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METHODS OF TEST TO OBTAIN FLEXIBLE PAVEMENT DEFLECTION MEASUREMENTS FOR DETERMINING PAVEMENT REHABILITATION REQUIREMENTS

CAUTION: Prior to handling test materials, performing equipment setups, and/or conducting this method, testers are required to read "**SAFETY AND HEALTH**" in Section G of this method. It is the responsibility of the user of this method to consult and use appropriate safety and health practices and determine the applicability of regulatory limitations before any testing is performed.

A. SCOPE

Three flexible pavement deflection-measuring methods varying in the type of the nondestructive deflection testing (NDT) are described. The methods consist of measuring the total deflection resulting from a load applied on the surface of a flexible pavement.

B. EQUIPMENT

The three primary types of deflection measuring methods consist of a probe, geophone, or seismometer that measures the pavement's vertical movement when the pavement is subjected to loading from either a rolling wheel, vibratory load, or falling weight. The following is a brief description of these three deflection-testing methods.

1. Rolling Wheel Loading - The device used for loading the measurement point should be able to exert a force equivalent to an 80 kN single axle test load. Since the early 1960's, Caltrans research data have been based on deflections obtained by using the *California Traveling Deflectometer*, as the rolling wheel load. Vertical movements (deflections) induced by the *California Traveling Deflectometer* were measured using the *Benkelman Beam.* The trailer of the *California Traveling Deflectometer* consists of a mechanical arm that places the probe between the dual wheels on a single rear axle. The dual wheels were reconfigured so that the probe is easy to insert. The probe measures the deflection of the pavement as the dual wheels pass the point. *The California Traveling Deflectometer* built by Caltrans was one of a kind and was operated for routine work until 1969, and for research work until 1980. After it was no longer practical to use it due to the age of its electronics, the trailer portion was retained, modified, and used to apply loads to pavement measurement points to perpetuate the standard deflection device. This trailer unit is now referred to as the *California Deflectometer* (Figure 1), and is used for loading the measurement site as a towed semi-trailer carrying an 80 kN single axle test load. The distance from the kingpin to the rear axle is 8.10 m. The tires are dual 279 mm × 572 mm in size, and are inflated to 483 kPa. The rear dual wheels have been reconfigured and welded to provide 155 mm between the footprints of one pair. The probe is inserted between one pair of dual tires. The truck then slowly creeps forward. As the dual tires depress the pavement while passing by the probe tip, the lower beam rotates and changes the reading

on the dial indicator. From this, the *California Deflectometer* deflection is determined.

In the development of Caltrans' flexible pavement overlay design method and most related past research, either the *California Traveling Deflectometer* or the *California Deflectometer* were used to load the pavement, while the *Benkelman Beam* was used to measure the induced deflection. The *Benkelman Beam* is an instrument that is normally used in conjunction with a rolling wheel load. The *Benkelman Beam* operates on a simple lever arm principle. It consists of a lower beam 3.66 m long that pivots at its third-point from an upper reference beam, which rests on the pavement behind the area of influence of the deflection basin. The front 2.44 m of the lower beam acts as a probe that moves vertically when the pavement deflects as the moving wheel load passes. The back 1.22 m then depresses a dial or digital indicator that displays half of the maximum deflection to within 0.025 mm. The probe is inserted between one pair of dual tires (as shown in Figure 1), so that its tip touches the pavement 1.37 m ahead of the center of the loading axle and the dial indicator is set to zero. (Other trucks may have different dual tire spacing but the spacing should allow beam placement between the wheels so there is no contact with the beam.) The truck then slowly creeps forward at approximately 3.2 Km/hr. As the dual tires deflect the pavement while passing by the probe tip, the lower beam rotates and the dial indicator will display half of the deflection. (Note that if the truck is going too fast, it is difficult to read the digital or dial display).

2. Vibratory Loading[1] - This type of loading is commercially available in both vehicle and trailer mounted models. All vibratory loading models operate on an oscillatory loading principle while stationary resulting in a dynamic deflection of a flexible pavement surface. During operation, the test vehicle must stop on the pavement while the deflection is being measured. The sensor placed at the center of loading plate measures the motion induced in the pavement. A control box, located in the vehicle, is used to operate the equipment and display the deflections.

   For purpose of flexible pavement rehabilitation design using the Caltrans deflection method, the vibratory loading-based deflection is converted to an equivalent *California Deflectometer* deflection by the use of correlation curves previously established between the two devices (discussed in Section E of this test method).

3. Falling Weight Loading[2] - A Falling Weight Deflectometer (FWD) is commercially available in both vehicle and trailer mounted models. FWD models vary primarily in the magnitude of the load. All FWD models operate on an impulse loading principle while stationary. An FWD provides an impulse load that can be varied depending on the height of fall and mass used. The energy is transferred to the pavement with a load pulse in approximately a half-sine waveform with 20 to 60 milliseconds duration through a plate that establishes a known load contact area. The sensor placed at the center of a loading plate measures the motion induced in the pavement. The pavement surface deflection is displayed on a computer screen located in the vehicle. The FWD should have a valid calibration certificate from one of the Strategic Highway Research Program (SHRP) Calibration Centers.

   For purpose of flexible pavement rehabilitation design using the Caltrans deflection method, the falling weight loading-based deflection is converted to

[1] Examples of this device include Dynaflect and Road Rater.

[2] Examples of this device include KUAB, Dynatest, and Phoenix JILS FWDs.

an equivalent *California Deflectometer* deflection by the use of correlation curves previously established between the two devices (discussed in Section E of this test method).

C. BACKGROUND DATA AND SELECTION OF TEST SITES

1. Preliminary Office Work:

   a. View computerized Photolog files and Pavement Condition Survey files to determine type of alignment, nature of distress and their locations, and unusual drainage conditions. If these files are not available or are outdated, the project should be visually inspected by the field operator or engineer to obtain these data prior to the deflection tests being performed, as explained in Section 2 below.

   b. Determine the existing structural section (layer materials and thicknesses) from contract records, previous deflection studies, or obtain it from the district. Note all variations. If the structural section data are not available or are outdated, schedule the coring crew to determine the existing structural section and condition.

   c. Review TASAS files (post-mile log) for the project location to determine locations of structures, intersecting streets, railroad crossings, etc.

   d. Obtain the design Traffic Index (TI) and design period from the district.

   e. Work with District Maintenance to arrange and schedule maintenance crew and equipment to perform traffic control, coring crew and equipment, and deflection testing crew and equipment.

2. Preliminary Field Work:

   Upon viewing the project in the field, determine if some of the following may be done in conjunction with the deflection data collection.

   a. Determine, photograph, and record the nature, extent, and limits of the various distresses (e.g., cracks, rutting, bleeding, raveling, patching, potholes, and localized failures). Also record the crack widths as hairline, 3 mm wide, 6 mm wide, or greater than 12 mm wide for all longitudinal, transverse, alligator, and block cracking. Record the crack frequency as isolated, occasional, intermittent, nearly continuous, or continuous. Note the limits of any structural section changes that are visible, local drainage problems, any vertical controls (e.g., curbs, gutters, structures, etc.), and any roadway intersections.

   b. Decide on the method of field deflection testing to be used. Two methods (Method A and Method B) varying in the extent of pavement coverage are available. Method A is the *preferred method that should be used on all projects*. However, depending on the local conditions, and taking into account sight distance, traffic, and type of facility, Method B may be used. Note that on one project, more than one method may be used, but good judgment with respect to test section consistency is needed. The two testing methods are described below and schematically illustrated in Figure 2.

      Method A – For all lanes considered for rehabilitation, measure deflection at 80-m intervals in the outside wheel path to obtain 21 deflection measurements per 1.6 lane-kilometer (13-14 measure-ments per lane-kilometer). If the project is shorter than 1.6 Km (such as in most freeway off-ramps and on-ramps), determine the size of the testing interval so as to obtain 21 deflection measurements within the traffic control area for the project. Begin testing at one kilometer post (KP) limit of the project, and proceed toward the other KP limit using the pre-determined test interval. Stagger testing pattern between adjacent lanes.

Method B – For each lane considered for rehabilitation, select one 300-m long test section that is "representative" of every 1.6 lane-kilometer of roadway. Select more test sections for each change in structural section or overall surface distress condition. The testing interval for deflection measurements would be approximately every 15 m to obtain 21 deflection measurements. If a project is less than 300 m in length, the entire project is considered the test section (similar to Method A), and determine the size of the testing interval to obtain 21 deflection measurements within the traffic control area for the project.

3. Deflection Testing Field Work:

   a. Reference each test section to an easily identifiable point in the field, or to known post mile limits.

   b. For safety considerations, discuss the test sections with traffic control personnel to include sufficient sight distance in both directions. Set up traffic control limits to avoid hazardous situations.

   c. Obtain representative photographs of each test section and all areas of major localized distress. Identify the project, lane, direction, location, and date the photographs. Photograph and identify any other important roadway features. Record all observed pavement conditions; road intersections, locations of large cuts and fills, vertical control features, post mile markers, and air and pavement surface temperatures. Also record any localized drainage and/or embankment settlement problems, any existing structural section data.

   d. Obtain deflection measurements per Method A or/and Method B.

   e. Obtain any necessary structural section information for each test section via coring. Determine the thickness and type of various materials in the structural section. When using Method A for deflection testing, take one core every 800 m (approximately) starting near either the initial or final kilometer post limit of the project, as illustrated in Figure 2. Alternatively, with Method B, obtain one core within each of the selected 300 m long test sections. Cores must be obtained from the outside wheel path of the tested lane. Photograph cores and record core data (e.g., layer depths, overall length, and base material type). Retain unused cores with unidentifiable materials for the engineer's review.

   f. Review all data for locations, direction, and completeness before leaving project site, and correct as necessary.

D. METHODS OF DATA COLLECTION

1. Rolling Wheel Loading *with Benkelman Beam* (WASHTO Method):

   a. Bring test vehicle to a stopped position at the beginning of the test section with the dual tires of the truck on the wheel path to be tested.

   b. Position the beam between the dual tires so that the probe is 1.37 m forward of and perpendicular to the rear axle.

   c. Activate the beam's vibrator and adjust the dial or digital indicator to read zero. If a digital display is used in lieu of a dial, a vibrator is not necessary.

d. Drive the test vehicle approximately 15 m forward at creep speed and record the maximum initial deflection reading (D_i) to the nearest 0.025 mm.

e. After the test vehicle has past the probe, the pavement rebounds and the dial indicator or digital display appears to be stabilized. Record the final reading (D_f) to the nearest 0.025 mm.

f. Record the *Benkelman Beam* pavement deflections on an appropriate data sheet. The *Benkelman Beam* pavement deflection is equal to $2D_i - D_f$. Also record the surface distress type in the vicinity of the test point, the ambient air and pavement surface temperatures during testing, test location description, equipment identification, and the date and time of testing. If the rolling wheel loading device is equipped with a laser for measuring deflections, follow the instructions provided with the equipment to obtain the deflection measurements.

2. Vibratory Loading:

   a. Prepare the unit for deflection testing.

   b. Calibrate the unit at the beginning of the shift.

   c. Bring the test vehicle to a stopped position at the beginning of the test section, centered on the outside wheel path, and take a measurement. The measurement from the sensor located at the center of loading is recorded as the pavement deflection.

   d. After each measurement, drive the test vehicle forward to the next measurement point.

   e. Record each of the vibratory loaded pavement deflections. Also record surface distress type in the vicinity of the test point, the ambient air and pavement surface temperatures during testing, the test location description, equipment identification, and the date and time of testing.

3. Falling Weight Deflectometer (FWD) Loading:

   a. Prepare the unit for deflection testing.

   b. Exercise the hydraulic system at the beginning of the shift.

   c. Bring the FWD to a stopped position at the beginning of the test section, centered on the outside wheel path, and take a measurement. Apply the loads using the following sequence:

      (1) One seating drop to ensure proper contact.

      (2) Three drops with an applied load of 40 kN ± 10 %.

      Deflections are recorded from the sensor located at the center of the loading plate for each drop except the seating drop. For this method, the average deflection from the three 40 kN drops is the FWD pavement deflection.

   f. After each measurement drive the FWD forward to the next measurement point.

   e. Record each of the FWD pavement deflection values. Also, record surface distress type in the vicinity of the test point, the ambient air and pavement surface temperatures during testing, the test location description, equipment identification, and the date and time of testing.

E. DOCUMENTATION AND CALCULATION

1. Compile all data produced by the preliminary office work, preliminary field work, and deflection testing field work, and organize the collected data. Create electronic files (spreadsheets, documents, photo presentations, etc.) for the project. Submit all data files the rehabilitation design engineer.

2. Calculations:

   a. Correlation – A correlation equation that relates deflection measurements obtained using any deflection device and the deflection measurements obtained using *California Deflectometer* (CD) can be developed and used to obtain the equivalent *California Deflectometer* deflection value. *California Deflectometer* is a one of its kind deflection device that is only available at Caltrans. In order to establish a reference deflection device with a wider availability, Caltrans investigated the relationship between the *California Deflectometer* deflections and deflections obtained using a special falling weight deflectometer (FWD). For this purpose, the FWD was selected to (a) provide 40 kN peak force, and (b) transfer the energy through a loading plate 300 mm in diameter. This special FWD is referred to herein as a reference FWD (FWD_{ref}). The relationship between deflections obtained using the two devices is $D(CD)=1.2\times D(FWD_{ref})$, where D is deflection value at approximately 21 ^{o}C. The coefficient of determination, R^2 for this equation is 0.93, and the number of data points used to derive it is equal to 439. Therefore, if an arbitrary deflection measuring device (e.g., an FWD other than the FWD_{ref}, rolling wheel, or vibratory load) is to be used for measuring deflections on State highways, run a correlation between that device and an FWD_{ref} that has a valid calibration certificate from one of the Strategic Highway Research Program (SHRP) Calibration Centers. The pavement for a correlation course should be relatively crack-free in the area of influence of the probe or sensor. The level of deflections should be in the same range as normal testing. The correlation equation representing the relationship between the deflection device to be used and the FWD_{ref} could be used to determine the *equivalent California Deflectometer* deflections for use in the Caltrans flexible pavement rehabilitation design.

   b. The pavement deflections produced by any type of loading device are converted to an equivalent *California Deflectometer* deflection, or an FWD_{ref} deflection, by the use of the proper correlation equation. Next, divide the project into a number of analysis units (sections) based on deflection measurements and structural section parameters. Then, for each analysis unit, compute the mean, standard deviation, and 80th percentile deflection (where 20% of the deflections are higher and 80% are lower than this level, and assuming normal probability distribution for the deflection data) from:

$$\overline{D} = \frac{\sum D_j}{n}$$

$$s_D = \sqrt{\frac{\Sigma\left(D_j - \overline{D}\right)^2}{n-1}}$$

$$D_{80} = \overline{D} + 0.84 \times s_D$$

where:

$\overline{D}$ = Mean of the *California Deflectometer* equivalent deflections in the analysis unit,

D_j = An individual (jth) *California Deflectometer* equivalent deflection in the analysis unit,

n = Total number of deflection measurements in the analysis unit,

D_{80} = 80^{th} percentile of the *California Deflectometer* equivalent deflections in the analysis unit, and

s_D = Standard deviation of the *California Deflectometer* equivalent deflections in the analysis unit.

3. Each deflection-measuring device to be used on State routes must be correlated with the *California Deflectometer* or a reference FWD (FWD_{ref}) at least once per year. The results of the correlation should be recorded in an appropriate form that is readily available.

4. The FWD used for either the correlation or for measuring deflections on State routes must be calibrated annually from one of the Strategic Highway Research Program (SHRP) Calibration Centers, and have the certificate readily available.

F. ANALYSIS OF DATA AND DESIGN OF PAVEMENT REHABILITATION STRATEGIES

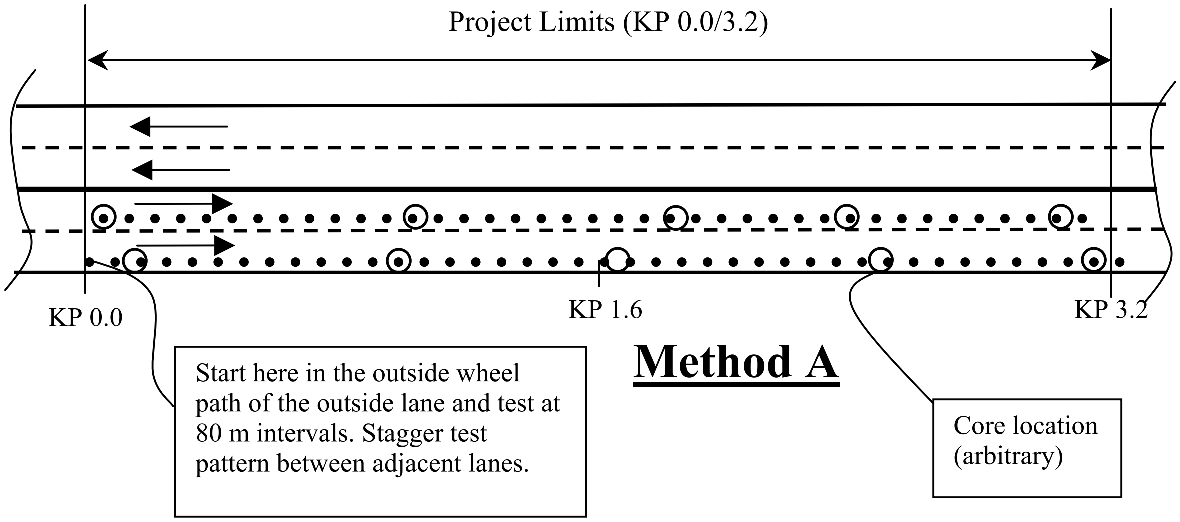
Refer to the "Flexible Pavement Rehabilitation Manual" prepared by the California Department of Transportation (Caltrans), Division of Engineering Services (DES), Office of Pavement Rehabilitation (OPR) of the Headquarters' Transportation Laboratory (TransLab). This manual is intended as a tool to provide guidance for those who are responsible for developing asphalt concrete pavement rehabilitation strategies for the State's highways based on flexible pavement deflection measurements as outlined above. The electronic version of this manual can be obtained from the Department's web site at www.dot.ca.gov/hq/esc/Translab/metspubs.htm.

G. SAFETY AND HEALTH

Prior to handling, testing or disposing of any waste materials, Caltrans testers are required to read Part A (Section 5.0), Part B (Sections 5.0, 6.0, and 10.0), and Part C (Section 2.0) of the *Caltrans Laboratory Safety Manual*. Users of this method do so at their own risk. Also Refer to Chapter 8 of the Caltrans Maintenance Manual for proper traffic control methods.

End of Text
(California Test 356 contains 9 pages)

Figure 1.
California deflectometer with Benkelman Beam placed between the dual tires of its rear axle.



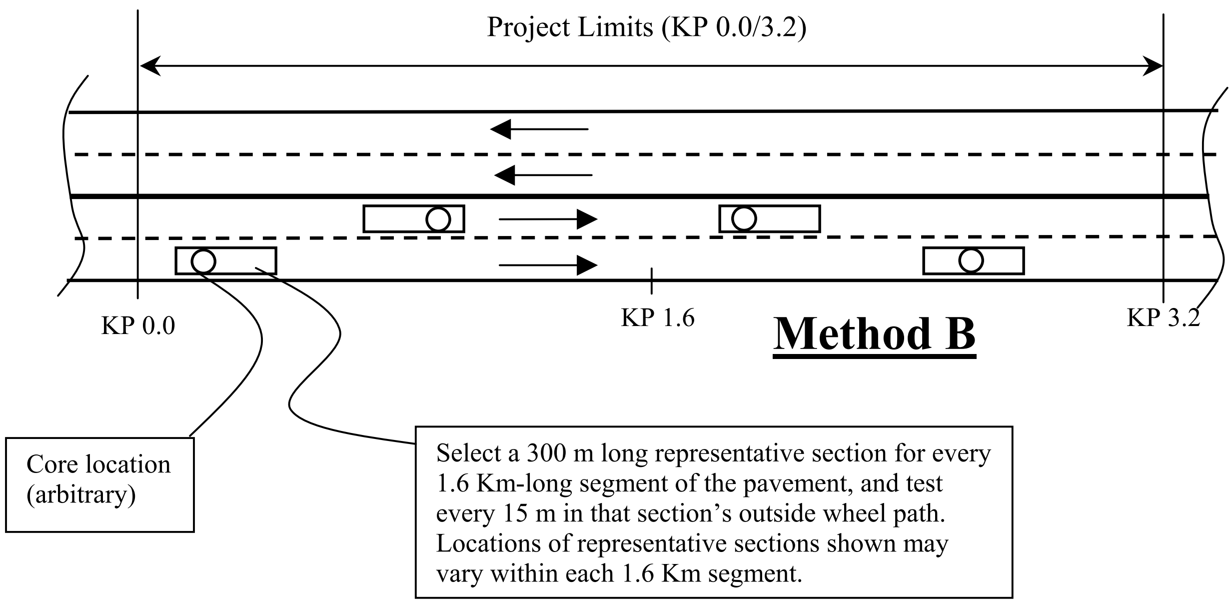


Figure 2.
Method A and Method B testing pattern for a four-lane highway in two lanes of one direction.