

EFFECT OF TEMPERATURE GRADIENT IN CONCRETE SLAB ON BACKCALCULATED MODULI

Shigeo Higashi, Institute of Construction Technology, Japan

Kunihito Matsui, Civil Engineering, College of Science and Engineering,

Tokyo Denki University Hatoyama, Japan,

Tatsuo Nishizawa, Civil Engineering, Ishikawa National College of Technology, Japan

INTRODUCTION

In recent years FWDs(Falling Weight Deflectometer) have come into frequent use in Japan for structural evaluation of pavement. Twenty FWDs are in service in academic, public and private sectors. They are superior to past measuring devices in quick and accurate measurement and good reproducibility of data. Due to renewed awareness of its durability, use of concrete pavement is increasing. Thus increased use of FWDs on concrete pavement is anticipated.

In contrast to asphalt pavement, concrete pavement possesses distinctive structural and topological features such as joints, corners, cracking, curling and possible void under the pavement. It is natural that these features affect measured results. Since FWDs make structural evaluation from measured surface deflections; the effect of these features on the evaluation is expected to be significant. Focusing on curling deformation of concrete pavement, FWD tests were conducted at the center and the corner of a pavement slab every two hours for 24 hours. Using the test data, the effect of temperature gradient in pavement on surface deflections and of backcalculated layer moduli is investigated in this paper.

DESCRIPTION OF TEST

Fig.1 shows the test pit for concrete pavement constructed in December 1994 at the yard in the Machinery Center, Kajima Road Co. Ltd. Since then, FWD tests have been conducted regularly. One cycle of tests composed of FWD tests conducted every two hours for 24 hours with a peak load of 98kN. Temperature in concrete is measured by thermocouples placed in the pavement. The FWD used here is manufactured by KUAB Co. The specification is given in Table 1 and Fig. 2.

MEASURED DEFLECTIONS

Daily Variation of Deflections

Concrete pavement undergoes curling due to nonlinear temperature distribution in the body of a pavement slab. If curling deformation becomes large, a part of the slab uplifts and loses contact with the base course, which results in a loss of base support. Concrete pavement decreases in stiffness and undergoes larger deflections than it does when the slab and the base course have good contact under the same magnitude of load. As an example of test data, a set of deflections measured at the center of the slab over a period of 24 hours on August 9th and 10th 1995 is presented in Fig.3.

The upper figure in Fig.3 illustrates change of temperature at various depths of the slab along with change of air temperature and the lower figure shows change of deflection at various locations from the center of the loading plate at the center of the pavement. The test was conducted in August.

Surface temperature of the concrete rose to 50 °C at 2 p.m. and the difference between top and bottom temperatures reached 16.9 °C. Deflections became largest at 2 p.m. Deflections through the night showed little change. Thus, deflection readings on concrete pavement undergo large change during the day owing to the temperature difference. Fig.4 describes the surface deflections measured at the center and corner of the slab on August 25th and 26th 1995. The deflections loaded at the center are the largest and those loaded at the corner are the smallest at 2 p.m. It may be concluded that this opposite trend is caused by curling of the slab.

Possible Cause of Change in Deflection

Deflections of concrete slabs vary with changes in temperature of the slab and with air temperature. Because it is expected that this variation is attributable to the temperature difference between the top and the bottom of the slab, the relationship between the temperature difference and surface deflections is examined.

Temperature gradient and deflections (D0 - D200)

Fig.5 shows test results conducted in May 1995 in which the air temperature difference was large. Temperature gradient is defined as,

$$\text{Temperature gradient (}^{\circ}\text{C /cm)} = [\text{Temperature at the top of slab (}^{\circ}\text{C)} - \text{Temperature at the bottom of slab (}^{\circ}\text{C)}] / \text{Slab thickness (cm)} \quad (1)$$

From Fig.5, the following observations are made:

1. A linear relationship exists between temperature difference and the surface deflections.
2. The relationship between the deflection at each measuring point and the temperature difference is approximately parallel to each other; however a little smaller effect of temperature gradient is observed on the deflection at the measuring points away from the loaded point.

Temperature gradient, average slab temperature and deflection at D0

Using the test data measured from December 1994 to August 1995 totaling 71 sets of data, temperature gradient and deflection D0 is plotted in Fig. 6. As the temperature gradient increases, the deflection at D0 also becomes larger based on the data taken over 24 hours. Because the temperature gradient mainly arises from the air temperature change during the day, it is not possible to determine the difference in deflection readings due to seasonal change. Assuming seasonal change is represented by average temperature in the slab, deflections at D0 and the corresponding average slab temperature are plotted in Fig.7. This figure expresses the increase in deflections as average slab temperature rises. Therefore, it is found that the deflection also varies with season.

From the above, it becomes clear that the combined effect of temperature gradient change in a day and seasonal change expressed by average temperature affects the deflection of the concrete slab. In order to express this relationship, a linear multi-regression analysis is made by selecting deflections at D0 as dependent variables and both temperature gradient and average slab temperature as independent variables. The following equation is obtained.

$$\text{Deflection at D0} = 186.24 + 0.857 \times \text{average slab temperature} + 77.9 \times \text{temperature gradient} \quad (2)$$

The correlation coefficient of the above equation is 0.904. Thus it is found that high correlation exists among deflections at D0, temperature gradient and average slab temperature.

This result is given in the form of a nomograph in Fig. 8. This figure shows that the deflection at D0 increases as temperature gradient increases and a slab warps upward. Deflection at D0 in summer is greater than that in winter by 35 μm , which shows the effect of average slab temperature on curling deformation of the slab. During the summer, constraint on both edges induces compression force in a longitudinal direction and increases the curling. However, since this concrete slab is a single slab constructed at the test pit, it might behave differently from actual concrete pavement in which multiple concrete slabs restrain each other from deforming. For this reason, it is important to collect FWD test data on a concrete pavement road.

BACKCALCULATION

Methodology

Static backcalculation is commonly practiced in Japan. Layer moduli are estimated such that computed deflections show good agreement with measured ones assuming peak load as static load and using peak deflection at each sensor. Static backcalculation is also adopted in this paper. Although dynamic backcalculation may be more suitable because of the nature of the test, since it is still under development, it will be presented in the near future.

Basic concept

One of the common methods for backcalculating layer moduli from surface deflections is the Gauss-Newton method. Uzan *et al* proposed a kind of pattern search that determines ratios of upper layer moduli over subgrade modulus followed by estimation of layer subgrade modulus. In this paper the Gauss-Newton method with layer modulus ratios based on Uzan's concept and a two-level backcalculation called the modified Gauss-Newton method has been developed. Since the modulus ratios are determined using the Gauss-Newton method, one can reduce the number of unknowns by one. This reduction significantly improves computational efficiency and stability.

Modified Gauss-Newton method

The concept of least square gives the following objective function,

$$J = \sum_{i=1}^N (u_i - z_i)^2 \quad (3)$$

where u_i is measured deflection at the location i and z_i is the corresponding calculated deflection. According to Uzan *et al* calculated deflection can be expressed as,

$$z_i = \frac{p a}{E_{sg}} f_i(\mathbf{C}), \quad C_k = \frac{E_k}{E_{sg}}, \quad \mathbf{C} = \{C_k\}, \quad (k=1, \dots, M-1) \quad (4)$$

where p = pressure, a = radius of contact area, E_{sg} = subgrade modulus of elasticity and M is the number of layers. f_i is normalized deflection at i . Once $\mathbf{C}$ is given, E_{sg} can be obtained by minimizing Eq.(3) as,

$$E_{sg} = \frac{p a \sum_{i=1}^N f_i^2}{\sum_{i=1}^N u_i f_i} \quad (5)$$

Assuming E_{sg} is known, application of the Gauss-Newton method results in the following update formula for $\mathbf{C}$,

$$\frac{p a}{E_{sg}} \sum_{k=1}^{M-1} \left(\sum_{i=1}^N \frac{\partial f_i}{\partial C_j} \frac{\partial f_i}{\partial C_k} \right) \Delta C_k = \sum_{i=1}^N \left(u_i - \frac{p a}{E_{sg}} f_i \right) \left(\frac{\partial f_i}{\partial C_j} \right) \quad (6)$$

This approach can reduce the number of unknowns by one.

Results of Backcalculation

Backcalculation has been conducted to estimate layer moduli of concrete pavement composed of three layers shown in Fig.9 using the data measured on January 18th and 19th, 1995 and on August 9th and 10th, 1995. The results are presented in Fig.10. However the figure does not manifest the apparent trend of layer moduli change which is expected from the change in

temperature profile of concrete during the days. The most likely reason is because of measurement error which has a significant effect on estimated layer moduli.

Thus, the layer moduli are backcalculated by keeping the layer modulus of concrete fixed as 29.4Gpa, because the concrete modulus is least likely to be affected by temperature distribution in concrete. Fig.11 illustrates the change of backcalculated moduli over a 24 hour period in winter and summer. Fig. 12 shows the relationship of temperature difference between upper and lower surfaces and the modulus of the base course. The subgrade modulus remains little changed over a 24 hour period both in summer and winter. The difference between the moduli in summer and in winter is also small. However the variation of the base course over 24 hour period is quite significant. This figure shows that the modulus of the base course tends to reduce when the temperature difference increases. The smaller estimate of the base course moduli during the day may be due to a gap caused by curling deformation of the concrete slab results in the loss of bearing capacity of the base course. From the backcalculation results, curling of the concrete is confirmed.

SUMMARY

From the foregoing investigation the following conclusions are drawn:

1. Concerning deflections measured by FWD, the following are established.
 - (a) Deflection at the center of a concrete slab becomes larger during the day and smaller at night. Whereas, the corner of the slab shows the opposite trend and the deflection at the corner is smaller during the day and larger at night.
 - (b) Deflection at D0 demonstrates a nearly linear relationship with the temperature gradient in the slab. The greater the temperature gradient becomes, the larger the deflection becomes.
 - (c) Deflection at D0 increases as the average temperature in the slab becomes higher.
 - (d) Considering the observations made in (b) and (c), Multi-regression analysis was conducted to find the relationship among D0 deflection, temperature gradient and average temperature in the slab, and
2. Backcalculation results show that the modulus of the base course is smaller during the day and larger at night. This confirms the curling of the concrete slab.

CONCLUSIONS

From FWD tests conducted every two hours for 24 hours at the same location (the center and the corner) of concrete pavement, it is confirmed that curling deformation significantly affects structural evaluation of the pavement. When FWD is employed for the evaluation of concrete slabs, the test requires careful consideration of 1) where data is taken on the slab, 2) the time of day of the test and 3) development of analysis technique that takes curling deformation into consideration.

REFERENCE

Uzan, J., Lytton, R.L. and Germann, F.P.(1989): General procedure for backcalculating layer moduli, Nondestructive Testing of Pavements and Backcalculation of Moduli (Ed. by A.I. Bush and B.Y. Baladi), ASTM STP 1026, pp.217-244.

LIST OF TABLE(S)

Table-1 Specification of FWD used (KUAB system)

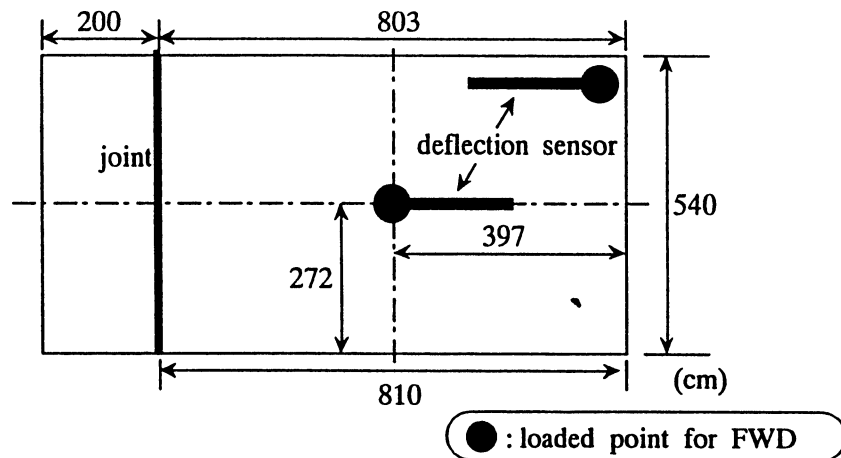
Table-1 Specification of FWD used (KUAB system)

ITEM	SPECIFICATION
load application	two-mass system
impulsive force	24.5, 49, 78.4, 98kN (98kN used in this study)
loading plate	diameter 300mm (devided into 4 parts)
deflection sensor position	0, 20, 30, 45, 60, 75, 90, 120, 150, 200cm from the center of loading plate (10 in all)
collected data	load deflection of each sensor, air and surface temperature, mesured time

LIST OF FIGURES

- Figure 1 Illustration of concrete pavement for testing
 Figure 2 Illustration of FWD profiles
 Figure 3 Changes in the temperature and deflection over a day
 (at the center of the slab)
 Figure 4 Comparison of the deflection data at the center and at the corner of the slab
 Figure 5 Relationship between temperature gradient and each deflection
 Figure 6 Relationship between temperature gradient and D0 deflection
 Figure 7 Relationship between average temperature and D0 deflection
 Figure 8 Nomograph representing interrelations among temperature of the slab, temperature gradient and D0 deflection
 Figure 9 Pavement model for backcalculation

plane view



sectional view

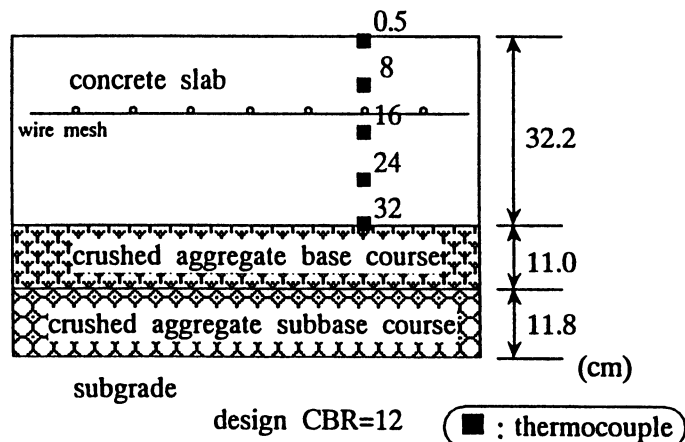


Figure-1 Illustration of concrete pavement for testing

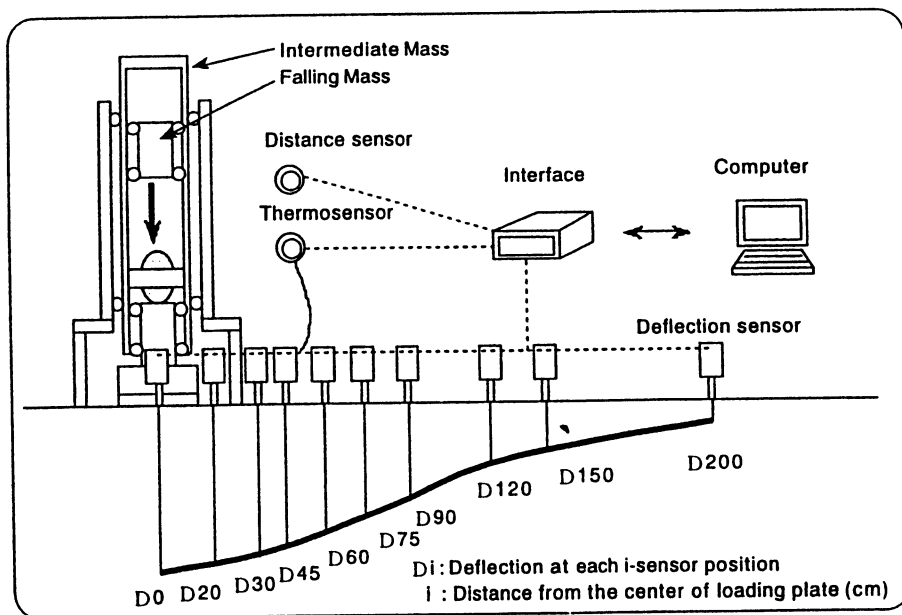


Figure-2 Illustration of FWD profiles

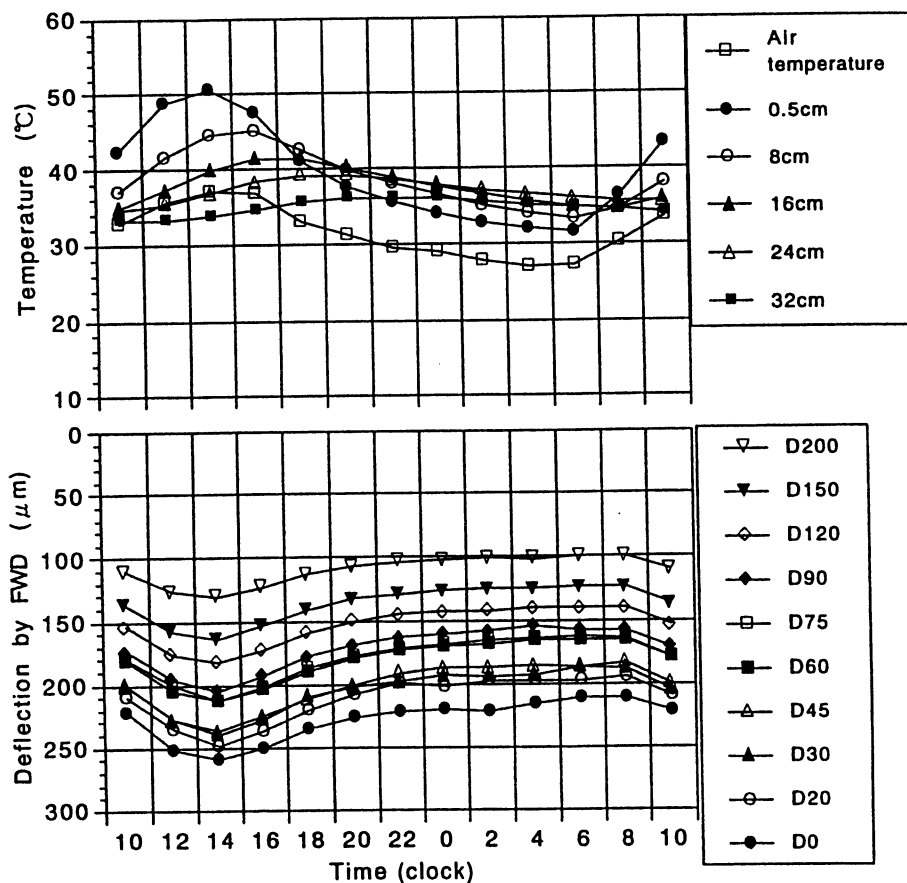


Figure-3 Changes in the temperature and deflection over a day
(at the center of the slab)

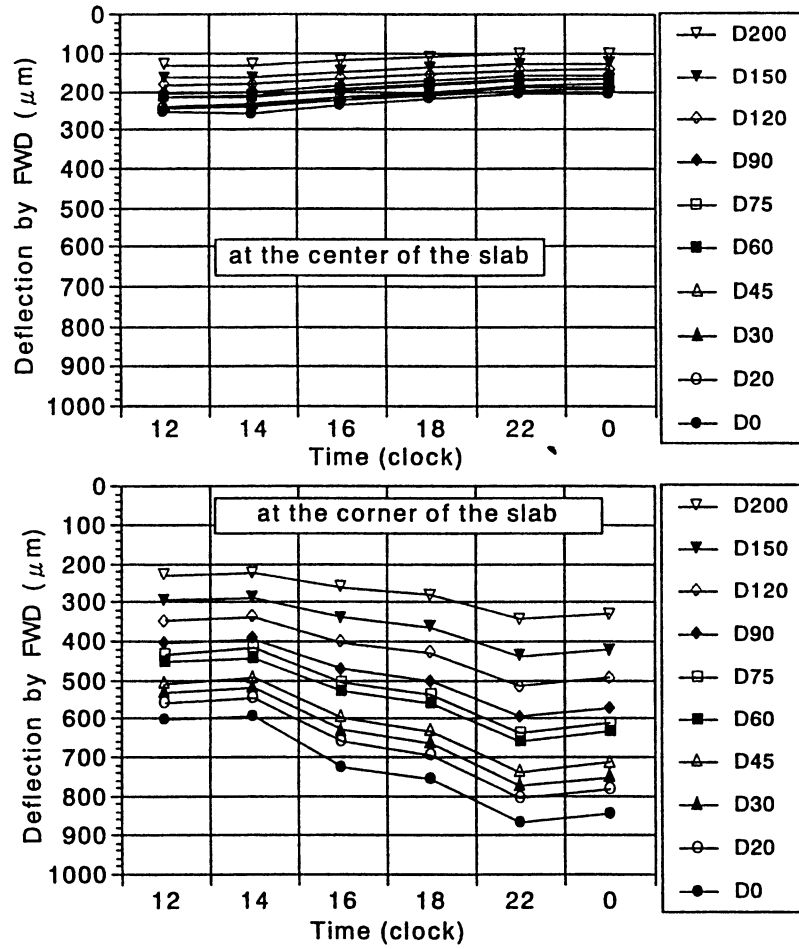


Figure-4 Comparison of the deflection data at the center and at the corner of the slab

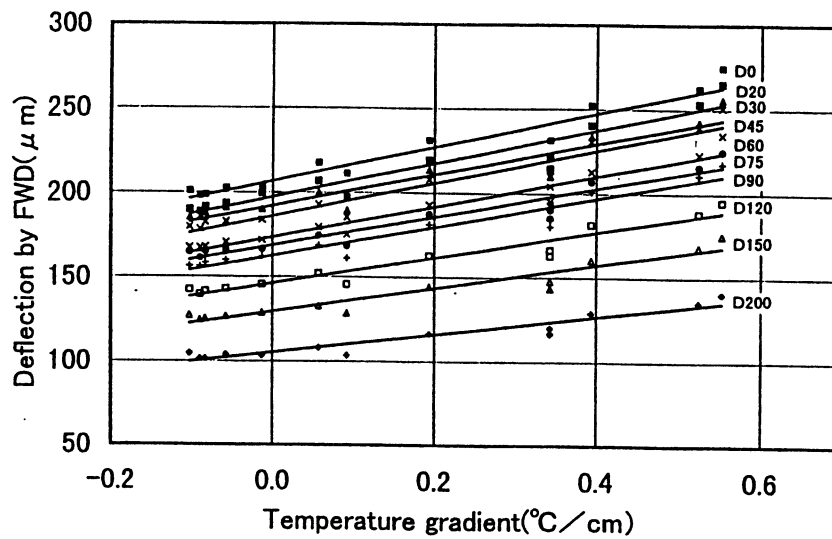


Figure-5 Relationship between temperature gradient and each deflection

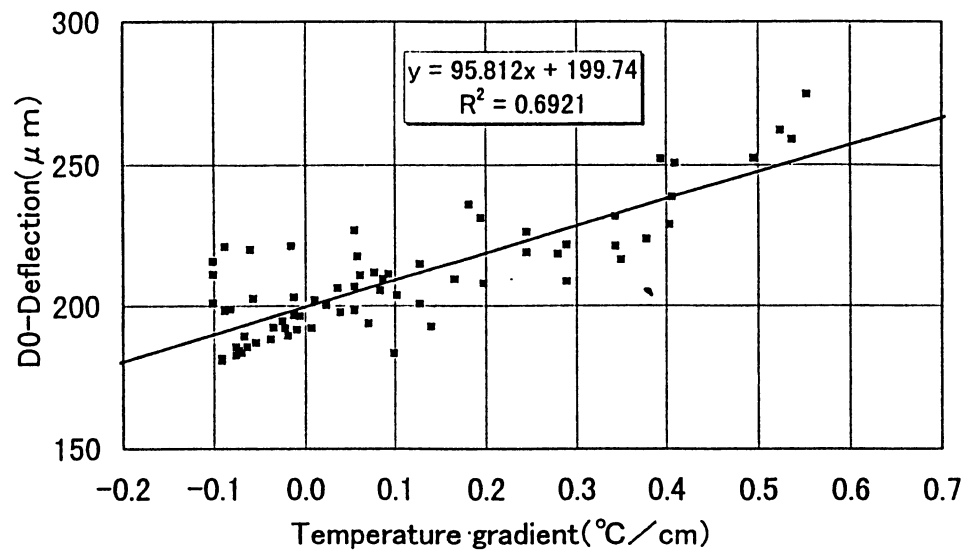


Figure-6 Relationship between temperature gradient and D0-deflection

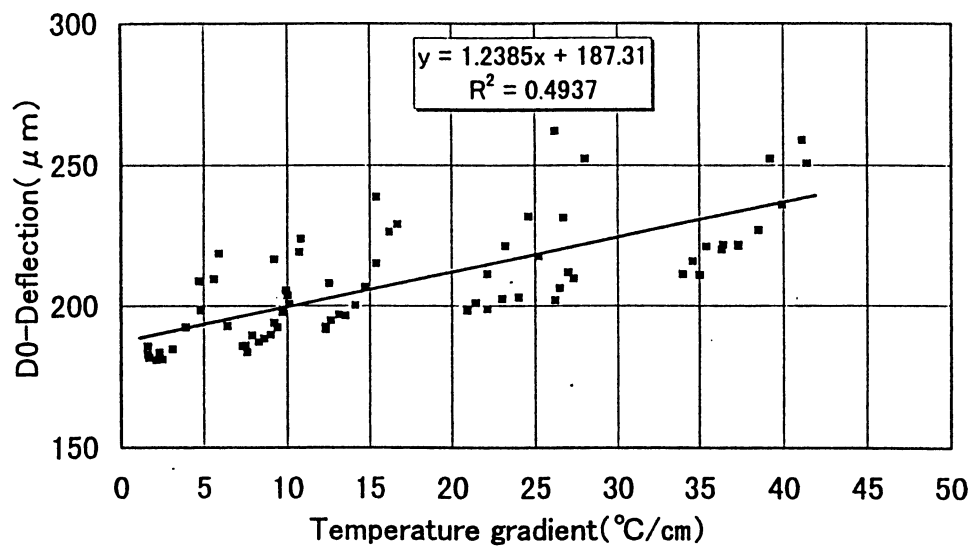


Figure-7 Relationship between average temperature and D0-deflection

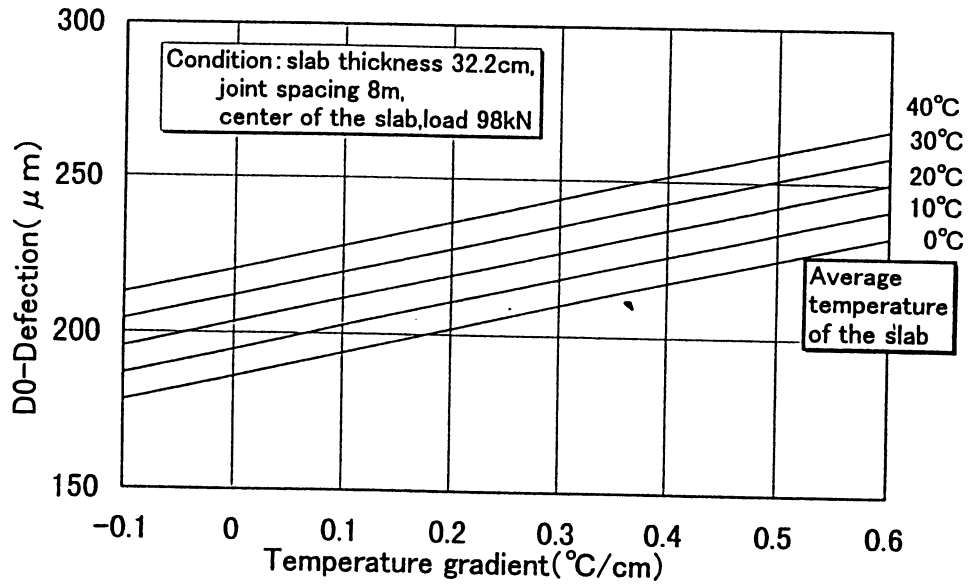


Figure-8 Nomograph representing interrelations among average temperature of the slab, temperature gradient and D0-deflection

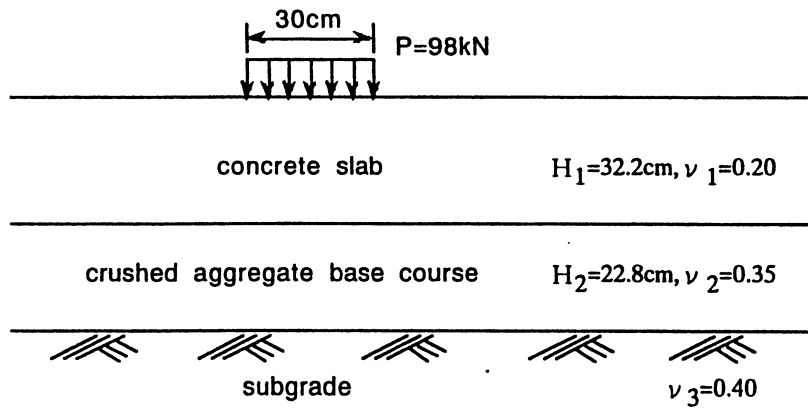


Figure-9 Pavement model for backcalculation

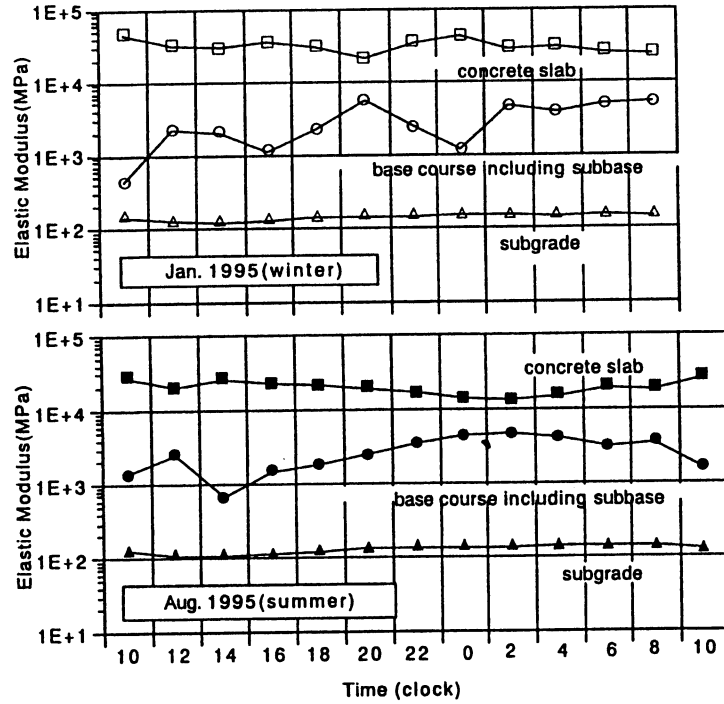


Figure-10 Elastic modulus of each layer by backcalculation
(layer modulus of concrete is not fixed)

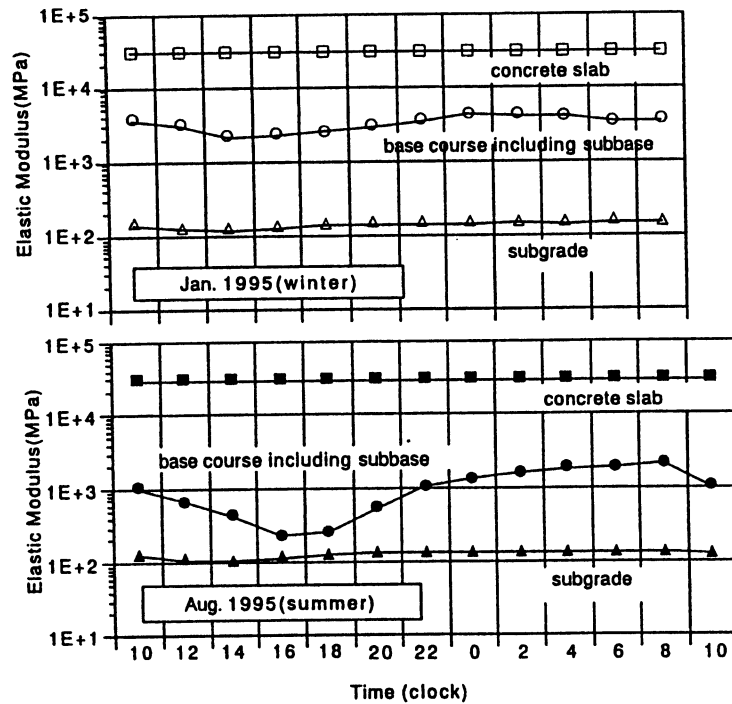


Figure-11 Elastic modulus of each layer by backcalculation
(layer modulus of concrete is fixed as 29400MPa)

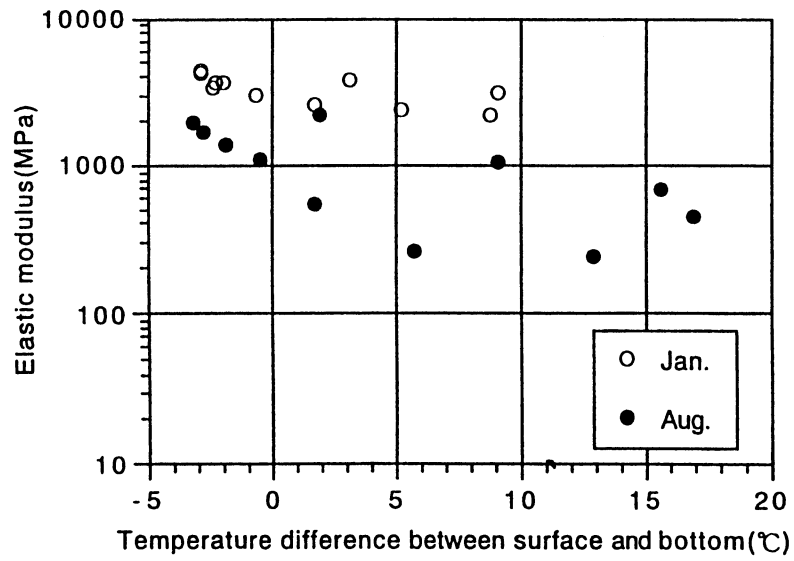


Figure-12 Relationship between elastic modulus of the base course and the temperature difference in the concrete slab