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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Guide for Nondestructive Testing of Pavements Using Cyclic-Loading Dynamic Deflection Equipment[1]

This standard is issued under the fixed designation D 4602; 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.

ϵ^1 NOTE—Paragraph 1.7 was added editorially in October 1998.

1. Scope

1.1 This guide covers the preparation, equipment, calibration of equipment, location of test points, magnitudes and configurations of applied loads, cyclic frequencies, and presentation of data for nondestructive testing of pavements using cyclic-loading dynamic deflection equipment.

1.2 Cyclic-loading dynamic deflection equipment includes a group of devices that induce a steady-state sinusoidal vibration in the pavement through cyclic generation of a dynamic load. All such devices apply a static load on the pavement surface, resulting in a static deflection, and then induce some sinusoidal load and consequent deflection around the static load and deflection through an applied steady-state dynamic load.

1.3 As there are great differences between various cyclic-loading dynamic deflection devices, this guide is intended to give uniformly-applicable guidance, rather than specific instructions, for their use. For instance, it will specify that calibration of the devices and their instrumentation be carried out at the frequencies and in accordance with procedures recommended by their manufacturers, rather than providing specific instructions. Also, data is specified for collection that should prove adequate for usual applications of such deflection data, but no procedures are included for "back-calculating" elastic moduli of pavement layers or other such applications.

1.4 This guide does not apply to static deflection equipment, such as the "Benkelman Beam," automated beam deflection equipment, such as the "California Traveling Deflectometer," or impulse deflection equipment, such as the "Falling Weight Deflectometer."

1.5 It is common practice in the engineering profession to use concurrently pounds to represent both a unit of mass (lbm) and of force (lbf). This implicitly combines two separate systems of units, that is, the absolute system and the gravitational system. It is scientifically undesirable to combine the use of two separate sets of inch-pound units within a single standard. This guide has been written using the gravitational system of units when dealing with the inch-pound system. In this system, the pound (lbf) represents a unit of force (weight). However, the use of balances or scales recording pounds of mass (lbm), or the recording of density in lbm/ft^3 should not be regarded as nonconformance with this guide.

1.6 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

2. Terminology

2.1 *Definitions of Terms Specific to This Standard:*

2.1.1 *test location*—the point at which the center of the applied load or loads are located.

3. Significance and Use

3.1 Nondestructive testing of pavements to obtain deflection data for use in pavement evaluation and overlay design has become common. While the diversity of equipment and data applications make specific procedures infeasible, this guide is intended to encourage the collection of sufficient deflection data, adequate calibration of equipment, and implementation of general procedures leading to better quality and more uniform deflection measurements.

4. Apparatus

4.1 The most common commercially available devices are

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the "Dynaflect" device and various models of the "Road Rater."[2]

NOTE 1—This guide has not been written with the intent to exclude any current or future manufacturer of equipment or of newer models or modifications of equipment listed herein to perform these types of tests. The subcommittee welcomes information on such devices for inclusion in future revisions of this guide.

4.2 *Dynaflect*—A trailer-mounted device that has a static weight of 2000 to 2100 lbf (8.88 to 9.24 kN) has been found to be satisfactory. The load is applied through two steel wheels, each 4 in. (102 mm) wide and 16 in. (406 mm) in diameter. The loading surface of each wheel is coated with urethane having a uniform thickness of about ⅜ in. (9.53 mm). These wheels are spaced 20 in. (508 mm) apart, center to center, and apply a total peak-to-valley dynamic force of 1000 lbf (4.45 kN) at a fixed frequency of 8 Hz. The total force applied varies from approximately 1500 to 2500 lbf (6.67 to 11.12 kN). Deflections are measured implicitly by five velocity transducers suspended from a "placing bar" that may be lowered to place the sensors on the pavement. Sensor 1 is located equidistant between and in axial alignment with the load wheels. The other four are also equidistant from the load wheels, located at intervals of 1 ft (0.30 m) toward the front of the trailer.

4.3 *Road Rater Devices*—Some models of Road Rater devices are trailer mounted, some models are mounted on the front of a vehicle, and other versions are mounted in a van so that the head is lowered just to the rear of the rear axle of the vehicle. Both loading frequency and magnitudes of dynamic loads may be varied by the operator. Depending on the model, normal operating frequencies range from 10 to 60 Hz and maximum dynamic forces range from 950 to 5500 lbf (2.00 to 24.46 kN). The four models in common use are as follows:

4.3.1 *Model 400B*—This model has a trailer weight of 3000 lbf (13.33 kN). Its maximum rated static load is 2400 lbf (10.66 kN), created by the weight of the force actuation system and hydraulic pressure against the trailer. The peak-to-valley magnitudes of dynamic forces applied range is from 500 to 3000 lbf (2.22 to 13.33 kN). The loads are applied through two standard loading plates 4 in. (102 mm) wide by 7 in. (178 mm) long, located on 9½ in. (241 mm) centers, with the long dimensions in the direction of trailer travel. Deflections are measured implicitly by four velocity transducers with sensor 1 equidistant between, and in axial alignment with, the load feet. The other sensors are located at 1-ft (0.30-m) intervals. Additional sensors may be provided with different lengths of placement bars, or the same sensors can be mounted at different locations.

4.3.2 *Model 400A*—This model is similar to the Model 400B, but is mounted on the front bumper of the vehicle and provides peak-to-valley magnitudes of dynamic forces from 450 to 950 lbf (2.00 to 4.23 kN). Five preset operating frequencies range from 10 to 40 Hz. The centers of the loading plates are spaced at 10-in. (254-mm) intervals. This model may have from two to four sensors, depending on the age of the unit.

4.3.3 *Model 2000*—This model has a trailer weight of 4300 lbf (19.1 kN), a maximum rated static load of 3800 lbf (16.9 kN), and a peak-to-valley dynamic force ranging from 1000 to 5500 lbf (4.44 to 24.46 kN). A van version utilizes the same range of dynamic force. Loads are usually applied through a single plate 18 in. (457 mm) in diameter. Sensor 1 is located at the center of the loading plate, with the other three (or more) sensors located at 1-ft (0.30-m) increments, as for the Model 400B and the Dynaflect. There is an optional model for which two rectangular plates 4 by 7 in. (102.6 by 177.8 mm) are substituted for the circular load plate.

4.3.4 *Model 2008*—This model has a trailer load of 7000 lbf (31.09 kN), a maximum rated static load of 5800 lbf (25.76 kN), and a peak-to-valley dynamic force ranging from 1200 to 8000 lbf (5.34 to 35.54 kN). The same load plate and transducers as used by Model 2008 are used for Model 2000.

4.4 Either single or dual circular loading plates or load wheels may be used.

4.5 Although not critical to calculations using results of dynamic deflection testing, most devices now have sensor 1 at the center of load (see Note 2) and the other sensors at 1-ft (0.30-m) intervals from that point. This appears to be a practical spacing, but greater spacing may sometimes be required for wide deflection basins experienced on heavy-duty airfield pavements. Similarly, most deflection measurement devices now have four or more sensors to satisfactorily measure the deflection basin. As many pavements have a number of different layers, five sensors is the preferred minimum number where layer elastic moduli are to be back-calculated. The number of layer moduli to be calculated cannot exceed the number of sensors.

NOTE 2—It is preferable that the sensors be in contact with the pavement and isolated from the loading plate (or plates).

5. Calibration

5.1 All cyclic-loading dynamic deflection devices shall be carefully maintained and calibrated in accordance with the manufacturers' operating and maintenance instructions for the devices. As a minimum, loading frequency and load cells measuring applied loads for devices with capabilities for varying magnitude and frequency of loading shall be checked every fifth day of production testing, or when the operator has reason to believe that indicated operating frequencies or measured loads are incorrect.

5.2 *Dynaflect*—Calibration of the dynamic-load application device for the Dynaflect requires specialized equipment generally not available except at the manufacturer's location. The device shall be calibrated at the time of purchase and certified results shall be furnished the purchaser. Potential error from variations in applied loads for this device is nominal; thus, retesting after leaving the factory is not considered a requirement. Calibration for applied load shall be conducted indirectly monthly by checking the frequency of the counter-rotating fly wheels with a strobe light. Velocity transducers shall be

[2] The Dynaflect device is manufactured by the SIE division of Geosource, Inc. of Fort Worth, TX. The Road Rater is manufactured by Foundation Mechanics, Inc. of El Segundo, CA. Cox and Sons, Inc. of California have built custom devices, including a very sophisticated device for the Federal Highway Administration nicknamed the "Thumper". The U.S. Army Engineer Waterways Experiment Station (WES) also uses a custom-built cyclic-loading dynamic device called the "WES 16-kip (71,172 N) Vibrator". Shell also developed a "4-kip (17,793 N) Vibrator" for pavement evaluation.

calibrated each day the device is in use.

5.3 *Road Rater*—The force transducer shall be calibrated daily by checking the measured force under the known mass of the mass unit. At the beginning of each project and at five-day intervals, a field calibration check of the velocity transducers as recommended by the manufacturer shall be conducted by placing all transducers equidistant from the load plate. If significant differences are noted for a transducer, it shall be returned to the manufacturer for check or calibration under standard calibration vibration. The manufacturer recommends that velocity transducers be returned annually for check and recalibration.

6. Test Locations

6.1 Locations selected for testing are necessarily dependent on the type of pavement, purpose of testing, and intended utilization of test data. It is common practice to make measurements in wheel paths for both highway or airfield pavements; for comparison, a limited number of measurements are often taken in less trafficked areas or along the edge of the pavement.

6.2 The distance between measurement series usually depends on: (*1*) type of pavement, (*2*) whether a single test is run at discrete intervals along the pavement or several tests are run at close spacing before moving another discrete interval for the next measurement series, and (*3*) on the length of the pavement to be tested. For example, a measurement series every mile may be adequate for 100 miles (161 km) of highway, whereas a single test every 300 ft may be warranted for a 10 000-ft (3048-m) runway. In the latter case, test series are usually conducted along parallel paths, with test locations staggered to provide closer spacing for individual tests. While test programs usually should be planned with some uniform discrete distances between test locations, additional testing shall be conducted where unusual conditions are noted (an example would be an intermediate location where moisture is noted seeping through cracks in the pavement).

6.3 While single measurements at discrete intervals are common, some prefer to run "measurement series" in close proximity to increase the confidence level in the test results at each location.

6.3.1 *Jointed Concrete Pavements*—In the case of jointed rigid pavements, tests are usually conducted in the wheel path at mid-slab and with the load near a joint and sensors spanning the joint to obtain data on joint efficiency. As wheel paths are difficult to locate on rigid pavements, the center of load for highway pavements may be placed between 18 and 24 in. (457 and 610 mm) from the edge of the pavement or the edge of the lane. Deflections are also often taken with the load located at corners for void detection. Where the test results are to be used for back-calculation of layer elastic moduli, it is usually preferable to test near the center of the slab to avoid edge effects.

6.3.2 *Continuously Reinforced Concrete Pavements*—Testing is usually conducted as for jointed rigid pavements, except that the discrete slabs between cracks are usually small and loading both at mid-slab and near a crack (in lieu of a joint) may not be appropriate for all measurements.

7. Magnitudes of Applied Loads

7.1 The nonlinear strain responses of the soil and soil-like components of a pavement structure introduce an apparent advantage for approximating as closely as possible the wheel loads expected in magnitude and applied pressure. Since only a few of the devices have been capable of producing such loads, procedures have been developed for establishing stress sensitivity of subgrade, subbase, and base materials in the laboratory and consideration of those stress sensitivities in analyses. While this can be done with reasonable success, it generally will be advantageous to use an applied load approximating as closely as possible the design wheel load or that of interest to reduce the extrapolation required.

7.2 Where deflection measurements by four or more sensors are to be used for back-calculation of layer moduli, it is useful to make measurements at several load levels if the device in use has the capability for varying applied loads. This allows approximate evaluation of stress sensitivity for the various layers from the deflection data.

8. Cyclic Frequency

8.1 The Dynaflect device operates at a fixed loading frequency of 8 Hz, but the frequency may be varied for most other devices.

8.2 Measured deflections are functions of the driving frequency of the force generator, so the frequency selected is important. Measured deflections for a particular applied load generally increase with increasing frequency to some maxima at frequencies in the range of 8 to 20 Hz, depending on the pavement structure, the applied load, and device characteristics. For higher frequencies, deflection magnitudes generally decrease with increasing frequency. The shapes of the force curves better simulate a sinusoid and measured errors are less in the frequency range where deflections are a maximum. Initial testing over a range of frequencies at the same test location is necessary to obtain the optimum frequency of loading for a particular combination of device, pavement structure, and applied load. Testing at frequencies at which response patterns are consistent is generally considered to be more important than duplicating traffic load frequencies.

8.3 It appears that the best correlation to a static response of the pavement for comparison to Benkelman Beam measurements will be obtained at 10 Hz or less.

9. Procedures

9.1 Procedures for conducting the specific testing shall be those furnished by the manufacturer of the device, as supplemented to reflect the general guidelines provided in this guide. General procedures independent of the device used are provided in 9.2.

9.2 The general procedure for deflection testing is as follows:

9.2.1 Measure ambient air temperature at the beginning of testing and at intervals of no more than 2 h while testing is in progress. Temperatures at the surface of asphaltic concrete surface layers also shall be measured at intervals of no more than 2 h if required for predicting pavement temperatures or normalizing deflections for a specific temperature. Where direct measurements of temperatures within asphaltic concrete surface layers are to be used, in lieu of calculated values for back-calculation of elastic moduli or for other analysis requirements, these measurements also shall be made at intervals of no more than 2 h.

NOTE 3—While not commonly done, some engineers require temperature measurements in Portland cement concrete surface layers to assist in consideration of curling or warping, or both, in the analysis. Others select a time of day when curling or warping is minimal to conduct measurements. Curling and warping can greatly affect measured deflections due to their effects on slab support.

9.2.2 Locate the device such that the center of load is at the selected test location and the sensor bar is parallel to the direction of travel (or across the joint for longitudinal or skewed joints).

9.2.3 Lower the sensor bar to position sensors and the loading plate (or plates), or loading wheels. Initiate force generation until stability is reached at the selected loading frequency and load magnitude.

NOTE 4—The sensor bars are lowered first (or automatically when the loading plate is positioned) for most devices. For the Dynaflect, the load wheels rotate downward and lift the trailer before the sensor bar is lowered.

9.2.4 Read and record measured deflections for each of the sensors, either manually on data sheets or directly if data recording is automated.

10. Report

10.1 Record the following information:

10.1.1 The time, date, identification of the pavement tested, operator, and type of device used.

10.1.2 Describe loading plates in detail.

10.1.3 Ambient temperature shall be entered at intervals of 2 h during testing. If required, for reasons discussed in 9.2.1, temperatures at or within the pavement surface also shall be recorded at intervals of no more than 2 h.

10.1.4 Identify the test location for each test in terms of station numbers, location on rigid pavement slab, inner or outer wheel path, or distance from other identifying features such as center of slab, cracks, or joints.

10.1.5 Enter measured deflections (Note 5) for each sensor so that the data may be used for calculating such parameters as spreadibility, or for back-calculating elastic layer moduli.

10.1.6 Record the magnitude of the applied dynamic load (Note 5) and the frequency of the force generator for each test, or series of tests when they remain constant.

NOTE 5—The deflection signal from the force and motion sensors are wave forms which contain noise and usually deviate from being truly sinusoidal. The amount of deviation varies with apparatus type, force level, frequency of testing, nature of contact with pavement surface, and with pavement and subgrade conditions. For these reasons, it is recommended that reported peak (or peak to peak) values of force and deflection be based on root-mean-square (RMS) processing of the electrical signal. Other methods which do not incorporate RMS processing are technically only correct for truly sinusoidal wave forms and can lead to significant errors and inconsistencies of reported values.

11. Keywords

11.1 cyclic-loading; deflection; elastic moduli; nondestructive