1.0 INTRODUCTION

1.1 Introduction to Elementary Pavement Design

Pavement in general can be defined as structure to withstand wheel load of vehicle used either for cargo or passenger transport. Therefore, design of pavement essentially involves determination of suitable thickness of pavement with specified characteristics of paving materials to be placed on the top of subgrade (softest part of pavement structure) to withstand wheel load. The basic mechanism of pavement design is based on the nature of dissipation of stress through the paving layers, so as to protect the subgrade soil from failure.

Due to geometric design of vehicle, the tyre pavement contact surface is very small when the vehicle load passes through the wheels, the stress on the top of the pavement becomes very high due to such small contact area.

It is, therefore, essential to know the nature of dissipation of stress through a layered system of granular materials, the stiffness of which reduces from top to bottom along a vertical section of a pavement. As the wheel load by vehicle on a pavement with a specific design speed does not remain static on a fixed point, therefore, the design load in pavement is considered as number of passes of a standard wheel load over a pavement section to be designed. Design of pavement therefore depends mainly up on the anticipated loading on pavement during its design period and also on the strength of subgrade on which the pavement is to be laid. It means that thicker pavement will be required for subgrade with lesser strength and vice versa if load repetition is constant. Similarly pavement having same subgrade strength would require thicker section for larger load repetitions and vice versa.

Mechanistic design procedure refer to those methods which incorporate models based on fundamental engineering mechanics to evaluate the state of stress in a pavement and predict response behavior and performance. But empirical procedures are those that depend on models developed from experience and observation of past performance. In the present work attempts are made to design the pavement by mechanistic–empirical design approach based on stress, strain and deflection based criteria. Keeping in view, the flexible pavement design deals primarily with structural aspects i.e. selection of appropriate materials, characterization of strength and layer thickness determination, it can be said that flexible pavement design principle is
manifested in mechanistic or mechanistic empirical (M–E) based design procedures that incorporate the treatment of life cycle costs and design reliability.

Present work is a combination of theoretical analysis and experiences obtained by different agencies based on pavement response from distress model. The thickness of pavement obtained by the proposed method is an output of a mixed approach, one from pure theoretical understanding and the other from real life pavement response.

1.2 Composition of Flexible Pavements

Conventional pavement is layered systems with stiffer materials on top where the stress intensity is high and softer materials at the bottom where the stress intensity is low. Fig.(1.1) shows, the cross section of a conventional flexible pavement.

![Sectional view of flexible pavement.](image)

**SURFACE / WEARING COURSE**

It is the top course of flexible pavement, sometimes called as wearing course or surface course. It is usually constructed by dense graded. Bituminous mix. It should be tough to resist distortion under traffic load and provide a smooth and skid resistant riding surface. Wearing course must be waterproof layer to protect the pavement from weakening effect of water. Premixed Carpet (PC) Semi–Dense Bituminous (SDAC), Concrete or Bituminous (BC) Concrete are considered as conventional material for wearing course.
BINDER COURSE

The binder course sometimes called the Bituminous base course and which is the Bituminous layer below the surface course. Binder course generally consists of larger aggregates and less asphalt and does not require as high a quality as the surface course. Bituminous Macadam (BM) or Dense Bituminous Macadam (DBM) is considered usually as binder course.

GRANULAR BASE COURSE

The base course is the material immediately below the surface of Binder course. It may consist of crushed stone, crushed slag, water bound macadam (WBM), wet mix macadam (WMM) or other equivalent granular construction. The CBR of granular base should be within 80% to 100%.

GRANULAR SUB–BASE :

The sub–base course is a layered material, which lies beneath the base course. The reason of using two different types of granular materials is for economy, which in other way satisfies the dissipation of stress with reasonable degree of reliability within the pavement structure. If the base course is open graded, the sub–base course with more fine can serve a filter between subgrade and the base course. According to IRC–37–2001 [45], the subbase material should have a minimum CBR of 20% for design traffic up to 2 Msa and 30% for traffic exceeding 2 Msa. It may consist of materials like sand, moorum, gravel, laterite, brick metal, crushed concrete crushed stone or combinations there of meeting the prescribed grading and physical requirements.

SUBGRADE

Subgrade is defined as the natural or compacted soil layer on the top of which sub–base layer is laid. It is also defined as the weakest or softest layer in a pavement system. The subgrade, whether in cut or fill should be well compacted to utilize its full strength and to economize thereby on the overall thickness of pavement required. If the subgrade is too soft, it is desirable to plan a layer of compacted subgrade with
desired density and optimum moisture content at least on top 500m portion of the road way width.

1.3 Previous Works on Pavement Design

1.3.1 Empirical Methods

Empirical methods can be defined as an approach of pavement design based on observation of past performances. The oldest of this method developed in 1929 [24] in which the subgrade was classified as uniform from A−1 to A−8 and nonuniform from B−1 to B−3. Subsequently (HRB 1945)[39] the method was modified in which soils were grouped from A−1 to A−7 and a group index was added to differentiate the soil within each group. Steele (1945)[67] discussed the application of such soil classification and group index in estimating the sub−base and total pavement thickness without a strength test. The empirical method with a strength test was first used by California highway department in 1929[38] Portar (1950)[58]. The thickness of pavement was related to the California Bearing Ratio (CBR), defined as the penetration resistance of a subgrade soil with respect to a standard crushed rock. Subsequently U.S. Corpse of Engineers (1940)[74] developed design approach for road and airfield pavement based on CBR concept. Design curves based on CBR method but incorporating the effect of equivalent wheel load was found in Kentucky[6] design curves. Wyoming method[55] is another modification of CBR design approach[33] which takes in to account the effect of precipitation, depth of water table, frost action and existing conditions of road and road traffic.

1.3.2 Limiting Shear Failure Method

In this method, it was proposed that the layer thickness could be designed using the bearing capacity approach, in which the stress developed in respective layers must be less than the corresponding bearing capacity of the individual layers. Barber[7] first proposed this approach in 1946, where he applied Terzaghi’s[38, 68] bearing capacity approach for pavement design. McLeod (1953)[52] proposed the use of logarithmic spirals to determine the bearing capacity of pavements. All these methods were reviewed by Yoder (1959)[78]. This is also one of the considerations in the South African pavement design method[53]. However, shear can be partly linked
with rutting failure of pavement, shear considerations alone cannot take care of the structural design of the pavement as a whole.

1.3.3 Limiting Deflection Methods

The limiting deflection method is used to determine the thickness of pavements so that the vertical deflection will not exceed the allowable limit. The Kansas State Highway Commission (1947) modified Boussinesq’s equation (Boussinesq, 1885)[20] and limited the deflection of subgrade to 2.54 mm. The U.S. Navy (1953) applied Burmister’s two–layer theory (Burmister, 1943)[21] and limited the surface deflection to 6.35 mm. The use of deflection as a design criterion has the apparent advantage that it can be easily measured in the field. Unfortunately, pavement failures are caused by excessive stresses and strains instead of deflections[77]. However for determination of thickness of strengthening of an in–service pavement, the deflection method is still used successfully for overlay design [30, 46]. Significance of deflection as a design criteria of Bituminous pavement has also been studied in Indian context (Biswas et al., 1995) [8, 10, 13].

1.3.4 Distress Model or Transfer Function

Multitude relationships have been developed to relate the state of the stress in a pavement to its overall performance. Currently mechanistic empirical methods for flexible pavements, the primary transform functions are those that relate (i) maximum wheel load tensile strain in the Bituminous layer eventual to fatigue cracking and wheel load compressive strain or stress at the top of the subgrade layer to rutting at the surface[26,27]. These models are derived through statistically based co–relations of pavement response with observed performance of laboratory test specimens and or with full-scale road test experiments. Transform functions are the most important component of a mechanistic empirical design procedure; unfortunately, a lot of models are available that do not show good agreement. Use of Rutting rate concept (Majidzadeh et al., 1976)[50] was promising. Shahin–McCullough (1972) [64] thermal cracking model may also be used to evaluate thermal cracking potential after construction of pavement. Miner’s (1945) [53] cumulative damage concept has been widely used to predict fatigue cracking. The major difference in various design
methods is the transform functions, which relate the tensile strain in bituminous layers to the number of allowable load repetitions. In the Asphalt Institute [4,5] and shell design [65] methods, the allowable number of load–repetitions ($N_f$) to cause fatigue cracking is related to tensile strain $\epsilon_t$ at the bottom of bituminous layer and the modulus of Bituminous mix ($E_1$).

$$N_f = f_1(\epsilon_t)^{-f_2} (E_1)^{-f_3} \quad \ldots (1.1)$$

Where $f_1$, $f_2$ and $f_3$ are constants and vary with the finding of different agencies for different degree of distress. Similar formulations can be seen in cracking model as proposed in IRC–37, 2001[45] which has been used in the present work.

In order to limit rutting, there are two procedures to limit rutting; one to limit the vertical compressive strain on the top of the subgrade and the other to limit the total accumulated permanent deformation on the pavement surface based on the permanent deformation properties of each individual layer. The allowable number of load repetitions $N_s$ to limit the rutting is related to the vertical compressive strain $\epsilon_c$ on the top of subgrade may be expressed as

$$N_s = f_4 (\epsilon_c)^{-f_5} \quad \ldots (1.2)$$

Eqn. (1.2) is used by several agencies [19,25,45,59,65,73] with different values of $f_4$ and $f_5$. The transform function used by IRC–37–2001[45] for prediction of rutting has been used in present work.

### 1.3.5 Mechanistic Empirical Methods

The mechanistic–empirical (M–E) method of design is based on the mechanism of materials that relates an input, such as wheel load, to an output or pavement response, such as stress or strain[72]. The response values were used to predict distress based on laboratory test or field performance data. Dependence on observed performance is necessary because theoretical understanding of design has not yet been proven adequate to predict pavement performance realistically.

Kerkhoven and Dormon (1953)[47] first suggested the use of vertical compressive strain on the surface of subgrade as a failure criterion to reduce permanent deformation, while Saal and Pell (1960)[63] recommended the use of horizontal tensile strain at the bottom of asphalt layer to minimize fatigue cracking, as
shown in Fig2.1 The use of the above concepts for pavement design was first presented in the United States by Dormon and Metcalf (1965)[29].

The use of vertical compressive strain to control permanent deformation is based on the fact that plastic strains are proportional to elastic strains in paving materials. Thus, by limiting the elastic strains on the subgrade, the elastic strains in other components above the subgrade will also be controlled; hence, the magnitude of permanent deformation on the pavement surface will be controlled as well. These two criteria have since been adopted by Shell Petroleum International (Claussen et al., 1977)[25] and the Asphalt Institute (Shook et al., 1982)[66] in their mechanistic–empirical methods of design. AUSTORoads(1992)[56] and AASHTO(1993)[2] methods are a major milestone in the history of mechanistic-empirical pavement design which considered a large number of variables for design of flexible pavement with a better degree of durability. The advantages of mechanistic-empirical methods are the improvement in the reliability of a design, the ability to predict the types of distress, and the feasibility of extrapolate from limited field and laboratory data[42]. AASHTO design guideline (2002)[3] is the latest one, which incorporates the concept of serviceability of pavement with more realistic prediction of traffic load, characterization of materials and design reliability with a better probabilistic approach.

1.3.6 Software for Pavement Design

The basic formulation of oldest software for pavement design is known as CHEV program (Warren and Dieckmann, 1963)[76] based on Burmistered layered theory [21,22]. The program initially was applied to linear elastic material but was modified by Asphalt Institute in the DAMA program to consider non–linear elastic granular material (Hwang and Witczak 1979)[44]. Subsequent modifications to Burmister layered theory have been able to formulate ELSYM–5 for elastic five-layer system under multiple wheel loads (Kopperman et al., 1986)[48]. Another program BISAR developed by shell, which considers not only vertical loads but also horizontal loads. (DeJong et al., 1973)[28]. Based on the multi-layered theory with stress dependent material properties, Finn et al. (1986)[32] developed PDMAP program for predicting fatigue cracking and rutting in Bituminous Pavements. Critical response
obtained from PDMAP was found very close to SAPI[31], which is a finite element–stress analysis program developed at the University of California.

A major disadvantage of the layered theory is the assumption that each layer is homogeneous with the same properties throughout the layer. This assumption makes it difficult to analyze layered systems composed of nonlinear materials, such as untreated granular bases and sub bases. The elastic modulus of these materials is stress dependent and varies throughout the layer, so a question immediately arises, which point in the nonlinear layer should be selected to represent the entire layer? If only the most critical stress, strain, or deflection is desired, as is usually the case in pavement design, a point near to the applied load can be reasonably selected. However, if the stresses, strains, or deflections at different points, some near to and some far away from the load, are desired, it will be difficult to use the layered theory for analyzing nonlinear materials. This difficulty can be overcome by using the finite element method.

Duncan et al. (1968)[31] first applied the finite element method for the analysis of flexible pavements. The method was later incorporated in the ILLI–PAVE computer program (Raad and Figueroa, 1980)[60]. Due to the large amount of computer time and storage required, the program has not been used for routine design purposes. As a result of AASHO road test, VESYS program was developed considering serviceability performance and reliability concept[61]. However, a number of regression equations, based on the responses obtained by ILLI–PAVE, were developed for use in design (Thompson and Elliot, 1985)[70]; (Gomez–Achecar and Thompson, 1986 )[35]. The nonlinear finite element method was also used in the MICH–PAVE computer program developed at Michigan State University (Harichandran et al., 1989)[36]. Latest software, based on mechanistic empirical method is MnPAVE 2003[54] is now widely used for design of pavements even with heavy duty axle loads.
1.4 **Scope of Present Work**

Present work is primarily aimed to find out different approaches of design of bituminous pavement by mechanistic–empirical method using concentration factor in a two layered system. Concentration factor \((n)\) used in present analysis is a function of modulus ratio in a two layered system (which consists of a paving layer and a layer of subgrade soil on which paving layer is to be laid). Therefore, concentration factor in an existing or proposed pavement is an indicator by which stresses or strains on the top of subgrade can be estimated. Application of specific concentration factor values therefore, characteristics a comparative strength of pavement and subgrade materials.

Use of concentration factor as defined in this work is an interesting aspect of stress distribution in a layered system of mass. Therefore attempts are made in this work to develop stress distribution formulation both under point load as well as circular load in a layered system. Stresses thus obtained can further be applied to estimate strain and deflection in a pavement system.

Basic objective of design of pavement is to find out a suitable thickness of paving layer on the top of subgrade so as to limit the deflections, stresses or strains that may likely to act as a result of wheel load application. Accordingly the objective of present work has been classified as –

(i) **Determination of Pavement thickness on the basis of vertical compressive stress on the top of the subgrade and validation of test results.**

(ii) **Determination of Pavement thickness on the basis of vertical compressive strain acting on the top of the subgrade and validation of test results.**

(iii) **Determination of Full depth Asphalt pavement thickness on the basis of Radial tensile strain acting at the bottom of bituminous layer and validation of test results.**

(iv) **Determination of Pavement thickness on the basis of elastic deflection occurring at pavement subgrade interface and validation of test results.**

(v) **Prediction of deflection bowl on the basis of deflections occurring at pavement subgrade interface, in order to formulate a design guideline of pavement.**