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Seasonal variations and in situ assessment of concrete pavement foundation mechanistic properties

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Abstract

In cold climates, pavement surface and foundation layers are subjected to seasonal temperature variation and freeze–thaw cycles. The number and duration of freeze–thaw cycles in the foundation layers can significantly influence the pavement performance. Seasonal variation in foundation layers is accounted for in pavement design by empirically adjusting the foundation layer moduli values. This paper presents results from in situ falling weight deflectometer (FWD) and dynamic cone penetrometer (DCP) tests conducted over a two-year period at five sites in Iowa; at one of these sites, temperatures of the foundation layers were continuously monitored during the testing period. FWD testing was conducted to determine the modulus of subgrade reaction (k) values. DCP testing was conducted to estimate California bearing ratio (CBR) values of the subbase and subgrade. Temperature data was analyzed to determine freezing and thawing periods and frost penetrations. Seasonal variations observed in the foundation mechanistic properties were compared with the assumed design values. Empirical relationships between the different mechanistic properties are explored.

1. Introduction

Pavements in northern hemisphere are subjected to seasonal temperature variations with freeze–thaw cycles that affect both pavement surfaces and foundation layers. Potential damages from freeze–thaw cycles include frost induced vertical heave, surface cracks, pumping of fines under traffic loading, and loss of support that reduces ride quality. Pavement foundation mechanistic characteristics such as stiffness and strength are significantly influenced by seasonal temperature variations and therefore have to be properly characterized as it has implications to design, construction, maintenance, and serviceability [9,33,36].

Various thickness design procedures have been developed since the 1970s for concrete pavement design. PCA [29] and AASHTO [1] design procedures are currently the most popularly used methods by the highway agencies in the U.S., while there is increasing interest in implementing the newly developed mechanistic-empirical design guide by AASHTO [2]. While the AASHTO [2] procedure is a significant advancement over the PCA [29] and AASHTO [1] procedures in terms of analyzing the pavement responses, the key design parameter used to characterize foundation layer support is still the modulus of subgrade reaction (k)

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value. Resilient modulus (M_r) value is one of design parameters in AASHTO [1] and AASHTO [2], but the M_r value is converted to k value using empirical relationships in the design process. AASHTO [1] provides suggested values for use in design as target M_r values for subgrade in frozen, thawed, and summer conditions. AASHTO [2] deals with seasonal variations in a much more sophisticated manner based on local climatic modeling data and laboratory test measurements to adjust modulus values for seasonal variations.

The k value is determined using a static plate load test, which can be time consuming and expensive to setup. Therefore, various alternative testing methods have been in use by state agencies to determine the k value. Deflection tests using falling weight deflectometer (FWD) is a popular choice for determining k value based on testing performed on pavement surface layers [30,1,2]. Dynamic cone penetrometer (DCP) test is another test device that has been recommended in the AASHTO [2] design guide as a method to determine California bearing ratio (CBR), which can be empirically correlated to k value. Most highway agencies assume k values during the design phase either based on experience and historically available data or limited field testing. For rehabilitated pavement designs, agencies in the U.S. typically use FWD testing data on the existing pavements, while for new pavements, CBR or M_r testing is typically performed on samples obtained from the field.

In this study, detailed field testing was conducted with the objective of measuring the seasonal variations in the field k values and compare them with what was assumed in the design. This field testing was conducted by using a Kuab FWD and DCP testing on five different pavement test sections in the State of Iowa eight times over a two year period (July 2010–July 2012). The pavement test sections varied in age from 6 to 56 years and showed varying level of distresses and ride quality (poor to good) at the time of testing.

Testing was conducted when the foundation layers were in frozen condition (winter), thawed condition, and in equilibrium condition (summer). DCP testing was conducted by drilling a hole in the pavement, and directly testing the foundation layer down to about 2 m below the surface. Both FWD and DCP test results were analyzed to estimate the k values and assess the differences in the estimated values. At one of the test sites, temperatures of the foundation layers were continuously monitored during the testing period. FWD testing was conducted to determine the modulus of subgrade reaction (k) values. DCP testing was conducted to estimate California bearing ratio (CBR) values of the foundation layers. Temperature data was analyzed to determine freezing and thawing periods and frost penetrations in the foundation layers. Seasonal variations observed in the foundation mechanistic properties were compared with the assumed design values. The findings in this paper will benefit engineers and agencies that design and construct pavements.

2. Background

2.1. Seasonal freeze–thaw cycles in pavements

Freeze–thaw cycles are common in cold regions and sometimes lead to freezing and thawing related pavement problems. Frost-stiffening and thaw-weakening primarily result from ice forming and melting within the soil. The stiffness and strength of the roadbed material decrease as the phase of the moisture changes from solid to liquid [19,22]. Three elements, the freezing front, thawing front, and moisture contents of the pavement layers, primarily influence the mechanistic properties of pavement foundations [23]. The significant influence of cyclic freezing and thawing on pavement performance means that it is important to investigate freeze–thaw conditions in pavements, such as frost penetration depths, numbers of freeze–thaw cycles, and the duration of freezing and thawing periods.

Hoover et al. [16] investigated the pavement freeze–thaw conditions over three winters (1957 through 1960) on US Highway 117 in Jasper County, Iowa. Hoover et al. observed seven thawing periods during 1957–1958 winter and nine during 1959–1960 winter. During the 1958–1959 winter, a large continuous frozen zone and several smaller, thawed zones were observed at shallow depths for short time within the frozen zone. Hoover et al. [16] also estimated the numbers of freeze–thaw cycles based on air temperature data that revealed 11 freeze–thaw cycles. Within the upper 0.4 m of the pavement, annual freeze–thaw cycles decreased from ten to one. The maximum frost penetrations reached around 1.05 m during the three winters.

Andersland and Ladanyi [3] reported that determining the 0 °C isotherm is an approach to analyze temperature variations in pavement focusing on freezing and thawing periods in pavement layers. Frozen and thawed zones versus time can be estimated from isothermal depth. Determination of this isotherm presents the maximum frost penetrations and the periods that pavements are susceptible to break-up. This period is defined as the time when the upper pavement layers are thawed while the lower layers are still frozen. Thawed water from upper layers cannot drain into lower frozen layers due to the low permeability. In these conditions, the bearing capacity of foundations may significantly decrease, and the upper pavements become more fragile under traffic loads. Andersland and Ladanyi [3] reported fragile conditions are a problem that pavement engineers need to identify, which is the primary reason why spring load restriction needs to be implemented in seasonal frost regions [28,26].

Johnson [22] estimated the frost penetrations of three locations in Iowa for four winters (2008 through 2012). The first three winters presented 1.1–1.4 m maximum frost penetrations, and the 2011–2012 winter presented a lower depth of 0.6 m frost penetrations in average. Johnson [22] also reported the numbers of freeze–thaw cycles at different depth during the 2010–2011 winter at one of the sites in this study (see Fig. 1). The upper 0.3 m of the pavement foun-

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