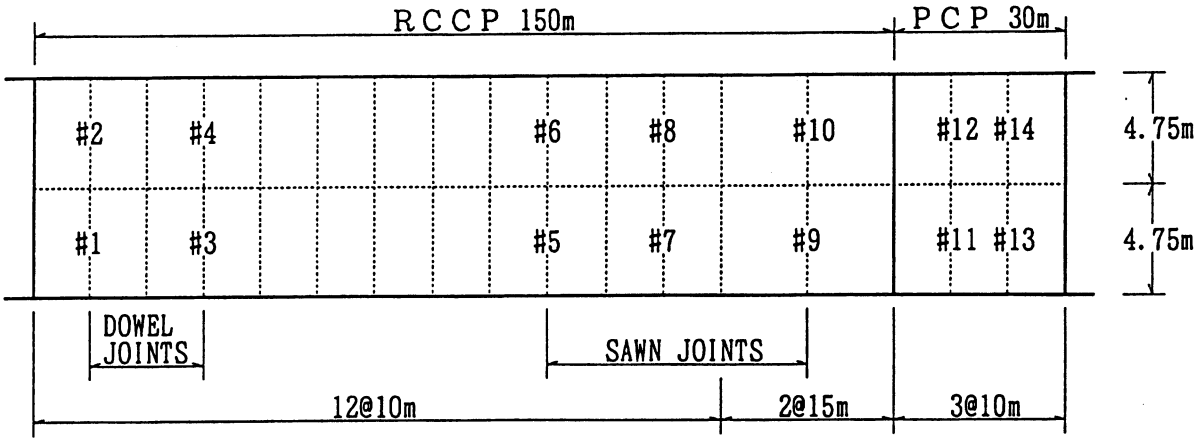


Fig 2. GENERAL VIEW AND JOINT SPACING OF KIKONAI TEST ROAD

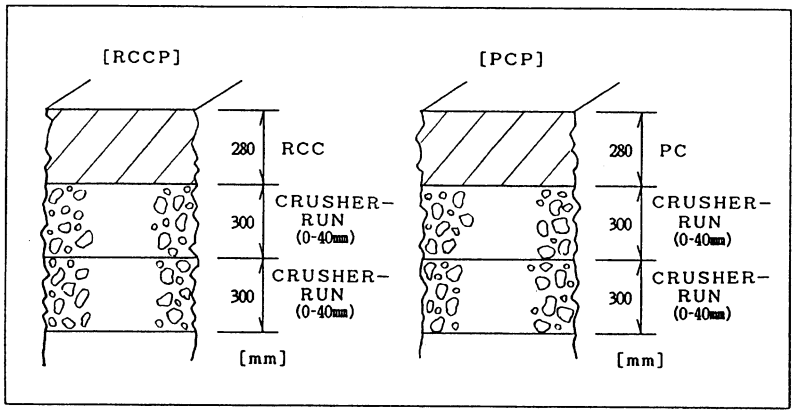


Fig 3. STRUCTURE OF PAVEMENT

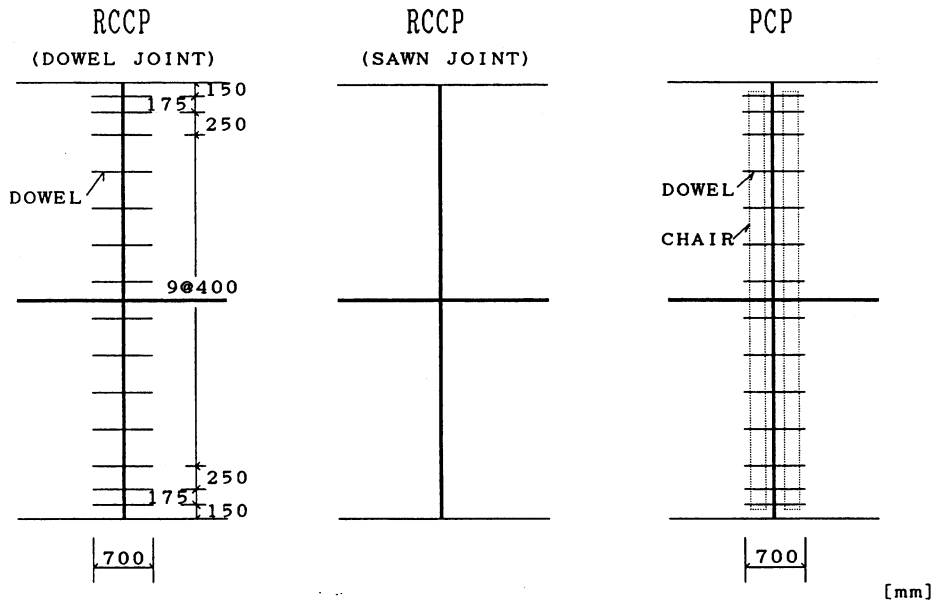


Fig 4. VIEW OF JOINTS

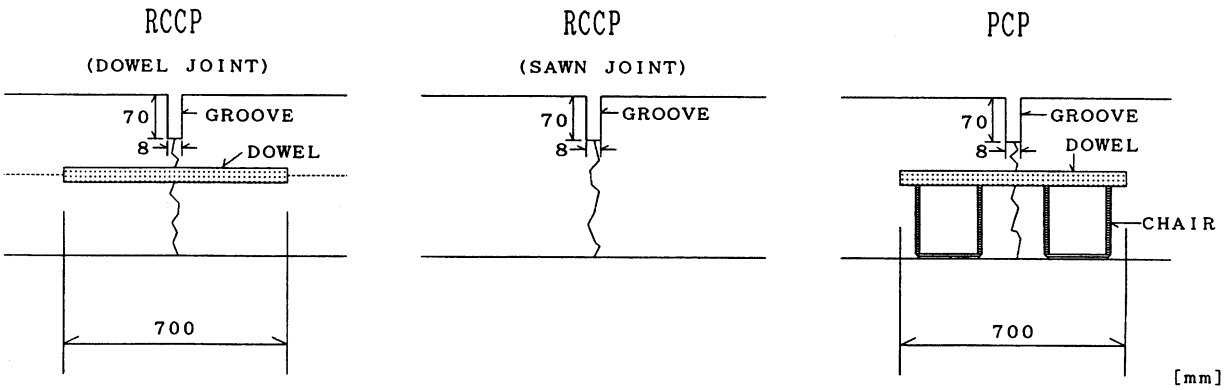


Fig 5. SECTION OF JOINTS

MEASUREMENT OF DEFLECTION BY FWD

For the survey of cracking in the joints, deflection measurement by FWD was conducted in November every year from 1989 to 1991.

In the FWD test, a mass is dropped onto the surface of the pavement, and the deflection is measured at points on the surface. The loading plate of the FWD is 300 mm in diameter and the load is 49 kN. The deflection measuring positions were 0, 300, 600 and 2000 mm from the center of the loading plate. [1]

In the deflection measurement at the joint portion, the loading plate is installed so that the edge of the loading plate touches the joint and, as shown in Fig. 6, deflections of both the loaded slab and unloaded slab were measured. [2]

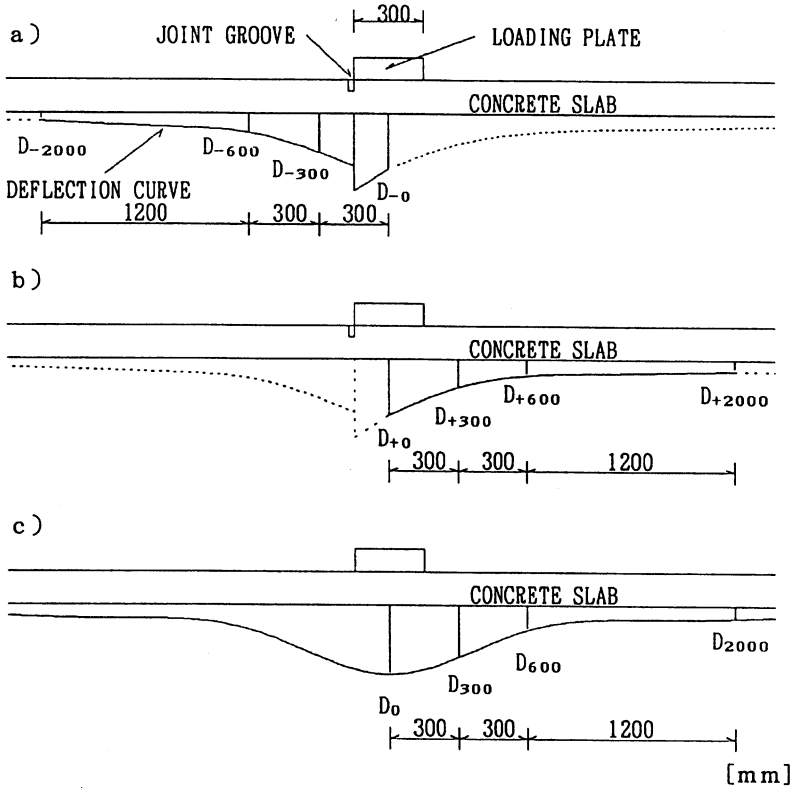


Fig 6. DEFLECTION CURVE

Table 2. FWD DEFLECTION AND LOAD TRASNFER EFFICIENCY

Type of Pavement	Type of Joint	Joint No.	Nov. 1989			Nov. 1990			Nov. 1991		
			D_0 [μm]	D_{300} [μm]	Ef [%]	D_0 [μm]	D_{300} [μm]	Ef [%]	D_0 [μm]	D_{300} [μm]	Ef [%]
RCCP	Dowel Joint	#1	127	88	81.9	81	73	94.8	82	75	95.5
		#2	120	98	89.9	93	84	94.9	116	104	94.5
		#3	114	95	90.9	151	114	86.0	139	107	87.0
		#4	122	105	92.5	140	134	97.8	158	122	87.1
	Sawn Joint	#5	123	102	90.7	88	82	96.5	94	85	95.0
		#6	129	106	90.2	99	93	96.9	115	106	95.9
		#7	123	108	93.5	218	75	51.2	236	90	55.2
		#8	128	103	89.2	94	87	96.1	196	75	55.4
		#9	126	103	90.0	99	91	95.8	226	92	57.9
		#10	128	104	89.7	198	94	64.4	221	83	54.6
PCP	Dowel Joint	#11	141	119	91.5	122	110	94.8	150	131	93.2
		#12	118	92	87.6	107	97	95.1	139	109	87.9
		#13	209	110	69.0	127	107	91.5	161	132	90.1
		#14	218	121	71.4	138	111	89.2	164	119	84.1

LOAD TRANSFER EFFICIENCY

Where there are no cracks, the deflection curve due to loading by FWD becomes symmetrical about the center of the loading slab, as shown in Fig. 6c. However, if there are cracks in the joint portion and the load transfer is not sufficient, the deflection curve becomes discontinuous at the crack, as shown in Figs. 6a and 6b.

The load transfer efficiency, is evaluated from a ratio of measured value of deflection near the joints. The load transfer efficiency (Ef) is determined from the deflection at a position 150 mm away from the joints of the loaded slab and from the deflection at a position 150 mm away from the joints of the unloaded slab. The formula for calculating the ratio is shown in Equation 1.

$$\mathbf{Ef} = \frac{\mathbf{D}_{-300}}{(\mathbf{D}_{-0} + \mathbf{D}_{-300})/2} \times 100 \ [\%] \qquad (1)$$

where, $\mathbf{D}_{-0}$ is the deflection at the center of the loading plate, and $\mathbf{D}_{-300}$ is the deflection at a position 300 mm from the center of the loading plate at the other side of the joint.

FWD deflection and load transfer efficiency (Ef) at each joint are shown in Table 2. The profile of the load transfer efficiency at the sawn RCCP joints are shown in Fig. 7 and those of the dowel joints in Fig. 8. Fig. 9 shows the profile in load transfer efficiency of PCP dowel joints.

In sawn RCCP joints (Fig. 7), Ef is close to 100%, even two years after service in some cases, while it suddenly drops to about 60% in other cases. In the former case, no cracks seem to have occurred, while some cracks have occurred in the latter case. In the RCCP, it was determined that, after two years, no cracks occurred in the sawn joints in certain areas where the joint spacing was 10 to 15 m.

On the other hand, the load transfer efficiency sometimes drops in the joints (Fig. 8) using dowel bars of RCCP and PCP joints (Fig. 9), but only to as low as about 80%, which is higher than that of sawn joints. This apparently occurs because the dowels transferred the stresses after the occurrence of cracks.

Ef was determined from the ratio of the measured values of deflection and was not based on a theory of stress and strain, so it is not possible to discuss the relation between Ef and the magnitude of stress of the concrete slab. Therefore, discussions on stress of concrete pavement become necessary by using an appropriate mechanical model which is capable of reflecting the measured values of deflection.

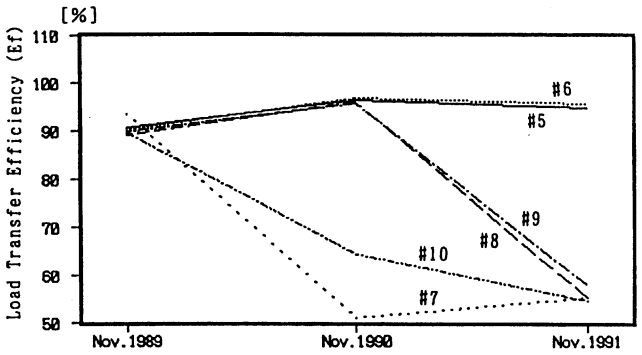


Fig 7. PROFILE OF LOAD TRANSFER EFFICIENCY (SAWN JOINTS OF RCCP)

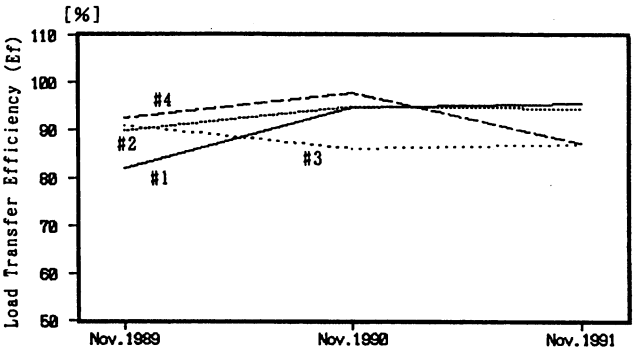


Fig 8. PROFILE OF LOAD TRANSFER EFFICIENCY (DOWEL JOINTS OF RCCP)

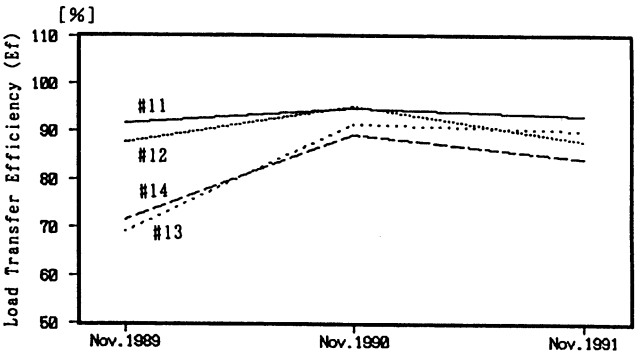


Fig 9. PROFILE OF LOAD TRANSFER EFFICIENCY (DOWEL JOINTS OF PCP)

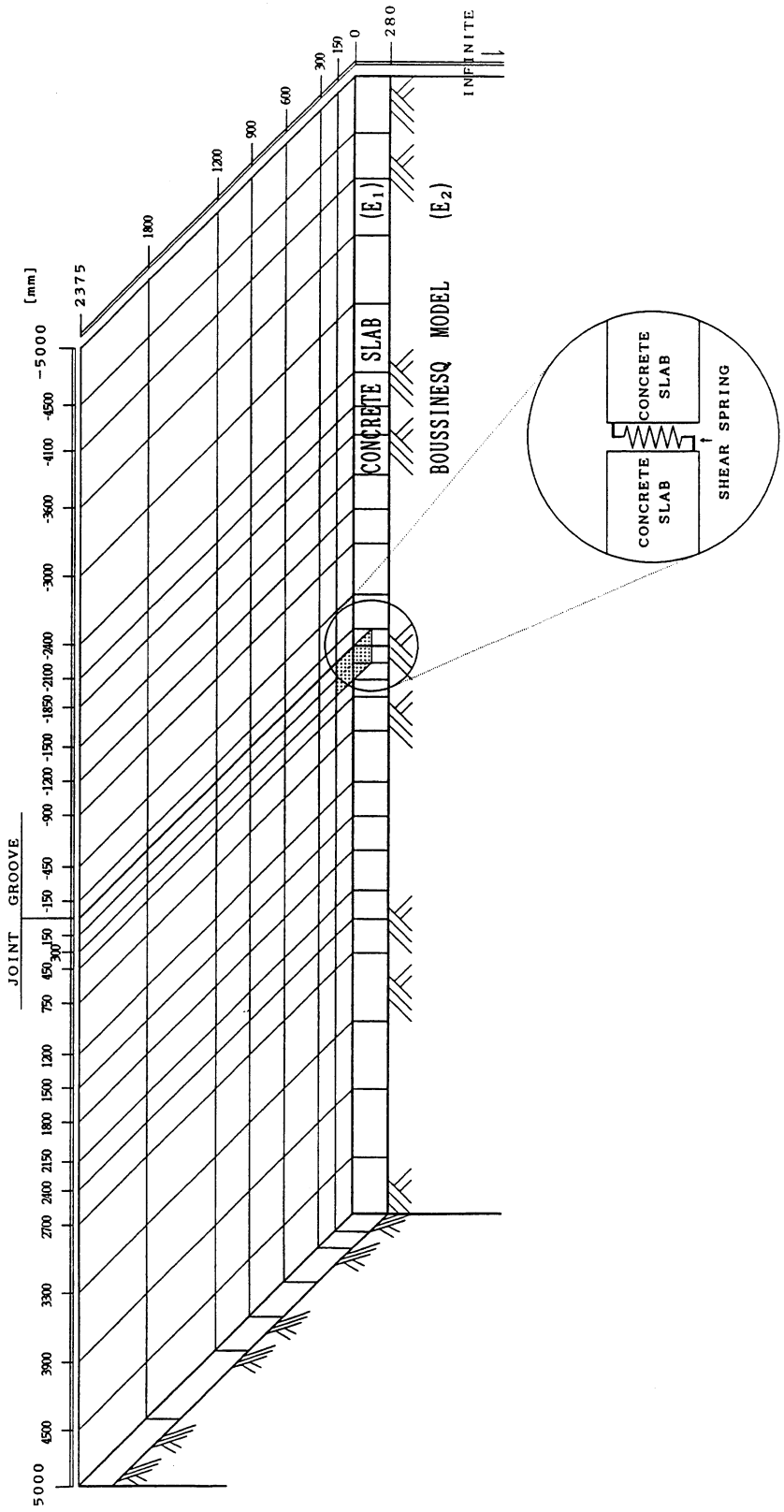


Fig 10. SHEAR SPRING MODEL

MECHANICAL MODEL USING SHEAR SPRING

Various models have been proposed for the mechanical behavior of the load of concrete pavement. However, only few proposals were made for models adequately simulating the load transfer at the joint.

Here, a plate finite element method was adopted as a model expressing the behavior of concrete pavement. A concrete slab is divided into plate elements based on the plate theory, and the subbase is considered to be a reaction acting on the plate. As a foundation model, Boussinesq's semi-infinite elastic body was adopted. Since the load transfer at the joint portion is made by shearing force, the joint elements, based on a shear spring model, are connected to the plate elements. The coefficient of shear spring will become an index of the load transfer capacity at the joints. Fig. 10 shows the shear spring model. [3-8]

BACKCALCULATING ANALYSIS USING SHEAR SPRING MODEL

From the FWD deflections measured at the joint, the elastic modulus of concrete (E1), elastic modulus of subbase (E2) and coefficient of shear spring (Gf) were determined by backcalculations using personal computers. The non-linear least square method was used as an algorithm. Backcalculations were conducted for five joints (#3, #4, #7, #11 and #12) on the Kikonai test road. The measured deflections at five joints are shown in Table 3. and the input data are shown in Table 4. The diameter of the loading plate of FWD was 300 mm but, in the backcalculating analysis, a 300-mm square loading plate was used. Backcalculated values of elastic modulus of concrete (E1), elastic modulus of subbase (E2) and coefficient of shear spring (Gf) are shown in Table 5. Table 5 shows the root mean square error, which was very small, ranging from 0.1 to 2.3 μm.

From Table 5, it can be said that the elastic modulus of concrete (E1) is 4.2×10^4 to 5.4×10^4 MPa and the elastic modulus of subbase (E2) is 1.4×10^2 to 2.0×10^2. The value of the coefficient of shear spring (Gf) varied greatly depending on the joints from 5 kN/m to 440,000 kN/m.

Table 3. MEASURED DEFLECTIONS AT THE FIVE JOINTS

Measured	Joint No.	Deflection [μm]							FWD Load
		D_{-2000}	D_{-600}	D_{-300}	D_{-0} / D_{+0}	D_{+300}	D_{+600}	D_{+2000}	[kN]
Nov. 1990	# 3	49	101	114	151				48.98
					152	123	107	48	48.98
Nov. 1990	# 4	50	112	134	140				48.58
					141	121	102	44	48.98
Nov. 1990	# 7	35	66	75	218				48.98
					216	182	151	62	48.98
Nov. 1990	# 1 1	42	91	110	122				48.98
					119	100	83	38	48.18
Nov. 1990	# 1 2	40	81	97	107				48.58
					108	88	75	35	49.38

Table 4. INPUT DATA OF BACKCALCULATION

Poisson's Ratio of Concrete	0.2
Poisson's Ratio of Subbase	0.35
FWD Load	49 kN
Elastic Modulus of Concrete (E1)	Unknown
Elastic Modulus of Subbase (E2)	
Coefficient of Shear Spring (Gf)	

Table 5. RESULTS OF BACKCALCULATION

	Nov. 1990 #3	Nov. 1990 #4	Nov. 1990 #7	Nov. 1990 #11	Nov. 1990 #12
Type of Joint	RCCP Dowel Joint	RCCP Dowel Joint	RCCP Sawn Joint	PCP Dowel Joint	PCP Dowel Joint
Elastic Moduli of Concrete (E1) (MPa)	46,600	41,700	54,200	44,100	53,300
Elastic Moduli of Subbase (E2) (MPa)	167	164	142	205	187
Coefficient of Shear Spring (Gf) (kN/m)	3,020	442,000	4.8	32,100	52,400
Max of Stress (MPa)	1.32	0.89	1.57	1.06	1.05
Root Mean Square Error (μm)	0.264	0.104	2.266	0.130	0.224

CALCULATIONS OF STRESSES USING SHEAR SPRING MODEL

Under the traffic load, the influence of the coefficient of shear spring on the flexural tensile stresses near the joint edge of concrete slab was investigated. The load was 49 kN, and the loading area was 300 mm square. The maximum flexural tensile stress occurred at the center of loading plate. By using the mean value (48,000 MPa) of the elastic modulus of concrete determined from the previously made results of backcalculation and the mean value (170 MPa) of the elastic modulus of subbase, the flexural tensile stress was calculated with the value of the coefficient of shear spring (Gf) varied from 1.0 kN/m to 1.0×10^6 kN/m. The results are shown in Fig. 11.

A value of Gf of 1.0×10^6 kN/m might be in the range in which no cracks have occurred, and maximum stress at that time was about 0.9 MPa. On the other hand, the load transfer by cracks was almost zero at Gf=1 kN/m. Maximum stress at that time was about 1.5 MPa, an increase of about 70% compared to the former. When Gf was smaller than 1.0×10^2 kN/m, the magnitude of the flexural tensile stress changed little.

The influence of the coefficient of shear spring on the compressive stress acting on the surface of subbase was investigated. The results are shown in Fig. 12. Its value was about 0.02 MPa at Gf=1.0×10^6 kN/m, but it increased more than 3 times to about 0.07 MPa at Gf=1.0 kN/m. It was also noticed that there is little variation in compressive stress which occurred in the subbase between a small Gf and a large Gf.

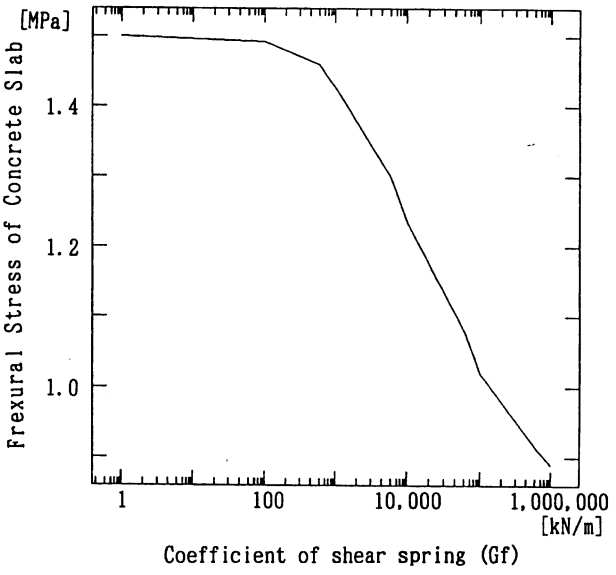


Fig 11. EFFECT OF COEFFICIENT OF SHEAR SPRING (Gf) ON STRESS OF CONCRETE SLAB

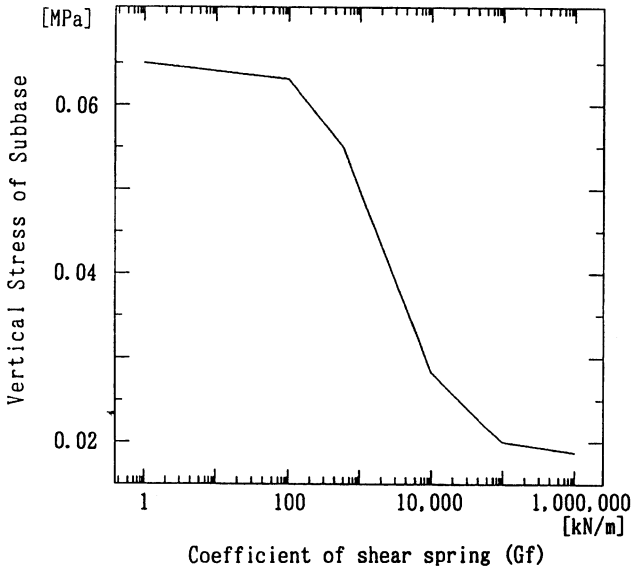


Fig 12. EFFECT OF COEFFICIENT OF SHEAR SPRING (Gf) ON STRESS OF SUBBASE

CONCLUSIONS

In this study, the deflection measurement by FWD is combined with the FEM analysis using shear spring, and a method for evaluating the load transfer capacity of concrete pavement joints has been proposed. The achievements obtained here are summarized as follows :

1) A shear spring model explaining joint behavior has been developed.

2) The load transfer capacity of joints, has been represented by the coefficient of shear spring.

3) The value of the coefficient of shear spring (Gf) is in the range of 5 kN/m to 440,000 kN/m.

4) The variable range of the load transfer efficiency based on the deflection is about 0.5 to 0.9, but Gf is about 5 kN/m to 440,000 kN/m, thereby clearly representing the differences which are due to joint construction.

5) The coefficient of shear spring strongly affects the influence on the flexural tensile stress in concrete slab and the compressive stress on the surface of subbase.

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