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Review Article to Road Ways Pavements Design and Soil Penetration Analysis Using FEM

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Abstract- Because of a substantial volume of commercial vehicles likely to use facility, the pavement structure has to receive careful consideration in design and choice of materials forming the pavement. Pavement costs constitute a significant proportion of total cost of highway facility. Hence, great care is needed in selecting right type of pavement and specification for the various courses that make up the pavement. The choice of pavement type, whether flexible or cement concrete, therefore, has to be very carefully exercised. Pavement associated traffic safety factors include skid resistance, drainability against hydroplaning, and night visibility. Cement concrete pavement has distinct initial advantage over bitumen pavement in this regard, as surface texturing forms integral part of the normal construction practice for such pavements. They also have superior night visibility by virtue of their lighter colour. Poorly designed and constructed concrete pavements are known to have very long service life. The cement concrete road constructed in the country in the past, though extremely limited in length, have an excellent service track, having given good service under condition much sever than those for which they are originally intended.

Keywords- Rigid pavement; Traffic; Joints; Cement concrete.

I. INTRODUCTION

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favorable light reflecting characteristics, and low noise pollution.

The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the sub-grade. Two types of pavements are generally recognized as serving this purpose, namely flexible pavements and rigid pavements.

This chapter gives an overview of pavement types, layers, and their functions, and pavement failures. Improper design of pavements leads to early failure of pavements affecting the riding quality.

1. Requirements of a pavement:
An ideal pavement should meet the following requirements:

- Sufficient thickness to distribute the wheel load stresses to a safe value on the sub-grade soil,
- Structurally strong to withstand all types of stresses imposed upon it,
- Adequate coefficient of friction to prevent skidding of vehicles,
- Smooth surface to provide comfort to road users even at high speed,
- Produce least noise from moving vehicles,
- Dust proof surface so that traffic safety is not impaired by reducing visibility,
- Impervious surface, so that sub-grade soil is well protected, and
- Long design life with low maintenance cost [1].

II. TYPES OF PAVEMENTS

The pavements can be classified based on the structural performance into two, flexible pavements and rigid pavements. In flexible pavements, wheel loads are transferred by grain-to-grain contact of the aggregate through the granular structure. The flexible pavement, having less flexural strength, acts like a flexible sheet (e.g. bituminous road).

On the contrary, in rigid pavements, wheel loads are transferred to sub-grade soil by flexural strength of the pavement and the pavement acts like a rigid plate (e.g. cement concrete roads). In addition to these, composite pavements are also available. A thin layer of flexible pavement over rigid pavement is an ideal pavement with most desirable characteristics. However, such pavements are rarely used in new construction because of high cost and complex analysis required [2,3].

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1. Flexible pavements

Flexible pavements will transmit wheel load stresses to the lower layers by grain-to-grain transfer through the points of contact in the granular structure (see Figure 1.1).

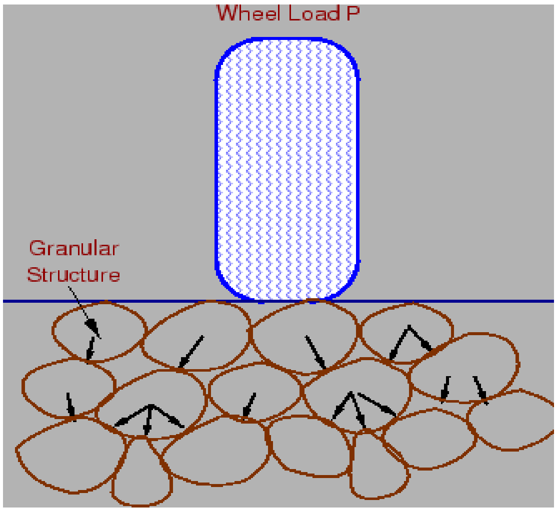

Fig 1. Load transfer in granular structure.

2. Deflection on flexible pavement:

The wheel load acting on the pavement will be distributed to a wider area, and the stress decreases with the depth. Taking advantage of these stress distribution characteristic, flexible pavements normally has many layers. Hence, the design of flexible pavement uses the concept of layered system. Based on this, flexible pavement may be constructed in a number of layers and the top layer has to be of best quality to sustain maximum compressive stress, in addition to wear and tear.

The lower layers will experience lesser magnitude of stress and low quality material can be used. Flexible pavements are constructed using bituminous materials. These can be either in the form of surface treatments (such as bituminous surface treatments generally found on low volume roads) or, asphalt concrete surface courses (generally used on high volume roads such as national highways).

Flexible pavement layers reflect the deformation of the lower layers on to the surface layer (e.g., if there is any undulation in sub-grade then it will be transferred to the surface layer). In the case of flexible pavement, the design is based on overall performance of flexible pavement, and the stresses produced should be kept well below the allowable stresses of each pavement layer.

3. Types of Flexible Pavements:

The following types of construction have been used in flexible pavement:

- Conventional layered flexible pavement,
- Full - depth asphalt pavement, and
- Contained rock asphalt mat (CRAM).

Conventional flexible pavements are layered systems with high quality expensive materials are placed in the top where stresses are high, and low quality cheap materials are placed in lower layers.

Full - depth asphalt pavements are constructed by placing bituminous layers directly on the soil sub-grade. This is more suitable when there is high traffic and local materials are not available [4].

Contained rock asphalt mats are constructed by placing dense/open graded aggregate layers in between two asphalt layers. Modified dense graded asphalt concrete is placed above the sub-grade will significantly reduce the vertical compressive strain on soil sub-grade and protect from surface water [5].

4. Typical layers of a flexible pavement:

Typical layers of a conventional flexible pavement includes seal coat, surface course, tack coat, binder course, prime coat, base course, sub-base course, compacted sub-grade, and natural sub-grade (Figure 2).

- **Seal Coat:** Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance.
- **Tack Coat:** Tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water. It provides proper bonding between two layer of binder course and must be thin, uniformly cover the entire surface, and set very fast.
- **Prime Coat:** Prime coat is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed. It provides bonding between two layers. Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, and forms a water tight surface.

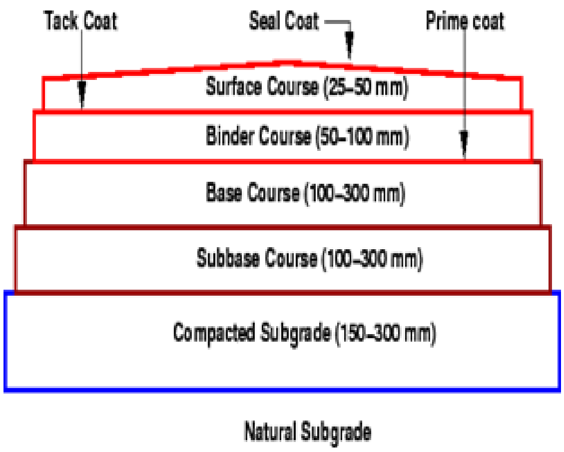

Fig 2. Typical cross section of a flexible pavement.

5. Surface course:

Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials.

They are usually constructed with dense graded asphalt concrete (AC). The functions and requirements of this layer are:

- It provides characteristics such as friction, smoothness, drainage, etc. Also it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade,
- It must be tough to resist the distortion under traffic and provide a smooth and skid- resistant riding surface,
- It must be water proof to protect the entire base and sub-grade from the weakening effect of water [6].

- **Binder course:** This layer provides the bulk of the asphalt concrete structure. Its chief purpose is to distribute load to the base course The binder course generally consists of aggregates having less asphalt and doesn't require quality as high as the surface course, so replacing a part of the surface course by the binder course results in more economical design [7].
- **Base course:** The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage it may be composed of crushed stone, crushed slag, and other untreated or stabilized materials [8].
- **Sub-Base course:** The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure If the base course is open graded, then the sub-base course with more fines can serve as a filler between sub-grade and the base course A sub-base course is not always needed or used. For example, a pavement constructed over a high quality, stiff sub-grade may not need the additional features offered by a sub-base course. In such situations, sub-base course may not be provided [9].
- **Sub-grade:** The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed. It should be compacted to the desirable density, near the optimum moisture content [10].

6. Failure of flexible pavements:

The major flexible pavement failures are fatigue cracking, rutting, and thermal cracking. The fatigue cracking of flexible pavement is due to horizontal tensile strain at the bottom of the asphaltic concrete. The failure criterion relates allowable number of load repetitions to tensile strain and this relation can be determined in the laboratory fatigue test on asphaltic concrete specimens.

Rutting occurs only on flexible pavements as indicated by permanent deformation or rut depth along wheel load path. Two design methods have been used to control rutting: one to limit the vertical compressive strain on the top of subgrade and other to limit rutting to a tolerable amount (12 mm normally). Thermal cracking includes both low-temperature cracking and thermal fatigue cracking [11].

7. Rigid pavements:

Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area below. A typical cross section of the rigid pavement is shown in Figure 1.3. Compared to flexible pavement, rigid pavements are placed either directly on the prepared sub-grade or on a single layer of granular or stabilized material. Since there is only one layer of material between the concrete and the sub-grade, this layer can be called as base or sub-base course.

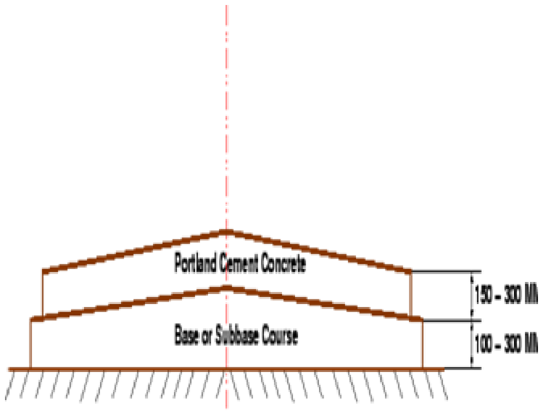

Fig 3. Typical Cross section of rigid pavement.

In rigid pavement, load is distributed by the slab action, and the pavement behaves like an elastic plate resting on a viscous medium (Figure 1.3). Rigid pavements are constructed by Portland cement concrete (PCC) and should be analyzed by plate theory instead of layer theory, assuming an elastic plate resting on viscous foundation. Plate theory is a simplified version of layer theory that assumes the concrete slab as a medium thick plate which is plane before loading and to remain plane after loading.

Bending of the slab due to wheel load and temperature variation and the resulting tensile and flexural stress.

- Elastic plate resting on viscous foundation
- Deflection on concrete pavement

8. Types of Rigid Pavements:

Rigid pavements can be classified into four types:

- Jointed plain concrete pavement (JPCP),
- Jointed reinforced concrete pavement (JRCP),
- Continuous reinforced concrete pavement (CRCP), and
- Pre-stressed concrete pavement (PCP).

8.1 Jointed Plain Concrete Pavement:

Are plain cement concrete pavements constructed with closely spaced contraction joints? Dowel bars or aggregate interlocks are normally used for load transfer across joints. They normally have a joint spacing of 5 to 10m.

8.2 Jointed Reinforced Concrete Pavement:
Although reinforcements do not improve the structural capacity significantly, they can drastically increase the joint spacing to 10 to 30m. Dowel bars are required for load transfer. Reinforcement's help to keep the slab together even after cracks.

8.3 Continuous Reinforced Concrete Pavement:
Complete elimination of joints is achieved by reinforcement.

8.4 Failure criteria of rigid pavements:
Traditionally fatigue cracking has been considered as the major or only criterion for rigid pavement design. The allowable number of load repetitions to cause fatigue cracking depends on the stress ratio between flexural tensile stress and concrete modulus of rupture. Of late, pumping is identified as an important failure criterion.

Pumping is the ejection of soil slurry through the joints and cracks of cement concrete pavement, caused during the downward movement of slab under the heavy wheel loads. Other major types of distress in rigid pavements include faulting, spalling, and deterioration.

III. PROBLEMS OF PAVEMENT DESIGN

1. The thin layer of bitumen coating between an existing bituminous layer and a new bituminous layer is:

- Seal coat
- Intermediate coat
- Tack coat
- Prime coat

2. Rigid pavements are designed by:

- Rigid plate theory
- Elastic plate theory
- Infinite layer theory
- Interlocking of aggregates

IV. PROBLEMS SOLUTIONS OF PAVEMENT DESIGN

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V. LITERATURE REVIEW

Aurea Holanda, FINITE ELEMENT MODELING OF FLEXIBLE PAVEMENTS: It is well-known that the analysis of flexible pavements is a difficult task, since the pavement system is multilayered and three-dimensional. To provide accurate displacements, strains and stresses, the system must consider the different characteristics of each layer. Granular layers, for example, present complex nonlinear stress-strain relationship, while the surface (asphalt) layer displays a time-dependent viscoelastic behavior. Furthermore, cracks and fatigue are some of the problems that the surface layer may present.

This paper addresses techniques used in the finite element modeling of flexible pavements. Therefore, appropriate constitutive models and numerical algorithms to represent the nonlinear resilient behavior of the unbound layers and the viscoelastic characteristics of the HMA layer are thoroughly discussed. These techniques are implemented in a computer system developed using an Object-Oriented Programming (OOP) approach.

Both axisymmetric and three-dimensional models are included. Several numerical examples will be analyzed in order to validate the implementation and assess the importance of the consideration of the nonlinear and time-dependent effects. The obtained results will be compared with available analytical and computational solutions.

Abdhesh Sinha, Finite element analysis of flexible pavement with different subbase materials:

BehzadGhadimi, Numerical modelling for flexible pavement materials applying advanced finite element approach to develop Mechanistic-Empirical design procedure: A layered structure with asphalt as a surface pavement is one of the usual pavement systems used in road and transportation. This structure is a combination of surface asphalt concrete and good quality granular materials called the base and subbase.

Through these layers, the traffic load is transferred to the existing ground beneath, which is called the subgrade. Since each layer is constructed of different types of materials with specific behaviours, the system is complex. The contribution of layers to the total strength of this structure is also complicated and difficult to define.

The total function of the layered system is mainly defined by the combined response of the layers to the dynamic loading from the traffic. Therefore, the traits of the materials in each layer should be accurately accounted for. A mechanistic-empirical (ME) design procedure has been developed to answer the demand for a design procedure that addresses these complications. In this approach, constitutive models are implemented to calculate the mechanical response of pavement structure in terms of stress, strain and displacement. These values are entered to sit in an empirical formula (called the transfer function) which connects them to pavement performance.

Following the introduction, this dissertation presents an inclusive review of published research and design methods. Various design codes are investigated and their differences are discussed. The concept of modelling in flexible pavement engineering is categorized into three types: analytical, experimental and numerical modelling.

Each of these approaches is discussed and explained. Since this research concentrates on the finite element simulation of unbound granular materials (UGM) in layered flexible pavement, there is a more detailed review of the literature regarding finite element modelling of flexible pavement.

S.K.Ahirwar, Finite Element Analysis of Flexible Pavement with Geogrids: Geogrids is being increasingly used as a reinforced material in various divisions of civil engineering. The flexible pavement is the one of major area, where the needs of improvement in performance of pavement service life, base course and subgrade. The finite element method is a best suitable tool for solving problems related to nonlinear nature of materials.

The objective of this article to access the functioning of geogrids in flexible pavement through finite element analysis with PLAXIS 2D software. The Mohr-coulomb model used for materials in the base layer,sub-base layer and subgrade layer and elastic model interface element used for geogrids to simulate the interaction condition. The triangular element of 15-noded is used for layers of pavements. The traffic intensity and thickness of each layer was use according to codal provisions of Indian road congress (IRC: 37-2012).

In the present study, axis-symmetric model is used in the PLAXIS 2D for investigating the effect of axial stiffness of geogrids in the pavement at different thickness of base layer. The finite element analysis results shows the reduction in vertical surface deformation when the geogrids were added between the pavement layers. Results of previously published research shows the improvement in pavement performance when geogrids used as reinforcement.

Jia Wang, THREE-DIMENSIONAL FINITE ELEMENT ANALYSIS OF FLEXIBLE PAVEMENTS: Flexible pavements or roads surfaced with asphalt have been in use for the past 100 years. Currently, the design of flexible pavements is largely based on empirical methods. However, there is currently a shift underway towards more mechanistic design techniques.

While layered elastic analysis and two-dimensional finite element (FE) methods have been generally been used to deternline stresses, strains and displacements in flexible pavements, they suffer several severe limitations.

To overcome these difficulties, three-dimensional (3D) FE analysis must be used to analyze pavement structqres. This study focuses on exploring the use of 3D finite-element methods to examine the response of flexible pavements.

For this study, an efficient 3D FE meshing tool was developed. This meshing tool allows us to develop models of layered system, inter-layer debonding and slip, various wheel and axle loadings.

The 3D FE models were tested by comparing predicted results with experimentally measured field data. Critical finite-element model dimensions were determined, and material properties were back-calculated to give good comparisons with field-measured data. Since the stress-strain response of granular materials is non-linear, the use of the stress-dependent K-8 model was investigated.

Two implementation methods were considered. It was shown that the analysis results are very different depending on the method of implementation. When applying wheel loads, it is quite typical that a constant tirefpavement pressure distribution is assumed over a rectangular or circular area. However, prior investigations have shown that spatially varying tirelpavement contact pressures can affect the response of pavements significantly. In this study, a model was developed to simulate spatially varying tire contact pressures based on previous published data.

Paranletric studies were performed to examine the effect of spatially varying tire pressures on pavement response. There studies showed that using spatially varying tirefpavement pressures yields stresses at the bottom of asphalt that are up to 30% larger than those predicted when uniform tirefpavement pressures are assumed.

The largest differential occurs in thin flexible pavement structures with a sub-base having a low stiffness. Further, the studies show that for thick pavement sections, predicted tensile stresses in the top of the asphalt are much larger when spatially varying tirefpavement contact pressures are considered.

Osama Mahmoud Yassenn, Dr. IntanRohani, Finite Element Modelling of Flexible Pavement: In this paper, finite element modeling of flexible pavement is discussed and general suggestions on using this method to determine structural criteria of flexible pavement is given. The paper suggests using linear elastic modeling in determination of flexible pavement expected fatigue and rutting damage life due to the low stress and strain levels caused by traffic loading.

The paper also suggests the use of falling weight deflectometer in obtaining elastic moduli of different flexible pavement layers rather than coring, triaxial test, or California bearing ratio tests.

The paper also discusses the different types of finite element modeling used to model the structural behavior of the pavement layers under traffic loadings. Furthermore, the tyre-pavement contact area, tyre pressure, primary response parameters and load equivalency factors were also discussed in this paper.

VI. PAVEMENT MATERIAL-GEOSYNTHETICS

Geosynthetics is the collective term applied to thin, flexible, sheets of material incorporated in or above soil to enhance its engineering performance. It comprises a variety of products largely grouped under geotextiles, geogrids, geomembranes and geo composites.

Applications of Geosynthetics fall mainly within the discipline of civil engineering and the design of these applications, due to the use of geosynthetics with soils, is closely associated with geotechnical engineering.

The earliest of civilizations used natural materials to improve soil behaviour. For instance, in the zigguraults of Babylonia, woven mats of reeds were used and in the construction of the Great Wall of China, tree branches along with leaves were placed. In India, it is common to see dry branches and leaves of trees being used to reinforce soft soil (or softened shoulder on the roadside) on which heavy laden trucks get bogged down during monsoon.

In the vast waterfront areas of Kerala, it has been an age old custom to spread coconut leaves on the ground before gravel/aggregate is laid over a road formation. Nature itself exercises control on erosion through vegetation (more specifically by the fine well spread roots which while supporting the plant upright, also hold the soil together). Walking on bundles of trees has enabled man to cover even marshy lands.

Such examples are plenty. In British India, a certain Col. Powell, while constructing retaining walls found that the thickness of the wall could be reduced by incorporating construction waste like bamboos, canvas, etc. into the backfill. Textile material was perhaps first used in road construction in South Carolina in the early 1930's.

One of the first mills to produce jute geotextile, popularly known as Soil Saver was established in Calcutta in the early forties. In the Ludlow Jute Mills a separate line was then established to manufacture this industrial by-product (as it was made from jute caddies, meaning waste jute). It was and even now is an export oriented product.

VII. CONCLUSION

This paper discussed the use of finite element analysis for flexible pavement and design. The paper suggests the use of linear elastic modelling for normal pavement structure with normal traffic loading.

The paper suggests the use of axisymmetric modelling for single axle with single tyre confirmation, while plain strain and three-dimensional modelling for dual and tandem axles.

The paper also suggests the use of falling weight deflectometer rather than coring, tri-axle test, or California bearing ratio tests in determination of elasticity moduli of pavement layers. The paper highlights the different methods of representing tyre pavement contacts area.

The paper highlights the main response parameters used to calculate load equivalency factors based on fatigue and rutting criteria, that is to say maximum tensile strain at the bottom of the asphaltic layer, and maximum compressive strain the top of the subgrade layer.

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