2.0 LITERATURE REVIEW

An extensive literature search was conducted to obtain a thorough knowledge about deflection tests, backcalculation of pavement layer moduli, and determination of effective structural number from the NDT tests. Also, the need to predict the deterioration of pavements and the role of empirical study in this respect was assessed from different studies.

2.1 The Need to Predict Deterioration

A World Bank study in 1987 estimated that a quarter of the paved roads outside urban areas in developing countries were in need of reconstruction, and that an additional 40 percent of paved roads required strengthening then or in the next few years *(Paterson et al. 1987)*. Similar situations have been arising in developed countries to varying degrees from the eighties. For example, the accelerated deterioration of federally-aided highways in the United States required a 44 percent increase in funding in 1982 to meet the repair and rehabilitation costs of the system. Extensive rehabilitation programs have also been planned in most European countries *(Paterson et al. 1987)*. A recent journal of the National Asphalt Pavement Association (NAPA) reveals the fact that "America's interstate highway system- 42,700 miles of it, once the envy of the world, is visibly deteriorating" *(NAPA 1998)*. The system already carries 2 ½ times the traffic it did in 1975, and congestion is still increasing. In the past seven years, highway capacity has grown 2% while the traffic has increased to 37% *(NAPA 1998)*. In May of 1998, the Congress passed the TEA-21 (Transportation Equity Act for the 21st Century), the six-year $216 billion highway bill for roads, bridges and mass transit. Until the year 2003, the bill is believed to guarantee that all incoming revenues to the Highway Trust Fund can only be used for highway and mass transit investments. It is also believed that even if the entire $216 billion is spent on repairing interstates, it would not be enough to restore, upgrade, and maintain them *(NAPA: Focus on Hot Mix Asphalt Technology 1998*).

Such projections at the international and national levels exemplify the problems facing the highway planners, financiers, managers and engineers everywhere at national or local levels and to varying degrees. The problem concerns deterioration of an aging road infrastructure and how best to control it, taking into account the best interests and constraints of the economy and resources. Largely because of the worldwide need for extensive rehabilitation programs in the 1980s and 1990s, and in order to avoid such sharp peaks in highway expenditure, increasing efforts are being made to develop and implement improved road management and planning tools. These tools are required for evaluating the allocation of financial needs of the road maintenance and rehabilitation programs, for evaluating the design and maintenance standards appropriate for the funding available to the highway sector, and for planning and prioritizing works in the program. Tools are also needed for evaluating the costs of road use as a basis of pricing and taxation in the transport sector *(Paterson et al. 1987)*.

All such projections and evaluations depend upon predictions of the rate at which roads in the network will deteriorate and of the effectiveness of different maintenance options, dependent on current state and projected trends of traffic, economic growth and available resources. At the heart is a model of road deterioration, which may be as simple as a fixed estimate of life, such as, paved roads need major rehabilitation every 20 years. The model may be more complex, for example, taking into account the traffic projections, existing road structure, and specific standards of service and design. Paterson et al. *(1987)* also argued that the increasing demands for improved management and planning techniques, and for economic justification of expenditures and standards in the highway sector, are placing much more exacting requirements on the models of road deterioration.

2.2 The Roles of Empirical and Mechanistic Methods

While much of the knowledge of pavement behavior historically has been based on theoretical considerations, empirical observations have always provided the basis for formulating the criteria to be applied in practice. The reason for this is clear. Under traffic and climate, the long term behavior of natural and treated road materials is influenced by numerous and complex factors and is highly variable. Thus the criteria for acceptable performance involves subjectively determined limits of riding quality and other modes of distress. The large number of variables involved, however, strains the method, and the capability to improve the structural efficiency of pavements. It also extrapolates design to the magnitude of loading and to the types of material that are beyond the scope of available field data. These have been the factors behind the recent effort toward developing the mechanistic analysis techniques *(Paterson et al. 1987).* Mechanistic methods are based on a theoretical analysis of the stresses included in a pavement under load, mechanical properties of materials, and experimental models of the behavior of materials under repetitive loadings at different environmental conditions. However, the methods need validation and calibration to the full range of real conditions. These methods currently lack the prediction of roughness and surface disintegration which are important determinants for maintenance needs *(Paterson et al. 1987).*

Empirical study can be used to quantify and distinguish the long term parallel effects of mixed traffic loading and environmental factors on pavement performance. Perhaps, it is the only method by which the real rates of distress development, the interaction between distress types, and the relative effectiveness of different maintenance activities can be quantified. On the other hand, mechanistic analyses and accelerated loading studies have been invaluable in identifying the fundamental variables and appropriate functional forms for the development of each type of distress *(Paterson et al. 1987).*

2.3 Structural Evaluation of Existing Pavements

Structural deterioration is defined as any condition that reduces the load-carrying capacity of the pavement *(AASHTO 1993)*. In the AASHTO Pavement Design Guide, the structural capacity of a new pavement is denoted as SC_0 (Figure 2.1). For flexible pavements, structural capacity is expressed by the structural number, SN. For rigid pavements, structural capacity is the slab thickness, D. For existing composite pavements (asphalt concrete overlay over Portland cement concrete, AC/PCC), the structural capacity is expressed as an equivalent slab thickness, D_{eff}. This research deals with the flexible pavements only.

The structural capacity of the flexible pavements declines with time and traffic. The effective structural capacity of existing flexible pavements is expressed as SN_{eff}. The primary objective of a structural evaluation program is to determine the effective structural capacity of the existing pavements. However, no single specific methods exists for evaluating structural capacity. The evaluation of effective structural capacity must consider the current condition of the existing pavement materials, and also consider how those materials will behave in the future. Three alternative methods are recommended by the 1993 AASHTO Guide to determine the effective structural capacity:

1. Structural capacity based on visual survey and material testing.

This involves the assessment of current conditions based on the distress and drainage surveys, and

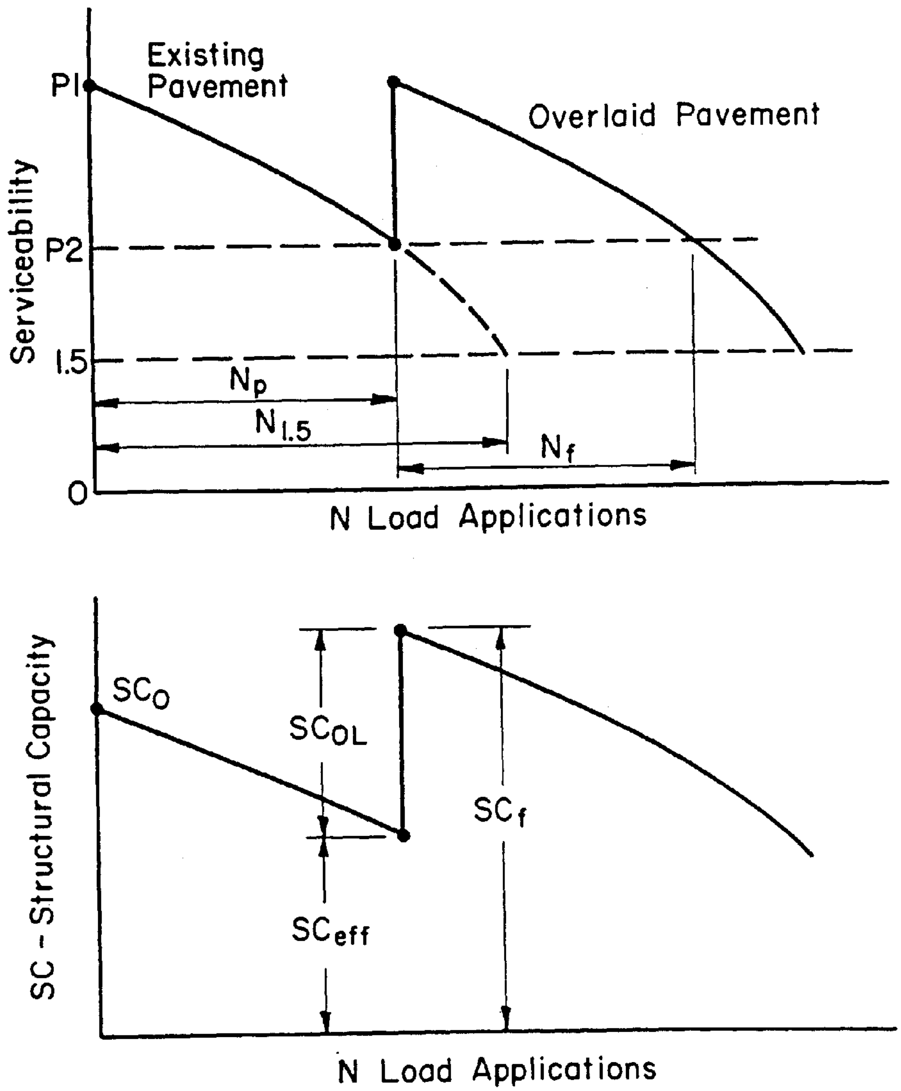

Figure 2.1 Illustration of Structural Capacity Loss Over Time And With Traffic ***(After AASHTO 1993)***

usually some coring and testing materials.

2. Structural capacity based on nondestructive deflection testing.

This approach is a direct evaluation of the in situ subgrade and pavement stiffness along the project.

3. Structural capacity based on fatigue damage from traffic.

Knowledge of past traffic is used to assess the existing fatigue damage in the pavement. This method is most applicable to the pavements which have very little visible deterioration.

2.4 Nondestructive Deflection Testing

Nondestructive deflection testing (NDT) is an extremely valuable and rapidly developing technology. When properly applied, NDT can provide a vast amount of information and analysis at a reasonable expenditure of time, money and effort. The analyses, however, can be quite sensitive to the unknown conditions and must be performed by knowledgeable, experienced personnel *(AASHTO 1993)*. For flexible pavement evaluation, NDT serves two functions:

1. To estimate the roadbed soil resilient modulus, and

2. To provide a direct estimate of SN_{eff} of the pavement structure.

For this research project, NDT data was used to calculate the effective structural number (SN_{eff}) of the pavement. The method recommended in the 1993 AASHTO Guide was followed in the process.

2.4.1 Temperature-Deflection Correction

A wide range in modulus of an asphalt material may occur as the temperature varies from cool to warm conditions. At very cold temperatures, the modulus of an asphalt mix may approach the stiffness values of Portland Cement Concrete (6.9 GPa to 13.78 GPa or 1 to 2 million psi) while at very warm temperatures, the mix may have an elastic modulus slightly greater than the high quality unbound stone base (3.4 MPa to 1.4 GPa or 50,000 to 200,000 psi). This is due to the fact that asphalt is a viscous material and its properties are highly dependent on temperature. Therefore, the FWD first sensor deflection data must be corrected and standardized (at 20ºC or 68°F) before it can be used in the calculation of effective structural number. However, the first task is to determine the average pavement temperature during the FWD deflection test.

2.4.2 Determination of Average Pavement Temperature

The most direct way to determine the temperature of the asphalt layers during an NDT deflection test is to physically measure the temperature. Care must be taken to recognize that with increased depth into the asphalt layer fairly high temperature gradients may occur at a given time. Thus in many cases, the measurement of temperature only at the surface will not suffice as an accurate measurement of the 'average' or 'effective' temperature of the entire layer. The thicker the asphalt layer, the greater the need to evaluate the overall pavement temperature for the entire layer rather than simply relying on the surface temperature measurements.

The 1986 AASHTO Guide recommended an alternative procedure for determination of effective pavement temperature which was adopted in the 1993 Guide. It is generally recommended that the pavement temperature be calculated from the graph provided by AASHTO at three depth locations within the pavement structure: (1) near surface (less than 25 mm or 1-inch depth), (2) mid layer, and (3) bottom of the asphalt concrete layer. The average temperature computed from these values then yields the estimate of the pavement temperature at the time of the FWD deflection testing. This procedure requires the following information:

1. Pavement surface temperature during the FWD test, and

2. Average air temperature data at the site for the five days previous to the FWD test.

Previous research indicated that this procedure showed excellent consistency when applied to some states in the U.S. *(AASHTO 1986)*. Therefore, in this study, the AASHTO approach was followed to calculate the average pavement temperature.

2.4.3 Effective Structural Number (SN_{eff})

At sufficiently large distances from the load, deflections measured at the pavement surface are due to the subgrade deformation only and are also independent of the size of the load plate *(AASHTO 1993)*. This permits the backcalculation of the subgrade resilient modulus (M_r) from a single deflection measurement and load magnitude using the following equation:

$$M_r = (0.24 * P) / (d_r * r) \qquad \textit{(2.1)}$$

where,

M_r = backcalculated subgrade resilient modulus, psi,
P = applied load, pounds,
d_r = deflection at a distance r from the center of the load, inches, and
r = distance from the center of the load, inches.

It should be noted that no temperature adjustment is needed in determining M_r since the deflection used is only due to subgrade deformation. The deflection used to backcalculate the subgrade resilient modulus must be measured far enough away that it provides a good estimate of the subgrade modulus, independent of the effects of any layers above, but also close enough that it is not too small to be measured accurately. The minimum distance may be found from the following relationship:

$$r \quad 0.7\, a_e \qquad \textit{(2.2)}$$

$$a_e = [\, a^2 + D^2 * (E_p/M_r)^{2/3}]^{1/2} \qquad \textit{(2.3)}$$

where, a_e = radius of the stress bulb at the subgrade-pavement interface, inches
a = NDT load plate radius, inches
D = total thickness of pavement layers above the subgrade, inches
E_p = effective modulus of all pavement layers above the subgrade, psi.

E_p values may be determined from the ratio E_p/M_r (Figure 1.2) or based on the following equation:

$$d_0 = 1.5pa\left\{ 1 \Bigg/ M_R\sqrt{1+\left(\frac{D}{a}\sqrt[3]{\frac{E_p}{M_R}}\right)^2} + \left[1-\frac{1}{\sqrt{1+\left(\frac{D}{a}\right)^2}}\right] \Bigg/ E_p \right\} \tag{2.4}$$

where, d_0 = deflection measured at the center of the load plate *(and adjusted to a standard temperature of 20°C or 68°F)*, inches

Once the E_p value is calculated, the effective structural number can be easily determined by the Equation 2.5 provided by AASHTO:

$$SN_{eff} = 0.0045 * D * (E_p)^{1/3} \tag{2.5}$$

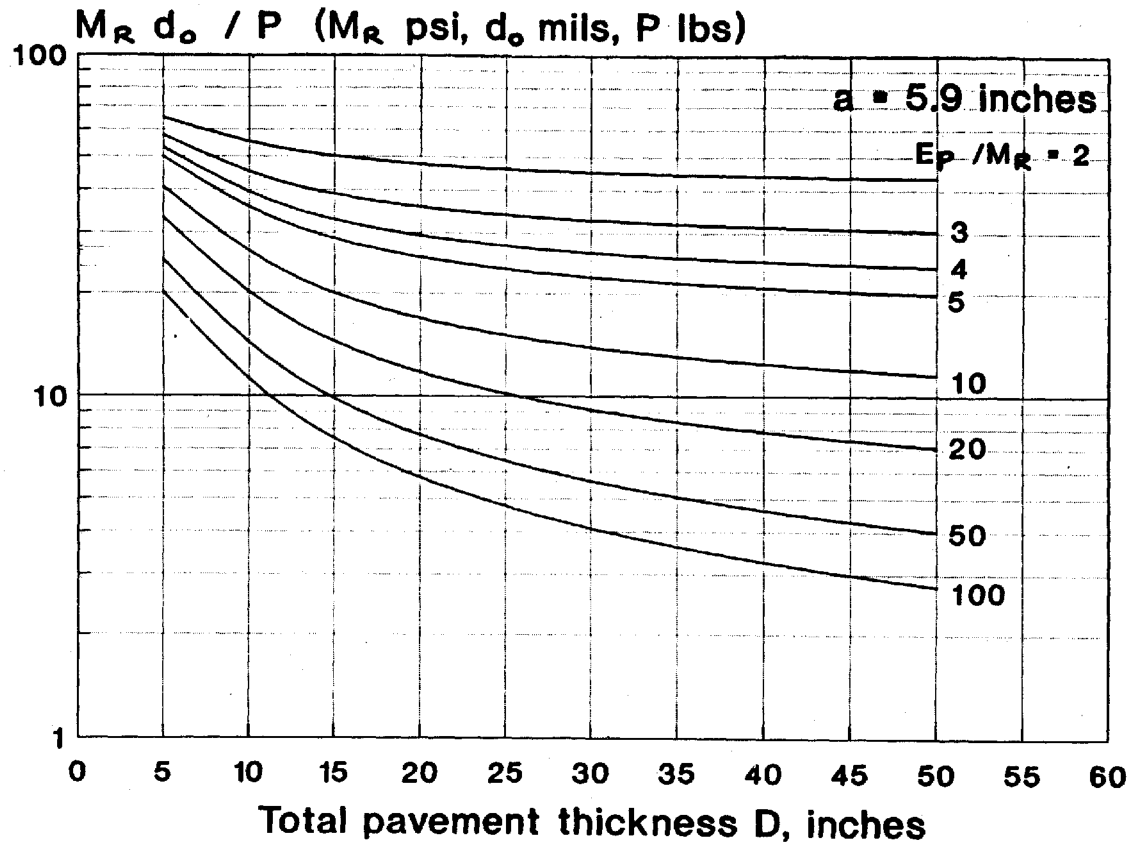

Figure 2.2 Determination of E_p/M_r *(After AASHTO 1993)*