11 Distress and Performance

A brand-new pavement at the start of its design life is expected to be one without any "distress" or undesirable features. Such features, which include rutting, cracking, patching, or roughness, are "undesirable" from the point of view of performance of the pavement—the more distress, the shorter the pavement's life—and at some point, the distresses are so great in intensity (e.g., deep ruts) as well as extent (e.g., 75% of the wheelpath area in a project area has cracks) that the pavement is considered to be "failed" or at the end of its design life.

The following sections explain the possible distresses and their relationship to the performance of a pavement.

11.1 DISTRESSES IN ASPHALT PAVEMENTS

There are different forms of distresses in asphalt pavements, each tied to a specific reason (such as poor mix design, construction, or environmental conditions) or a combination thereof, and most happening as a result of traffic. Figure 11.1 lists the common distresses in asphalt pavements. The different distresses are described in the following sections, in alphabetical order.

11.1.1 Bleeding

Bleeding is the appearance of asphalt binder on the surface of the pavement. This is a surface defect caused by excessive asphalt binder in the surface asphalt mix layer. It is measured in square meters. The different conditions of bleeding include discoloration, covering of aggregate with a thin reflective surface, and loss of texture.

11.1.2 Block Cracking

Block cracking refers to a pattern of cracks that divide the surface into approximately rectangular pieces (>0.1 m^2). Such cracks occur due to shrinkage of asphalt mix because of volume changes in the base or subgrade. It is measured in square meters, and its severity can be described as low (crack width ≤6 mm or sealed cracks whose width cannot be measured, with sealant in good condition), moderate (crack width >6 mm but ≤19 mm or any crack with mean width ≤19 mm and adjacent low-severity random cracking), and high (crack width >19 mm or any crack with mean width ≤19 mm and adjacent moderate- to high-severity random cracking).

11.1.3 Corrugations

Corrugations are ripples formed laterally across an asphalt pavement surface. These occur as a result of lack of stability of the hot mix asphalt (HMA) at a location where traffic starts and stops or on hills where vehicles brake downgrade. The causes of the lack of stability are too much or too soft asphalt, a high sand content, and an excessive presence of smooth and rounded aggregate in the mix.

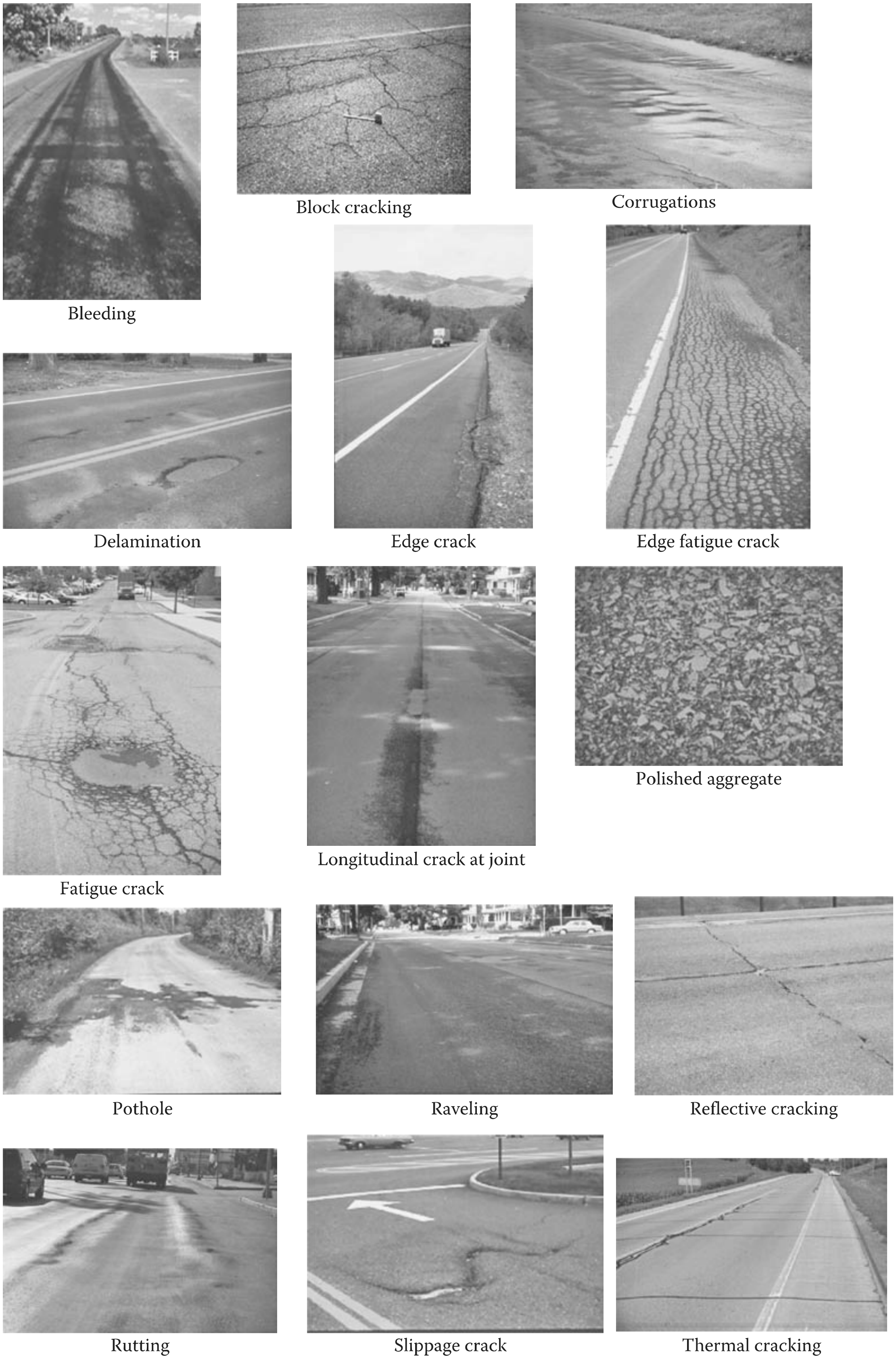

FIGURE 11.1 Common distresses in asphalt pavements. (Courtesy of Ed Kearney.)

11.1.4 Delamination

Delamination is the separation of the top wearing layer from the layer underneath. It is caused by poor bond or by failure of the bond between the two layers. The poor bond can be due to improper surface preparation or tack coat before the application of the wearing layer and/or a relatively thin wearing layer. The loss of bond can be caused by environmental factors such as ingress of water and repeated freeze–thaw cycles.

11.1.5 Edge Cracks

Edge cracks are found in pavements with unpaved shoulders. They are crescent shaped or fairly continuous cracks that intersect the pavement edge. The cracks are located within 0.6 m of the pavement edge adjacent to the shoulder. Longitudinal cracks outside of the wheelpath and within 0.6 m of the pavement edge are also classified as edge cracks.

The cracking is due to the lack of lateral (shoulder) support, base or subgrade weakness caused by frost action, and inadequate drainage. It is measured in meters, and severity is reported as low (cracks without breakup or loss of material), moderate (loss of material and breakup in up to 10% of the cracked area), or high (loss of material or breakup in more than 10% of the cracked area).

11.1.6 Fatigue Cracks and Edge Fatigue Cracks

Fatigue cracks generally begin at the wheelpath. Edge fatigue cracks are formed due to poor underlying support at the edge of the pavements with paved shoulders. This distress, found on wheelpaths, begins as a series of interconnected cracks and develops into a chicken wire/alligator pattern. Interconnected cracks give rise to many-sided, sharp-angle pieces, usually with a maximum length of 0.3 m. Repeated tensile stress/strain at the bottom of the asphalt mix layer, caused by traffic, leads to fatigue cracking. It starts from the bottom and moves upward. The cracked area must be quantifiable in order to be counted as a fatigue crack. The cracked area should be measured in square meters, for each of the three severity levels: low, medium, and severe. If, within an area, there are different severity levels and they cannot be distinguished, the entire area should be rated as for the highest severity rating. A *low*-severity area is one in which there are no or few connecting cracks, the cracks are not spalled or sealed, and there is no evidence of pumping. *Moderate*-severity areas are those in which the cracks are interconnected, forming a complete pattern, and cracks may be slightly spalled or sealed, with no evidence of pumping. In a *high*-severity area, the cracks are interconnected with moderate or severe spalls, forming a complete pattern; pieces may move under traffic; cracks may be sealed; and pumping may be evident.

11.1.7 Longitudinal Joint Cracks

Longitudinal joint cracks develop at construction joints because of poorly paved joints or improper construction techniques. They are measured in meters, and their severity is expressed in the same manner as in block cracking.

11.1.8 Polished Aggregate

Polished aggregate is the exposure of coarse aggregate due to wearing away of the asphalt binder and fine aggregates from the surface asphalt mix. It is measured in square meters.

11.1.9 Potholes

Bowl-shaped holes, with a minimum plan dimension of 150 mm in the pavement surface, are called *potholes*. There are four main causes of potholes: (1) insufficient thickness of the pavement to support traffic through winter–spring freeze–thaw cycles; (2) poor drainage, leading to accumulation of excess water; (3) failures at utility trenches and castings; and (4) paving defects and unsealed cracks. For a distress survey, the number of potholes and the square meters of affected area are recorded. Severity levels can be reported as low (<25 mm deep), moderate (25 mm < depth < 50 mm), or high (>50 mm deep).

11.1.10 Raveling

Raveling refers to wearing away of the pavement surface by loss of asphalt binder and displacement of aggregates. The process starts as loss of fines and can continue to a situation with loss of coarse aggregate and a very rough and pitted surface. Raveling is caused by the action of water that finds its way through the surface of the pavement because of poor compaction and hence low density and relatively high voids, and it can initiate the potholing process. It is measured in square meters.

11.1.11 Reflective Cracking

Reflective cracks are those in asphalt overlays caused by discontinuities in the pavement structure underneath. This can be due to old cracked asphalt pavement or joints in concrete pavement underneath. The severity levels are recorded in the same manner as in block cracking.

11.1.12 Rutting

A *rut* is defined as a longitudinal depression in the wheelpath, with or without transverse displacement. It can be measured with a straight edge or a profiler at regular intervals. A rut is a physical distortion of the surface, and it also prevents the cross drainage of water during rains, leading to accumulation of water in the ruts and increasing the potential of hydroplaning-related accidents. Generally a rut depth of 0.5 in. is considered a rutting failure. Rutting is the result of repeated loading, which causes accumulation, and increase of permanent deformations. Rutting can be (1) low- to moderate-severity rutting—one-dimensional densification or vertical compression near the center of the wheelpath, caused by densification of mixes with excessive air voids in the in-place mix under traffic; (2) moderate- to high-severity rutting—a depression in the wheelpath along with humps on either side of the depression, caused by lateral flow due to plastic deformation, resulting from shear failure of the mix under traffic, and generally associated with very low air voids in the mix; and (3) rutting accompanied by cracks on the surface of the pavement, caused by rutting in underlying layers, such as the subgrade or subbase.

11.1.13 Slippage Crack

Slippage cracks are typically crescent- or half-moon-shaped cracks produced when vehicles brake or turn, which causes the pavement surface to slide or push. This is caused by a low-strength HMA or a lack of bond between the surface and lower courses.

11.1.14 Thermal Cracks

Thermal cracking occurs in the form of transverse cracking, which is defined as cracks that are predominantly perpendicular to the pavement centerline. These cracks occur at regular intervals. Thermal cracks can be caused by the fracture of asphalt mix due to a severe drop in temperature or by thermal fatigue caused by repeated low- and high-temperature cycles. The severity of thermal cracking is measured by the width of the crack. A low-severity transverse crack is one with a mean width of ≤6 mm, or a sealed crack with sealant material in good condition and a width that cannot be determined. A medium-severity transverse crack is one with a mean width >6 and ≤19 mm, or any crack with a mean width ≤19 mm and adjacent low-severity random cracking, while a high-severity crack has a mean width >19 mm, or ≤19 mm but with adjacent moderate- to high-severity random cracking. Only cracks that are >0.3 m in length are counted. The number and length of transverse cracks at each severity level are recorded. The entire transverse crack is to be rated at the highest severity level that is present for at least 10% of the total length of the crack. The length, in m, is the total length of the crack. If the cracks are sealed, then the length of cracks with sealant in good condition (for at least 90% of the crack) should be measured at each severity level. Part of the thermal transverse crack extending into a load-induced fatigue crack area is not counted.

11.2 DISTRESSES IN CONCRETE PAVEMENTS

The different types of distresses found in PCC pavements are described next. Figure 11.2 summarizes the different distresses.

11.2.1 Corner Breaks

A corner portion of the slab is separated by a crack. The crack intersects the adjacent transverse and longitudinal joints, and is approximately at a 45° angle with the direction of traffic. The length of the sides is from 0.3 m to one-half the width of the slab on each side of the corner. Corner breaks are measured by counting the number that is encountered per unit length. For a low-severity level, the crack is not spalled more than 10% of the length of the crack, and there is no faulting. For a moderate-severity level, the crack is spalled >10% of its total length, or the faulting of the crack or joint is <13 mm and the corner piece is not broken into two or more pieces. For a high-severity level, the crack is spalled at moderate to high severity >10% of its total length, the faulting of the crack or joint is ≥13 mm, or the corner piece is broken into two or more pieces or contains patch material.

11.2.2 Durability Cracking (or "D" Cracking)

In this type of distress, the cracking is due to freezing and thawing and usually initiates at construction joints. These are usually closely spaced crescent-shaped hairline cracks that appear like the letter D. D-cracks are measured by recording the number of slabs with "D" cracking and square meters of area affected at each severity level. The slab and affected area severity rating is based on the highest severity level present for at least 10% of the area affected. For low-severity distress, D-cracks are close together, with no loose or missing concrete pieces, and no patches in the affected area. For moderate severity, D-cracks are well defined, and some small concrete pieces are loose or have been displaced. For high severity, D cracking has a well-developed pattern, with a significant amount of loose or missing material, and may have been patched.

11.2.3 Longitudinal Cracking

These are stress cracks that are predominantly parallel to the pavement centerline and are measured in meters. For low-severity distress, crack widths are <3 mm in width, with no spalling and no measurable faulting, or are well sealed and with a width that cannot be determined. For moderate-severity distress, crack widths range between 3 and 13 mm, with spalling <75 mm, or faulting up to 13 mm. For high-severity distress, crack widths are <13 mm, with spalling <75 mm, or faulting <13 mm.

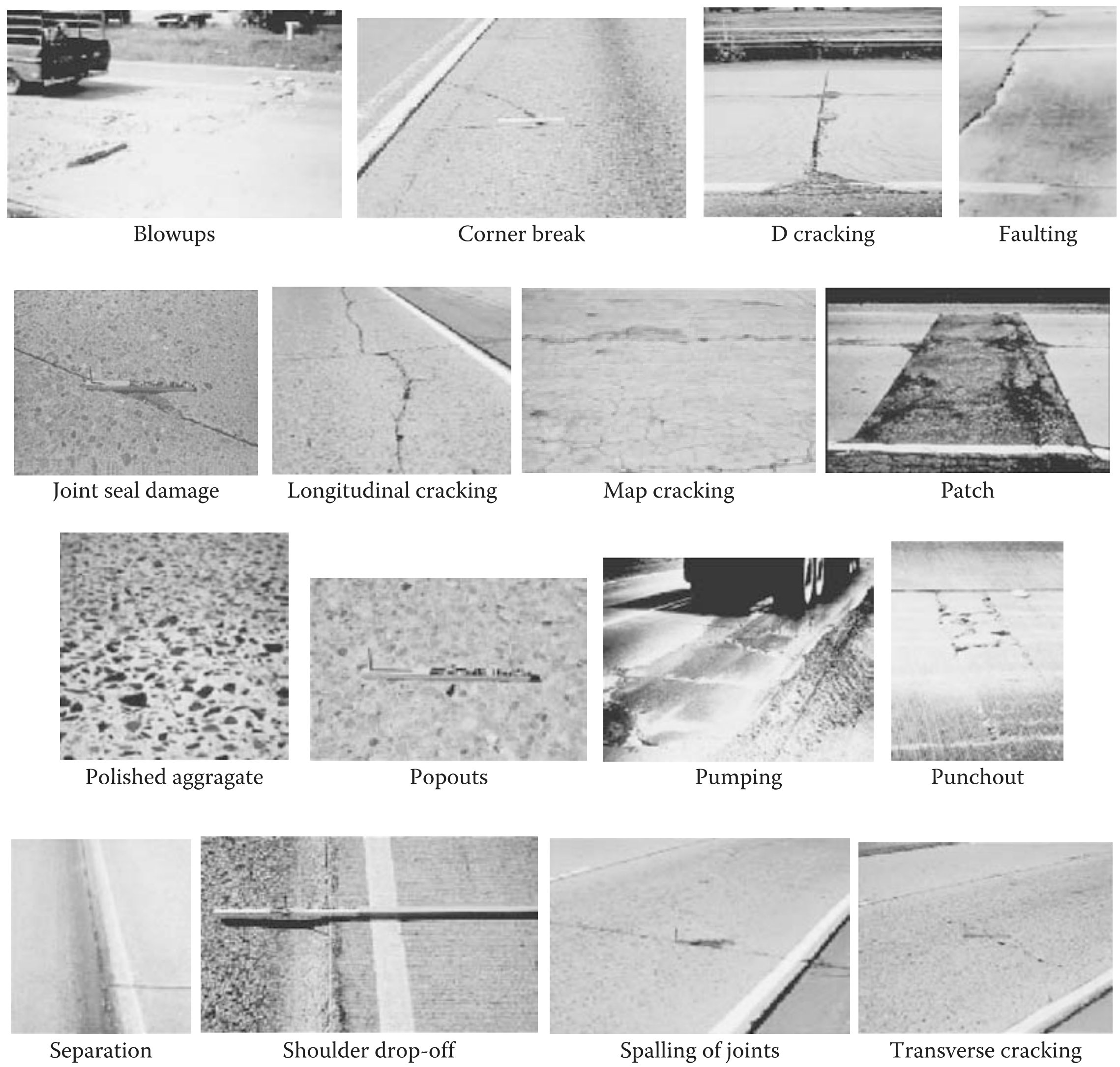

FIGURE 11.2 Distress in PCC pavements. (From Distress Identification Manual for the Long term Pavement Performance Program, FHWA-RD-03-031, June 2003.)

11.2.4 Transverse Cracking

These are stress cracks that are predominantly perpendicular to the pavement centerline and are measured in meters. For low-severity distress, crack widths are <3 mm, with no spalling and no measurable faulting, or are well sealed similar to longitudinal cracking. For moderate-severity distress, crack widths are >3 and <6 mm, with spalling <75 mm, or faulting up to 6 mm. For high-severity distress, crack widths are >6 mm, with spalling >75 mm, or faulting >6 mm.

11.2.5 Spalling of Transverse Joints

This distress consists of cracking, breaking, chipping, or fraying of slab edges within 0.3 m from the face of the transverse joint, and is measured in frequency of occurrence and meters. For low-severity distress, spalls are <75 mm wide, measured to the face of the joint, with loss of material, or spalls with no loss of material and no patching. For medium-severity distress, spalls are 75–150 mm wide, measured to the face of the joint, with loss of material. For high-severity distress, spalls are >150 mm wide, measured to the face of the joint, with loss of material, or broken into two or more pieces or contain patch material.

11.2.6 Map Cracking and Scaling

Map cracking: A series of interconnected cracks that extend into the upper surface of the slab. Usually, larger cracks are oriented in the longitudinal direction of the slab and are interconnected by finer transverse or random cracks. These are measured in frequency of occurrence and in square meters.

Scaling: Scaling is the deterioration and flaking of the upper concrete slab surface, normally in areas of 3–13 mm, and may occur anywhere over the pavement. This is measured by the number of occurrences and the square meters of affected area.

11.2.7 Polished Aggregate

Exposed and polished coarse aggregate occur due to surface mortar and paste loss, which results in a significant reduction of surface friction. Distress is measured in square meters of affected surface area. The level of severity is not applicable for this distress. Diamond grinding also removes surface texturing, but this condition should not be recorded as polished aggregate.

11.2.8 Popouts

Popouts are small pieces of pavement broken loose from the surface, ranging in diameter from 25 to 100 mm, and ranging in depth from 13 to 50 mm.

11.2.9 Blowups

Blowups are slab length changes resulting in localized upward movement of the pavement surface at transverse joints or face cracks, and are usually accompanied by shattering of the concrete in that area. Distress is measured by recording the number of blowups. Severity levels are not applicable. However, severity levels can be defined by the relative effect of a blowup on ride quality and safety.

11.2.10 Faulting of Transverse Joints and Cracks

This occurs as a result of elevation difference across a joint or crack. Distress is measured in millimeters, to the nearest millimeter at a location 0.3 and 0.75 m from the outside slab edge (this is approximately the location of the outer wheelpath). For a widened lane, the wheelpath location will be 0.75 m from the outside lane edge stripe. Faulting is recorded as positive (+) if the "approach" slab is higher than the "departure" slab; if the approach slab is lower, faulting is recorded as negative (–). Faulting on PCC pavements can be measured using a Federal Highway Administration (FHWA)-modified Georgia faultmeter.

11.2.11 Lane-to-Shoulder Dropoff

This is a difference in elevation between the edge of the slab and the outside shoulder, and usually occurs when the outside shoulder settles. Distress is measured at the longitudinal construction joint between the lane edge and shoulder. Distress is recorded to the nearest millimeter at 15–25-m intervals. The recorded value is negative (–) if the traveled surface is lower than the shoulder.

11.2.12 Lane-to-Shoulder Separation

This is a widening of the joint between the edge of the slab and the shoulder. Distress is measured to the nearest millimeter at intervals of 15–25 m along the lane-to-shoulder joint. It should be documented if the joint is well sealed or not at each shoulder location. Severity levels are not applicable.

11.2.13 Patch/Patch Deterioration

A patch is a portion greater than 0.1 m^2, all of the original concrete slab that has been removed and replaced, or additional material applied to the pavement after original construction. For a low-severity-level distress, the patch displays low-severity distress of any type, there is no measurable faulting or settlement, and pumping is not evident. For a moderate-severity level, the patch has moderate-severity distress of any type or faulting or settlement up to 6 mm, and pumping is not evident. For a high-severity level, the patch has a high-severity distress of any type, or faulting or settlement >6 mm, and pumping may be evident.

11.2.14 Water Bleeding and Pumping

This is the ejection or seepage of water from beneath the pavement through cracks. The residue of very fine materials deposited on the surface that were eroded (or pumped) from the support layers, causing staining, aids in recognizing pumping phenomenon. This is measured by recording the number of occurrences of water bleeding and pumping and the length in meters of affected pavement with a minimum length of 1 m. The combined length of water bleeding and pumping cannot exceed the length of the test section.

11.2.15 Punchouts

Punchouts are broken areas enclosed by two closely spaced (commonly <0.6 m) transverse cracks, a short longitudinal crack, and the edge of the pavement or a longitudinal joint. They also include "Y" cracks that exhibit spalling, breakup, or faulting. The number of punchouts should be recorded at each severity level. It should be noted that the cracks that outline the punchout are also recorded under "longitudinal cracking" and "transverse cracking." Punchouts that have been completely repaired by removing all broken pieces and replacing them with patching material (rigid or flexible) are rated as patches. For low-severity distress, transverse cracks are tight and may have spalling <75 mm or faulting <6 mm, with no loss of material and no patching. For moderate distress, spalling >75 mm and <150 mm or faulting >6 mm and <13 mm exists. For a high-severity rating, spalling is >150 mm, or concrete within the punchout is punched down by >13 mm, is loose and moves under traffic, is broken into two or more pieces, or contains patch material.

11.2.16 Joint Seal Damage

Joint seal damage is any condition that enables incompressible materials or a significant amount of water to infiltrate the joint from the surface. Common types of joint seal damage are extrusion, hardening, adhesive failure (bonding), cohesive failure (splitting), complete loss of sealant, and the intrusion of foreign material in the joint such as weed growth in the joint. This distress is measured by recording the number of longitudinal joints that are sealed and the length of sealed longitudinal joints with joint seal. The severity level is not applicable.

11.3 CONSIDERATION OF PERFORMANCE

A pavement is constructed for the safe and smooth passage of traffic. There is a need to quantify the extent to which the pavement is serving its purpose, or its "performance." Such quantification can be done with respect to distress conditions exhibited by the pavement at any time after its construction.

The AASHO Road Test introduced the concept of serviceability to measure performance. It was necessary to characterize the pavement sections in terms of their condition, in order to develop relationships between the performance and the factors affecting the performance. First, the concept of present serviceability rating (PSR) was introduced. PSR (Figure 11.3) 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.

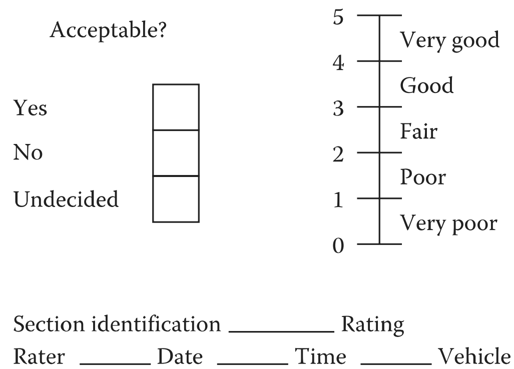

FIGURE 11.3 Concept of present serviceability rating.

The PSR ranges from 1 to 5, starting from a perfect 5 and decreasing with the passage of traffic. To characterize pavements in terms of the serviceability rating, the pavement serviceability index (PSI) was then introduced on the basis of observed distress conditions:

$$\text{PSI} = 5.03 - 1.91\log\left(1+\overline{\text{SV}}\right) - 1.38\text{RD}^2 - 0.01\sqrt{\text{C+P}} \quad \text{(flexible pavement)}$$

$$\text{PSI} = 5.41 - 1.80\log\left(1+\overline{\text{SV}}\right) - 0.09\sqrt{\text{C+P}} \quad \text{(rigid pavement)}$$

where
SV is the mean of the slope variance in the two wheelpaths (measured with the CHLOE profilometer or Bureau of Public Roads [BPR] roughometer)
C, P are the measures of cracking and patching in the pavement surface
C is the total linear feet of Class 3 and Class 4 cracks per 1000 ft^2 of pavement area

A Class 3 crack is defined as opened or spalled (at the surface) to a width of 0.25 in. or more over a distance equal to at least one-half the crack length. A Class 4 crack is defined as any crack that has been sealed. RD is the average rut depth (in.). P is expressed in terms of ft^2 per 1000 ft^2 of pavement surfacing. The basic idea was that just like PSR (numerically the same value as PSI), PSI would drop over time (i.e., with the passage of traffic), starting from an initial p_0 to a terminal p_t. The curve can be expressed with an equation as follows (Figure 11.4):

$$p_o - p = (p_0 - p_t)\left(\frac{W}{\rho}\right)^{\beta}$$

where
β and ρ depend on pavement structure (thickness and stiffness) and loading
β determines the shape of the graph
β is the number of loads at which $p = 1.5$
W is the cumulative load

Note that performance at any time can be expressed as the area under the serviceability curve from the beginning to the point under consideration. The serviceability of the pavement at any time can be "raised" by rehabilitation, such as an asphalt mix overlay.

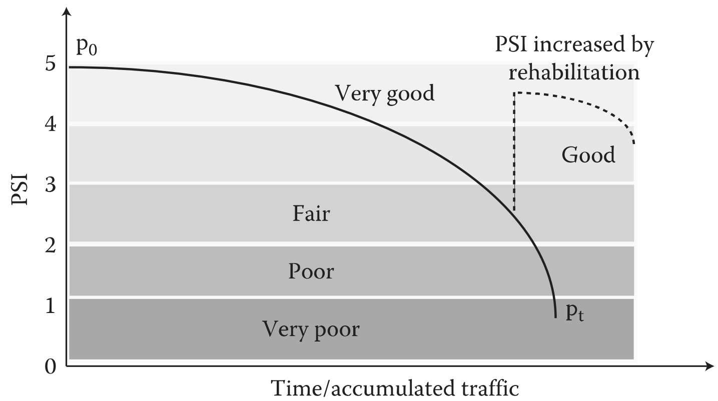

FIGURE 11.4 Plot of PSI versus time.

11.4 DAMAGE

In the AASHTO design process, the loss of serviceability (ΔPSI) is referred to as *damage*. This damage is considered to be caused by traffic, environmental conditions, and age. In mechanistic–empirical pavement design processes, the performance of the pavement is expressed in terms of distresses. The distresses are predicted on the basis of models (commonly referred to as *transfer functions*) relating mechanistic response (stress/strain) to observed distress. Note that such models need to be calibrated for specific regions, climate, materials, and construction conditions. In more sophisticated methods, a damage index is calculated from a mechanistic response, and the damage index is used to compute accumulation of distress with time. Damage is defined as the deterioration of the pavement due to the action of traffic over different environmental conditions. Such deterioration happens as a result of change in the engineering properties of the pavement layer materials.

This damage does not happen altogether at the same time, but rather progressively—or, more precisely, in increments—with the passage of every vehicle or, if expressed in time, every hour during its service. Note that the damage at every hour is not the same—it can be higher, for example, due to a heavier vehicle moving over it at that hour, or due to a lowering of the modulus of the asphalt mix layer due to a high temperature that hour. Therefore, the most rational approach is to consider and compute the damage in each and every increment by considering the relevant traffic (class of vehicle) and the pavement material properties (with respect to environmental conditions such as temperature) for that increment period (say, 1 h). The damage at any increment can be expressed as follows:

$$D = \frac{n}{N}$$

where

n is the calculated load applications

N is the allowable number of load applications

Note that the allowable number of loads is dependent on the condition of the pavement layer at any increment period—hence, N is different for different increment periods.

The total damage at any point is computed by summing up all of the damages over time, up to that time, as follows (commonly referred to as *Miner's hypothesis*; Miner, 1945):

$$\text{Total damage} = \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{o} \frac{n_{ijk}}{N_{ijk}}$$