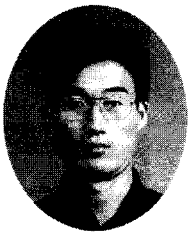
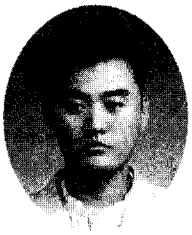
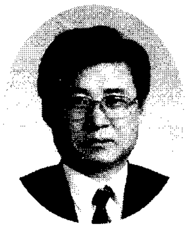
Structural Behavior of Cement Concrete Pavement at Transverse Joint Using Model Test







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Abstract

This paper presents behavior of concrete pavement at transverse joint subject to static test load. The test was conducted on 1/10 scale model in the laboratory. Load transfer across the crack is developed either by the interlocking action of the aggregate particles at the faces of the joint or by a combination of aggregate interlock and mechanical devices such as dowel bars. In this study, significant three variables considered to the performance of joints were selected. : (a)diameter of dowel bars(2.5mm, 3.0mm, 4.0mm), (b)presence or absence of dowel bars, (c)aggregate types(crushed stone, round stone). Experimental results were analyzed to find relationships among displacement of discontinuous plane at jointed slab, load transfer efficiency and joint opening, etc. Displacement of discontinuous plane at joint was decreased according to the increase of dowel bar diameter. In addition, it is found that model slabs made using crushed stone had better load transfer characteristics by aggregate interlock than model slabs made using similarly graded round stone. Displacement of discontinuous plane was increased according to the increase of loading. In addition, it was decreased as dowel diameter(2.5mm, 3.0mm, 4.0mm) was increased. In the case of slab without dowel bars, displacement of discontinuous plane was greatly increased and load transfer efficiency of slab applied crushed stone was shown 30 percent greater than round stone. In addition, load transfer efficiency of slabs, which were made using crushed and round stone without dowel bars, was decreased to 20 percent and 30 percent, respectively as it was compared with slabs made using dowel bars.

Keywords : load transfer efficiency, aggregate interlock, discontinuous plane at jointed slab transverse joint, crushed stone, round stone, dowel bars.

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1. Introduction

Since the 1920s, pavement analysis and design have gradually developed by theoretical and empirical methods. However, there has been no suitable method up to now and our domestic analysis and design are based on the empirical AASHTO method. It is necessary to develop the method of pavement analysis and design considering domestic characteristics. Upon the recent survey on the defects of JCP (Jointed Concrete Pavement), it is reported that many portions of damage are occurred at transverse joints$^{(1)}$. Therefore, transverse contraction joints are provided in concrete pavements to relieve internal stresses caused by initial shrinkage due to moisture loss during curing, which is restrained by base or subbase friction during longitudinal expansion and contraction caused by temperature changes, and thermal and moisture gradients between the top and bottom of the slab. Joints are the weakest parts of the system. If internal stresses are not relieved by transferring loads adequately from one slab to the next, critical distresses such as faulting, pumping, spalling and corner cracking will occur.

The purpose of this paper is to evaluate the structural behavior of concrete pavements at joint edge. For the study, we have performed static load test in the laboratory.. The specimen was scaled down to 1/10 for one lane of JCP according to the laws of similitude.The similitude requirement applied this test is conducted in order to satisfy similitude of loading, geometry and material. And the mix proportion of a test model is derived from the stress-strain behavior of actual concrete and model concrete. Significant three variables considered to the performance of joints were selected for the study: (a) diameter of dowel bars(2.5 mm, 3.0 mm, 4.0 mm), (b)presence or absence of dowel bars, (c)aggregate types (crushed stone, round stone).

2. Experiments

2.1 Description of model specimens

(1) Model specimens size

The test specimen, shown in Fig. 1, is concrete slab of 36 cm width and 120 cm length divided transversely at midlength by the joint in which the load-transfer system is installed.

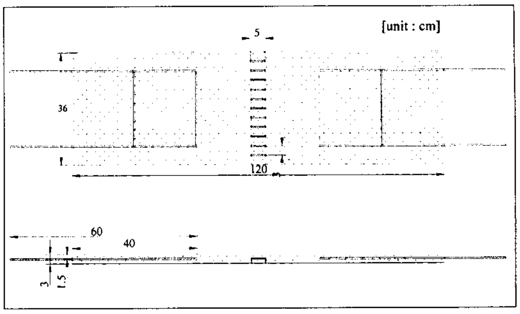

Fig. 1 Size of model specimen

(2) Model dowel bar

The dowel bars of the load-transfer system used in this study, shown in Fig. 2, are varied in three types of diameters(2.5mm, 3.0mm, 4.0mm). Just prior to concreting, the free or sliding half of each dowel was coated with heavy oil to prevent bonding of the concrete.

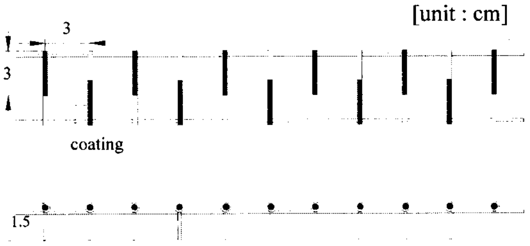

Fig. 2 Structure of model dowel bar

2.2 Manufacture of model specimens

(1) Materials and Mix proportions

Materials are as shown in Table 1. The maximum aggregate size used was No. 4 (4.75mm). High early-strength cement was used throughout the investigation, and the aggregates are consisted of two separate mixtures of coarse and fine, very narrowly graded crushed sand passing sieve

No. 10. Mix proportion is shown in Table 2. For the study, two types of aggregates(crushed stone, round stone)were used. From various stress-strain curves varied with sand-aggregate ratio(s/a) and cement-aggregate ratio(c/a), mix proportions considered to the performance of model specimens were selected. Table 3 shows eight specimens used in the study. And static load is applied to the test.

Table 1 Material property of model specimen

Cement	Model Coarse Aggregate (G_m)	Model Fine Aggregate (S_m)
· Type : High Early-strength Cement · Specific Gravity : 3.12	Aggregate between Sieve No.4 and No.10	Aggregate Passing Sieve No.10

Table 2 Mixing proportions of model specimen

Agg. Types	C/a (%)	S/a (%)	Unit Content (kgf/m³)					
			W	C	S_m (*)	G_m (*)	Admixtures	
							Air-entraining agent	Water-reducIng agent
Round Stone	30	27	180	360	324	864.6	0.72	3.6
Crushed Stone	31	28	187.5	375	337.5	873.75	0.75	3.75

* S_m : Model Sand, G_m : Model Gravel

(2) Joint forming

Prior to the placement of concrete specimens, steel partition with 0.8 mm width and 7.5 mm height is installed in order to form transverse joint. Once the specimen was properly placed, the form was disassembled and removed together with the steel partition used to create the joint opening. By this procedure all of the specimens were successfully handled and placed in the testing machine without any damage to the joint system.

Table 3 Test specimens

Loading Type	Specimen Types	Coarse Aggregate Types	Dowel Bar Diameter	Number of Specimens
Static Test	Preliminary test		3.0 mm	2
	Slab with dowel bars	Crushed Stone	2.5 mm	1
	Slab with dowel bars	Crushed Stone	3.0 mm	1
	Slab with dowel bars	Crushed Stone	4.0 mm	1
	Slab without dowel bars	Crushed Stone	-	1
	Slab without dowel bars	Round Stone	-	1
	Slab with dowel bars	Round Stone	3.0 mm	1
	Total			8

(3) Experimental procedure and Measurement

Table 4 shows test apparatus used in the study. Table 5 shows loading similitude between full-size slab and model specimen. The static test loads are ranged from about 100 to 550 kgf by 100-kgf increments. For each load increment, measurements were obtained with LVDT to determine the relative deflection of the slab surfaces at the joint.

Table 4 Test apparatus

Measurement Kinds		Types	Observation
Tensile Testing Machine		Instron 4483	Tensile Strength of Dowel Bar
Universal Testing Machine		Shimadzu 100ton	Compressive and Flexural Strength of Cylinder Specimen
Fatigue Testing Machine		Instron 1332 20ton	Main Test of Slab Specimen
DATA LOGGER		UCAM-20PC	Data Acquisition
Displacement and Strain Measurement	LVDT	10, 25, 50 mm	Deflection Measurement of Slab
	Ω - Type Gage	5.0 mm	Displacement Measurement of Discontinuous Plane

Table 5 Loading Similitude

Types	Full-Size Slab	1/10 Scale Model
Loading Magnitude	8.2tf Single Axial Load (18kips)	82 kg(0.18 kips)
Loading Area	1300 cm^2(200 in^2)	13 cm^2(2 in^2)
Loading Pressure	6.3 kgf/cm^2 (90 psi)	6.3 kgf/cm^2 (90 psi)

Strain gage(Ω - Type), shown in Fig. 3, was attached at the side of joint in order to measure displacement of discontinuous plane at jointed slab. After the preliminary tests with the representative specimens, loading increment was determined. Fig. 4 shows test loading system adopted for studying.

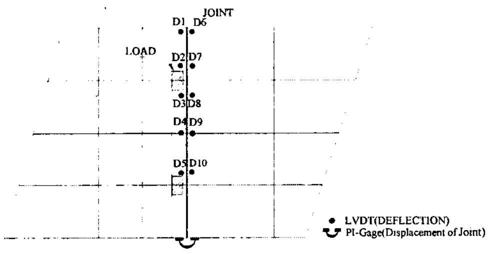

Fig. 3 Plan of test slab and instrumentation

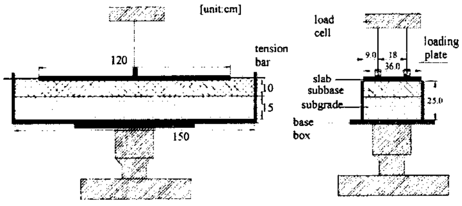

Fig. 4 Loading system

3. Results and Discussions

Transverse cracks may also be initiated by combinations of curling, warping and load-related stresses. The loss of aggregate interlock and deterioration of load transferring device due to opening of these cracks permit increased slab deflections as well as the infiltration of water and intrusion of incompressible material into the cracks. These factors, in turn, lead to pumping and crack deterioration through faulting and spalling. Several formulas for computing load transfer efficiency have been adopted by various researcher. The definition of load transfer efficiency used here are as follows:

$$LT_f = (d_{ul} / d_l) \times 100 \qquad (1)$$

Where,

LT_f: load transfer (%)

d_{ul} : deflection of the unloaded side of the crack joint.

d_l : deflection of the loaded side of the crack or joint.

The test equipment allows placement of slabs in tension before and during testing to simulate thermal and drying shrinkage in the field. Based on the equation (2) proposed by Darter and Barenberg$^{(2)}$, the constants shown in Table 6 were used to control the crack opening width. The widths of joint opening used in the test are ranged from about 0.3 mm to 0.4 mm.

$$\Delta L = CL(a_t \Delta T + \varepsilon) \qquad (2)$$

Where,

ΔL : joint opening

a_t : thermal coefficient

ε : dry shrinkage coefficient of concrete

L : transverse joint spacing

ΔT : temperature change

C : dimensionless empirical adjustment factor caused by slab-base frictional restraint

Table 6 Constant applied for joint opening calculation

Transverse joint spacing (L)	Thermal coefficient (a_t)	Temperature change (ΔT)	Dry shrinkage Coefficient of concrete (ε)	Adjustment factor (C)
600 mm	1.0×10^{-5}/℃	30 ℃	2.5×10^{-4}	0.8

3.1 Displacement of Joint and Load Transfer Efficiency

Transverse contraction joints are constructed in concrete pavements to relieve tensile stresses, and when they are properly spaced transverse crack is controlled by the contraction joints. Contraction joints are most frequently constructed by sawing or forming a narrow groove in the pavement to the depth required to produce a plane-of-weakness. At the plane-of-weakness, restrained contraction forces produce a crack below the groove.

Table 7 and Fig. 5 show the influence of dowel diameter concerning displacement of discontinuous plane at joint and load transverse efficiency. Based on the above results, displacement of discontinuous plane was increased according to the increase of loading. Displacement of discontinuous plane, such as those shown in the table, was decreased as dowel bar diameters(2.5 mm, 3.0 mm, 4.0 mm) were increased. The crack opening of these dowel bar diameters are ranged from 0.05 mm to 0.12 mm, 0.042 mm to 0.069 mm, and 0.029 mm to 0.052 mm, respectively. However, displacements of discontinuous plane were slightly increased when the static test loading was greatly increased.

Table 7 Displacement of discontinuous plane and load transfer efficiency

Loading Steps (kgf)	$D_{2.5}$		$D_{3.0}$		$D_{4.0}$	
	Displacement of Joint (mm)	Load Transfer Efficiency (%)	Displacement of Joint (mm)	Load Transfer Efficiency (%)	Displacement of Joint (mm)	Load Transfer Efficiency (%)
100	-	90.30	-	93.08	0.029	96.87
200	0.050	88.59	0.042	92.70	0.035	95.37
300	0.070	88.31	0.050	92.58	0.038	94.96
350	0.080	88.02	0.056	92.56	0.040	94.73
400	0.090	87.91	0.061	92.13	0.042	95.12
450	0.110	87.55	0.065	92.33	0.044	94.85
500	0.110	86.74	0.069	92.09	0.048	94.59
550	0.120	86.61	-	91.99	0.052	94.38

From the results, it is considered that development of displacement is restrained by bearing forces between concrete and dowel bars. Fig. 6 shows relationship between displacement of discontinuous plane and load transfer efficiency. In the case of 2.5 mm dowel bars, displacement of discontinuous plane was greatly increased compared with 4.0 mm dowel bars. In addition, load transfer efficiency was slightly increased when the dowel bar diameters(2.5 mm, 3.0 mm, 4.0 mm) were increased. Load transfer efficiencies of 2.5, 3.0, and 4.0 mm dowel bars are ranged from 86.61 to 90.30 percent, 91.99 to 93.08 percent, and 94.38 to 96.87 percent, respectively. From the test results, it is considered that bearing stress of 2.5 mm dowel bar is greater than that of the other dowel bars because of the relatively greater displacement of discontinuous plane at joint.

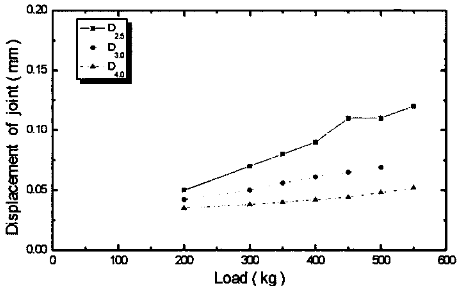

Fig. 5 Relationship between displacement of joint and loading varying dowel bar diameter

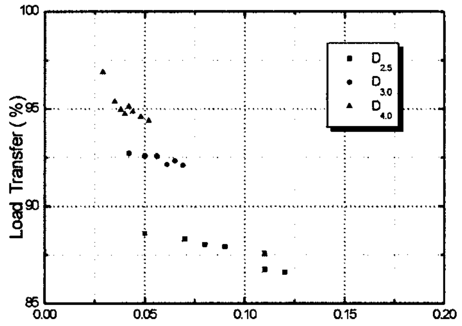

Fig. 6 Relationship between displacement of joint and load transfer efficiency varying dowel bar diameter

Snyder(3) in his analytical studies of dowel reactions has concluded that the maximum bearing stress of the concrete is very sensitive to the dowel bar's diameter, which might be the most sensitive parameter of all. In addition, it has been reported that the smaller diameter can cause a dramatic increase in the maximum stress.

In table 8, and Fig. 7 and 8, displacement of joint-load transfer efficiency is utilized to show the effect of variations in absence or presence of dowel as well as aggregate types(crushed stone, round stone). In the case of slab manufactured by round stone(such as natural gravel), displacement of joint was shown greater than that of crushed stone. In the case of non-dowel, displacement of joint was greatly increased and load transfer efficiency of slab using crushed stone was shown 30 percent greater than that of round stone.

Angular, rough-surfaced aggregates(such as crushed stone) generally provide better interlock and load transfer over narrow crack openings than do round stones, smooth-surfaces aggregates (such as natural gravels). This contention is supported by Colley and Humphrey(4), who contend that concretes made using crushed stone had higher load transfer effectiveness values than those made with natural round gravels.

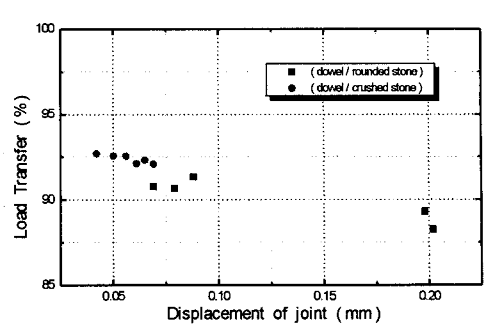

Fig. 7 Relationship between displacement of joint and load transfer efficiency varying aggregate types (In case of slab with dowel bar)

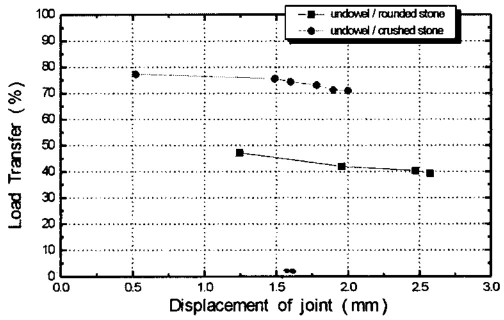

Fig. 8 Relationship between displacement of joint and load transfer efficiency varying aggregate types (In case of slab without dowel bar)

Table 8 Crack opening and load transfer efficiency varying aggregate

Loading Steps (kgf)	Round Stone				Crushed Stone			
	Slab with dowel bar		Slab without dowel bar		Slab with dowel bar		Slab without dowel bar	
	Displacement of Joint (mm)	Load Transfer Efficiency (%)	Displacement of Joint (mm)	Load Transfer Efficiency (%)	Displacement of Joint (mm)	Load Transfer Efficiency (%)	Displacement of Joint (mm)	Load Transfer Efficiency (%)
100	0.046	-	1.243	47.18	-	-	0.521	77.26
200	0.069	90.79	1.955	41.95	0.042	92.70	1.489	75.50
250	0.079	90.67	2.471	40.34	0.048	-	1.598	74.35
300	0.088	91.34	2.573	39.27	0.050	92.58	1.780	73.09
350	0.198	89.30	-	-	0.056	92.56	1.896	71.24
400	0.202	88.27	-	-	0.061	92.13	1.999	70.92
450	-	-	-	-	0.065	92.33	-	-
500	-	-	-	-	0.069	92.09	-	-
550	-	-	-	-	-	91.99	-	-

3.2 Dowel Bar Diameter and Load Transfer efficiency

Fig. 9 shows relationship between static test load and load transfer efficiency as the dowel bar's diameter was varied. In this figure, it can be seen that load transfer efficiencies are decreased with increasing static test load. It is also shown that load transfer efficiency of 2.5 mm dowel is decreased relatively higher compared with these of the other dowel bars.

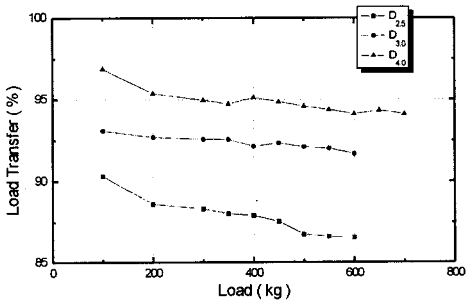

Fig. 9 Relationship between dowel bar diameter and load transfer efficiency (at midlength of jointed slab)

3.3 Relation Displacement of Joint and Joint Opening

Fig. 10 shows relationship between load transfer efficiency and crack opening in the case of slab without dowel. In this study, if there is no crack opening, load transfer efficiency would be 100 percent. These data were plotted by the third poly regression on the above supposition in order to indirectly compare with Colley's study$^{(4,5)}$ which reported relationship between the joint opening and load transfer efficiency in the field test. When the displacement is smaller than 1.0 mm, it is shown that the load transfer efficiency of field test is higher than that of laboratory test. After the 1.0 mm displacement, load transfer efficiency of crushed stone in the laboratory was not greatly decreased to the constant level. In whole aspects, it is considered that the results of the slab using the round stone without a dowel bar is similar to the field test result. The loss of load transfer efficiency, in this study, of the displacement of discontinuous plane ranged from 0.5 mm to 1.0 mm was presented 20 percent greater than that of the field test. At the load transfer efficiency of 75 percent, which is known as pumping and faulting are prevented from the transverse joint, displacements of jointed slab using the round and crushed stone are shown 0.4 mm, and 0.75 mm, respectively. However, joint opening of field test was 1.0 mm. Fig. 11 shows relationship between load transfer efficiency and

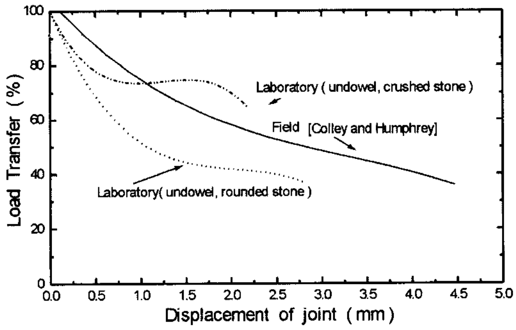

Fig. 10 Relationships between load transfer efficiency and displacement of jointed slab without dowel bar

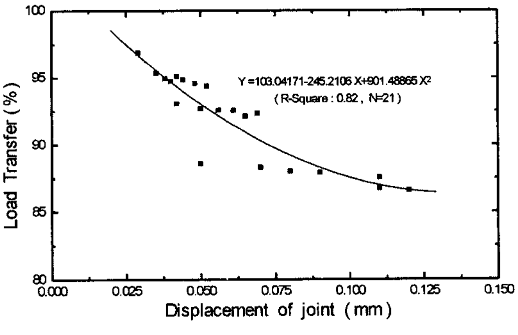

Fig. 11 Relationships between load transfer efficiency and displacement of jointed slab with dowel bar

displacement of joint in the case of slab with dowel bar. From this figure, It can be recognized that load transfer efficiency of slab without dowel bar was greatly decreased with the increase of displacement in comparison with Fig. 10.

4. Conclusions

To analyze the behavior of concrete pavement at joint subject to static test load, the test was conducted on 1/10 scale model in the laboratory. The test results are given below.

(1) The displacement of discontinuous plane at jointed slab was increased according to the increase of loading. However, it was decreased as dowel bars' diameter(2.5 mm, 3.0 mm, 4.0 mm) was increased. These values of displacement were ranged from 0.05 mm to 0.12 mm, 0.042 mm to 0.069 mm, 0.029 mm to 0.052 mm, respectively. From these results, it is considered that development of displacement at jointed slab is restrained by bearing forces between concrete and dowel bar. It means that concrete bearing stress is diminished in accordance with the increment of dowel bar diameter.

(2) In the case of slab without dowel bar, displacement of joint was greatly increased. The load transfer efficiency of slab using crushed stone was 30 percent greater than that of round stone. In addition, load transfer efficiency of slabs which were made using crushed and round stone without dowel bar, was decreased to 20 percent, and 30 percent, respectively, when the slabs were compared with slabs made using dowel bar.

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