A State-of-the-Art Review of Different Conditions Influencing the Behavioral Aspects of Flexible Pavement

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Abstract. The paper provides a state-of-the-art review of different conditions influencing the behavioral aspects of flexible pavement. The conditions which influence the pavement behavior are loading intensities and tyre pressure intensity, environmental conditions, surface and subsurface temperature, seepage, thickness combinations of different component layers, material properties, etc. Current pavement design and analytical procedures are discussed and questioned. The life of the road is theoretically designed for repetition of standard axle load, wherein, negligence in consideration of overloaded vehicles and high tyre inflation pressures even up to 1 MPa is noticed. The latest developments in the design and analytical procedures of pavements are highlighted. An overview of finite element modeling efforts involving different aspects is also presented. A combined effect of various actual conditions in the field affecting the pavement performance needs to be studied in details, therefore, there is a demand for an application of analytical tool which can accommodate the details of the complex system. In this connection, it should be noted that the versatile finite element solution technique holds a bright promise. Therefore, it is proposed to discuss at length the application of the finite element method towards the design of the flexible pavements.

Keywords: Flexible pavement · Finite element analysis

1 Introduction

Direct or indirect application of empirical relationship is the backbone of current pavement design procedures which are based on long-term experience and field tests such as AASHO Road Test [27, 34]. A good pavement design is one that provides the expected performance with appropriate economic consideration. The material characterisation of different pavement layers and traffic loading are the primary inputs into the mechanistic model. These approaches are reasonably accurate for design purposes in early years but the scenario has been changing due to rapid change in axle load and its

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configuration which has to be considered for its worst effect while designing flexible pavements. The enhanced study is necessary to find fatigue and rutting distress developed in different layers of flexible pavements due to the combined effect of different environmental parameters (like seepage, temperature etc.) and overloading with inflated tire pressure. Flexible pavements are subjected to various conditions which affect the pavement response, but it is practically not possible and even feasible to make a combination of all above parameters in a field, which creates a need to develop a model which considers a multifaceted system comprising of characteristics of the various environmental condition. FEM is a multidisciplinary tool which can analyze or evaluate the combined effect of above parameters which will be helpful to predict the behavioral aspects of flexible pavement. Day by day increasing the flow of commercial vehicles along with excessively loaded trucks beyond double its capacity and changes in environmental factors has been responsible for reducing the life of pavement [26]. In the present paper various improvements in the design procedures and its application to the present day condition are discussed in details.

2 Literature Review

Empirical methods, limiting shear failure methods, limiting deflection methods, regression methods based on pavement performance of road tests (like AASHTO) and mechanistic-empirical methods are the five basic categories on which the flexible pavement design methods are dependent [14]. The disadvantage of an empirical approach like CBR method of design is that the outcome is based on particular set of environmental, material, and loading conditions. The design is not validated to the other conditions. The major approach for designing a pavement along with stability and safety is the riding comfort wherein the methods based on limiting shear failure approach fails to address. Pavement distresses in the form of potholes, fatigue in the form of cracking and rutting are caused due to excessive stresses and strains developed in the pavement which is not seen in the methods which are based on the limiting deflection approach. The design equations based on AASHTO method which is a result of road test can be applied only to the conditions for which it was formulated [2, 21]. For its application to other conditions extensive modifications based on theory or experience is needed. The Shell method and the Asphalt institute method are the most promising mechanistic-empirical methods which use strain at critical locations to control permanent deformation. The ability to predict the type of distress is the advantage of M-E design approach over the other approaches.

Traffic and loading, materials, environment, and failure criteria are four broad categories in which design factors are distributed. The axle loads, the number of load repetitions, wheel spacing, tyre-pavement contact area and vehicle speed should be included in traffic and loading factors. In mechanistic design procedure, the mention traffic inputs are used in the structural model except for the number of repetition which is used in distress model.

Temperature and seepage both affect elastic moduli of the various layers which ultimately affects the performance of pavement [14, 27]. As in a case of elastic moduli which is temperature dependent the design of pavement should be done considering the dynamic behavior of the various material, increasing traffic, and uneven climatic conditions incorporated during analysis. Along with temperature and precipitation, in the particular areas wherein environmental factors like frost penetration, freezing index, the nearness of ground water table are the factors which need to be considered in the analysis. The climatic models including the heat transfer model, etc. For determining the temperature distribution with respect to space and time, the moisture equilibrium model for determining final moisture distribution in the subgrade, and infiltration-drainage model for predicting the degree of saturation of granular bases can be used in mechanistic design procedure [14]. Zuo et al. [39] observed seasonal temperature and water content variations and evaluated their effects on predicted pavement life. The results of the parametric study showed that the temperature averaging period, the temperature gradient in the asphalt, and the timing and duration of a wet base and subgrade conditions affect the estimation of pavement life. To determine the responses of pavement such as stresses, strains, and displacement in critical components inputs should be given in the form of basic material properties like modulus and poison's ratio in structural models. Those responses are then used in the various failure criteria's in the form of distress model including fatigue cracking, rutting, and low temperature cracking, from which the reliability level and their final design are obtained.

Pavement responses such as stress, strains, and deflection caused due to load, material properties, climatic condition is determined in mechanistic design, which is then empirically correlated to the pavement performance. A number of such mechanistic pavement response models have been developed over the years, ranging from Boussinesq's one-layer model to multi-layer elastic theories to finite element models. Boussinesq [14] formulated a simple formulation for determining stresses, strains and deflections of a homogeneous, isotropic, linear elastic half-space, with Young's modulus and Poisson's ratio subjected to a static point load. Boussinesq's equations were originally developed for a static point load. Later, Boussinesq's equations were further extended by other researchers for a uniformly distributed load by integration [37]. Boussinesq's closed form solution is a very simple and useful approach to mechanistic pavement analysis. Yoder and Witczak [37] suggested that Boussinesq theory can be used to estimate subgrade stresses, strains, and deflections when the base and the subgrade have similar stiffness. Burmister [14] developed a solution for two layers and subsequently for a three layers system. Several layered analytical elastic models have been developed which are generally based on Burmister. Finite element analysis methods have been developed to model flexible pavement responses. Duncan et al. [7, 14] first applied the finite element method for the analysis of flexible pavements.

Helwany et al. [13], illustrated the usefulness of finite element method by discretising a three layer pavement system with the right boundary at a distance of about 8 times the loaded radius subjected to different types of loading. Two-dimensional followed by three-dimensional analysis is performed after validating the analysis with reported case histories to measure the critical performance parameters. Modified Duncan model is used to represent the nonlinear behavior of granular base layer. 2-D axis-symmetrical finite element analysis is performed using the computer program DACSAR. The analysis is further elaborated to 3-D analysis using Nike-3D computer program.

Park et al. [33] focused on the behavior of low volume roads under nonlinear finite element model (FEM). Single tyre load of 40 KN [4] was used for analysis of side boundary. For this study nonlinear finite element model with stress, dependency is developed. The single tyre load used for analyses side boundary is 10 times tyre radii and at 2 m depth and resilient modulus is noted at 3 different locations i.e. at the surface, near and edge of loading point. Further, this study can be extended by adding, more layers (increasing thickness) of AC and including base and sub base. This model can be very helpful for selection of proper materials with proper characteristics which further improves the analysis process. By comparing the developed nonlinear finite element model with a linear model, it was concluded that nonlinear FEM was more suitable to calculate reduced tension in the bottom half of unbound base layers. Upon further comparison with field tests, it was observed that nonlinear stress-dependent finite element method was reliably closer to the observed measurements. Proper selection of materials is also necessary to improve the prediction of the behaviors using developed stress dependent nonlinear FEM.

Saad et al. [5] reported the use of three-dimensional finite element analysis (FEA) for elastoplastic models with ADINA program. The work focuses on the analysis of conventional flexible pavement foundation systems, dynamic response, corresponding to fatigue, strain at the bottom of the asphalt concrete layer and rutting strain at the top of subgrade material. A convenient FEA model was developed considering the domain size and traffic load simulation, which was then examined using sensitivity analysis to interpret the influence of foundation parameters on pavement response. A primary analysis was performed with a view to compare the effect of the elastoplastic material as foundation material with the linear elastic material as the foundation materials. From the analysis, it is noticed that the elastoplasticity caused an increase in rutting strain, maximum tensile strain, and maximum vertical surface deflection. The model sensitivity analysis considering elastoplastic materials, highlights that subgrade material has little or no impact on fatigue strain but reduces rutting strain remarkably. Regardless of subgrade quality, the analysis performed by Saad et al. [6] illustrates that a strong base quality significantly decreases fatigue, strain for thick and thin bases as compared to the weak base. While the reduction in base thickness showcased an increase in fatigue, strain while rutting strain constantly increased.

Siddharthan et al. [24] assessed field pavement responses for a variety of loadings in different environmental conditions by various off-road vehicles three-dimensional moving load analysis, which investigated contact stress distribution by bulky off-road vehicle tyres and compared with computed and actual pavement behavior. Thin and thick pavements were tested for three types of empty and loaded vehicles. Field testing for relatively thin and relatively thick flexible pavement was tested under three types of empty and loaded off-road vehicles. Each pavement section was instrumented with pressure cells, deflection gages, and strain gauges at the bottom of the asphalt–concrete layer. The generated finite-layer approach could handle complex surface loadings such as multiple loads and non-uniform tyre-pavement contact stress distributions.

The beneficial effect of high modulus geosynthetic materials into the foundation of pavement is documented in the study conducted by Saad et al. [6] for the improvement in the critical parameters. It was concluded from the study that the geogrid reinforcement when placed at bottom of the AC layer, rutting strain reduced up to 48% and was independent of base thickness and subgrade quality. In the thin base pavement of 152.4 mm it was observed that rutting strain reduced in the range of 2–34%. When placed at one-third from base bottom rutting strain value decreases significantly, but can be increased by using the sound base material.

Diefenderfer et al. [8] developed a model for predicting the pavement temperature, which is beneficial to those who need to determine the pavement temperature profile in order to calculate in situ pavement engineering characteristics. By using ambient temperature trends from historical records, these models can predict anticipated future pavement temperatures and thus aid researchers in determining the amount of time that pavements are subjected to critical temperatures.

Immanuel and Timm [16] used layered elastic analysis to compare predicted vertical stress in the base and subgrade layers to field measured vertical pressures obtained from the National Center for Asphalt Technology (NCAT) Test Track. The authors found that the predicted pressure was only a reasonable approximation up to vertical pressures of 82 kPa in the base and 48 kPa in the subgrade. Wu et al. [36] calculated the vertical stress at the bottom of base layer using the multilayer elastic program ELSYM5 and compared it to data from the Louisiana ALF. The study found the calculated vertical stresses to be two to eight times higher than the measured field values.

Masad et al. [32] focused on comparative analysis of using isotropic and anisotropic models in flexible pavement response along with an evaluation of permanent deformation and fatigue cracking using NCHRP 1-37A [20] design guide. Anisotropic properties were assumed for unbound base and subbase layers to measure surface deflection which reduced unrealistic tensile stresses which were assumed in the isotropic model in the granular base. Finite element predictions were comparatively analyzed with AASHO road test measured deflections.

The anisotropic nonlinear model depicted longer fatigue lives which reduces the need for large shift factors while establishing a relationship between empirical laboratory calculations to field conditions. The study highlights total permanent deformation in asphalt layers to be more considering anisotropic properties in NCHRP 1-37A model. For the anisotropic, model high tensile stresses were calculated in the lower regions of asphalt layers and total rutting for the model was more than an isotropic model. The Mechanistic-Empirical Pavement Design Guide (MEPDG) recommends using the multilayer elastic program JULEA, which is a modified version of WESLEA, and linear models to compute flexible pavement responses [19, 20]. Pavement analysis procedures that are derived from the theory of elasticity are based on simplifications of the real condition.

Mulungye et al. [22] generated a two-dimensional four layer model using ANSYS/ED to evaluate structural performance of finite element method considering factors like tyre pressure, wheel configuration and axle load variations of a transportation truck. The results obtained from the model analysis were verified with in situ full-scale test data. Andrew et al. [3] propose a simulation model that utilizes transient, two-dimensional finite difference method to calculate the temperature distribution in asphalt pavements in reaction to hourly thermal environmental conditions and to calculate associated thermal stresses. The study uses the stiffness index to evaluate the thermal stress distribution in asphalt pavements and initial thermal stress maps during the seasonal and diurnal freeze and thaw cycles. The generated numerical model permitted an hour-by-hour calculation of the pavement temperature and thermal stress distribution in two-dimensional cross section. Pavement tilt angle had a substantial impact on the pavement temperature distribution while precipitation and evaporation had a cooling effect on the pavement surface temperatures. Lower thermal stresses were observed when higher thermal conductivity layers were placed on the pavement top surface. For a more realistic prediction of pavement temperatures, the numerical model can be further extended to consider the effects of snow and mushy zones.

Su et al. [18] studied evaluation of shear stress in the pavement, so as to know the actual influence of tyre-pavement contact pressure on pavement shear stress in asphalt mix years are applied and studied and then the analysis is done and on semi-rigid asphalt pavement. For analysis in 3D FE model, single axle load with dual tyres was applied Shear stress value comes maximum at tyre edge. The maximum shear stress occurs as 60 mm below the tyre edge. Also, it is noticed from the work that vertical loading and tyre pressure are also the factors which are responsible for producing shear stresses.

Ziari et al. [12] analyses the use of steel slag in asphalt mixture to replace fractional fine aggregates. Steel slag is a material with an environmental issue which cannot be decomposed nor incinerated. These materials are brittle in nature but rich in carbon and silicon, which makes it strong enough to be replaced for fine aggregates to save the environment. Significant outcomes from the study show that the maximum size up to 4.75 mm and an optimum replacement was 10%. The various parameters such as strength index, high-temperature stability, and water stability are up to mark and improve creep stiffness when broken slag is used.

Tarefdar et al. [23] studied the six existing pavement section's design guides and parameters like mean, maximum likelihood, median, the coefficient of variation, and density distribution function of subgrade strength R value were determined. The outputs obtained were then compared in reliability and thickness. Probabilistic procedure yield lesser reliability values than AASHTO. The procedure based on the coefficient of variation of R value deals properly with the subgrade variability. Increasing the minimum R-value for sub-excavation does not necessarily provide an exact solution to meet design reliability. To mitigate different distresses; alternative designs were suggested for the existing pavement thicknesses by modifying material and subgrade properties.

Ranadive et al. [25] illustrates that axisymmetric analysis of flexible pavement is carried out by a computer program (ANSYS), and different performance parameters of pavement were studied for varying conditions of thickness. The increase in thickness of the base course and sub-base course layer does not help to reduce stress and deflection as compared to asphalt concrete layer in which it is observed that there is a substantial reduction in stress as there is an increase in thickness of asphalt concrete. Also, it is reported that the maximum deflection of flexible pavement under wheel load varies with an increase in thickness of the different layers of the component. It reduces when BC layer thickness increases, while increases when base-course and sub-base course thickness increases. As stiffer materials are employed in the upper layers, the noticeable reduction in subgrade stress and deflection is observed. For any given subgrade soil type, this allows a reduction of the thickness of the stiffer layer over a similar thickness of unbound granular material to satisfy the requirements of an allowable subgrade distress or limiting deflection criteria. The Interface between asphalt concrete layer and base course layer affects the distribution of stress in the lower layers of the road structure. Analytical methods can predict the performance of flexible pavement, which helps to bypass costly field experiments; hence it is beneficial to society. Sahoo et al. [35] studied the effect of nonlinearity in a granular layer on critical pavement responses of low volume roads. From the sensitive analysis, a subgrade depth of 2000 mm and length of 1800 mm in the longitudinal direction is determined. To model the non-linearity of granular material, the author used Drucker- Prager plasticity model. From reported work, it is found that the vertical strain on top of subgrade and central deflection increases by 9% and 7% respectively when compared to the values obtained using linear elastic analysis. The author recommends consideration of non-linearity in granular layers for more accurate modeling of pavement.

Rahman et al. [29] focuses on pavement response subjected to various traffic factors like different axle configuration, tyre imprint areas, and inflation pressure. Three-dimensional finite element analysis regarding fatigue and permanent deformation using ABAQUS software was performed. Three layers of pavement were considered as asphalt surface, granular base and subgrade which were assumed to respond linearly and elastically to the static load applied. Interaction properties were assumed as having frictionless contact between two adjacent layers. ABAQUS software was used to measure horizontal tensile and vertical compressive strains. From the considered study it was summarized that tyre imprint area needed to be a rectangle with two semicircles on either side and was considered to be a region of more extensive research work.

Wang et al. [11] analyzed the effects of truck tyre types based on tyre geometries and specifications obtained from tyre manufacturers. A two-dimensional finite element analysis was conducted to investigate truck tyre types affected the near surface pavement response. A 2-D finite element based models were generated using tyre geometries and structure along with tyre pavement interaction models. Tyre-pavement contact stress, top down, cracking and instability rutting based interaction models were also generated.

Although noise factor was not considered in the study of tyre pavement interaction models which was limited to the study of tyre contact stress distributions only. Another major limitation of the study was that the only radial truck tyre and static loading condition were only considered. The material property was considered as linear elastic (no wear or permanent shape change) for single load application. ADINA version 8.3 was used to generate a 2-D model using finite element analysis.

For same axle load dual and wide based tyres generated very close contact stress to the recommended inflation levels while super, the single tyre had highest contact stress. Maximum shear stress and principal stress were much higher for super single tyre than dual and wide based tyres which indicated that the super single tyre might cause more damage to the near surface pavement than other two combinations.

The IRC: 37-2012 [15] guidelines for the design of flexible pavement recommends using the IITPAVE, which is a modified version of FPAVE developed under the research scheme R-56 for layered system analysis.

Gogoi et al. [30] studied to investigate if there is any co-relation in rutting and fatigue distress. Tensile strength and vertical strain on subgrade are used to find out fatigue and rutting stresses values respectively. For analysis purpose, data was collected from federal highway agency (FHA), the USA for the same month of any given year where no maintenance activity had been conducted. It was observed that initially fatigue and rutting increased, but afterward, fatigue cracking level reached up to 5%, rutting increases appreciably. The study does not give any cause or effect of these stresses but proposes two regression equation which can be used to forecast their progression. The work can be further extended to know whether their progression is interrelated during their formation which can be useful for the design of pavements and distress progression models.

Kranthi Kumar et al. [17] studied the use of reclaimed asphalt pavement (RAP) in hot bituminous and cold bituminous mixes as surface or a base layer. RAP obtained from the National Highway near Rajkot of Gujarat state was a laboratory experimented with a combination of RAP and virgin aggregates. The obtained RAP portion was mixed with by both hot as well as cold bitumen mixes procedure and tested for different mix proportions with virgin aggregates.

Pavement performance for both mixes was carried out using Mechanistic-Empirical Pavement Design Guide (MEPDG). RAP proportion for various mixes was varied from 0 to 40% and evaluated for properties like resilient modulus of Bituminous Concrete (BC) mixes, phase angle, indirect tensile strength (ITS), total rutting, bottom top cracking, international roughness index (IRI) for base course material.

Inferences were drawn by laboratory testing of different mixes and it was concluded that up to 20% RAP be used in BC and DBM layers with VG30 bitumen routinely. As per MEPDG calculations, BC mixes with 20% RAP may give equal or better results than a mix of fresh aggregates and VG30 bitumen in terms of rutting, cracking and IRI. Percentage of stone dust variations from 10 to 20% for 3 and 4% bitumen emulsion respectively does not affect resilient moduli and ITS. Resilient moduli and ITS were found to be higher for RAP mixes with 4% bitumen emulsion than 3% bitumen emulsion. RAP can be extensively used for both cold and hot mixes.

Sinha et al. [1] Illustrates the usefulness of finite element method to study the performance of a flexible pavement with different types of local materials in its sub base. Three types of naturally occurring materials, namely; course sand, conventional subbase material, stone dust and four types of industrial waste materials; Blast furnace slag, granulated blast furnace slag, Linz-Donawitz slag and fly ash were used. In this work multilinear elastoplastic hardening model in ANSYS was used and the effect of type of subbase on the life of the pavement is evaluated. In the study, the right boundary was placed at 110 cm from the outer edge of the loaded area, which is more than 7 times the radius 150 mm of the applied load. A uniform pressure of 575 kPa was applied to a circular contact area having a radius of 150 mm causing a single axle load of 40.80 KN.

Tapase and Ranadive [28, 34], reported the usefulness of two-dimensional finite element analysis to study the effect of variation in thickness of different component layers on the critical parameters. They noted that the tensile strain at the bottom of the bituminous layer (BL) and compressive strain on top of the subgrade decrease with an increase in the thickness of BL, which ultimately results in an increase of fatigue and rutting lives.

3 Observations and Future Research Direction

A literature survey showed that considerable progress has been made in the development of response models for mitigating various parameters influencing pavement performance, ranging from Boussinesq's one-layer model to multi-layer elastic theories to finite element models. However, some areas of designing pavement are still not addressed properly.

Some of the debatable issues are discussed below:

Out of the various factors affecting the performance of the pavement, the combined effect of temperature, seepage and loading condition is missing. As the analysis is based on a number of assumptions, only a single parameter at a time is addressed as reported in a number of literature. Conventional construction materials like aggregates are becoming progressively scarce on account of environmental concerns as well as legal restrictions on quarrying while the construction activity has expanded phenomenally. This has shifted focus from the large scale use of conventional aggregates to use of local, recycled and engineered marginal aggregates in construction. So here the scope is to use alternative materials for conventional materials like aggregate and bitumen, which can be partially or completely replaced by alternative materials or waste materials like fly ash, granulated blast furnace slag, plastic, rubber, e-waste, etc. which are creating disposal problems. So here the scope is to analyze the suitability of waste materials in different component layers of flexible pavement.

From the literature, it is noticed that emphasize is given to the factors responsible for the deterioration of pavement in the form of fatigue and rutting of pavement which is theoretically related to CBR values of the subgrade. So here need is to estimate the pavement life in the form of a number of standard axles or cumulative standard axles which can be correlated with the fatigue life and rutting life as per the criteria recommended by various codes in practice like IRC: 37-2012 [15] for the actual subgrade condition. Effect of temperature on pavement, during day time and night time as well as due to seasonal changes, can be studied in details. Seepage through subgrade results in a decrease in the life of the pavement, similarly, the effect of water table on swelling and shrinkage property of subgrade can be studied. The effect of excess wheel loading, modern tyre pressures cannot be neglected. However, from the past studies and through the recommendations of the Indian Road Congress (IRC) and AASHTO code of practice, wheel load, tyre pressure and their combinations can be shortlisted which can be correlated with actual field conditions.

Current pavement design and analytical procedures rely mostly on the direct and indirect application of empirical approach [26, 27] wherein most of the analytical models are based on linear elastic theory. Even though the approach is simple and is to analyze it does not reflect the realistic approach to the nonlinear behavior of underneath granular layers and viscoelastic behavior of bituminous layer. To incorporate the complex behavior of the present pavement system along with modern loading configuration more realistic analysis is required hence there is need of 3D modeling.

2D Finite element models including axis-symmetric, plain strain, plain stress are used effectively for the evaluation of critical pavement responses on various condition which are influencing the pavement behavior. An appropriate combination of 2D and

3D finite element analysis will not only give the realistic result but also help in achieving the optimum computational time.

Material constitutive models such as linear-elastic, nonlinear-elastic [10], viscoelastic and elastoviscoplastic models as per the requirements and environmental conditions should be employed to describe the behavior of the materials in different layers of the pavement. In the current design procedures value of elastic moduli is considered constant throughout its design life which is impossible. Elastic moduli is a dynamic entity which depends on environmental factors.

Also, the work can be extended to enhance the scope to calculate various entities like the effect of the forces arising out of frost and thawing cycles, the entities such as distribution of seepage pressures, gradients and exit gradients, etc. Even though researchers presented a number of improvements in the design and analytical procedures, still there is a clear need for developing a more rigorous analytical tool which will enhance the above-mentioned scope and can be extended to study the combined effect of various parameters simultaneously. This calls for more intensive research in this area in the coming years for the design of sustainable flexible pavements.

Hence the paper describes an outline for future research which is under progress using versatile finite element method.

4 Projected Methodology for Finite Element Analysis

The selected observations from the literature study will be considered for analysis including the viscoelastic behavior of bituminous layer, nonlinearity in granular base layers. Initially, it is proposed to carry the rigorous two-dimensional finite element analysis of the parameters selected for analysis using a multipurpose software ANSYS. Further, the three-dimensional analysis will be carried on the identified area of more interest from the two-dimensional analysis for more accurate prediction of results. In finite element analysis, a continuum is discretized into finite elements, over which the material properties and governing relationships are applied and expressed in terms of unknown values at corners. Set of equations is formed by considering the above continuum with appropriate loading and constraints. A solution of these equations gives the approximate behavior of the continuum considered for analysis [9, 38]. Figure 1 shows a general methodology adopted for flexible pavement design. The pavement configuration including the number of layers, the thickness of each layer, and the type of material are shortlisted from the available code of practice. The basic material properties required for the structural models are the moduli of BL, base layer and subgrade; those for the distress models involve the various failure criteria. In structural models/finite element models, the use of load intensities, contact radius and contact pressure from the traffic inputs and the number of repetitions is used by distress models. Pavement response includes stresses, strains, and deflection. Those are evaluated from the structural models and are used as inputs for distress models. The distress models include fatigue and rutting criteria. If reliability for a certain distress is beyond the minimum level required, the assumed pavement configuration is unsuitable; likewise, for all shortlisted trials, the procedure is implemented. It is apparent from details presented in Fig. 1 that the finite element method of solution constitutes a primary component of the design process.

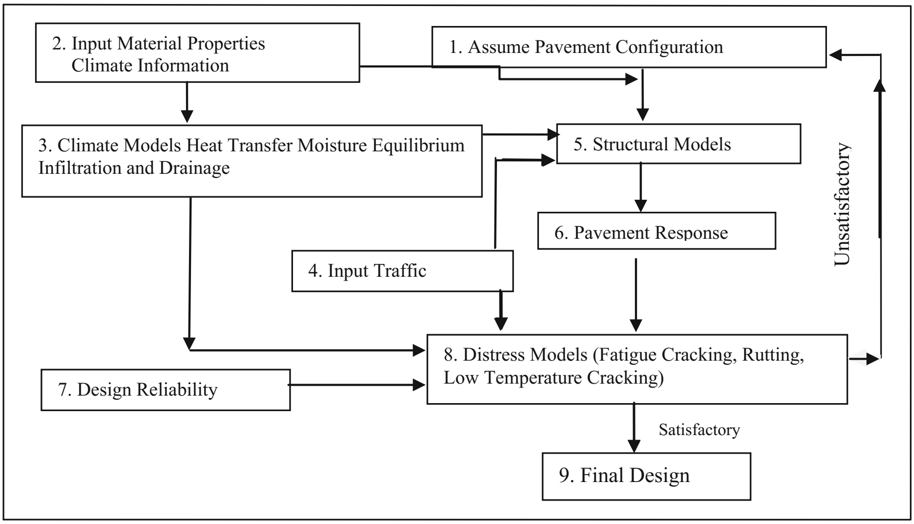

Fig. 1. General methodology for flexible pavement design [14]

It is apparent from details presented in Fig. 1 that the finite element method of solution constitutes a primary component of the design process. The method of analysis is too well known to need any more detailed description, hence only the salient features governing the problem under consideration are discussed herein.

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