JOINT MOVEMENT AND LOAD TRANSFER CHARACTERISTICS OF CONCRETE OVERLAY

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Abstract : A test section of concrete overlay was constructed and monitored for one year to evaluate the feasibility as the rehabilitation alternatives for deteriorated concrete pavements in Korea. The test section included both Bonded Concrete Overlay (BCO) and Unbonded Concrete Overlay (UBCO). During one year after construction, joint movement (variation of crack width at joints) and load transfer characteristics have been monitored at various temperature conditions. Findings and recommendations can be summarized as follow: BCO showed much less joint movement than UBCO. Cracks occurred within a couple of days after construction showed significantly larger width than those occurred later. For UBCO, undoweled section showed much lower load transfer efficiency than doweled section, especially at the low temperatures. Load transfer efficiency is better correlated with the concrete temperature under the joint than with the surface temperature. A temperature correction procedure for standardizing the measured load transfer efficiency is proposed.

Key Word: concrete overlay, load transfer, crack width, dowel bar, slab temperature

1. INTRODUCTION

In many cases, distresses in concrete pavements initiate from their joints since the continuities of the slabs are lost or at least inadequate at the joints. Sufficient load transfer is one of the key factors for ensuring satisfactory performance of the joints. Excessive deflections due to the loss of load transfer result in failures such as pumping, faulting and cracking.

Effective load transfer can be achieved by installation of dowel bars or by aggregate interlocking at the joints. It is believed that the crack width under joint is one of the major factors for the aggregate interlocking. The crack width variations (hereafter joint movements) and the load transfer efficiency (LTE) at joints for various temperature conditions are investigated in this study through the monitoring of the test section of concrete overlays.

Temperature condition at the time of LTE measurement is an important factor for the interpretation of the measurement results since the crack width at the joint varies with temperature. LTE of the old concrete is one of the input parameters for the design of bonded concrete overlay.

According to the AASHTO overlay design guide (AASHTO, 1993), the measurement of LTE may be performed at any temperature condition only if the temperature is lower than 80 °F (26.7 °C). Since, however, the LTE may vary with the slab temperature even in the temperatures lower than 26.7 °C, there should be a certain type of temperature correction to the measurements to standardize the results.

In this study following subjects were studied through a trial construction of concrete overlay test section;

- joint movement of concrete overlays due to the drying shrinkage and the variation of slab temperatures,
- effectiveness of dowel bar on the load transfer,

- effect of slab temperature on LTE, and
- temperature correction procedure for standardizing the measured LTE

Although the findings of this study are obtained from a monitoring of concrete overlays, many of the findings can also be applied to newly constructed concrete pavements.

2. TEST SECTION

In order to evaluate the feasibility of constructing concrete overlays in Korea, a test section was constructed and monitored for one year. The test section included 2-lane, 290-m section on the 88 Express Highway(13 years old) in Korea. Overlay types included both Bonded Concrete Overlay (BCO) and Unbonded Concrete Overlay (UBCO).

The existing pavement structure of the test section consists of a 29-cm selected material layer and a 20-cm granular subbase under 30-cm concrete slab as shown in Figure 1. The joints were doweled and spaced at every 5 m. The major distresses were cracking and local settlements. For the BCO section, most of the distresses had been repaired before overlay.

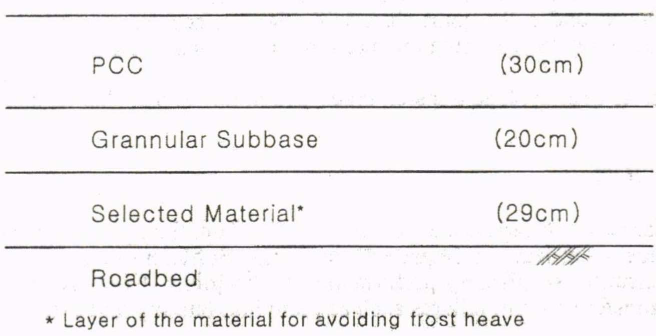


Figure 1. Existing pavement structure of the test section

Overlay thickness was designed in accordance with AASHTO pavement structural design guide (AASHTO, 1993). Designed thickness was 10 cm for BCO and 25 cm for UBCO. A 6-cm BCO section was also constructed, but not discussed in this paper. The UBCO section had both doweled and undoweled joints for comparison. The length of a unit section was 60 m and the transient area between the unit sections had 0.5% longitudinal gradient to smooth the thickness differences. Figure 2 shows the layout of the test section.

Construction conformed to the AASHTO specification (AASHTO, 1990). Overlay concrete was placed on Oct. 16, 1996 after required surface treatments. High early-strength slag cement was used to minimize the time of traffic closure. The compressive strengths of the concrete at 3, 7, and 28 days were 236, 368, and 536 kg/cm^2, respectively. Traffic was opened 4 days after the concrete placement.

For the BCO section, all transverse joints were sawed in the overlay directly over the existing joints and joints formed by full-depth repair made during the pre-overlay repair procedures. The depth of saw cut was 1 to 2 cm greater than the design thickness of the overlay concrete. For the UBCO section, on the other hand, all transverse joints were mismatched with the existing joints. The saw depth were 1/3 of the overlay thickness. Joint spacing was 5 m for both BCO and UBCO.

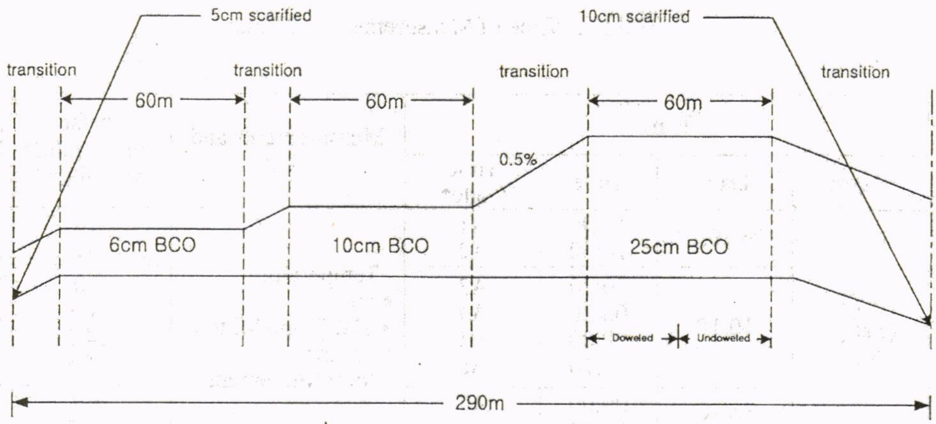


Figure 2. Layout of the test section

3. DATA COLLECTION

Various measurements were performed on the test section including temperatures (both slab and air), joint movements, and LTE at joints. Time of measurements is listed in Table1.

3.1 Joint Movements

In order to investigate the early-age joint behavior and joint movement patterns for different overlay types, the joint movements for all the transverse joints were monitored. The term 'joint movement' in this paper means the variation of the crack width under the joint due to drying shrinkage and temperature variation. Joint movements were measured using a mechanistic strain gauge as shown in Figure 3. Possible lateral movements by slab warping due to the temperature gradients were ignored in the analysis.

3.2 Load Transfer Efficiency(LTE)

LTEs were tested using Falling Weight Deflectometer (FWD) at the transverse joints of the overlays and old concrete near the test section at various seasons listed in Table 1. The basic purpose of the measurements was to investigate the relationship between slab temperature and LTE.

The measurements were performed according to the procedure recommended by AASHTO(1993). The load plate was placed on one side of the joint with the edge of the plate touching the joint (Figure 4). The deflections at the center of the load plate and at 12 inches (30 cm) form the center were measured. The LTE is computed from the following equation (AASHTO, 1993).

$$LTE = 100 \times (D_{ul} / D_l) \times B \qquad (1)$$

where,

LTE = load transfer efficiency,
D_{ul} = unload side deflection,
D_l = loaded side deflection, and
B = slab bending correction factor.

Table 1. Time of Measurement and Tests

Time				Measurements and Test	Surface Temperature of Slab(°C)
Season	Date	Time	Time Code*		
Fall (Early-Age)	'96.10.17	13:00	A1	- Temperature • air • slab(Top, Middle, Bottom) - Joint Movement	18
		18:00	A2		11.8
	10.18	00:20	A3		10
		06:20	A4		8.9
		09:00	A5		14.2
		14:10	A6		16.8
	10.19	06:00	A7		8.2
		15:50	A8		17.7
Winter	11.22	10:25	B1	- Slab Temperature (Surface) - Joint movements - LTE	-
		15;00	B2		-
Summer	'97. 7. 8	15:20	C1		24
		21:55	C2		20
	7.10	10:00	C3		22
		13:40	C4		37
Fall	10.16	10:15	D1		19
		14:00	D2		27
		20:30	D3		11
	10.17	06:00	D4		7

* See Figures 5 and 6

4. RESULTS AND FINDINGS

4.1 Joint Movement Patterns

The purpose of analyzing the joint movement patterns was to investigate the variation pattern of crack width at joints for different overlay types. The analysis results also gave valuable information to the analysis of LTE. Figures 5 and 6 show the joint movement patterns for 10-cm BCO and 25-cm UBCO sections, respectively. The times of the measurements in the Figures are listed in Table 1. The positive values(+) of the joint movement in the Figures represent the opening of the cracks at joins, and the negative values(-) represent the closeness of the cracks. Findings form the Figures can be summarized as follow:

- The general range of the joint movement was much smaller in BCO (-1.5 to +1.2 mm) than in UBCO (0 to +8.0 mm). This can be explained by that the joint movements in BCO is totally depend upon those of old concrete and that there is no drying shrinkage in the old concrete. On the other hand, in UBCO, drying shrinkage of the newly overlaid concrete widened the cracks at the joints. In addition, there were significant variations in joint movement in UBCO sections compared to BCO sections. This can be explained as follows. For the UBCO sections, crack widths at joints vary with the time of crack occurrence. Early-age cracks are much wider than the cracks occurred later. Therefore crack width in the UBCO sections have larger variations. For the BCO sections, on the other hand, joint movements are totally depend upon the movements of old concrete which are relatively small since the location of joint saw cut is exactly the same as the old concrete(Figure 9).

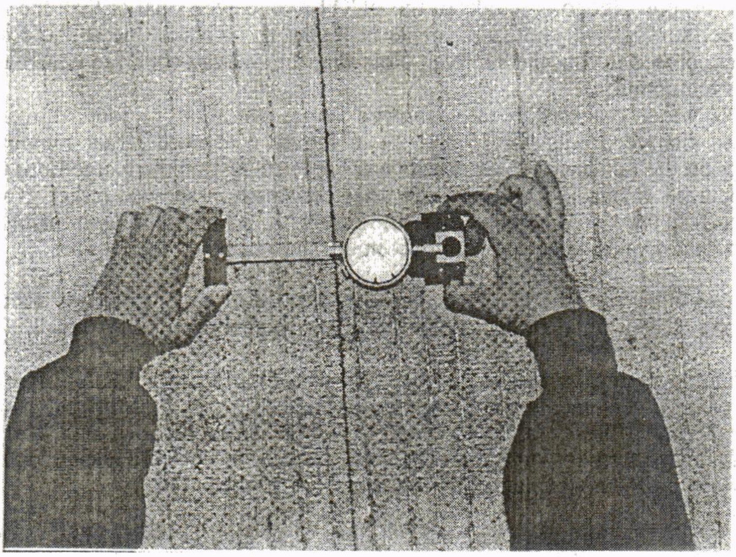


Figure 3. Mechanical Strain Gauge for measuring joint movement

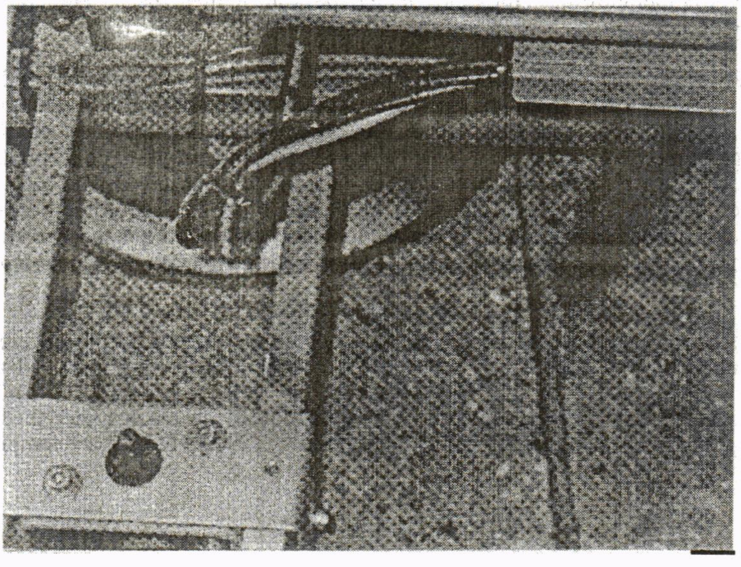


Figure 4. LTE test using FWD

- During the summer, the joint widths of the BCO became even smaller than the initial joint width. Note the negative joint movements in Figure 5. This is due to the cracks in the old concrete closed during the summer. Note that the overlay concrete was placed in fall (at a lower temperature).
- For UBCO wider cracks generally showed larger variation in joint movement with temperature change. Joints 45, 35 and 39 in Figure 6 showed larger movements than others. During the fall survey these cracks were opened beyond the gauge limit (10 mm).
- Cracks occurred within a couple of days after construction showed larger in width than those occurred later. That is shown in Figure 7, which is drawn using the joint movement data. Cracks occurred within 24 hours showed larger than 4 mm.

It is inferred carefully from the first three findings that BCO could give less damage to the joint sealant than UBCO since the range of the joint movement is relatively small.

For the last finding, a similar results had been observed earlier in a CRCP (Continuously Reinforced Concrete Pavement) test section constructed in Texas (Suh and McCullough, 1994). Figure 8 shows the Texas experience, in which the cracks occurred within 3 days showed significantly larger in width than those occurred later. Possible reason for the greater width of early-age cracks are explained by Suh and McCullough (1994).

Wide cracks, even though they are under joints, can give a detrimental effect to the performance of the joints. Therefore it is recommended that the time of crack occurrence be delayed as late as possible by controlling the time of concrete placement, temperature of the concrete mixture, and so on.

4.2 Location of Reference Temperature of LTE Measurements

LTE varies with the time of measurement, because the crack width under joint varies with the slab temperature even at the same joint. In the strict sense of the word, the slab temperature is the concrete temperature near the crack under the joint (called 'basic temperature' in this paper) as shown in Figure 9.

Figure 10 shows a comparison of LTE distribution for the surface temperature and the 'basic temperature'. Theoretically, LTE for the joint should have the similar value when it is measured at a similar temperature condition. In other words, the same LTE can be resulted from the same temperature condition. When the surface temperature is concerned, however, almost same LTEs were obtained even in largely different temperature conditions as shown in Figure 10(a). Data A and B (or C and D) in Figure 10(a) showed similar LTE. But the difference in the surface temperature was large (12 °C). On the other hand, the similar LTEs can be expected if they are measured in the same 'basic temperatures' as shown in Figure 10(b).

The big difference of data A and B in LTEs can not be interpreted by the difference in the surface temperature (Figure 10(a)) while they are well differentiated in Figure 10(b).

Therefore it can be said that the concrete temperature near the crack under the joint(basic temperature) gives better consistency in correlation with LTE than the surface temperature.

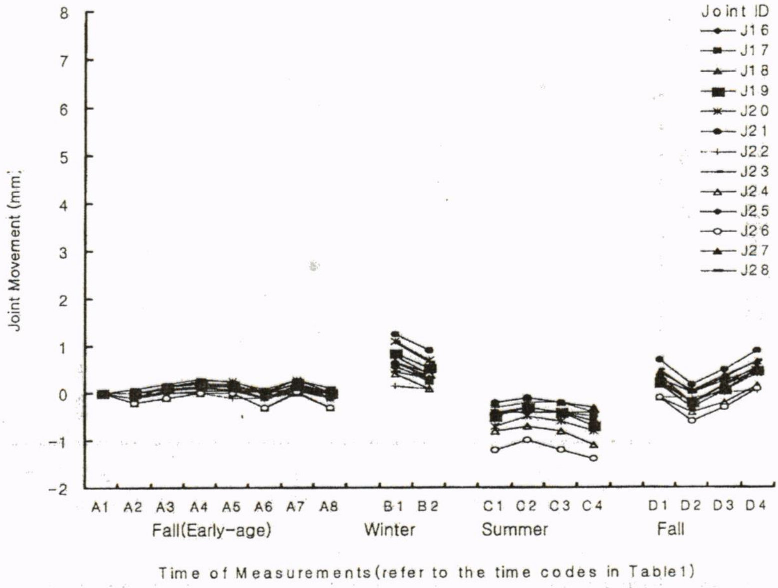
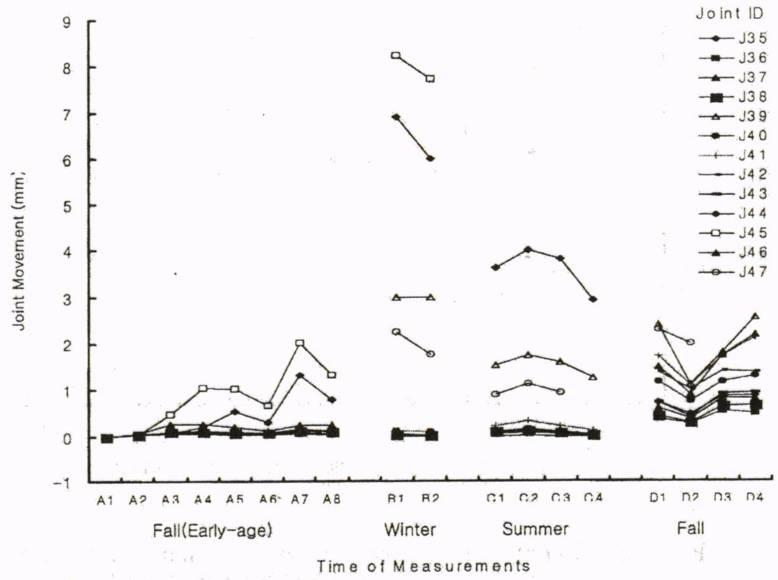


Figure 5. Joint movement patterns for 10Cm BCO section



* Cracks were opened beyond the gauge limit for the following cases :
J45 measurements at C1, C2, C3, C4 surveys, J35, J45 measurements at D1, D2, D3, D4 surveys ;
J47 measurement at D3, D4 surveys.

Figuer 6. Joint movement patterns for 25Cm UBCO section

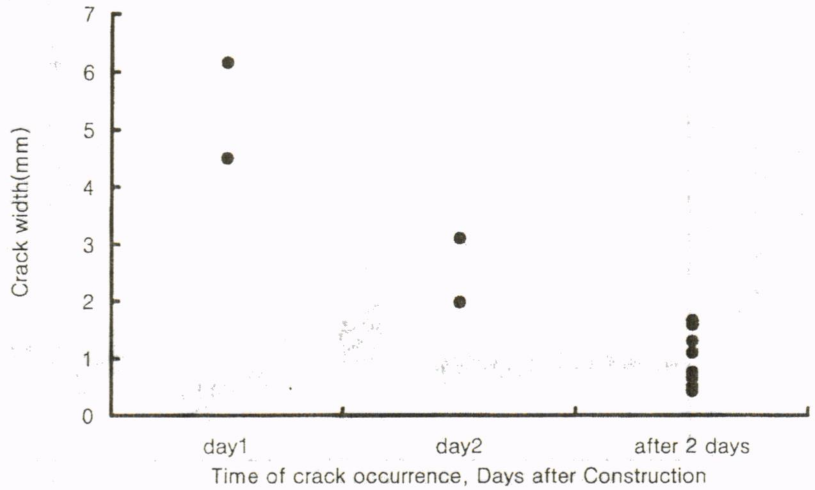


Figure 7. Effect of the time of crack occurrence on the crack width (this study)

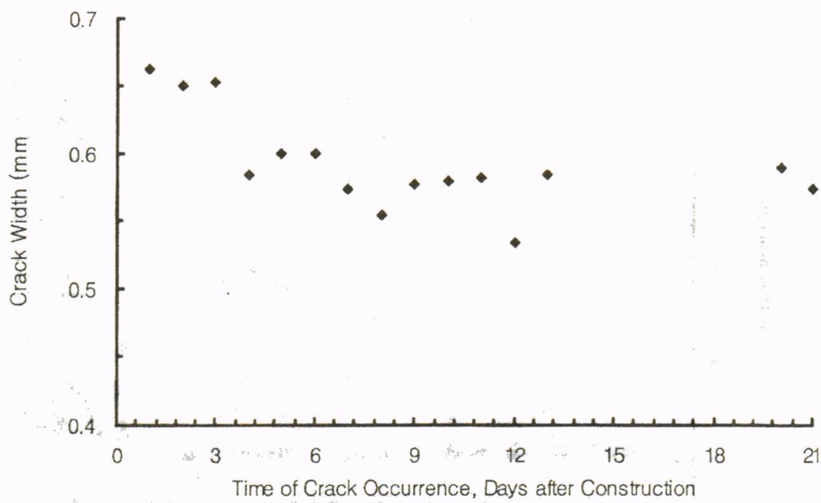


Figure 8. Effect of the time of crack occurrence on the crack width
(Texas experience, Suh and McCullough (1994))

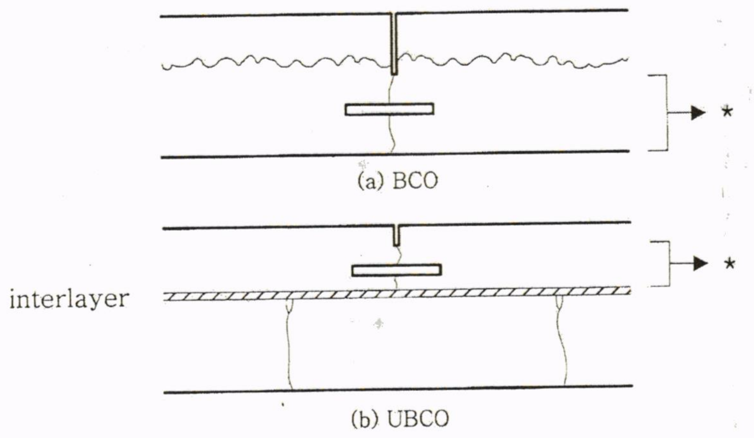


Figure 9. Location of the basic temperature for LTE analysis

4.3 Effect of Dowel Bars on LTE

For UBCO, the use of dowel bar played an important role of ensuring good lead transfer especially when the slab temperature was low (wide crack). Figure 11 shows the LTE pattern for doweled and undoweled UBCO. It can be seen, in the undoweled section, that the LTE decreased drastically with temperature drop.

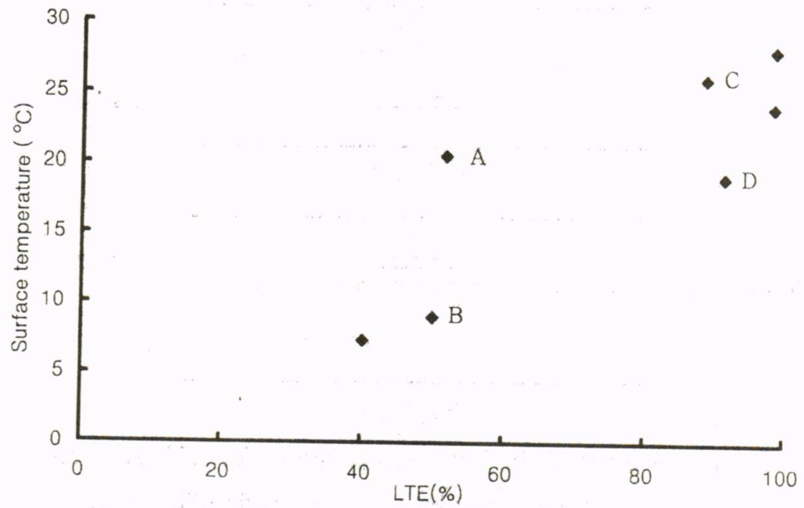
Adequate load transfer was provided when the temperature was high for both doweled and undoweled sections because all the cracks were tight. Since, however, load transfer of undoweled joints totally relied on the aggregate interlocking, when the cracks under the joints were wide, they loosed the load transfer capability. On the other hand, for doweled joint, a certain level of load transfer could be provided by dowel bars even when the cracks were wide.

4.4 Sensitivity of Temperature to LTE for Old Concrete

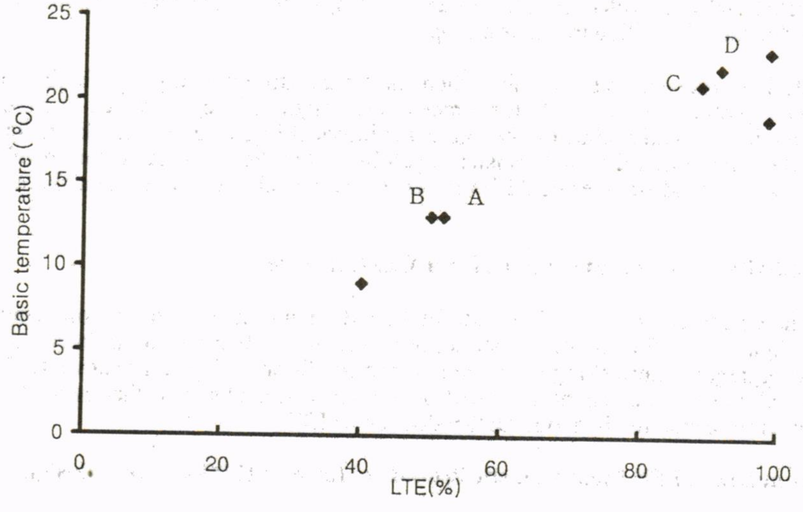
For the new concrete, if it was doweled, the LTE did not drop even in the low temperature as seen in Figure 11. For the old concrete, however, the LTE might drop, because the dowel bars and aggregate interlocking might be in loose condition. Figure 12 shows LTE pattern of 13-year old concrete pavement near the test section. It was observed that every 1 °C drop in slab temperature resulted in about 2.6% reduction in LTE.

4.5 Recommened LTE Measurement Procedure for AASHTO Overlay Design

According to the AASHTO overlay design guide(AASHTO, 1993), the measurement of LTE may be performed at any temperature lower than 80 °F (26.7 °C). Considering that the LTE does vary with temperature condition, even in lower than 80°F, it is recommended that the LTE measurement procedure of the AASHTO overlay design guide be revised as follows. Firstly, develop a standard model for the relationship between the slab temperature ('basic temperature') and LTE as shown in Figure 12. Secondly, select a standard temperature for the design LTE. Then, measure LTE and the surface temperature of the concrete during 6:00~8:00 p.m. Assuming that the surface temperature is the same as the 'basic temperature' during this time, the design LTE can be determined from the slope of the standard model using the measured LTE and the surface temperature.



(a) LTE distribution for the surface temperature



(b) LTE distribution for the 'basic temperature'

Figure10. Comparison of LTE distribution for the surface temperature and the 'basic temperature'

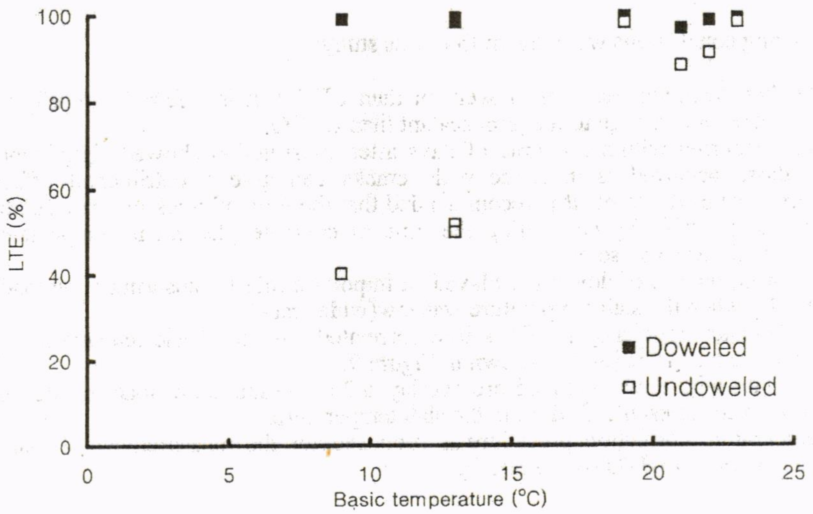


Figure 11. LTE pattern for doweled and undoweled UBCO

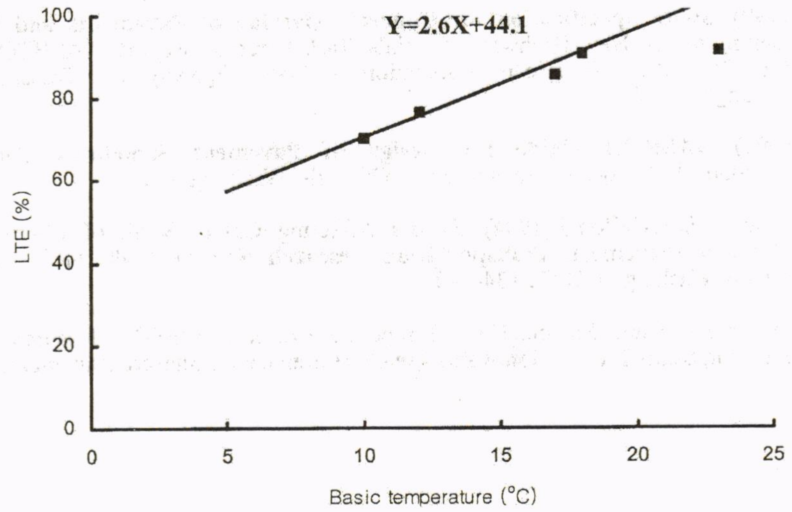


Figure12. LTE pattern of old concrete near the test section (doweled)

5. CONCLUSIONS

The following conclusions were drawn from this study:

- BCO showed much less joint movement than UBCO. It is inferred carefully that BCO could make less damage to the joint sealant than UBCO.
- Cracks occurred within a couple of days after construction showed significantly wider than those occurred later. Since wide cracks can give a detrimental effect to the performance of the joints it is recommended that the time of crack occurrence be delayed as late as possible by controlling the time of concrete placement, temperature of the concrete mixture, and so on.
- For UBCO, the use of dowel bar played an important role for ensuring good load transfer especially when the slab temperature was low(wide crack).
- Load Transfer Efficiency (LTE) is best correlated with the basic temperature (concrete temperature under the joint as shown in Figure 9).
- In old slabs with dowel bars, before overlay, a 2.6% reduction of load transfer efficiency was observed for each 1 ℃ drop in the slab temperature.
- A temperature correction procedure is proposed for the measurement of load transfer efficiency for AASHTO overlay design.

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