development of a methodology for structural evaluation.

## 1.2 Surface Deflections in Pavement Evaluation

Surface deflections have been used for many years as pavement performance indicators. In 1955, results from the WASHO Road Test established the values of 45 and 35 mils as limiting values of allowable maximum deflection under an 18 kip axle for flexible pavements in spring and fall respectively (1). Following the concept developed in the WASHO Road Test, many other investigators and agencies adopted and established their own limiting deflection criteria (2,3,4).

Subsequently, researchers related the limiting deflection criteria to traffic (5,6), and to combined traffic and thickness of the asphalt concrete layer (7,8). Limiting deflection criteria for different types of structures and traffic for both airport and highway pavements were developed (9,10,11,12). Correlations between surface deflections and the Present Serviceability Index derived from the AASHO Road Test were modified and incorporated into a pavement design method (14,15). Table 1.1 summarizes some typical limiting deflection criteria reported in the literature.

In the early 1950's, while developing light vibrators for wave propagation analysis of pavements, Shell investigators in Holland proposed a limited stiffness value of 1,100 kips/in to prevent cracking of the asphalt concrete pavement surface (16). The stiffness value, defined as the load required to produce a unit deflection, became especially popular in the field of airport pavement evaluation (12,17,18).

Parallel to the development of limiting deflection and stiffness criteria, researchers considered the curvature of the deflection basin, but few limiting curvature criteria were developed. Furthermore, there is no unique definition of curvature nor any established method for its measurement. Different geometric functions are used to describe the deflected shape of the pavement's surface: a circle (19), a sine curve (15), and a parabola (20). Criteria are reported for radius of curvature (19), the ratio between the size of the deflection basin and the maximum deflection (21), the "slope" of the deflection basin (22), and the product between the radius of curvature and the maximun deflection (20). Table 1.2 summarizes limiting stiffness and curvature criteria for pavement evaluation.

Once a limiting deflection criterion is established and adopted, the evaluation scheme is generally complemented by a method for the determination of the overlay required to reduce the measured deflections below a desired limit. The Asphalt Institute (5), the TRRL (10), and others have developed such methods that are widely used.

The limiting deflection and curvature criteria, developed over long years of observations, experience, and empirical correlations with performance indicators, proved to be unsatisfactory for pavements, materials, and environmental

TABLE 1.1 Limiting Deflection Criteria for Pavement Evaluation

| Reference | Deflection Criteria | Remarks |
|---|---|---|
| WAASHO ( 1 ) | Spring $\Delta_{max}$ = 45 mils<br>Fall $\Delta_{max}$ = 35 mils | Conventional flexible pavements. Deflections measured under 18 kip axle. |
| Hveem ( 4 ) | $\Delta_{all} \leq$ 50 mils ( 1 )<br>$\Delta_{all} \leq$ 17 mils ( 2 ) | (1) Surface treatment; (2) AC layer thickness = 4 in. Deflections measured under 15 kip axle.<br>$\Delta_{all}$ = allowable maximum deflection |
| Carneiro ( 3 ) | 20 mils $\leq \Delta_{max} \leq$ 35 mils | Conventional flexible pavements. Benkelman beam deflections under 18 kip. axle, 80 psi tire pressure. |
| Whiffin et al ( 6 ) | 20 mils $\leq \Delta_{max} \leq$ 30 mils (1)<br>5 mils $\leq \Delta_{max} \leq$ 15 mils (2) | (1) Asphalt concrete over granular base.<br>(2) Asphalt concrete over cement treated base. Traffic volume considered. Benkelman beam deflections under 14 kip axle, 85 psi tire pressure. |
| State of California (8) | $\Delta_{all}$ = f(Tac,N) | $\Delta_{all}$ = Allowable maximum deflection<br>Tac = Thickness of AC layer<br>N = Number of repetitions of a 5 kip EWL<br>Examples:<br>$\Delta_{all}$ = 80 mils for Tac = 1.5 in. and N = 10,000<br>$\Delta_{all}$ = 37 mils for Tac = 1.5 in. and N = $10^6$<br>$\Delta_{all}$ = 46 mils for Tac = 6 in. and N = 10,000<br>$\Delta_{all}$ = 22 mils for Tac = 6 in. and N = $10^6$ |
| Asphalt Institute ( 5 ) | $\Delta_{all}$ = f(DTN, Temp) | DTN = Design traffic number = average daily 18 kip axle loads<br>$\Delta_{all}$ = Allowable maximum deflection (plus two standard deviations)<br>Examples:<br>$\Delta_{all}$ = 22 mils for DTN = 1000<br>$\Delta_{all}$ = 100 mils for DTN = 2<br>Benkelman Beam Deflections |
| Lister ( 7 ) | N = f($\Delta_{in.}$, pavement type) | N = Cumulative number of 18 kip axle repetitions<br>$\Delta_{in.}$ = Initial Benkelman beam deflection (14 kip axle)<br>Graphical relations between N and $\Delta_{in.}$ for different pavement types. For AC pavement with granular base layer:<br>$\Delta_{in.}$ = 20 mils; N = $4.5\times10^6$<br>$\Delta_{in.}$ = 40 mils; N = $0.5\times10^6$ |
| Nagumo et al (13) | $\log N = 0.179\Delta^2 - 1.117\Delta + 6.772$ | N = Number of repetitions to failure of heavy loads (over 18 kip)<br>Δ = Benkelman beam deflections |
| Joseph and Hall (11) | $\Delta = 1.1315/N^{0.233}$ | Δ = Initial deflection (mils) under a given load<br>N = Repetitions to failure of that load |