Portable Falling Weight Deflectometers for Tracking Seasonal Stiffness Variations in Asphalt Surfaced Roads

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August 1, 2005

Words in text = 3549
Tables = 5
Figures = 10
Total = 7299
ABSTRACT
Modulus (stiffness) is one of the primary inputs to mechanistic pavement design procedures and provides insight into long term pavement performance. Despite the importance of modulus, some aspects of pavement construction and management are still based on measurement of parameters that are not directly connected with long-term performance or on empirical based judgments. The goal of this research was to evaluate the effectiveness of the portable falling weight deflectometer (PFWD) in evaluating the support capacity of pavements during spring thaw. The performances of seven asphalt surfaced low volume roads were evaluated through spring thaw and recovery. Instrumentation was used to measure frost penetration in the test sections on days when measurements were made. Comparisons were made to the traditional falling weight deflectometer (FWD). It was shown that the PFWD was able to follow seasonal stiffness variations and compared well with FWD derived moduli on asphalt surfaces. Recommendations were made for using a PFWD to determine when to place and remove seasonal load restrictions.

INTRODUCTION
Pavements in areas with seasonal freezing and thawing are often damaged by frost heave and thaw weakening in addition to normal load-induced pavement distress. To minimize damage, many road maintenance agencies impose load restrictions on selected roads during damage-susceptible periods. Although the maximum allowable load and the duration of the reduced load period vary widely among agencies, they try to strike a balance between minimizing the disruption to the local economy caused by the load restrictions and minimizing road damage. Although modulus is a key parameter in determining damage-susceptibility of the pavement section, the imposition of spring load restrictions is often based on visual observation combined with the pavement manager’s judgment. Modulus could be monitored during spring thaw and through recovery using falling weight deflectometers (FWDs). However, FWD purchase, operation, and maintenance are expensive. Second, even if a state owns a FWD, it can only monitor a finite number of roads within the spring thaw period. As a result, determining when the road has thawed and recovered sufficient strength to remove the restriction is left to personal experience and subjective judgment. The purpose of this study was to investigate a practical method of measuring stiffness of pavement structures during spring thaw. The premise was that this could be accomplished using a portable falling weight deflectometer (PFWD). The performance of seven asphalt surfaced low volume roads located in Maine, New Hampshire, and Vermont were evaluated through spring thaw and recovery. Instrumentation was used to monitor the extent of frost in test sections on days when measurements were made. Comparisons were made to the traditional FWD. More specifically, the portable falling weight deflectometer (PFWD) was evaluated as a means of optimizing timing for load restriction placement and removal on secondary roads in New England as well as to develop guidelines for use on pavement structures typical of New England low volume roads.

FIELD TEST SITES
The performance of seven asphalt surfaced roads was monitored during the spring of 2004. Three of the roads were part of previous or ongoing New England Transportation Consortium (NETC) and Maine Department of Transportation (MaineDOT) research projects (1)(2)(3)(4) and one was part of ongoing research by the United States Forest Service (USFS) (5). The NETC and MaineDOT sites were reconstructed within the last ten years and are not posted
during spring thaw, but had the advantage of being instrumented as will be discussed below. Additional roads were selected in consultation with NETC, USFS, MaineDOT, and the Vermont Agency of Transportation (VAOT). The additional roads in Maine, New Hampshire, and Vermont that were selected met the following criteria: asphalt or gravel surface, low traffic volume, and presence of seasonal weight restriction during the spring melt. A summary of each site is provided in Table 1.

**INSTRUMENTATION**

Typical instrumentation included thermocouples, thermistors, or frost tubes to monitor subsurface thermal regime, and vibrating wire piezometers, standpipe piezometers, or time domain reflectometry (TDR) probes to monitor subsurface moisture regime. Additional details on instrumentation are provided in Steinert et al. (1). Instrumentation at some sites was read manually on FWD test dates, and instrumentation at other sites was recorded hourly by a Campbell Scientific datalogger.

**PFWD DESCRIPTION**

The PFWD is a light, portable device that measures elastic modulus (stiffness) of construction layers including subgrades, base/subbase courses, and pavements. Several commercially available PFWDs exist. The Prima 100 PFWD, manufactured by Dynatest International, was used for this study.

The PFWD operates on the same principle as the FWD, but it is small enough to be easily moved and operated by one person. The PFWD creates a non-destructive shock-wave through the soil as a result of the impact of a falling mass (10, 15, or 20 kg (22, 33, or 44 lb)) from a variable drop height (10 to 850 mm (0.4 to 33.5 in.)). The impact force is transmitted to the underlying surface by means of a 100, 200, or 300 mm (3.9, 7.9, or 11.8 in.) diameter loading plate. The Prima 100 PFWD uses two types of sensors: a load cell for measuring the impact force from the falling weight, and one to three geophones for calculating the deflection of the surface. The Prima 100 PFWD records force, pressure, and deflection with respect to time, which are stored automatically in a Personal Digital Assistant (PDA). The Prima 100 PFWD and PDA are shown in Figure 1.

Equations, developed by Boussinesq, are manipulated to provide modulus from the two measurements. The software calculates the composite elastic modulus according to Equation 1.

$$E = \frac{f \cdot (1 - v^2) \cdot \sigma_0 \cdot a}{d_0}$$

Equation 1

Where:

- \(E\) = Elastic Modulus,
- \(\mu\) = Poisson’s ratio (default: 0.5),
- \(\sigma_0\) = Applied stress at surface,
- \(a\) = Radius of loading plate,
- \(d_0\) = Deflection,
- \(f\) = Factor that depends on the stress distribution
  - Uniform: \(f = 2\) (default)
  - Rigid plate: \(f = \pi/2\)
  - Parabolic, granular: \(f = 8/3\)
FIELD TESTING PROCEDURES

PFWD Measurements
With the PFWD, six measurements were taken at each of three different drop heights, at a minimum of eight test locations per site. The drop heights were approximately 850, 630, and 420 mm (34, 25, and 17 in.). Only the results obtained from the 850 mm (34 in.) drop height were used for comparison. Three deflection sensors were used with spacing as follows (as measured from the center of the loading plate): 0, 207, and 407 mm (0, 8, and 16 in.). Additional geophones provide a means by which moduli can be backcalculated for individual layers. Surface deflections determined from additional geophones were not used in the results presented in this paper. Only values obtained from measurements from the center geophone were used for analysis and comparison. The PFWD measurements were taken utilizing a 20 kg (44 lb) drop weight and a 300 mm (11.8 in.) loading plate. In all cases, the first reading was neglected and the average of the remaining five was used for analysis and comparison. These and other adjustable input parameters are summarized in Table 2.

FWD Measurements
The MaineDOT provided a FWD for seasonally posted roads in Maine. The United States Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) provided a FWD for test sites in Rumney, New Hampshire. The Vermont Agency of Transportation (VAOT) provided a FWD for seasonally posted low volume roads in Vermont. FWD measurements were taken at each test site.

MaineDOT FWD
The MaineDOT utilizes a JILS Model 20C Falling Weight Deflectometer manufactured by Foundation Mechanics, Inc. The unit has a constant drop weight of 340.2 kg (750 lb) and a loading plate diameter of 304.8 mm (12 in.). Deflection sensors are spaced at 0, 305, 457, 610, 914, 1219, and 1524 mm (0, 12, 18, 24, 36, 48, and 60 in.). Prior to testing, the FWD operator conducts a force calibration. One drop each at six different loads is performed. The loading sequence is as follows: 26.7, 40.0, 53.4, and 71.2 kN (6, 9, 12, 16, 9, and 9 kips). Data collected was interpreted using DARWin v. 3.1.002 software (6).

CRREL & VAOT FWD
CRREL and the VAOT utilized a Dynatest Model 8000 Falling Weight Deflectometer. The Model 8000 FWD has a loading range of 7 to 120 kN (1.5 to 27.0 kips). The CRREL FWD utilized a loading plate with a diameter of 457 mm (18 in.) while the diameter of the VAOT FWD was 300 mm (11.8 in.). Deflection sensors on the CRREL FWD were spaced at 0, 305, 610, 914, 1219, 1524, and 1829 mm (0, 12, 24, 36, 48, 60, and 72 in.). The VAOT FWD had one additional sensor at 203 mm (8 in.) from the center of the loading plate. The CRREL test program targeted four drops at each of four different drop heights. VAOT FWD testing followed the Strategic Highway Research Program (SHRP) FWD testing protocol administered by the Long Term Pavement Performance (LTPP) division of the Federal Highway Administration (FHWA). This testing procedure includes three seating drops and four drops each at four different drop heights that target four different loads. FWD results obtained from CRREL and
VAOT were used to determine individual layer moduli. Evercalc 5.0 (7), developed by the Washington State Department of Transportation, was used for backcalculating moduli.

SEASONAL STIFFNESS VARIATIONS
PFWD composite modulus, and for sites where available, FWD asphalt, subbase, subgrade, and composite modulus are plotted versus date in Figures 2 through 6. In general, the moduli are high when the pavement section is frozen and during the early part of the period when section is partially thawed. At some field sites there are significant differences in moduli from nearby test locations and from one week to the next. This behavior was especially evident at Kennebec Road, Witter Farm Road, and Route 126.

Freeze-thaw cycling and corresponding moduli changes were observed at Kennebec Road, Witter Farm Road, and Route 1A. At these sites partial thawing occurred at or near March 16, 2004 before the return of freezing temperatures. A distinct increase in modulus occurred at each site on approximately March 24, 2004. All three sites are located within a 32 km (20 mi) radius of Bangor, Maine.

The composite moduli generally decreased as thawing progressed. It was anticipated that a distinct minimum modulus would be reached near the end of the thawing period followed by increasing modulus due to drainage of excess water in the subbase and subgrade soils. This behavior was observed at the Buffalo Road, Knapp Airport Parking Lot, and to a lesser extent, the Stinson Lake Road test sites. All three sites reached distinct minimum values at or near the end of March. However, at the remaining sites, the composite modulus at the end of thawing was approximately equal to, or in some cases greater than, the value measured in late June or early July. Average PFWD and FWD composite moduli at the end of the thawing period and in mid to late June are summarized in Table 3.

Backcalculated layer moduli are used as the basis for PFWD comparison. FWD derived moduli indicate that Kennebec Road, Buffalo Road, and Knapp Airport Parking Lot exhibited some degree of thaw weakening and recovery. Moduli derived from PFWD measurements also follow similar trends. PFWD moduli also followed similar trends to FWD moduli at test sites where no thaw weakening occurred. Three of these test sites, Witter Farm Road, Route 126, and Route 1A, were all fully reconstructed within the last ten years with non frost susceptible materials, and, as a result, did not experience thaw weakening as shown in Figure 6. Based on these observations, the PFWD and conventional FWD are equally effective in tracking the composite moduli changes during spring thaw.

RECOMMENDED SPRING THAW TESTING PROCEDURES
Few straightforward procedures exist that aid in determining the need for weight restrictions, the magnitude of the restriction, and when to place and remove the restriction from asphalt surfaced, low volume roads. The basis of methods for placing and removing load restrictions include observing the pavement structure for signs of distress; measuring surface deflections, subsurface temperature, and/or subsurface moisture (8), and more recently, predicting thaw from air temperature data (9). A recommended procedure for using a PFWD to determine if a road should be posted for weight restriction and then a procedure to determine the duration of the restriction is outlined in the following paragraphs.

As discussed by Rutherford, et al. (10) many factors exist that should be considered when determining whether seasonal load restrictions are necessary at a particular location. Some of these factors are listed below.
1. Pavements with surface deflections 45 to 50% higher during spring thaw than summer.
2. Pavements with frost susceptible subbase and subgrade material.
3. Pavement with subgrade soils classified as ML, MH, CL, and CH.
4. Roads which have historically exhibited deterioration during the spring thaw period.
5. Pavements in which distress has been observed (fatigue cracking and rutting).

The procedure that is recommended for use of the PFWD should be applied with due consideration of the factors listed above. A procedure for using the PFWD to place and remove load restrictions is presented and then is applied to the field sites monitored as part of this study. The procedure relies on comparing composite moduli during the spring thaw to fully recovered values measured during summer and fall months. Thus, the underlying premise is that composite modulus is the primary factor controlling damage to the road section.

The researchers selected 80% of the fully recovered composite modulus as the trigger value for application and removal of load restrictions. The selection of 80% is arbitrary since the amount of damage that would occur at the reduced modulus depends on individual pavement sections, allowable vehicle weight, and traffic levels. Individual transportation agencies should examine these issues in light of the amount of damage that is acceptable to the road during the spring thaw period and the consequences to the regional economy that are created by weight restrictions. The authors are currently proceeding with supplemental research aimed at objectively determining at what percent recovery the weight restriction should be lifted. Subsequent refinement of the 80% trigger value is based on allowable pavement damage.

The procedure outlined in the following steps can be used to determine when to apply and remove load restrictions. In addition, it can be used as a screening procedure to identify roads that do not require posting.

1. For each road to be monitored, identify critical sections of the road that are most susceptible to spring thaw damage based on pervious performance, soil type, access to ground water, or other factors. Within each critical section, select four test points. Test points should span the inside and outside wheelpaths in both travel lanes, if present. The location of the points should be marked so that the same locations can be tested on each test day.
2. Set up the PFWD with the 850 (33.5 in.) drop height, 20 kg (44 lb) drop weight, and 300 mm (12 in.) diameter loading plate.
3. Set up the Personal Digital Assistant (PDA) based recording software using the input parameters presented in Table 2.
4. Establish moduli for each test point that are representative of the fully recovered period by taking readings at each test point during the summer and early fall. Readings should be taken on days that correspond to periods that are relatively dry. A reading at an individual test point is the average of drops 2 through 6. The results from drop 1 are discarded. It is recommended that readings be taken on four days spanning the summer and early fall. Average the four daily readings at each point to obtain the fully recovered composite modulus for that point. Finally, average the recovered composite modulus from each test point to obtain the recovered composite modulus for the section. Multiply this value by 80% to obtain the trigger value for load restriction application/removal.
5. Using the same test points and testing techniques that were used to establish the baseline values, take periodic readings at the start of the spring thaw. During the critical thawing
period, it may be necessary to take readings daily. Taking readings in the afternoon is preferred to avoid the influence of possible refreezing during the previous night. A reading at an individual test point is the average of drops 2 through 6. The results from drop 1 are discarded. Apply the load restriction when the average of the composite moduli at the test points in the section drops below 80% of the baseline (recovered) values.

6. Continue to take periodic readings, at least weekly. Once the average of the composite moduli at the test points in the section readings exceed 80% of the baseline (recovered) values for two consecutive sets of measurements the load restriction may be removed.

7. Sites where the moduli remain above 80% of the recovered value are potential candidates for roads that do not require posting.

Of the seven asphalt surfaced test sites monitored during the spring of 2004, two (Buffalo Road and Knapp Airport Parking Lot) showed distinct minimum composite moduli during the thawing period before increasing into the recovery period. The procedure was also used with available results from the FWD. Dates for placing and removing the restrictions are summarized in Table 4. The procedure is shown graphically for the Buffalo Road site in Figure 7. In general, the posting and removal dates determined by the PFWD and FWD agree within one week.

It should be noted that the recovered composite modulus used in the application of the recommended procedure were based on a single reading date in June rather than the average of four reading dates in late summer and early fall. Thus, the interpretation of the duration of the load restriction may have been somewhat different had the latter readings been available. Moreover, readings were taken weekly, whereas the composite modulus can experience a dramatic reduction over this period. This illustrates the importance of taking readings more frequently during the thawing period. This research found that roads that have undergone full depth reconstruction with 125 mm (5 in.) or more of pavement supported by 600 mm (24 in.) of non-frost susceptible base (Witter Farm Road, Route 1A, and Route 126) did not experience a seasonal reduction in the composite modulus and thus do not require seasonal weight restrictions.

**COMPARISON OF PFWD AND FWD COMPOSITE MODULI**

Composite moduli derived from traditional FWD measurements were supplied to the researchers by MaineDOT for asphalt surfaced test sites located in the State of Maine. AASHTOWare DARWin v. 3.1.002 software was used by the MaineDOT to backcalculate composite and subgrade moduli. This program is based on AASHTO deflection analysis procedures. DARWin does not provide individual layer moduli, only a composite modulus for asphalt and subbase layers and a modulus for the subgrade layer. This was beneficial because the PFWD also provides composite moduli. Percentages of various layers contributing toward the composite value would of course differ for the PFWD modulus and the Darwin modulus; nevertheless, values are closer than comparing composite modulus with individual layer moduli.

For each site, backcalculated moduli were plotted against composite moduli as measured with the PFWD. Regression analyses yielded correlation coefficients ranging from 0.336 (Route 1A) to 0.950 (Witter Farm Road). Correlation coefficients tended to increase as pavement thickness decreased as shown in Figure 8. Three test sites with asphalt thicknesses less than or equal to 127 mm (5 in.) produced the best correlation with $r^2 = 0.873$. Two test sites with an asphalt thickness of 152 mm (6 in.) followed with $r^2 = 0.559$. However, when excluding moduli greater than 4000 MPa the correlation improves with $r^2 = 0.802$. Route 1A served as the single test site with a 180 mm (7 in.) asphalt thickness and produced the poorest correlation with $r^2 =$
0.336. Data from all sites is shown in Figure 9. Regression analysis yielded a correlation coefficient of 0.531, however, when excluding all moduli greater than 4000 MPa (Figure 10), the correlation improved with $r^2 = 0.809$. Overall, a strong correlation exists between the PFWD composite moduli and FWD derived composite moduli for asphalt surfaced roads. Mean moduli for individual asphalt thicknesses are shown in Table 5. The FWD and PFWD composite moduli are lower for the 178 mm (7 in.) asphalt thickness than the 127 mm (5 in.) thickness.

CONCLUSIONS
The conclusions listed below are based on the work presented in this report and the experience of the researchers in using a PFWD.

1. PFWD composite moduli follow similar trends to composite moduli and subbase moduli as determined from FWD measurements on asphalt surfaced roads.
2. The correlation between composite modulus derived by the PFWD and traditional FWD increases with decreasing asphalt thickness.
3. The PFWD can be used as a tool to evaluate whether specific roadways experience strength loss during the spring thaw and thus warrant load restrictions. For roads where load restrictions are placed, the PFWD can be used as an aid in determining when restrictions should be placed and removed.

ACKNOWLEDGMENTS
The authors would like to acknowledge the New England Transportation Consortium for providing funding for this research project. Additional thanks to the Maine Department of Transportation, U.S. Army Corps of Engineers Cold Regions Research & Engineering Laboratory, Vermont Agency of Transportation, NH Department of Transportation, USDA Forest Service, and the Town of Rumney, New Hampshire.

REFERENCES


Transportation Consortium, by the Department of Civil and Environmental Engineering, University of Maine, Orono, Maine, pp. 316.


(6) AASHTOWare® DARWin 3.1™ - Pavement Design and Analysis System, Computerized version of 1993 AASHTO Guide for Design of Pavement Structures


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TABLE 1 Summary of Asphalt Surfaced, Seasonally Posted, Low Volume Road Field Test Sites

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Location</th>
<th>HMA Thickness mm (in.)</th>
<th>Subbase Aggregate Thickness mm (in.)</th>
<th>Subgrade Type</th>
<th>Instrumentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kennebec Rd</td>
<td>Hampden / Dixmont, Me.</td>
<td>152 (6)</td>
<td>203 (8)</td>
<td>Silty Sand</td>
<td>Thermocouples, Piezometers,</td>
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<td>Stinson Lake Rd</td>
<td>Rumney, N.H.</td>
<td>127 (5)</td>
<td>305-381 (12-15)</td>
<td>Silty Clay To Silty Sand</td>
<td>Thermistors, Standpipe piezometer, TDR²</td>
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<tr>
<td>Buffalo Rd</td>
<td>Rumney, N.H.</td>
<td>127 (5)</td>
<td>300 (12)</td>
<td>Silty Sand</td>
<td>Thermocouple, Frost Tube</td>
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<tr>
<td>Knapp Airport Parking Lot</td>
<td>Berlin, Vt.</td>
<td>127 (5)</td>
<td>300 (12)</td>
<td>Silty Sand</td>
<td>Frost Tube</td>
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<td>Witter Farm Road</td>
<td>Orono, Me.</td>
<td>127 (5)</td>
<td>483 (19) 288 (11.3)</td>
<td>Silty Clay</td>
<td>Thermocouples, Standpipe piezometers</td>
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<td></td>
<td></td>
<td>127 (5)</td>
<td>483 (19) 326 (12.8)</td>
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<td></td>
<td></td>
<td>127 (5)</td>
<td>635 (25)</td>
<td>Silty Clay</td>
<td>Thermocouples, Piezometers</td>
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<td>Route 126</td>
<td>Monmouth / Litchfield, Me.</td>
<td>150 (6)</td>
<td>600 (24)</td>
<td>Silty Clay To Silty Sand</td>
<td>Thermocouples, Piezometers</td>
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<td></td>
<td></td>
<td>150 (6)</td>
<td>300 (12)</td>
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<td></td>
<td></td>
<td>150 (6)</td>
<td>150 (6) grindings</td>
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<td>Route 1A</td>
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<td>Silty Clay To Sandy Gravel</td>
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<td></td>
<td>180 (7)</td>
<td>640 (25)</td>
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<td>180 (7)</td>
<td>640 (25)</td>
<td>Silty Clay To Sandy Gravel</td>
<td>Thermocouples, Piezometers</td>
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1 – HMA = hot mix asphalt
2 – TDR = time domain reflectometry
TABLE 2  Prima 100 PFWD Input Parameters used for this study

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<tr>
<th>Setup Menu Item</th>
<th>Input Parameter</th>
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<td>Pretrig time (ms)</td>
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<td></td>
<td>Pulsebase (%)</td>
<td>24*</td>
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<td></td>
<td>Trig Level (kN)</td>
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<td>View</td>
<td>Sample Time (ms)</td>
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<td>Mechanical</td>
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<td></td>
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<td>D_{1j}, offset (cm)</td>
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<td></td>
<td>D_{2j}, offset (cm)</td>
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<td></td>
<td>D_{3j}, offset (cm)</td>
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<td>Formula</td>
<td>Poisson’s Ratio</td>
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<td>Stress Distribution, f</td>
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* - default values recommended by manufacturer.
### TABLE 3 Summary of PFWD and FWD Composite Moduli at the End of Thawing and During Recovery Periods

<table>
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<tr>
<th>Field Test Site</th>
<th>Test Section</th>
<th>Date of Complete Thaw</th>
<th>Average PFWD Composite Modulus (MPa)</th>
<th>Average FWD Composite Modulus (MPa)</th>
<th>Date of Final Reading</th>
<th>Average PFWD Composite Modulus (MPa)</th>
<th>Average FWD Composite Modulus (MPa)</th>
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<tr>
<td>Witter Farm Road</td>
<td>Control</td>
<td>4/20</td>
<td>524</td>
<td>446</td>
<td></td>
<td>6/28</td>
<td>434</td>
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<tr>
<td></td>
<td>2</td>
<td>3/25</td>
<td>999</td>
<td>751</td>
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<td>1</td>
<td>4/16</td>
<td>466</td>
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<td>6/29</td>
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<tr>
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<td>D-2</td>
<td>3/16</td>
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<td></td>
<td>308</td>
</tr>
<tr>
<td></td>
<td>E-3</td>
<td>3/23</td>
<td>457</td>
<td>474</td>
<td></td>
<td></td>
<td>319</td>
</tr>
<tr>
<td>Stinson Lake Road</td>
<td>1</td>
<td>4/19</td>
<td>279</td>
<td>NA</td>
<td></td>
<td>6/9</td>
<td>179</td>
</tr>
</tbody>
</table>

*NA – Composite modulus unavailable for spring thaw field test sites outside of Maine.*
TABLE 4 Summary of Load Restrictions for Spring Thaw Field Test Sites

<table>
<thead>
<tr>
<th>Test Site</th>
<th>Restriction Posting Date</th>
<th>Date of Minimum Modulus</th>
<th>Restriction Removal Date</th>
<th>Date of Final Reading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PFWD</td>
<td>FWD</td>
<td>PFWD</td>
<td>FWD</td>
</tr>
<tr>
<td>Knapp Airport Parking Lot</td>
<td>NA</td>
<td>NA</td>
<td>3/26</td>
<td>4/2</td>
</tr>
</tbody>
</table>

NA – not available, could not be determined from available data.
### TABLE 5  FWD and PFWD Mean Composite Moduli for Different Asphalt Thicknesses

<table>
<thead>
<tr>
<th>Asphalt Thickness (mm in.)</th>
<th>PFWD Mean Composite Modulus (MPa)</th>
<th>FWD Mean Composite Modulus (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>127 (5)</td>
<td>645</td>
<td>557</td>
</tr>
<tr>
<td>150 (6)</td>
<td>483</td>
<td>658</td>
</tr>
<tr>
<td>180 (7)</td>
<td>503</td>
<td>505</td>
</tr>
</tbody>
</table>
FIGURE 1  (a) Prima 100 PFWD and (b) Personal Digital Assistant.
FIGURE 2 Stiffness variations at Kennebec Road (Section 1), Hampden/Dixmont, Maine.
FIGURE 3 Stiffness variations at Buffalo Road, Runney, New Hampshire.
FIGURE 4 Stiffness variations at Stinson Lake Road, Rumney, New Hampshire.
FIGURE 5 Stiffness variations at Knapp Airport Parking Lot, Berlin, Vermont.
FIGURE 6 Stiffness variations at Witter Farm Road (Control Section), Orono, Maine.
FIGURE 7 Buffalo Road, Rumney, New Hampshire.
FIGURE 8 (a) Comparison of FWD and PFWD composite moduli for asphalt thicknesses ≤ 127 mm (5 in.) and (b) Comparison of FWD and PFWD composite moduli for asphalt thicknesses equal to 152 mm (6 in.).
Equation \( Y = 0.747X + 177.978 \)

Coef of determination, \( R^2 \) = 0.802

FIGURE 9  Comparison of FWD and PFWD composite moduli for all asphalt surfaced test sites.
FIGURE 10 (a) Comparison of FWD and PFWD composite moduli for all asphalt surfaced test sites and (b) Comparison of FWD and PFWD composite moduli for all asphalt surfaced test sites and moduli ≤ 4000 MPa.