Mustansiriyah University / College of Engineering

Highway &Transportation Engineering Department

Highway Maintenance Course

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Presented by:

Assistance Prof. Dr.Siham I Salih

Assistance Prof. Dr.Sady A.Tayh

Lecture Five

Pavement Condition Rating Systems

Based on measurements of roughness, surface distress, skid resistance and deflection, pavements can be assigned a score that reflects their overall condition.

This score, sometimes called a pavement condition rating, quantifies a pavement's overall performance and can be used to help manage pavement networks. By carefully choosing the rating scale (called the condition index), pavement condition scores can be used to (Deighton, 1997[1])

- Trigger treatment. For instance, once a pavement's condition rating reaches a certain level, it can be scheduled for maintenance or rehabilitation. •
- Determine the extent and cost of repair. A pavement condition score is a numerical representation of a pavement's overall condition and can thus be used to estimate the extent of repair work and the likely cost. •
- Determine a network condition index. By combining pavement condition scores for an entire road network, a single score can be obtained that gives a general idea of the network condition as a whole.
- Allow equal comparison of different pavements. Since a pavement condition score accounts for all types of pavement performance measures it can be used to compare two or more pavements with different problems on an equal footing.

A pavement condition index is simply the scale, or series of numbers, used to describe a pavement condition.

Typical pavement condition indices may be based on a scale of 0 to 5 or perhaps 0 to 100. The proper pavement condition index depends upon the objectives of whatever system is used to manage a particular pavement network (called a Pavement Management System or PMS). This section presents two pavement condition index methods.

1. Present Serviceability Index (PSI)

The present serviceability index (PSI) is based on the original AASHO Road Test PSR. Basically, the PSR was a ride quality rating that required a panel of observers to actually ride in an automobile over the pavement in question.

Since this type of rating is not practical for large-scale pavement networks, a transition to a non-panel based system was needed.

PSI ranges from 5 (excellent) to 0 (essentially impassable), and is still used today throughout the country. It is often a good choice for a smaller, less sophisticated pavement rating system.

To transition from a PSR serviceability measure (panel developed) to a PSI serviceability measure (no panel required), a panel of raters during 1958 to 1960 rated various roads in the states of Illinois, Minnesota, and Indiana for PSR.

This information was then correlated to various pavement measurements (such as slope variance (profile), cracking, etc.) to develop PSI equations.

Further, the raters were asked to provide an opinion as to whether a specific pavement assessed for PSR was "acceptable" or "unacceptable" as a primary highway (see Figure 1).

Thus, although PSI is based on the same 5-point rating system as PSR it goes beyond a simple assessment of ride quality

About one-half of the panel of raters found a PSR of 3.0 acceptable and a PSR of 2.5 unacceptable. Such information was useful in selecting a "terminal" (or failure) serviceability (PSI) design input for empirical structural design equations.

It is interesting to note that the original AASHO Road Test rater opinions are based on car ride dynamics; it is unclear whether such levels are acceptable for trucks.

Pavement performance can then be defined as "The serviceability trend of a … (pavement segment) with increasing number of axle applications" (Highway Research Board, 1972[2]). Figure 1 further demonstrates this concept.

Concept of Pavement Performance Using Present Serviceability Index (PSI) (Hveem and Carmany, 1948))

2. Present Serviceability Rating (PSR)

The AASHO Road Test (Highway Research Board, 1972[2]) developed a definition of pavement serviceability، the present serviceability rating (PSR), that is based on individual observation. PSR is defined as "The judgment of an observer as to the current ability of a pavement to serve the traffic it is meant to serve" (Highway Research Board, 1972[2]).

To generate the original AASHO Road Test PSR scores, observers rode around the test tracks and rated their ride using the quantitative scale shown in Figure 1.

This subjective scale ranges from 5 (excellent) to 0 (essentially impassable). Since PSR is based on passenger interpretations of ride quality, it generally reflects road roughness because roughness determines ride quality.

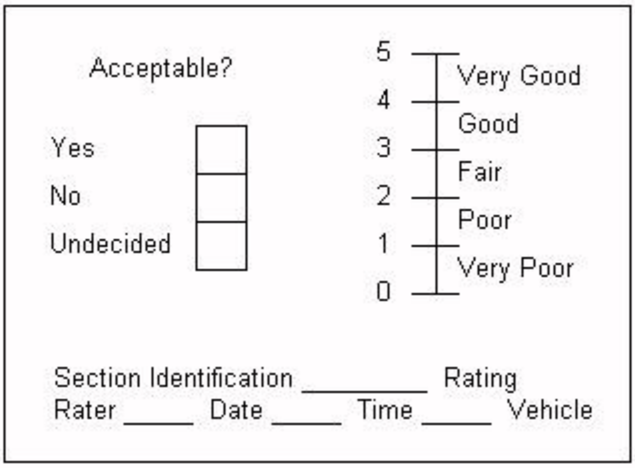

Figure 1. Reproduction of an individual present serviceability rating form.

3. Roughness

Pavement roughness is generally defined as an expression of irregularities in the pavement surface that adversely affect the ride quality of a vehicle (and thus the user).

Roughness is an important pavement characteristic because it affects not only ride quality but also vehicle delay costs, fuel consumption and maintenance costs.

The World Bank found road roughness to be a primary factor in the analyses and trade-offs involving road quality vs. user cost (UMTRI, 1998). Roughness is also referred to as "smoothness" although both terms refer to the same pavement qualities.

3.1Measurement

Today, roughness is typically quantified using some form of either present serviceability rating (PSR), international roughness index (IRI) or other index with IRI being most prevalent

3.2Interational Roughness Index (IRI)

The international roughness index (IRI) was developed by the World Bank in the 1980s (UMTRI, 1998). IRI is used to define a characteristic of the longitudinal profile of a traveled wheeltrack and constitutes a standardized roughness measurement. The commonly recommended units are meters per kilometer (m/km) or millimeters per meter (mm/m). The IRI is based on the average rectified slope (ARS), which is a filtered ratio of a standard vehicle's accumulated suspension motion (in mm, inches, etc.) divided by the distance traveled by the vehicle during the measurement (km, mi, etc.). IRI is then equal to ARS multiplied by 1,000. The open-ended IRI scale is shown in Figure 2.

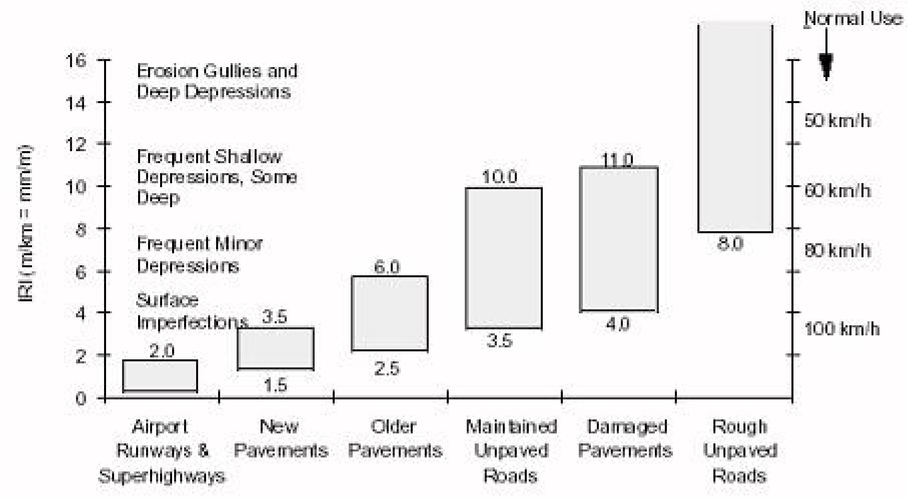

Figure 2. IRI roughness scale (replotted from Sayers et al., 1986).

3.3 Correlations Between PSR and IRI

Various correlations have been developed between PSR and IRI. Two are presented here. One was reported in 1986 by Paterson:

$PSR = 5e^{-0.18(IRI)}$ Another correlation was reported in a 1992 Illinois funded study performed by Al-Omari and Darter (1992):

$$PSR = 5e^{-0.26(IRI)}$$

For example , This study used data from the states of Indiana, Louisiana, Michigan, New Mexico, and Ohio for both flexible and rigid pavements. The associated regression statistics are R2 = 0.73, SEE = 0.39, and n = 332 sections. Correlations are highly dependent upon the data that are used.

3.4 Measurement Techniques

The equipment for roughness survey data collection can be categorized into the four broad categories shown in Table 1.

Table 1. Roughness Measuring Equipment

The following discussion with a few modifications was taken directly from the “Pavement Condition Data Collection Equipment” article in the FHWA Pavement Notebook (1989[4]).

Equipment / Technique	Complexity
Rod and level survey	most simple
Dipstick profiler	simple
Profilographs	simple
Response type road roughness meters (RTRRMs)	complex
Profiling devices	more complex

3.4.1 Survey

A survey (performed by a survey crew) can provide an accurate measurement of the pavement profile. The use of surveys for large projects, however, is impractical and cost prohibitive.

Figure 3. Dipstick 2000.

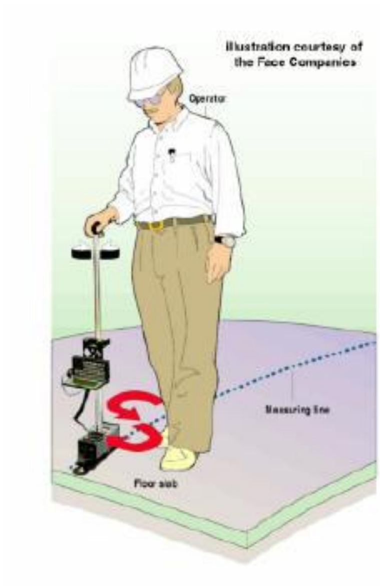

Figure 4. Dipstick Operation.

a. Dipstick Profiler

The dipstick profiler can be used to collect a relatively small quantity of pavement profile measurements. The Dipstick Profiler (see Figures 3 and 4) consists of an inclinometer enclosed in a case supported by two legs separated by 305 mm (12 in.). Two digital displays are provided, one at each end of the instrument. Each display reads the elevation of the leg at its end relative to the elevation of the other leg. The operator then "walks" the dipstick down a premarked pavement section by alternately pivoting the instrument about each leg. Readings are recorded sequentially as the operator traverses the section. The device records 10 to 15 readings per minute. Software analysis provides a profile accurate to ± 0.127 mm (± 0.005 in.). A strip can be surveyed by a single operator in about one-half the time of a traditional survey crew. The dipstick is commonly used to measure a profile for calibration of more complex instruments.

b. Profilographs

Profilographs have been available for many years and exist in a variety of different forms, configurations, and brands. Due to their design they are not practical for network condition surveys. Their most common use today is for rigid pavement construction inspection, . The major differences among the various profilographs involve the configuration of the wheels and the operation and measurement procedures of the various devices.

Profilographs have a sensing wheel, mounted to provide for free vertical movement at the center of the frame (Figure 5). The deviation against a reference plane, established from the profilograph frame, is recorded (automatically on some models) on graph paper from the motion of the sensing wheel (Figure 6). Profilographs can detect very slight surface deviations or undulations up to about 6 m (20 ft) in length.

Figure 5: Profilograph

Figure 6: Profilograph output:

c. Response Type Road Roughness Meters (RTRRMs)

The third category of roughness data collection equipment is the response type road roughness meters (RTRRMs), often called "road meters". RTRRM systems are adequate for routine monitoring of a pavement network and providing an overall picture of the condition of the network. The output can provide managers with a general indication of the overall network condition and maintenance needs

RTRRMs measure the vertical movements of the rear axle of an automobile or the axle of a trailer relative to the vehicle frame. The meters are installed in vehicles with a displacement transducer on the body located between the middle of the axle and the body of a passenger car or trailer. The transducer detects small increments of axle movement relative to the vehicle body. The output data consists of a strip chart plot of the actual axle body movement versus the time of travel.

The disadvantage of a RTRRM is that its measured axle body movement vs. time depends on the dynamics of the particular measurement vehicle, which results in two unwanted effects (UMTRI, 1998[1]):

- Roughness measuring methods have not been stable with time. Measures made today with road meters cannot be compared with confidence to those made several years ago.
- Roughness measurements have not been transportable. Road meter measures made by one system are seldom reproducible by another.

Because of these two effects, profiling devices are becoming more popular.

d. Profiling Devices

Profiling devices are used to provide accurate, scaled, and complete reproductions of the pavement profile within a certain range. They are available in several forms, and can be used for calibration of RTRRMs. The equipment can become fairly expensive and complex. Three generic types of profiling systems are in use today:

- Straight edge. The simplest profiling system is a straight edge. Modifications to the straight edge, such as mounting it on a wheel, result in a profilograph.

- Low speed systems. Low speed systems such as the CHLOE profilometer are moving reference planes. The CHLOE is a long trailer that is towed at low speeds of 3 to 8 kph (2 to 5 mph). The slow speed is necessary to prevent any dynamic response measurement during the readings. A few agencies still use the CHLOE to calibrate their RTRRMs.

- Inertial reference systems. Most sophisticated road profiling equipment uses the inertial reference system. The profiling device measures and computes longitudinal profile through the creation of an inertial reference by using accelerometers placed on the body of the measuring vehicle to measure the vehicle body motion. The relative displacement between the accelerometer and the pavement profile is measured with either a "contact" or a "non-contact" sensor system.

The earliest profiling devices used a measurement system in direct contact with the pavement to measure profile. Several contact systems have been used, and are still in use today. The French Road Research Laboratory developed the Longitudinal Profile Analyzer (APL) in 1968.

Systems used today in the United States are frequently installed in vans (Figure 7) which contain microcomputers and other data handling and processing instrumentation. Older profiling devices are usually contact systems, while the more recently manufactured devices use non-contact sensors. The non-contact systems use probes, either acoustic or light, to measure differences in the pavement surface. For instance, the South Dakota road profiler simultaneously collects three ultrasonic profiles, one for each wheelpath and one for the lane center. These profiles are used to calculate (by computer) a mathematical measure of roughness and an estimate of rutting at specified intervals along the roadway. A hybridized South Dakota road profiler combines the three ultrasonic sensors with two laser sensors, one for each wheelpath, for simultaneous measurement of the same roadway by two different sensor types under identical conditions (Virginia Transportation Research Council, 1996[5]). Integrated analysis units can continuously collect a wide variety of data at highway speeds such as:

- Transverse profile/rutting
- Pavement texture
- Pavement condition or distress
- GPS coordinates
- Panoramic right-of-way video
- Pavement video
- Feature location

Figure 7. South Dakota Road Profiler (van-mounted)

Figure 8. Imaging survey van used by the state materials office of the Florida DOT. The profiler is the grey/silver box attached on the front bumper

Table 2. Roughness Data Collection Equipment (from FHWA, 1989[4]

Roughness Data Collection Device	Principle of Measurement	Relative Initial Cost	Relative Data Collection Cost (Network)	Relative Degree of Accuracy	Approximate Decade of Development	Extent of Current Use	Projected Extent of Use
Dipstick	Direct Differential Measurement	Low	Impractical	Very High	1980s	Limited, Used for Calibration	Same as Current Use
Profilographs	Direct Profile Recordation	Low	Impractical	Medium	1960s	Extensive for Const. Acceptance	Same as Current Use
BPR Roughometer	Device Response	Low	Low	Medium	1940s	Limited	None
Mays Meter	Vehicle Response	Low	Low	Medium	1960s	Extensive	Decreasing Continuously
South Dakota Road Profiler	Direct Profile Recordation	Medium	Low	High	1980s	Growing	Rapidly Increasing
Contact Profiling Device	Direct Profile Recordation	High	Medium	Very High	1970s	Limited	Decreasing
Non-Contact Profiling Device	Direct Profile Recordation	High	Medium	Very High	1980s	Medium	Increasing Continuously

4. Surface Distress

Surface distress is "Any indication of poor or unfavorable pavement performance or signs of impending failure; any unsatisfactory performance of a pavement short of failure" (Highway Research Board, 1970[1]). Surface distress modes can be broadly classified into the following three groups:

Fracture. This could be in the form of cracking (in flexible and rigid pavements) or spalling resulting from such things as excessive loading, fatigue, thermal changes, moisture damage, slippage or contraction.

Distortion. This is in the form of deformation (e.g., rutting, corrugation and shoving), which can result from such things as excessive loading, creep, densification, consolidation, swelling, or frost action.

Disintegration. This is in the form of stripping. raveling or spalling, which can result from such things as loss of bonding, chemical reactivity, traffic abrasion, aggregate degradation, poor consolidation/compaction or binder aging.

Thus, surface distress will be somewhat related to roughness (the more cracks, distortion and disintegration – the rougher the pavement will be) as well as structural integrity (surface distress can be a sign of impending or current structural problems).

4.1 Photo Gallery

An extensive pavement distress discussion (with photos) can be found at:

HMA Pavement Distress
PCC Pavement Distress

These galleries include all the major types of pavement damage/distress. Each distress discussion includes (1) pictures if available, (2) a description of the distress, (3) why the distress is a problem and (4) typical causes of the distress. The gallery is organized alphabetically and the pictures are not included in the Module list of figures.

4.2 Measurement

Measures of distress can be either subjective or objective. A simple example of a subjective measurement may be a rating of high, medium, or low based on a brief visual inspection. Objective measurements, which are generally more expensive to obtain, use different types of automated distress detection equipment.

4.3 Measurement Techniques

Measurement techniques are mostly visual. Older techniques, used teams of individuals who drove across every mile of pavement to be measured. Speeds were usually quite slow (on the order of 16 km/hr (10 mph)) and measurement was done visually. More current methods record pavement

surface video images at highway speed using a specially equipped van (see Figures 9 and 10) that is outfitted with high resolution cameras. Evaluation is either done manually by playing the video back on specially designed workstations (see Figure 11) while trained crews rate the recorded road surface (see Figure 4) or automatically by computer software (see Figure 12). Advantages of these more current methods are (Sivaneswaran and Pierce, 2001

- Safety. Data are collected at highway speed, eliminating the need for driving at slow speeds or on the shoulder.
- Accurate and complete distress data. Each distress along with its extent, severity and location is identified and stored in a database. The system is also less prone to rating errors.
- More effective quality control. A centralized evaluation location and less subjective data make quality control much better.
- More efficient data collection. Surface distress, rut and roughness data are all collected at the same time using the same data collecting vehicle.
- Video and digital images are available for other users. They are available to bridge and maintenance personnel and can be made available on the Internet in the future.

Figure 9. WA DOT pavement condition rating van.

Figure 10. Inside a pavement condition rating van.

Figure 11. Pavement condition rating video images.

Figure 12. Pavement condition rating station.

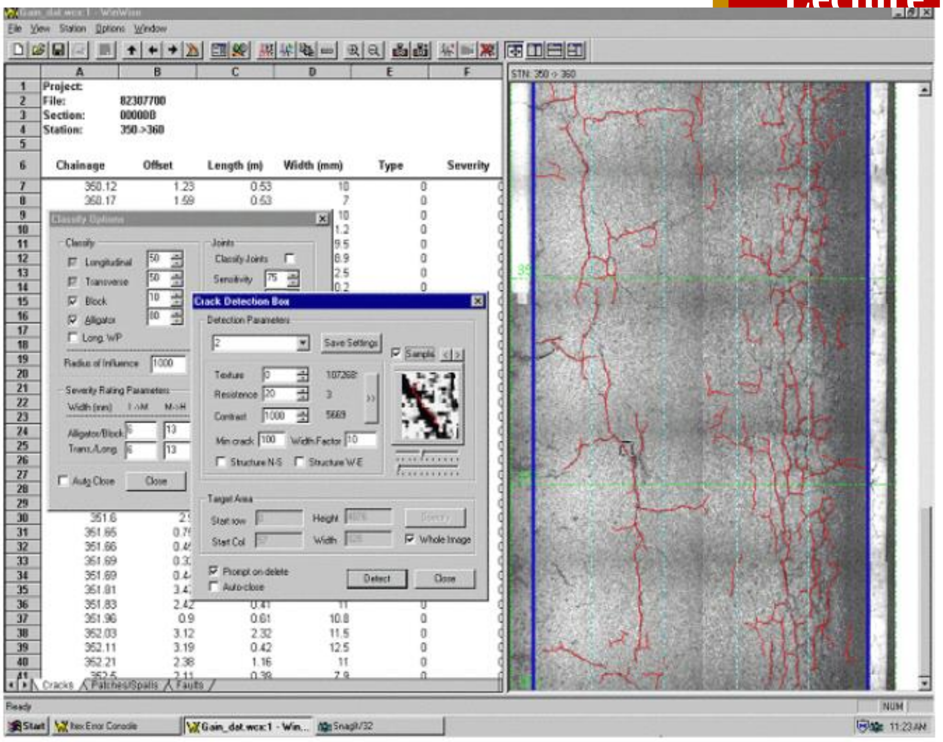

Figure 13: Screen Shot from a Computer-Based Automatic Crack Detection System (Image from [Roadware'

Integrated analysis units can collect pavement surface distress data in the previously described manner as well as collect data on a variety of other characteristics at highway speeds such as:

- Transverse profile/rutting
- Grade, cross-slope
- Pavement texture
- GPS coordinates
- Panoramic right-of-way video
- Pavement video
- Feature location

5. Skid Resistance

- Skid resistance is the force developed when a tire that is prevented from rotating slides along the pavement surface (Highway Research Board, 1972. Skid resistance is an important pavement evaluation parameter because:
- Inadequate skid resistance will lead to higher incidences of skid related accidents.
- Most agencies have an obligation to provide users with a roadway that is "reasonably" safe.

- Skid resistance measurements can be used to evaluate various types of materials and construction practices.
- Skid resistance depends on a pavement surface's micro texture and macrotexture (Corley-Lay, 1998). Micro texture refers to the small-scale texture of the pavement aggregate component (which controls contact between the tire rubber and the pavement surface) while macrotexture refers to the large-scale texture of the pavement as a whole due to the aggregate particle arrangement (which controls the escape of water from under the tire and hence the loss of skid resistance with increased speed) (AASHTO, 1976. Skid resistance changes over time. Typically it increases in the first two years following construction as the roadway is worn away by traffic and rough aggregate surfaces become exposed, then decreases over the remaining pavement life as aggregates become more polished. Skid resistance is also typically higher in the fall and winter and lower in the spring and summer. This seasonal variation is quite significant and can severely skew skid resistance data if not compensated for (Jayawickrama and Thomas, 1998.

. 5.1 Measurement

Skid resistance is generally quantified using some form of friction measurement such as a friction factor or skid number.

Friction factor (like a coefficient of friction): $f = F/L$

Skid number: $SN = 100(f)$

where: F = frictional resistance to motion in plane of interface

L = load perpendicular to interface

It is not correct to say a pavement has a certain friction factor because friction involves two bodies, the tires and the pavement, which are extremely variable due to pavement wetness, vehicle speed, temperature, tire wear, tire type, etc. Typical friction tests specify standard tires and environmental conditions to overcome this.

In general, the friction resistance of most dry pavements is relatively high; wet pavements are the problem. The number of accidents on wet pavements are twice as high as dry pavements (but other factors such as visibility are involved in addition to skid resistance). Table 1 shows some typical Skid Numbers (the higher the SN, the better).

Table 3. Typical Skid Numbers (from Jayawickrama et al., 1996

.

Table 3 : Skid resistance Typical Skid Numbers

Skid Number	Comments
Less than 30	Take measures to correct
≥30	Acceptable for low volume roads
31 – 34	Monitor pavement frequently
≥35	Acceptable for heavily traveled roads

5.2 Measurement Techniques

Skid testing in the U.S. may occur in a number of ways, this section covers some of the more common methods including:

- The locked wheel tester
- The spin up tester
- Surface texture measurement

a. Locked Wheel Tester

The most commonly used method in the U.S. for skid resistance testing uses some form of a lock wheel tester (see Figure 14& 15). Basically, this method uses a locked wheel skidding along the tested surface to measure friction resistance. A typical lock-wheel skid measurement system must have the following:

- A test vehicle with one or more test wheels incorporated into it or as part of a towed trailer.
- A standard tire for use on the test wheel. The standardized skid-test tire, a tubeless, bias-ply G78x15 tire with seven circumferential grooves, is defined by AASHTO M 261 or ASTM E 501. A newer tire, one with no grooves, appears to be gaining acceptance as well. By defining the standard test tire, the tire type and design are eliminated as variables in the measurement of pavement skid resistance.
- A means to transport water (usually 750 to 1900 liters (200 to 500 gallons)) and the necessary apparatus to deliver it in front of the test wheel at test speed

- A transducer associated with the test wheel that senses the force developed between the skidding test wheel and the pavement
- Electronic signal conditioning equipment to receive the transducer output signal and modify it as required
- Suitable analog and/or digital readout equipment to record either the magnitude of the developed force or the calculated value of the resulting Skid Number (SN)

Figure 14. Lock Wheeled Skid Tester

Figure 15. Lock Wheeled Skid Tester

To take a measurement, the vehicle (or trailer) is brought to the desired testing speed (typically 64 km/hr (40 mph)) and water is sprayed ahead of the test tire to create a wetted pavement surface. The test tire braking system is then actuated to lock the test tire. Instrumentation measures the friction force acting between the test tire and the pavement and reports the result as a Skid Number (SN).

Standard locked-wheel friction tests are:

- AASHTO T 242: Frictional Properties of Paved Surfaces Using a Full-Scale Tire
- ASTM E 274:Skid Resistance of Paved Surfaces Using a Full-Scale Tire

b. Spin Up Tester

A spin up tester has the same basic setup as a locked wheel tester but operates in an opposite manner. For a spin up tester, the vehicle (or trailer) is brought to the desired testing speed (typically 64 km/hr (40 mph)) and a locked test wheel is lowered to the pavement surface. The test wheel braking system is then released and the test wheel is allowed to "spin up" to normal traveling speed due to its contact with the pavement. Mathematically, the friction force at the tire/pavement interface at any moment corresponds to that which would be present if the locked tire were pulled along the pavement at the testing speed (Wambold et al., 1990). The spin up tester offers two advantages over the locked wheel tester:

No force measurement is necessary, the force can be computed by knowing the test wheel's moment of inertia and its rotational acceleration (Wambold et al., 1990. Force measuring devices for the locked wheel tester cost a significant amount of money.

Because the test tire is in contact with the pavement while locked for a much shorter time than the locked wheel tester, it significantly reduces test tire wear.

c. Surface Texture Measurement

Because pavement skid resistance is tied to surface macrotexture, some methods seek to measure a pavement's macrotexture then correlate it with skid resistance as measured by some other, more traditional method. The simplest surface texture measurement is the sand patch test (ASTM E 965). The test is carried out on a dry pavement surface by pouring a known quantity of sand onto the surface and spreading it in a circular pattern with a straightedge. As the sand is spread, it fills the low spots in the pavement surface. When the sand cannot be spread any further, the diameter of the resulting circle is measured. This diameter can then be correlated to an average texture depth, which can be correlated to skid resistance. A texture depth of about 1.5 mm (0.06 inches) is normally required for heavily trafficked areas.

Laser or advanced image processing equipment are capable of determining surface macrotexture from a vehicle moving at normal travel speeds. One particular device, the Road Surface Analyzer (ROSAN), a series of non-contact pavement surface texture measurement devices, has been developed by the FHWA's Turner Fairbanks Research Center Pavement Surface Analysis Laboratory. The ROSAN (see Figure 16) can be used for measuring texture, aggregate segregation, grooves, tining, joints, and faulting (FHWA, 2001). ROSAN systems have been used in a number of NCHRP and FHWA sponsored studies. Some integrated analysis units can use surface texture measuring to estimate skid resistance.

Figure 16. Prototype ROSAN device (circa 1998).

The one drawback to this method is that a pavement's surface macrotexture does not entirely determine its skid resistance. Therefore, correlation between surface macrotexture and skid resistance is often difficult to extrapolate into any general guidance.

6.Deflection

Pavement surface deflection measurements are the primary means of evaluating a flexible pavement structure and rigid pavement load transfer. Although other measurements can be made that reflect (to some degree) a pavement's structural condition, surface deflection is an important pavement evaluation method because the magnitude and shape of pavement deflection is a function of traffic (type and volume), pavement structural section, temperature affecting the pavement structure and moisture affecting the pavement structure. Deflection measurements can be used in methods to determine pavement structural layer stiffness and the subgrade . Thus, many characteristics of a flexible pavement can be determined by measuring its deflection in response to load. Furthermore, pavement deflection measurements are non-destructive.

6.1 Measurement

Surface deflection is measured as a pavement surface's vertical deflected distance as a result of an applied (either static or dynamic) load. The more advanced measurement devices record this vertical deflection in multiple locations, which provides a more complete characterization of pavement deflection. The area of pavement deflection under and near the load application is collectively known as the "deflection basin".

6.2 Measurement Techniques

There are three broad categories of nondestructive deflection testing equipment:

- Static deflections
- Steady state deflections
- Impact load deflections (FWD)

The general principle is to apply a load of known magnitude to the pavement surface and analyze the shape and magnitude of the deflection basin to assess the strength of the pavement structure (Figure 17).

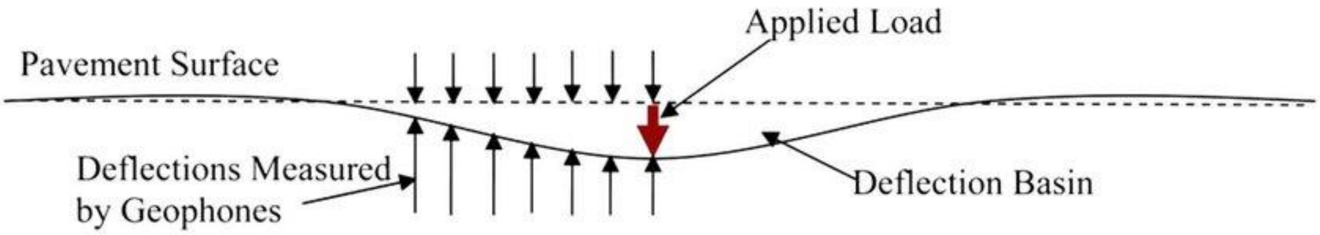

Figure 17. Deflection measurement schematic.

6.3Static Deflection Equipment

Static deflection equipment measure pavement deflection in response to a static load.

a. Benkelman Beam

The Benkelman Beam (Figure 2), developed at the Western Association of State Highway Organizations (WASHO) Road Test in 1952, is a simple device that operates on the lever arm principle. The Benkelman Beam is used with a loaded truck – typically 80 kN (18,000 lb) on a single axle with dual tires inflated to 480 to 550 kPa (70 to 80 psi). Measurement is made by placing the tip of the beam between the dual tires and measuring the pavement surface rebound as the truck is moved away (see Figure 18&19). The Benkelman Beam is low cost but is also slow, labor intensive and does not provide a deflection basin.

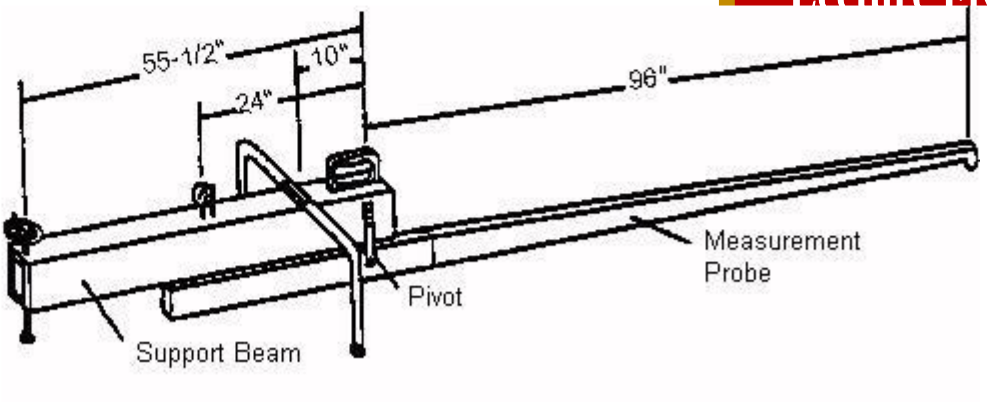

Figure 18. Benkelman beam schematic.

Figure 19. Benkelman beam in use

Standard Benkelman Beam tests are described in:

AASHTO T 256: Pavement Deflection Measurements

ASTM D 4695: General Pavement Deflection Measurements

b. Steady State Deflection Equipment

Steady state deflection equipment measure the dynamic deflection of a pavement produced by an oscillating load. These devices consist of a dynamic force generator (that produces the oscillating load), a motion measuring instrument (to measure the oscillating load), a calibration unit and several deflection measuring devices (transducers, accelerometers, seismometers, etc.). The main advantage that steady state deflection equipment offer over static deflection equipment is that they can measure a deflection basin. The most common steady state deflection equipment are the Dynaflect and the Road Rater.

The steady state deflection equipment (Figure 20) is stationary when measurements are taken with force generator (counter rotating weights) started and deflection sensors (transducers) lowered to the pavement surface. Figure 21 is a plot of a typical force output and Figure 22 shows the location of the equipment's loading wheels and five transducers. The equipment is most suitable for use on thinner pavements including low volume rural highways, county roads, municipal streets, and parking lots (IMS, 2001).

Figure 20. Dynaflect.

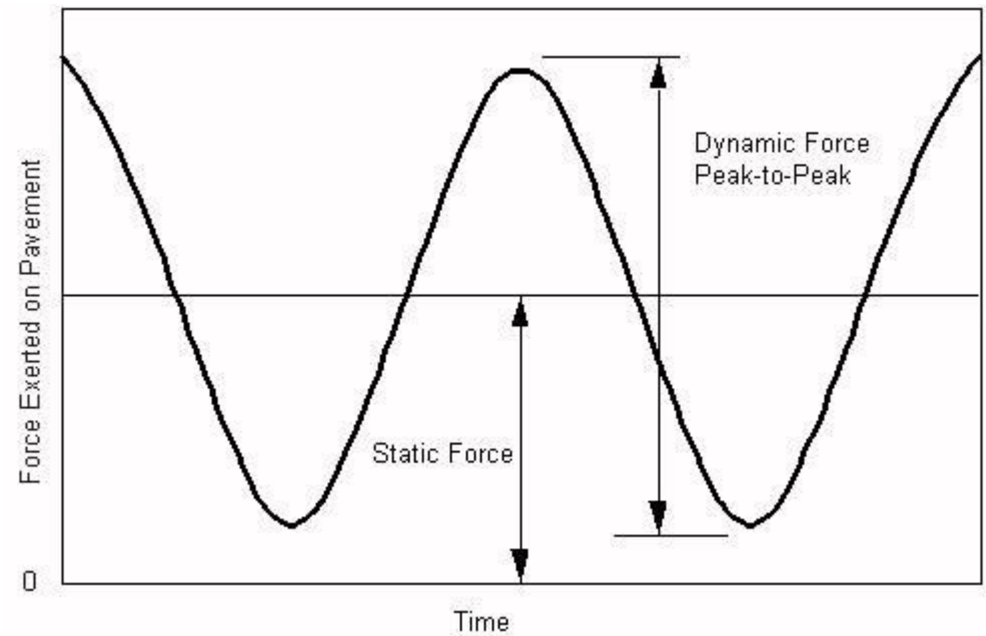

Figure 21. Dynaflect force output.

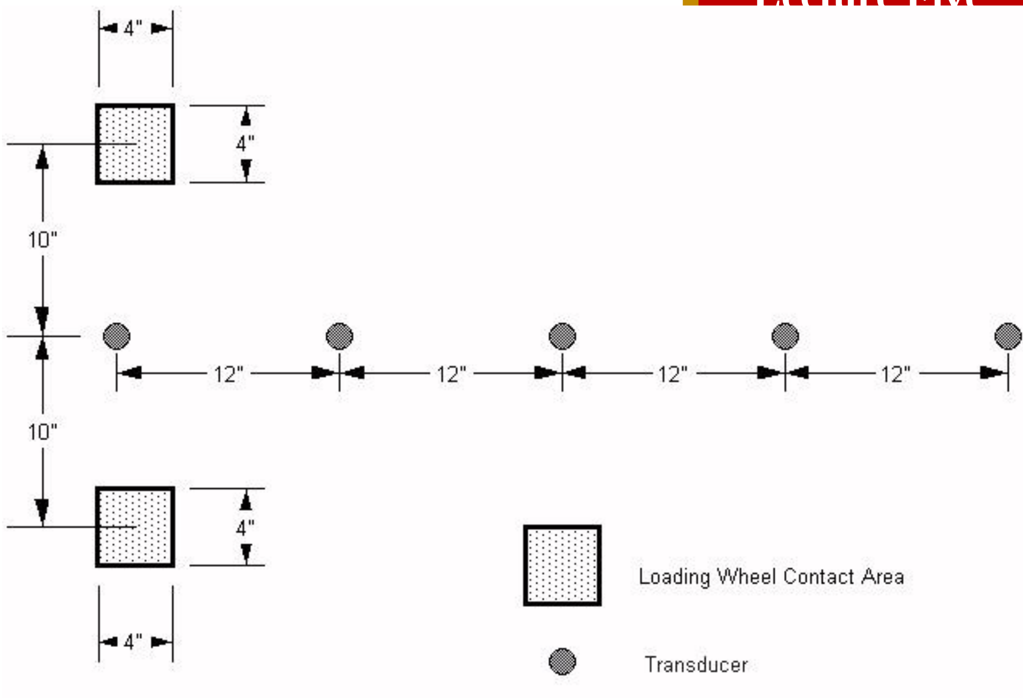

Figure 22. Standard location of Dynaflect loading wheels and transducers.

The Road Rater (Figure 23) is the other popular type of steady state deflection equipment. It must also be stationary to start and operates in a similar fashion to the Dynaflect.


Figure 23. Road Rater.

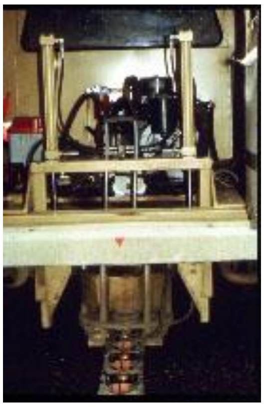
Figure 23. Road Rater.

Standard stead state deflection tests are described in:

AASHTO T 256: Pavement Deflection Measurements

ASTM D 4695: General Pavement Deflection Measurements

c. Impact (Impulse) Load Response

All impact load devices deliver a transient impulse load to the pavement surface. The subsequent pavement response (deflection basin) is measured by a series of sensors. The most common type of equipment is the falling weight deflectometer (FWD) (Figures 24 through 28). The FWD can either be mounted in a vehicle or on a trailer and is equipped with a weight and several velocity transducer sensors. To perform a test, the vehicle is stopped and the loading plate (weight) is positioned over the desired location. The sensors are then lowered to the pavement surface and the weight is dropped. Multiple tests can be performed on the same location using different weight drop heights (ASTM, 2000). The advantage of an impact load response measuring device over a steady state deflection measuring device is that it is quicker, the impact load can be easily varied and it more accurately simulates the transient loading of traffic. Results from FWD tests are often communicated using the .

Figure 24. FWD impulse loading mechanism (foreground) and sensors (background).

Figure 25. FWD.

Figure 26. Dynatest 8000 FWD.

Figure 27. KUAB FWD.

Figure28: JILS FWD.

The standard impact load response test method is:

ASTM D 4694: Standard Test Method for Deflections with a Falling Weight Type Impulse Load Device

Correlations Between Deflection Measuring Equipment

In general, correlations between deflection devices should be used with caution. Too often, a correlation is developed for a specific set of conditions that may not be present for those using the correlation. It appears that the best approach is to obtain pavement parameters (such as layer moduli) from the specific device being used. However, that said, a few of many such correlations that have been developed follow.

d. Benkelman Beam to FWD

(based on unpublished data collected by the Washington State DOT Materials Laboratory in 1982-1983)

$$BB = 1.33269 + 0.93748\,(FWD)$$

where: BB = Benkelman Beam deflection (inches × 10^{-3})

FWD = FWD center-of-load deflection (inches. × 10^{-3}) corrected to a 9,000 lb. load applied on a 11.8-inch diameter plate

$R^2 = 0.86$ Standard Error = 3.20 mils Sample Size = 713

e. Benkelman Beam to Dynaflect

(based on Hoffman and Thompson, 1981

$$BB = 20.63\ (D)$$

where: BB = Benkelman Beam deflection (inches x 10^{-3})

D = Dynaflect center-of-load deflection (inches x 10^{-3})

$$R^2 = 0.72$$

f. Benkelman Beam to Road Rater

(based on Hoffman and Thompson, 1981

Comparing a Benkelman Beam load at 9,000 pounds on dual tires with 70-80 psi inflated tires and Road Rater at 8,000 pound peak-to-peak load at 15 Hz on a 12 inch diameter plate on a stabilized pavement:

$$BB = 2.57 + 1.27(RR)$$

where: BB = Benkelman Beam deflection (inches x 10^{-3})

RR = Road Rater (Model 2008) center-of-load deflection at 8,000 pounds and 15 Hz (inches x 10^{-3})

$$R^2 = 0.66$$

The Western Direct Federal Division, Federal Highway Administration, Vancouver, Washington provides the following correlation for the Benkelman Beam to Road Rater Model 400:

$$BB = 8.0 + 9.1026\ (D_0)$$

where: BB = Benkelman Beam deflection (inches x 10^{-3})

RR = Maximum deflection from Road Rater Model 400 (deflection location between load pads) at a load of 1,300 pounds at 25 Hz

7.Other Pavement Condition Rating Systems

One common method for evaluating pavements is to establish a pavement condition rating system that associates deduct (penalty) points with specific distress type, severity, and extent combinations. These points can then be summed and subtracted from some upper limit or maximum value (100 in Washington State's case) to give an overall rating of a pavement's structural condition. The equations that describe how to convert from severity and extent of a certain distress type to an index number, or score, vary from state to state and can be rather complex.