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Standard Test Method for Prediction of Asphalt-Bound Pavement Layer Temperatures[1]

This standard is issued under the fixed designation D7228; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers a means of predicting temperatures within the asphalt-bound layer(s) of a flexible pavement section.

1.2 Deflection testing commonly involves the measurement of pavement surface temperatures. This standard is based on temperature relationships developed as part of the Federal Highway Administration (FHWA) Long Term Pavement Performance (LTPP) Seasonal Monitoring Program.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D4694 Test Method for Deflections with a Falling-Weight-Type Impulse Load Device

D4695 Guide for General Pavement Deflection Measurements

D4602 Guide for Nondestructive Testing of Pavements Using Cyclic-Loading Dynamic Deflection Equipment

D5858 Guide for Calculating *In Situ* Equivalent Elastic Moduli of Pavement Materials Using Layered Elastic Theory

2.2 *AASHTO Standards:*[3]

T256-00 Standard Method of Test for Pavement Deflection Measurements

T317-02 Standard Method of Test for Prediction of Asphalt-Bound Pavement Layer Temperatures

2.3 *Federal Highway Administration:*[4]

FHWA-RD-98-085, Temperature Predictions and Adjustment Factors for Asphalt Pavements, June 2000

LTPP Guide to Asphalt Temperature Prediction and Correction, Online Temperature Prediction and Correction Guide—TOC, November 2002

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *BELLS* —an acronym based on the initials of the four developers of the method: Baltzer, Ertman-Larsen, Lukanen, and Stubstad.

3.1.2 *depth*—the distance below the surface of the top layer of asphalt.

3.1.3 *1-day air temperature*—the average of the minimum and maximum air temperatures at the location of testing during the previous complete 24-hour day.

4. Summary of Test Method

4.1 *Input Data Elements:*

4.1.1 *IR Temperature*—The exposed surface temperature of an asphalt pavement is measured, preferably with an infrared (IR) temperature sensing device that is properly calibrated.

4.1.2 *Time of Day*—The time of day the temperature measurement takes place is recorded.

4.1.3 *1-Day Temperature*—The average 1-day air temperature of the previous complete 24-hour day is determined and recorded.

4.1.4 *Pavement Depth*—The depth at which an estimate of the asphalt layer temperature is required is specified.

4.2 The input data elements are entered into a regression formula that predicts the temperature within the asphalt pavement at depth.

5. Significance and Use

5.1 Analysis of deflection data from asphalt pavements almost always requires that the raw deflections or the analysis results from the load-deflection data be adjusted for the effects of pavement surface course temperature. Measuring the temperature at-depth normally requires that a hole be drilled into the pavement, partially filled with fluid, and the temperature measured with a hand-held device. Alternatively, thermistors or other temperature instrumentation may be permanently installed at various locations.

5.2 Current deflection testing equipment is often equipped with surface temperature sensing devices, for example an

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001.

[4] Available from Federal Highway Administration (FHWA) 400 Seventh Street, SW Washington, DC 20590.

infrared thermometer that measures the surface temperature at every test location. To adequately adjust the deflection or deflection results for the effects of temperature, the temperature at some depth must be known.

5.3 This test method provides a means of estimating the temperature at-depth from the pavement surface temperature, the time of day, the previous day's high and low air temperatures, and the desired depth where the temperature is to be estimated. Utilization of this method results in a significant savings in time over the conventional practice of manually drilling holes into the pavement, and it results in a significant increase in the volume of temperature data (one pavement temperature for each test point) and the ability to record temperature variations between test points.

6. Apparatus

6.1 *Surface Temperature Measurement Device*—The surface temperature measurement device can be an infrared (IR) thermometer mounted on a deflection device, a hand-held IR thermometer, or a surface contact thermometer. The temperature measurement device should be calibrated according to the manufacturer's recommendations.

7. Calculation

7.1 *BELLS Method*—The BELLS method for production testing (called BELLS3 in other publications) has been derived based on temperature measurements taken on pavement surfaces that have been shaded for a short period (less than one minute) of time. The following equation is valid for approximately 30 seconds of shading:

$$T_d = 0.95 + 0.892*\mathrm{IR} + \{\log(d) - 1.25\}\{-0.448*\mathrm{IR} + 0.621*(1-\mathrm{day}) + 1.83*\sin(\mathrm{hr}_{18} - 15.5)\} + 0.042*\mathrm{IR}*\sin(\mathrm{hr}_{18} - 13.5) \quad (1)$$

where:

T_d = pavement temperature at depth d, °C,
IR = infrared surface temperature, °C,
log = base 10 logarithm,
d = depth at which asphalt temperature is to be predicted, mm,
1-day = average of the minimum and maximum air temperatures, °C, for the previous complete 24-hour day before testing,
sin = sin function in 18-hour clock system, with 2π radians equal to one 18-hour cycle, and
hr_{18} = time of day, in 24-hour system, but calculated using an 18-hour temperature rise and fall cycle, as indicated in 7.1.1 and 7.1.2.

7.1.1 When using the sin (hr_{18} – 15.5) decimal time function, only use times from 11:00 to 05:00 hrs. If the actual time is not within this time range, then calculate the sin as if the time is 11:00 hrs (where the sin = –1). If the time is between midnight and 05:00 hrs, add 24 to the actual decimal time. Then calculate as follows: If the time is 13:15, then in decimal form, 13.25 – 15.50 = –2.25; –2.25/18 = –0.125; –0.125 × 2π = –0.785 radians; sin (–0.785) = –0.707. In this case an 18 hour sin function is assumed, with a flat (= –1) sin segment between 05:00 and 11:00 hours.

7.1.2 When using the sin (hr_{18} – 13.5) decimal function, only use times from 09:00 to 03:00 hrs. If the actual time is not within this time range, then calculate the sin as if the time is 09:00 hrs (where the sin = –1). If the time is between midnight and 03:00 hrs, add 24 to the actual (decimal) time. Then calculate as follows: If the time is 15:08, then in decimal form, 15.13 – 13.50 = 1.63; 1.63/18 = 0.091; 0.091 × 2π = 0.569 radians; sin (0.569) = 0.539. In this case an 18 hour sin function is assumed, with a flat (= –1) sin segment between 03:00 and 09:00 hours.

NOTE 1—BELLS has been verified using the LTPP database at both mid depth and third depth temperature points. The regressions derived from the data at either depth were virtually identical; therefore, they were combined in deriving the BELLS equations. The asphalt layer thicknesses covered in the database were primarily between 50 mm and 300 mm; therefore temperature prediction depths within the AC layer should be limited to between 25 mm and 150 mm beneath the surface. Although this test method may be used for at-depth temperatures greater than 150 mm through extrapolation, the results have not been verified or calibrated to date. Since the equation's boundary condition at depth = 0 is inconsistent with the input IR temperature value, the determination of an at-depth payment temperature less than 25 mm is not recommended.

NOTE 2—The database used to derive the BELLS equations consists primarily of data gathered during daylight hours between approximately 06:00 hrs and 18:00 hrs. Although the test method may be used outside of this time frame through extrapolation of the 18-hour sinusoidal relationships, the results have not been verified or calibrated to date.

8. Report

8.1 The type of temperature measuring device, the measurement shading conditions, the time of measurement, the date of measurement, and the depth at which the temperature was calculated should be identified.

9. Precision and Bias

9.1 A precision and bias statement for this standard has not been developed at this time. Therefore, this standard should not be used for acceptance or rejection of a material for purchasing purposes.

NOTE 3—The BELLS equation for production testing (BELLS3) was derived using the LTPP database (10 304 observations; R-squared = 0.975). The regression's standard estimate of error was ±1.9°C based on an adjustment using the LTPP database for 30 seconds of shading. Using the regression approach on this database, by definition there was no bias.

10. Keywords

10.1 asphalt temperature; backcalculation; Benkelman beam; dynaflect; falling weight deflectometer; FWD; layer moduli; pavement temperature correction; road rater

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE SOURCE CODE FOR CALCULATING THE PREDICTED ASPHALT TEMPERATURE BY THE BELLS METHOD

X1.1 Explanation

X1.1.1 *Purpose*—The source code is presented to illustrate application of the temperature prediction equations, particularly the application of the 18-hour sin functions.

X1.1.2 *Language*—The source code is written in BASIC and can be run on a number of basic interpreters or compilers, or easily converted to other computer languages.

X1.2 Example Source Code Listing X1.2

```
'Program to illustrate the implementation of the BELLS3 equation
'for routine testing with approximately 30 seconds of surface shade.
'*****************************************************************

CLS

INPUT "Input Surface Temperature "; ir
INPUT "Input Hour of test "; hr
INPUT "Input Minutes past the hour "; min
INPUT "Input the depth for predicting the asphalt temperature "; d
INPUT "Input average air temperature for the day before the test
date "; air

decimal.hrs = hr + min / 60

IF decimal.hrs > 11 OR decimal.hrs < 5 THEN
    IF decimal.hrs < 5 THEN decimal.hrs = decimal.hrs + 24
    sine15.5 = SIN(2 * pi * (decimal.hrs - 15.5) / 18)
  ELSE
    sine15.5 = -1
END IF

IF decimal.hrs > 9 OR decimal.hrs < 3 THEN
    IF decimal.hrs < 3 THEN decimal.hrs = decimal.hrs + 24
    sine13.5 = SIN(2 * pi * (decimal.hrs -13.5) / 18)
  ELSE
    sine13.5 = -1
END IF

td = 0.95 + 0.892 * ir
logdepth = LOG (d) / LOG (10) – 1.25
firstbracket = –0.448 * ir + 0.621 * air + 1.83 * sine15.5
last.term = 0.042 * ir * sine13.5
td = td + logdepth * firstbracket + last.term
```

X1.3 Example Temperature Calculation

X1.3.1 The following link, LTPP Guide to Asphalt Temperature Prediction and Correction, courtesy of FHWA, provides a spreadsheet macro to calculate any at-depth pavement temperature: http://www.tfhrc.gov/pavement/ltpp/fwdcd/index.htm. When using this link, refer to the "BELLS3" calculation cells for routine pavement testing methods.

IR temperature	=	12.5°C
Time of day	=	08:10 hrs
Mid-depth of pavement surface course	=	75 mm
Previous 1-day average air temperature	=	23°C

$$T_{75\ mm} = 0.95 + 0.892*12.5 + \{\log(75) - 1.25\} \times \{-0.448*12.5 + 0.621*(23) + 1.83*\sin(2\pi \times (11.00 - 15.5)/18\} + 0.042*12.5*\sin(2\pi \times (08.17 - 13.5)/18 \quad (X1.1)$$

$$T_{75\ mm} = 0.95 + 0.892*12.5 + \{1.875 - 1.25\} \times \{-0.448*12.5 + 0.621*(23) + 1.83*-1\} + 0,042*12.5*-0.958 \quad (X1.2)$$

$$T_{75\ mm} = 0.95 + 11.15 + 0.625 \times \{-5.6 + 14.28 - 1.83\} - 0.50 = 15.9°C \quad (X1.3)$$