Temperature Dependency of Dynamic Deflection Measurements on Asphalt Pavements

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Research efforts were directed toward analyzing the effect of relatively high service temperatures on the deflection parameters and establishing correction factors for more accurate estimation of asphalt pavement performance. For this purpose, a continuous program of Dynaflect measurements extending over 2 years was carried out on full-depth asphalt pavement test sections in Kuwait. Measured deflection basins were correlated with those predicted by applying elastic layer theory. Cores were taken for laboratory characterization of the pavement materials under simulative conditions. Both measured and predicted values indicated a reduction in the maximum Dynaflect deflection parameter between the load wheels at pavement temperatures exceeding 40°C. The reduction in measured deflection values increases with the decrease of both asphalt layer thickness and its stiffness. Within the temperature range for normal Dynaflect measurements, corrections have been developed for the evaluation of elastic modulus values of both asphalt layers and subgrade. These correction factors have been related to a standard pavement temperature for the condition of no temperature gradient within the pavement. Corrected measured values were found to be reflecting the changes in the deflection behavior of the road pavement during high service temperatures.

It has been shown that measurements of the dynamic load-deflection response of asphalt pavements are indicative of pavement structural capacity and can provide an effective tool for pavement analysis and evaluation (1,2). Temperature in hot and arid regions is the major climatic factor affecting the evaluation of pavement bearing capacity. In such areas, surface pavement temperature varies widely within a day and with the seasons of the year and may approach 70°C during the summer period (3,4). Under such temperature conditions, experience in applying Dynaflect criteria in the evaluation of pavement conditions has indicated a significant temperature dependency for asphalt pavement structures.

The study described in this paper was concerned with field measurements of the dynamic deflection characteristics of full-depth asphalt pavement sections with different thicknesses in Kuwait. The specific objectives of the study were as follows:

1. To analyze deflection parameters versus temperature for all measurements taken at various times during specific days throughout the seasons of the year to provide an indication of the operative temperature dependency for each asphalt pavement thickness and

2. To recommend temperature correction factors for the evaluation of both subgrade and asphalt layer moduli.

EXPERIMENTAL PAVEMENT SECTIONS AND TEST MEASUREMENTS

The pavements studied for their deflection-temperature behavior consisted of five full-depth asphalt pavements with thicknesses of 100, 150, 200, 250, and 300 mm. Each pavement was 3 m wide and about 8 m long. All asphalt pavement sections were laid at one site in Shuwaikh near the Road Research Centre. The subgrade soil is a typical local sandy soil in the desert area of Kuwait that has a California bearing ratio of 8. Asphalt layers were all of hot-plant asphalt concrete (AC), locally designated as AC type II, and with a maximum aggregate size of 20 mm.

The field and laboratory testing program was undertaken for the purpose of evaluating in place properties of the asphaltic layers and the subgrade soil. For the asphalt concrete layers, data on thickness, bulk density, asphalt content and sieve analysis were determined. Tests were performed on 100-mm-diameter cores obtained from the pavement sections, by measuring dynamically the diametral resilient modulus. The tests were conducted at four testing temperatures (20°, 35°, 45°, and 55°C), under a haversine load pulse of stress level equal to 0.8 MPa, and with a load frequency of 8.3 Hz, which is similar to the loading condition applied by the Dynaflect.

Thermocouples were fixed at intervals in the asphalt pavement at a depth of 5 cm to measure and collect data on temperature gradient during the hours between 6:00 a.m. and 6:00 p.m. over the 2-year deflection measurement period. The time at which no temperature gradient in the pavement layer occurs was estimated from the recorded temperature data. This temperature condition, called starting pavement temperature (SPT), was found to occur at about 2.5 hr after sunrise on days when the skies were clear. The change of SPT with mean monthly air temperature (MMAT) through the whole year in Kuwait is shown in Figure 1. From the MMAT-SPT relation established, one can estimate at any season of the year the base temperature used to calculate the deflection-temperature correction factor.

Dynaflect deflection measurements were taken on the surface of the five full-depth asphalt pavement sections during the daytime hours, at 6:00 a.m. (2.5 hr after sunrise), 10:00 a.m., 2:00 p.m., and 6:00 p.m. These measurements were repeated each month during the entire period and covered MMAT values ranging from 14°C and 38°C.

Deflection parameters considered in this analysis included maximum deflection and the deflection basin. Because the maximum deflection (W_1) cannot sufficiently delineate the differences caused by the performance of pavement components at different temperatures, some other parameters associated with the

Figure 1. MMAT versus SPT.

LOG(SPT) = 0.856 + 0.022 (MMAT)
CORRELATION COEFF. = 0.97
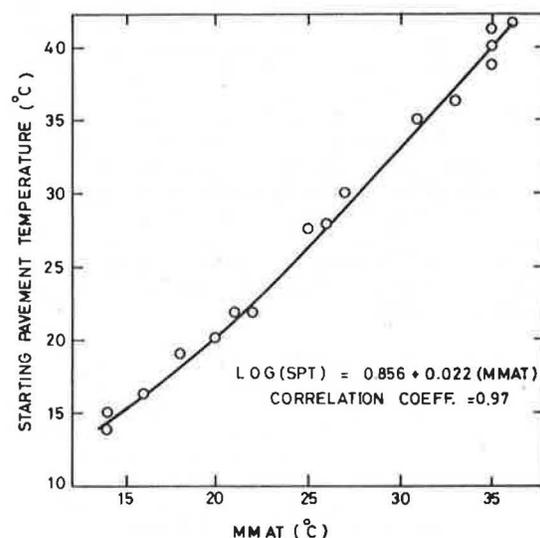
deflection basin have also been included, such as surface curvature index (SCI) and spreadability (SP). The formulas for these two parameters are as follows:

$$SCI = W_1 - W_2 \tag{1}$$

$$SP(\%) = |(W_1 + W_2 + W_3 + W_4 + W_5)/5W_1| \times 100 \tag{2}$$

where W_1 through W_5 are the measured Dynaflect deflection readings for sensors 1 through 5.

DEFLECTION-TEMPERATURE RELATION

Average measured deflection parameters for all asphalt pavement thicknesses show normal response for temperature changes during the season in which temperatures are relatively low (MMAT = 18°C). However, at relatively high temperatures, deflection parameters W_1 and SCI initially increase with the rise of pavement temperature but finally reach a maximum at a certain time during the day, after which they begin to decrease for almost the rest of the daytime hours. At MMAT = 35°C, deflections reached their maximum values at about 8:00 a.m.; at a lower MMAT of 27°C, maximum deflection values were measured at about noon. The time at which maximum deflection values were measured was found to be that at which asphalt pavement layers reach an average temperature of about 40°C. For the spreadability parameter, there is also evidence of such a reversal in the values measured at the same temperature.

This phenomenon of reversal in deflection parameters is due to changes in the shape of the deflection basins detected by the Dynaflect sensors at pavement temperatures exceeding 40°C. Both measured deflection values W_1 (between the dual load wheels) and W_5 (at 1,200 mm from the load wheels) have been found to decrease with increasing temperatures for all asphalt pavement thicknesses tested in this region of high service temperature. For this reason, the use of such deflection parameters is normally limited to conditions under which average pavement temperatures are lower than 40°C.

Temperature gradients in the asphalt layer during the daytime hours were found to have a significant effect on measured deflections, especially during the summer months. Therefore, it was considered that deflection parameters would correlate best with pavement temperature conditions of no gradient or at SPT. To analyze the temperature dependency of the different asphalt pavement thicknesses, deflection parameters measured at SPTs ranging from 15°C to 40°C have been plotted for different asphalt layer thicknesses. The linear regression lines of parameters W_1, SCI, and SP plotted as functions of SPT in Figure 2 show that temperature dependency increases with increasing thickness of the asphalt layer. The deflection parameters for the thinnest asphalt pavement structure (100 mm) were less dependent on temperature dependency values. In addition, the thickness of the asphalt layer has less effect on measured deflection parameters in the higher temperature range. Measured values of the parameter W_5 are affected to some degree by asphalt layer thickness within the range of temperatures considered in this study.

EVALUATION OF PAVEMENT COMPONENT MODULI

In this analysis procedure, the measured deflection parameters at different temperatures are translated into moduli of pavement component layers, which are in turn used to evaluate the structural condition of the pavement. The moduli of pavement component layers were calculated by using the BISAR computer program. Dynaflect deflection measurements W_1 through W_5 and pavement thickness were used to back-calculate the in situ values of asphalt pavement layer modulus (E_1) and to provide an estimate of subgrade modulus (E_2) with respect to pavement temperature changes.

The results of the computer analysis for determining the in situ sandy subgrade soil modulus (E_s) indicate that E_s is a function of asphalt pavement thickness (h). At SPT = 20°C, E_s increases from 105 MPa for h = 100 mm to 150 MPa for h = 300 mm. No significant effect was noted for pavement temperature (up to a maximum of about 35°C) on subgrade modulus values. At higher temperatures (above 35°C), E_s values for all asphalt sections tested increased significantly.

The variation of deviatoric stresses under the fifth sensor position with SPT has been analyzed. The thinner asphalt pavement shows the highest rate of decrease in deviatoric stress with increase in temperature. Because the deviatoric stress effect under the W_5 position and on typical sandy subgrade soil is much less, it will respond to the load with a much smaller modulus. Figure 3 shows factors for correction of subgrade modulus values predicted from deflection measurements to a standard E_s value of an asphalt layer 100 mm thick at SPT = 20°C. These correction factors vary with the structural characteristics of the particular pavement components under investigation.

To arrive at a temperature correlation factor, the effective asphalt pavement moduli $[(E)_{T_i}]$ were calculated by using measured deflections for different asphalt pavement thicknesses and measurement

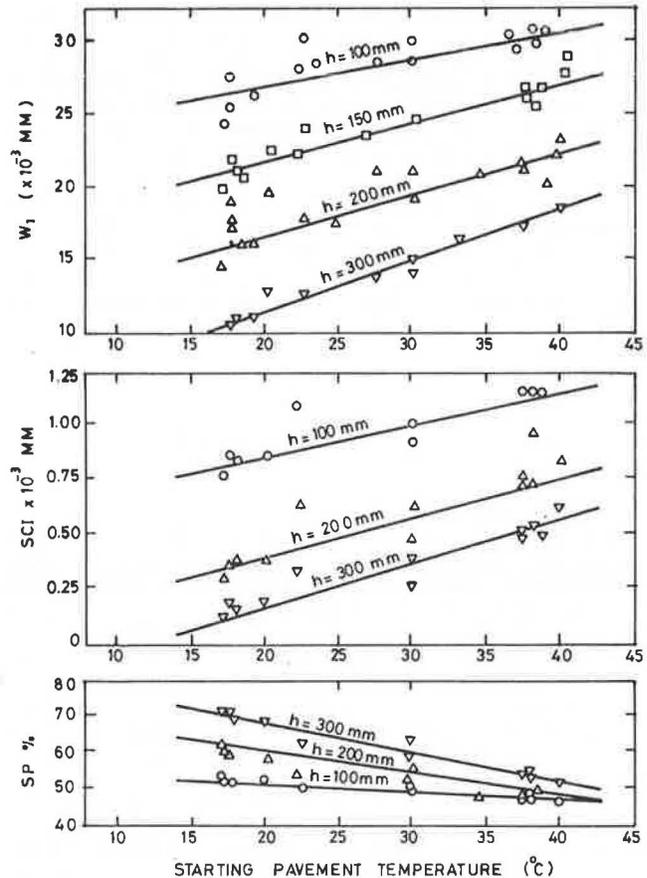Figure 2. Measured Dynaflect parameters versus SPT.

STARTING PAVEMENT TEMPERATURE (°C)

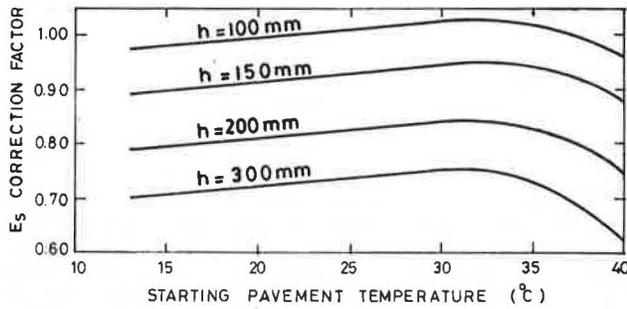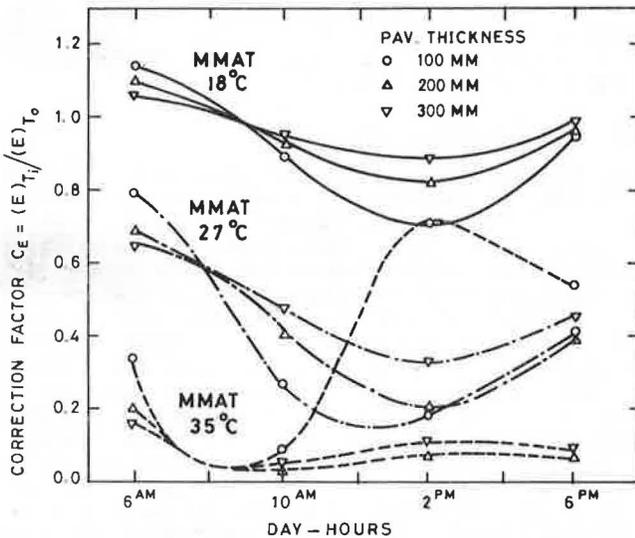Figure 3. Subgrade modulus correction factor [(E_s)T_i/(E_s)T_o] versus SPT.

Figure 4. Correction factors for asphalt pavement temperature gradients at three MMATs.

times to represent different MMAT. Figure 4 shows typical data for relating $(E)_{T_i}$ to a reference value $[(E)_{T_o}]$ predicted from deflections measured at SPT = 20°C.

Temperature gradients in asphalt pavement layers were found to significantly affect the relation between deflection and temperature, especially at relatively high service temperatures. Therefore, it was considered likely that deflection would correlate best with SPT instead of temperature measured at half the depth of the asphalt pavement layer.

Figure 4 shows that for MMAT = 35°C the effective values of asphalt pavement moduli after 8:00 a.m. increase with the increase in temperature during the rest of the daytime hours. This is attributable to the measured reduction in deflections for pavement structures with temperatures exceeding 40°C.

CONCLUSIONS

Based on the analysis of measured dynamic deflection parameters, the following conclusions were drawn:

1. Reasonably accurate predictions of layer moduli can be made for full-depth asphalt pavement sections through back-calculation of measured deflections up to a maximum average pavement temperature of 40°C. When the pavement temperature exceeds this limit serious discrepancies in deflection values occur, and these seriously affect the accuracy of calculated effective modulus values for pavement components.

2. Temperature gradients in asphalt pavement layers significantly affect measured deflection parameters, especially at relatively high service temperatures. The temperature dependency of deflection parameters for each pavement structure was found to correlate best with the condition of no temperature gradient (SPT).

3. Within the temperature range for normal Dynaflect measurements, correction factors for the evaluation of elastic modulus values of asphalt layers and subgrade have been related to a standard pavement temperature for the condition of no temperature gradient.

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