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Effect of Shear Modulus on the Performance of Flexible Pavement

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ABSTRACT

A mechanistic model of flexible pavement was considered and constructed to study the effects of shear modulus on performance of various pavement layers. The objective of this study was to quantify the effects of interlayer bonding by varying of the shear modulus of the contact layer. Flexible pavements are complex structures consisting of several layers of asphalt and granular materials. This pavement layers including overlays are subjected to wheel load due to improper bonding may cause slipping of layers and which will induce parabolic deformation on the top surface of the pavement. The elastic property is influenced mainly by shear modulus of the contact layer with other parameters being constant. Bonding is assessed due to increase or decrease of critical stress values when static loading condition is maintained with constant elastic properties except shear modulus for the contact layer. Stress distribution is extremely influenced by the adhesion conditions at the layer interface. The response of the pavement is assessed from the critical stresses developed. Various analysis software such as KENPAVE, ABACUS, BISAR and ANSYS are available. Present study involves analysis using ANSYS software. Critical stress values for varying shear modulus in range for 9000kg/cm^2 to 12000kg/cm^2 have effect on the bonding characteristics which is the key factor for pavement response. Performance is determined due to the effect of the elastic properties.

Key words Bituminous layers, bond stress, shear modulus, wheel load, bonding, adherence and critical stress

INTRODUCTION

The flexible pavement is generally designed and constructed in several layers for effective stress distribution across the pavement layers under the varying heavy traffic loads. The viscous nature of the flexible pavement, allows its different layers to sustain significant plastic deformation, although distresses due to repeated heavy loading over time which is the most common failure mechanism. The flexible pavement works as a single structure due to good bonding between the different layers. The bonding of the layers of the flexible pavement is mainly characterized by the response of the pavement under the wheel load. It is believed that, the pavement stress distribution is extremely influenced by the adhesion at the layer interface. Poor adhesion at layer interface may cause adverse effects on the structural strength of the pavement system and form numbers of premature failures. The basic assumption for structural response of pavement is asphalt layers are completely bonded with each other, while they may not be completely bonded [1]. The bonding is accessed by introduction of the contact layer in a five layered pavement consisting of sub-grade, sub-base, base, binder course and wearing course. The elastic property which mainly influence on the bonding of the contact layer with all other layers is shear modulus [3]. The shear modulus is one of the several quantities for measuring stiffness of the material. The shear modulus describes the material's response to shear stress. The shear modulus is concerned with the deformation of a solid when it experiences force parallel to the surface of the pavement. The shear modulus leads to the intrusion of critical stresses in the pavement layers. Increasing value of critical stress indicates poor bonding of the contact layer with the other layers of the flexible pavement.

Therefore it is necessary to create a model for calculation of the pavement response under the load and to enhance the bonding. The poor bonding pavement layers is subjected to laying without analysis may lead to slip failure and early deterioration of the pavement before its desired life. Lack of bonding destroy continuity, decrease structural strength, and allow water to enter sub layers. Bituminous tack coat is laid to ensure contact of the aggregates of the various layers of the flexible pavement. The study involves creation of 3D mechanistic model using ANSYS APDL with the assigning of the elastic properties namely Elastic Modulus, Poisson's ratio and shear modulus as per IRC372001 and analysis of the effect of the shear modulus on performance of pavement. The values of the critical stress for various values of the shear modulus are used to enhance the bonding of the layers. The values of elastic modulus and poison's ratio are tabulated in table 1.

The Objectives of this paper are as follows -

- Understand the effects of the bonded interface on stress distribution in the contact layer.
- Evaluate the performance of pavement due to shear modulus and obtain critical stress values.
- To enhance the performance of the pavement due to effect of shear modulus.

MODELING

Construction of Model

Modelling involves defining of the nodes, key points, type of the material etc. Model is a geometry resembling to the actual structure of layers of the flexible pavement. A 3D realistic model flexible pavement layers is modelled using ANSYS APDL (Ansys Parametric Digital Library) software where in all the material properties of the various layers is defined. ANSYS APDL is a mechanical tool which is used efficiently to setup, solve, post process linear analysis and obtain the results as well as the deformations. The model consists of six layers namely sub-grade, sub-base, base, binder course, contact layer and wearing course as shown in Fig. 1.The elastic properties such as modulus of elasticity and poison's ratio are obtained as per IRC 372001.The shear modulus of the contact layer is varied in the range of 9000 to 12000 kg/cm2.The Elastic modulus of contact layer is kept constant as that of the top layer and a poison's ratio of 0.4 is adopted and these parameters are kept constant while the shear modulus is varied in the specified range in order to assess the performance of the pavement.

Analysis

The analysis is done by converting complex problem into simpler steps for determining the unknowns using some Eqns..Various types of analysis are done such as thermal analysis, structural analysis, fluid analysis, magnetic analysis and electric analysis. The present analysis is done using the finite element method considering the finite number of elements in the volume. The analysis is structural type defining the elastic properties and the load condition as well as the degrees of freedom restrained. So as to determine the stresses which are transferred from node to node as the effect of the load. The model considered in present analysis a solid volume 3 dimensional defining the dimensions in three directions i.e. x, y and z directions. The 3D finite element analysis is carried out in order to assess the stresses imposed due to the contact of the layers and inducing of the stresses due the effect of wheel load. As stress due load and due to effect of shear modulus has direct influence on performance of pavement as elastic due to bonding. The stress distribution may not be uniform at the surfaces of layer across the full width. The deformation of the flexible pavement due to inducing of the stresses due to loading will be maximum under the point of action of the load on the surface.

The static analysis is done in order to obtain the critical stress values of the contact layer to assess its bonding with the other layers of the flexible pavement. The stresses induced due to variance of shear modulus have maximum and minimum values. The analysis is done to obtain minimum values or the critical stress which has greater significance on the performance of pavement i.e. by deformation caused due effect of loading. The stresses are determined from various types of Equations such as linear, logarithmic, polynomial and exponential Eqns. Analysis can be performed with the various types of the analysis software such Abacus, Kenpave, Circkly, Bisar ,Ansys etc. The ANSYS software being used to carry out the present analysis study. There are three major steps to perform analysis using Ansys they are pre processing where in the material properties along with the type as well as behaviour of the material is defined. Second step is the assigning of the load with the specification of analysis whether static, dynamic, transient, harmonic etc. Final step is to solve which involves the determination of deformations from the longitudinal section of the flexible pavement.

SECTIONS

The section is a schematic representation of the regular shaped geometry defining the length, breadth and thickness as in case of volumes. The section may be preferably 2D or 3D.The pavement section is made up of several layers laid over one another. The volumes of the various layers of the flexible pavement namely sub-grade layer, sub-base layer ,base layer of depth, binder course ,contact layer of depth and surface layer are created using modelling volumes tool in ANSYS APDL providing the values of the coordinates in x, y and z directions. Where x direction defines the width of the pavement direction represents the length of the stretch of the pavement and z direction represents the depths or the thicknesses of the individual layers. The flexible pavement layer sections consists of the sub-grade layer of thickness 200cm,sub-base layer of thickness 15 cm, base layer of thickness 10cm,binder course of thickness 9cm,a contact layer of 1cm and wearing course of thickness 5cm. The width of the pavement is restricted to 350cm.The length of the stretch is restricted to 1800cm. A point load i.e. Equivalent single wheel load of 5100kg and is analyzed for the stresses due to the wheel loads. As the standard axle wheel load defined by IRC 372001 is 10200kg per axle made up of two wheels which is converted into equivalent single wheel load. Critical stress values for corresponding shear modulus are obtained. The critical stress values are obtained from nodal solutions as Z-component stresses which gives the response of the pavement under varying shear modulus [5]. The width for all the layers of the section is kept constant .The displacement due to loading is carried up to a stretch of 9mm.All the dimensions for the section are keyed in with by defining a central node and other dimensions are specified with respect to this central node. The bottom nodes of the section are restrained from all degrees of freedoms (DOFs) i.e. from the displacements, rotations etc. The model used for study purpose is of mechanistic type of section analyzed by finite element method through software by defining certain parameters involved as the material properties. Being a layered structure, the life of an asphalt pavement not only depends on the strength and stiffness of its individual layers, but also on the bond between the layer sections [4]. The Fig. shows the depths adopted for the individual layers

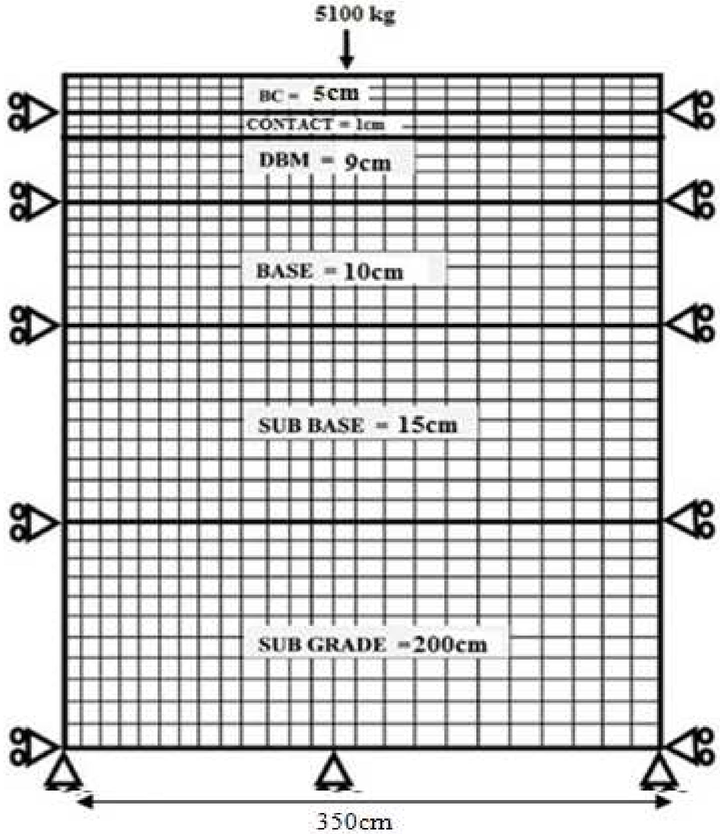


Fig. 1 2D view of the model showing Pavement layers with the thicknesses of the individual layers and loading At the bottom restrained from all DOFs and sides from rotation in X direction

Table -1 Values of Initial Modulus of Elasticity and Poison's Ratio

	E – value (kg/cm2)	μ – value
Sub-grade Layer	300	0.45
Sub-base Layer	701	0.3
Base Layer	992	0.3
Binder Course	2696	0.4
Wearing Course	4033	0.4
Contact Layer	4300	0.4

FINITE ELEMENT ANALYSIS

The formulation for structural analysis is generally based on the three fundamental relations equilibrium, constitutive and compatibility. There are two major approaches to the analysis Analytical and Numerical. Analytical approach which leads to closed-form solutions is effective in case of simple geometry, boundary conditions, loadings and material properties. However, in reality, such simple cases may not arise. As a result, various numerical methods are evolved for solving such problems which are complex in nature. For numerical approach, the solutions will be approximate when any of these relations are only approximately satisfied. The numerical method depends heavily on the processing power of computers and is more applicable to structures of arbitrary size and complexity. It is common practice to use approximate solutions of differential Eqns as the basis for structural analysis. This is usually done using numerical approximation techniques. Few numerical methods which are commonly used to solve solid and fluid mechanics problems are given below

- Finite Difference Method
- Finite Volume Method
- Finite Element Method

The finite volume method is a discretization method which is well suited for the numerical simulation of various types (elliptic, parabolic or hyperbolic, for instance) of conservation laws; it has been extensively used in several engineering fields, such as fluid mechanics, heat and mass transfer or petroleum engineering. This is the numerical method to obtain the solution of elasticity Equations consistent with the boundary conditions. It may be used on arbitrary geometries, using structured or unstructured meshes, and it leads to robust schemes. An additional feature is the local conservatively of the numerical fluxes that is the numerical flux is conserved from one discretization cell to its neighbor. This last feature makes the finite volume method quite attractive when modeling problems for which the flux is of importance, such as in fluid mechanics, semi-conductor device simulation, heat and mass transfer. Finite difference method consists in replacing the governing partial differential Eqns of elasticity and the Eqns defining the boundary conditions by the corresponding finite difference Eqns. The basis of the finite element method is the representation of a body or a structure by an assemblage of sub-divisions called Finite Elements. Adjoining elements may be thought of as being connected at common points, termed as nodes or nodal points. Finite element method is a numerical approach by which a general differential Eqn can be solved in an approximate manner. The solution that we are going to get from finite element method is an approximate and in some cases, this approximate solution may match with exact solution. Then simple functions are chosen to approximate the variation of the actual displacements over each finite element. Such assumed functions are called Displacement Functions of Models. The unknown magnitudes of the displacement functions are the displacements at the nodal points. Hence, the final solution will yield the approximate displacements at the nodal points. The displacement model can be expressed in various simple forms, such as polynomials and trigonometric functions. Any continuum/domain can be divided into a number of pieces with very small dimensions. These small pieces of finite dimension are called 'Finite Elements'. These elements are connected through number of joints which are called 'Nodes'. Finite element method was used to analyze the pavement section resting on sub grade soils. The software ANSYS APDL was used for finite element modelling. The elements may be 1D elements, 2D elements or 3D elements .The physical object can be modeled by choosing appropriate element such as frame element, plate element, shell element, solid element, etc.. The pavement section was modeled as a 3-D axisymmetric problem and 20-noded structural solid element was used for the analysis.20 nodded solid implies any element which is created utilizes maximum of 20 nodes. The Model is as shown in fig 2.Per element six nodes are created. A six-layered flexible pavement system was modeled and analyzed. Fig. 2 shows the typical model for six layered flexible pavement resting on sub grade soil. The thickness of each layer in the pavement was modeled as per Indian practice code IRC 37-2001.

The individual layers are constructed by volumes with specified thickness one above the other starting from sub grade to the wearing course. To ensure contact between these layers these are connected using tack coats in actual practice by varying the rate of application but it software the layers are glued by the glue tool in the operate section of Booleans in the modelling step. Various types of analysis such as static, modal, harmonic, transient, spectrum and Eigen buckling can be performed in the software. Static analysis is carried out with linear, elastic and isotropic material. However non linear, damping and thermal problem analysis can also be done. Structural damping is dependent on factors such as damping force, relative displacement and the friction parameter. Modal analysis is a method of structural mechanics involves determination of frequencies due vibrations. Mechanics involves behaviour of the material due to the effect of vibrations and displacement. Transient analysis involves use of algorithms, control options and initialization of convergence. Also in case of transient analysis time for load repetitions is to be specified in order to determine the frequency of the analysis due to repetitions of loading. Harmonic analysis involves the specification of waves and generalization of Fourier analysis. Spectrum analysis involves spectrum of frequencies or related quantities such as energies. Eigen buckling method involves buckling analysis. Buckling analysis is a technique used to determine buckling loads critical loads at which a structure becomes unstable and buckled mode shapes the characteristic associated with a structure's buckled response. This method involves Eigen vectors. The Ansys software can also be used for non linear analysis problems also. The various non linear analysis methods involves various parameters such as density, elastic, non elastic and viscoelastic analysis can be done. A set of simultaneous Eqns involving differential Eqns of variables and functions. A wheel load equal to single axle wheel load obtained by conversion of standard axle load into Equivalent Single Wheel Load of 5100kg has been assumed to be applied as a point load at the surface and distributed [6]. The point load will cause deformation of the pavement which indicates the pavement when subjected to loading behaves by deforming. The load is transferred from layer to layer due to contact with each other. For application of Finite Element Method in the layered flexible pavement Analysis, the layered system of infinite extent is reduced to an approximate size with finite number of elements of smaller dimension. The ends are retained in all directions at the bottom nodes while the edges are restrained with roller supports in X direction. This is done in order to avoid the bulging of the model sideways in the horizontal plane. Linear analysis methods assume elastic behaviour and the displacements induced. There are number of methods such as Newton Rapson method, Sparse matrix method, Triangular matrix method etc.

The elasto-plastic analysis was carried out by the method of sparse matrix to evaluate the primary response of the pavement resting on sub grade soils. The critical stress values in various directions are plotted as given in table 2. The critical stress values can be determined from various Eqns such as linear, logarithmic, polynomial and exponential. However various other differential Eqns can also be used but they would not yield accurate results. Hence Eqns with approximate values accurate or near to those in the table are adopted. The solution is based on the dependent variable and independent variable. The Eqns are obtained by plotting scatter graph in Ms excel by inputs in the tabulated format in X and Y directions of the plot with Shear modulus along X direction and Critical stresses along Y direction then adding trend line with the displaying of Eqn for the coefficient of correlation value approximately near to 1.Minimum stress values for corresponding shear modulus are used to determine the response of the pavement section. A check has been performed by substituting values of shear modulus. Sparse matrix method is a numerical analysis using matrix in which most of the elements are zero. Refer Eqn (1).On contrast, if most of the elements are non zero then the matrix is considered dense matrix consisting of non zero elements. The sparse matrix method is used in present study for elasto-plastic analysis of 3-D axisymmetric finite element model of the layered flexible pavement geometry. The volume numbering is turned on the plot control tab to know the volume number created as Volume 1(V1), Volume 2(V2), Volume 3(V3), Volume 4(V4), Volume 5 (V5) and Volume 6 (V6) for the six layered flexible pavement model constructed using the software. Basic geometry as volume for individual layer after construction in the model is as shown below -

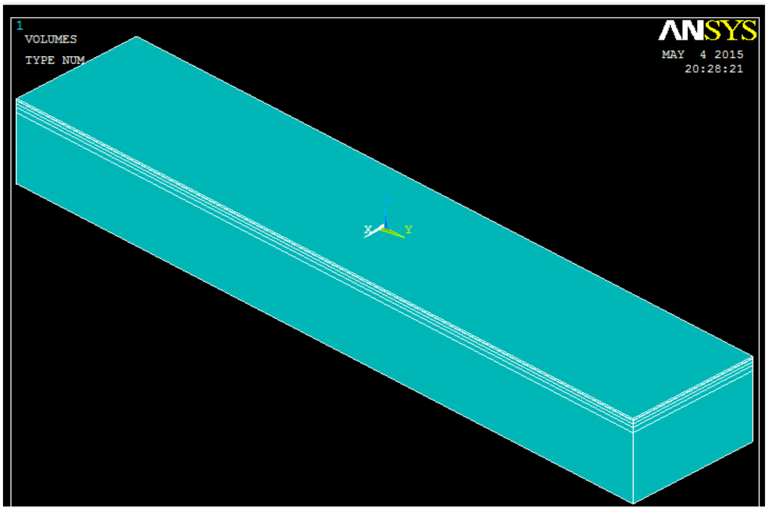


Fig. 2 3D model of six layered flexible of pavement modelled as volume with Solid element as 20-node-186

Sparse Matrix Method

The Sparse matrix is used for solving static Eqns, it involves factorizing the matrix. The sparse matrix is a direct solver. It directly solves for (x), in the static Eqn

$$[L](x)= (F) \quad (1)$$

This method is similar to the frontal solver. The frontal solver actually triangularizes [L] and the back-substitutes for (x). This is time-consuming process and is also a hard drive hog (since the full [L] is factorized). Sparse solvers, on the other hand, take advantage of the fact that [L] is sparse and banded (usually non-zero terms near diagonal) to reduce memory requirements. Thus reducing the time for analysis with quick results as nodal solutions and elemental solutions. Sample matrix is given by the Eqn (1)

$$\begin{bmatrix} L_{11} & \\ l^T_{12} & l_{22} \end{bmatrix} \begin{bmatrix} L^T_{11} & l_{12} \\ & l_{22} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{22} \\ a^T_{12} & a_{22} \end{bmatrix}$$

L_{11} and A11 are (n - 1)-by-(n -1)

$L_{11}L^T_{11} = a_{11}$,

L11l12 = a_{12},

$l^T_{12}l_{12} + l^2_{22} = a_{22}$

The L matrix is a frontal solver matrix of triangular form. The software automatically sorts the data and solves for the unknowns. The analysis gives stress values with the corresponding node number in x, y and z directions. The various z component minimum stress values induced is determined as the critical stress. Such values for various shear modulus are obtained and are tabulated .The minimum value of stresses for shear modulus of 9000 kg/cm2 are tabulated. The stress can be obtained from various Eqns consisting of one dependent variable and another independent variable. Various types of Eqns are exponential, linear, logarithmic, power Eqn, polynomial Eqn and moving average method. The Eqns some of which are used in the present case are given as follows -

Linear Eqn is an algebraic Eqn with a constant whose graph is a straight line and is of the form

$$y = mx+c$$

$$m = 1E\text{-}05,\ c = -8.502$$

$$y = 1E\text{-}05x - 8.502 \quad (2)$$

Where to obtain stress(y) substitute shear modulus(x)

Logarithmic Eqn consisting of logarithmic function i.e. ln function which is an antilog value of the x

$$y = 0.099\ln(x) - 9.323 \quad (3)$$

Where to obtain stress(y) substitute shear modulus(x)

Polynomial Eqns are available for determining the unknown in second degree and third degree Eqns. The second degree Eqn of the form ax^2+bx^2+c

a = -3E-10, b = 2E-05, c = - 8.538

$y = -3E\text{-}10x^2 + 2E\text{-}05x - 8.538$ (4)

Where to obtain stress(y) substitute shear modulus(x)

The selection of a particular type of Eqn depends on the value of coefficient of correlation with individual Eqns. The Eqns with the coefficient of correlation equal to value 1 or near to value 1 gives approximate or accurate results. The substitution of the shear modulus in above Eqns yielded approximate stress values. The graph of shear modulus vs. stress is plotted which shows decreasing value of the stresses for contact layer with high value for shear modulus of 9000kg/cm2 to low value for 12000kg/cm2.Further increase in values of shear modulus beyond specified range gives constant value of the stresses. These decreasing values indicate good bonding of the contact layer with that of other layers. Thus shear modulus has direct influence of the performance of the pavement as in our case load and other parameters are kept constant. Similarly for the same volume model the shear modulus is varied accordingly with other parameters such as elastic modulus, thickness, load and poison's ratio kept constant. The graph of shear modulus or modulus of rigidity vs critical stress values induced in the contact layer are plotted with shear modulus along X direction and critical stress along Y direction of plot determining various Eqns. Refer to the Fig. 3, 4 and 5.Also refers to the Eqns (2), (3) and (4).

SOFTWARE ANALYSIS PROCEDURES

The analysis of the 3D model using ANSYS APDL software involves the following steps

1. Run the ANSYS APDL software from the start window, the global user interface opens. Go to file and select **Change job name** give appropriate job name. Go to change directory and change the location in order to save file in a known folder or location. In the Ansys main menu select preferences tab choose structural and click on **OK**. Define the type of element go to the Pre-processor tab and select Element type. Choose add element, click on add choose **20solid186** as in our case select **OK**. This is selected because of the maximum number of nodes are required for assessing the stresses induced due the effect of loading.
2. Go to Material properties tab in the Pre-processor in order to define the properties of the material of various layer. In our case elastic analysis is being carried out. Hence elastic properties considered are elastic modulus '*E* ' and poison's ratio 'µ'. All layers except Contact layer are created as Structural-Linear-Elastic-isotropic with specified value of the modulus of elasticity and poison's ratio as in table 1.The contact layer is modelled as Orthotropic material defining modulus of elasticity, poison's ratio and shear modulus. Shear modulus value as G in x, y and z directions.
3. The geometry of the model is created from modelling tab selecting volume block by dimensions and the key input for dimensions are as specified in the Fig. 1.The dimensions in x, y and z directions are keyed in with respect to the centre. Plot of the model is done with the Z axis upwards. The sub grade layer of depth 200cm is keyed in z coordinate of the dimensions with x as 350cm and y as 1800cm.Similarly repeated for all other layers Sub base, base, binder, contact and surface layer.
4. After the model is created the properties of the individual layers are to be assigned by selecting the mesh attributes tab from the meshing menu of the pre-processor, pick volumes and select individual layer with the mouse pointer according to the numbering given for model properties assigned by selecting ok when the layer selected turns pink. Similarly done for all layers. Once all the layers are assigned with properties to ensure contact glue the layers using Glue in the Booleans of the operate tab of modelling. Pick two volumes at a time to glue them together. The top three layers i.e. surface; contact and binder are glued together selecting them at a time. After glued the entire model when picked will be picked as one volume.
5. Meshing refers to the dividing of the large model in similar small and finite number of the models creating the elements of smaller size for effective stress transfer due to the loading. The meshing is done by selecting the mesh option in the meshing and selecting volume sweep choosing pick all. A number of nodes created are accessed from the numbering option in the plot ctrls tab in the GUI window. This numbering is helpful for applying the wheel load as point load on a particular node at the centre on the top surface layer. For all models varying the shear modulus of contact layer, node is applied on the same node number selected.
6. The type of analysis is specified in the solution menu by selecting analysis choosing new analysis as static. The loads are specified in the load menu of the solution by applying structural force/displacement. Our present study is concerned with the analysis due to static load condition. The Degree of freedoms(DOF's) are specified by applying load as structural displacement on nodes and selecting to bottom most nodes by picking the in the box for the sub grade layer and choosing All DOF's with value as zero. Click on **OK**. The sides are restrained from moment in the X-direction by applying displacement and selecting the UX in the direction and selecting the side edges as per the Fig. 1.this is done in order to prevent the model from side bulking.
7. Now the wheel load of 5100 kg is to be applied on the wearing course which is done by selecting apply loads option in the solution tab and choosing structural force on nodes with keying in the node number of the central node of the top surface with choosing the direction as Fz value as -5100(negative sign indicated downward

direction).This value is equivalent single wheel load (ESWL) as per IRC 372001.The load is applied parallel to the surface of the pavement.

8. Go to solve menu in the solution select **Current Ls** (Longitudinal section) and analysis starts by the method of sparse matrix. Once the analysis is done a window appears as solution is done. Now go to General Post processing step to assess the deformation by clicking on the plot results and choose the deformed shape. Obtain the displacement value as dx.
9. To assess the critical stress values go to list results and choose nodal solution select stress as Z component stresses. A PRNSOL window listing the node number and stresses in x, y and z direction is displayed. Also maximum stress and minimum stress are displayed. As loading is done in Z direction so we are concerned with stress variation in Z direction. The analysis is repeated varying the shear modulus of the contact layer in the range of 9000 to 12000 kg/cm^2 keeping the properties of other layers constant and the corresponding minimum or critical stress values are tabulated as given in table 2.A Eqn is generated by plotting the graph of shear modulus vs. critical stress with the shear modulus as X axis and critical stress values along Y axis. The values of the stress are verified by substituting the values of shear modulus as x to obtain critical stress y in the Eqn (1).

RESULTS

Step 1 Creation of the model as volume defining the element as solid. Other elements such as beam, plate, fluid element can also be created. Initially the volume is created defining the volume by block with specified dimensions. Similarly all layers are created as the blocks one above the other. The creation of the desired geometry as per the specifications of IRC 372001.Here the material properties such as modulus of elasticity and poison's ratio are defined. Also individual layer is assigned to the attributes. The horizontal line in the Y direction represents the stretch of the pavement influenced due to load. The dimension in the X direction represents the width of the pavement layers and dimensions in the Z direction represent thickness of the layers. The volume after creation is as shown in Fig. 6.

Step 2 Discretization of the whole volume into finite number of elements meshing the whole block volume into known number of maximum nodes. As the stress due to variation of shear modulus is transferred from layer to layer through the joints called nodes. Meshing can only be done after assigning the mesh attributes to layers. An individual element of mesh is mode up maximum of six faced element.

Step 3 Defining the boundaries in terms of the Degrees of freedom i.e. number independent ways in which a system can move. In present study the bottom nodes are restricted against displacements, rotations etc. Hence the bottom nodes are restricted for all DOFs while the edges are restricted for the rotation in the X direction i.e. Ux. The step involving restricting the sideways in order to avoid side bulging. Longitudinal section after assigning of restrictions is as follows

Step 4 This step involves assigning of the point load and the model is ready to be analyzed. The analysis is carried out to obtain results. The software automatically solves by linear method of sparse matrix once the solve current Ls is selected in the solution menu. The analysis is completed when a window of solution is done pops up and the results will be stored which are obtained from general post process in window PRNSOL displaying node number and stresses shown in Fig. 10.

Table -2 Shear Modulus and Corresponding Critical stress values

Shear Modulus (kg/cm^2)	Critical Stress (kg/cm^2)
9000	8.418
9300	8.414
9600	8.411
9900	8.408
10200	8.405
10500	8.403
10800	8.400
11100	8.397
11400	8.394
11700	8.392
12000	8.389

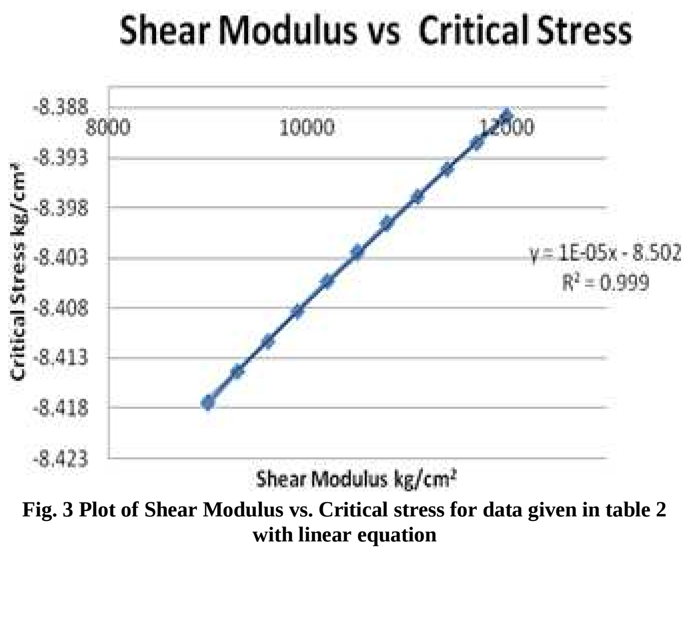


Fig. 3 Plot of Shear Modulus vs. Critical stress for data given in table 2 with linear equation

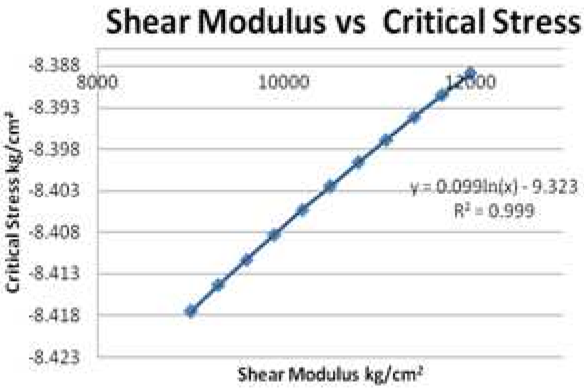


Fig. 4 Plot of Shear Modulus vs. Critical stress for data given in table 2 with logarithmic equation

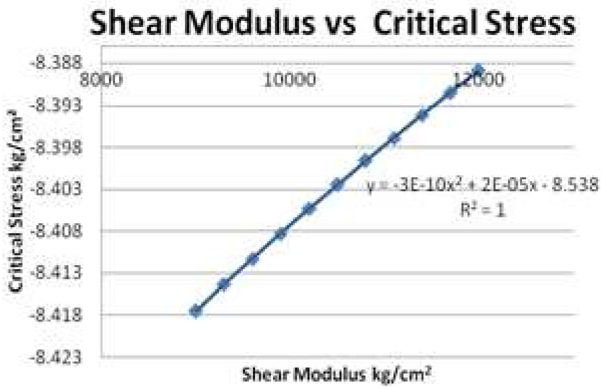


Fig. 5 Plot of Shear Modulus vs. Critical stress for data given in table 2 with second degree polynomial Eqn

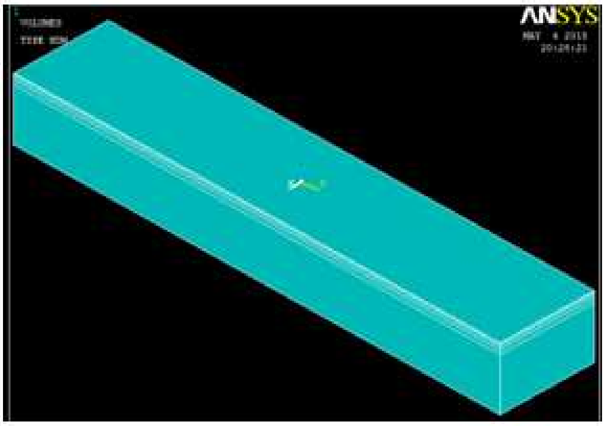


Fig. 6 3D model of various layers representing volumes of various layers

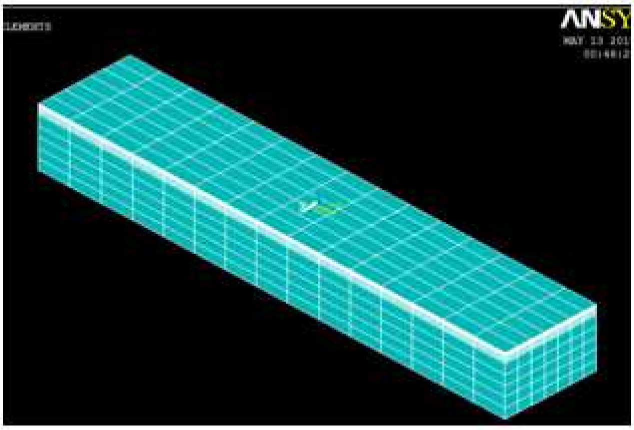


Fig. 7 3D model of various layers of pavement meshed by volume sweep for finite element analysis

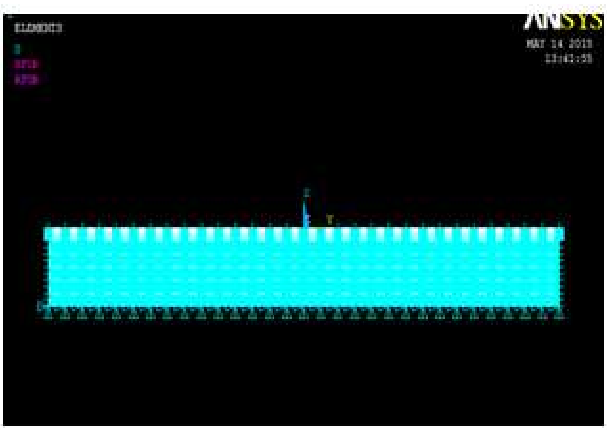


Fig. 8 3D model of with ends restrained bottom nodes for all DOFs and sides for rotation in X direction

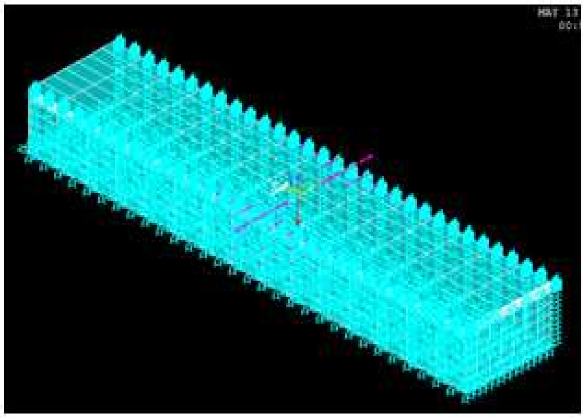


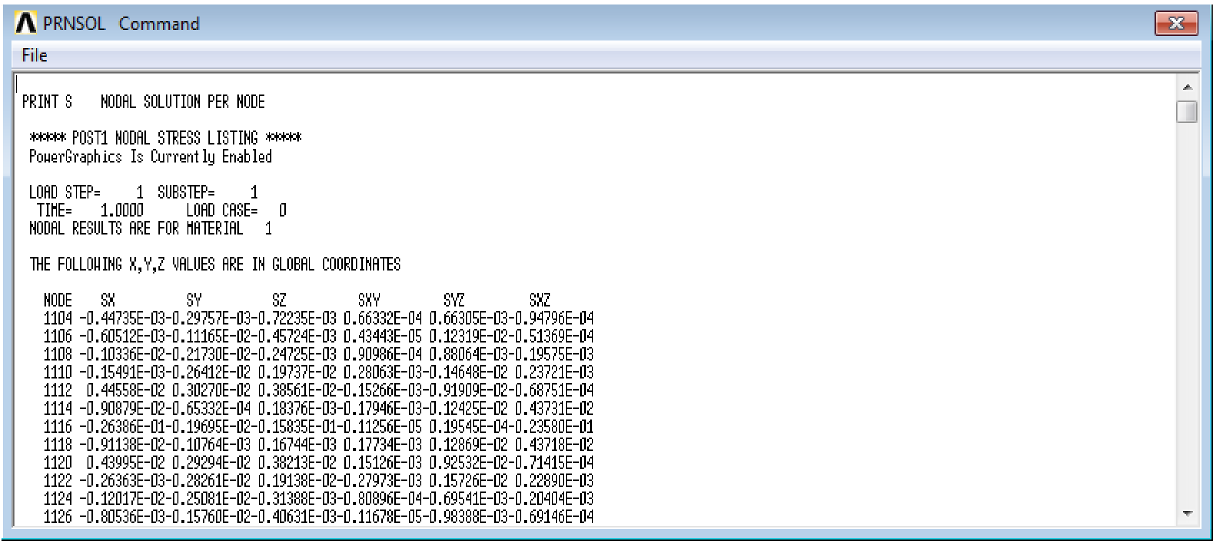
Fig. 9 3D model of with ends restrained and point load ready to analyzed

EVALUATION OF BENEFITS

The proposed methodology is a mechanistic type of design approach for design of flexible pavement used to evaluate the response by pavement under wheel load with varying the values of shear modulus (elastic property) of the contact layer in the specified range with other parameters kept constant. The bonding characteristics can be assessed by analysis using the critical stress criteria. It is a better method for characterizing different material properties and loading condition. Has the ability to evaluate the performance of the pavement for the bonding criteria on an economic basis. Bonding characteristics accessed based on the shear modulus criteria.

Pavement Response

The 3-D axisymmetric isotropic finite element model of flexible pavement was developed using the commercial software ANSYS APDL and pavement response is evaluated by obtaining various critical stress values corresponding to the shear modulus. Increasing values of the critical stress indicates poor bonding. While decreasing values of critical stress indicates better bonding condition. The study involved varying shear modulus of the contact layer and keeping all other parameters constant such as modulus of elasticity and poison's ratio. In the present study the critical stress values in the contact layer are observed to be decreasing indicating good contact or bonding of this layer with the other top and bottom layers. This signifies better bonding of the contact layer whose shear modulus mainly influence on the performance or response of the pavement. Better bonding ensures greater performance under varying traffic loads as well as greater durability rather than early deterioration. The stress values due to varying of the shear modulus of contact layer show decrease with increase in shear modulus. This signifies good bonding and ensures greater life of the pavement under the present considered parameters. Thus shear modulus of the contact layer has direct influence on the performance of the pavement due to the effect of stresses induced by loading with Equivalent single wheel load. And the deformation under the point load i.e. 9.9mm which shows that the pavement has responded under the given equivalent single wheel load of 5100 kg. This method of model analysis helps in non destructive evaluation of the flexible pavement model under the effect of shear modulus. Better adhesion at the interface of the layers of the flexible pavement is assessed by the adopted methodology.


PRNSOL Command

File

PRINT S NODAL SOLUTION PER NODE

***** POST1 NODAL STRESS LISTING *****
PowerGraphics Is Currently Enabled

LOAD STEP= 1 SUBSTEP= 1
TIME= 1.0000 LOAD CASE= 0
NODAL RESULTS ARE FOR MATERIAL 1

THE FOLLOWING X,Y,Z VALUES ARE IN GLOBAL COORDINATES

NODE	SX	SY	SZ	SXY	SYZ	SXZ
1104	-0.44735E-03	-0.29757E-03	-0.72235E-03	0.66332E-04	0.66305E-03	-0.94796E-04
1106	-0.60512E-03	-0.11165E-02	-0.45724E-03	0.43443E-05	0.12319E-02	-0.51369E-04
1108	-0.10336E-02	-0.21730E-02	-0.24725E-03	0.90986E-04	0.88064E-03	-0.19575E-03
1110	-0.15491E-03	-0.26412E-02	0.19737E-02	0.28063E-03	-0.14648E-02	0.23721E-03
1112	0.44558E-02	0.30270E-02	0.38561E-02	-0.15266E-03	-0.91909E-02	-0.68751E-04
1114	-0.90879E-02	-0.65332E-04	0.18376E-03	-0.17946E-03	-0.12425E-02	0.43731E-02
1116	-0.26386E-01	-0.19695E-02	-0.15835E-01	-0.11256E-05	0.19545E-04	-0.23580E-01
1118	-0.91138E-02	-0.10764E-03	0.16744E-03	0.17734E-03	0.12869E-02	0.43718E-02
1120	0.43995E-02	0.29294E-02	0.38213E-02	0.15126E-03	0.92532E-02	-0.71415E-04
1122	-0.26363E-03	-0.28261E-02	0.19138E-02	-0.27973E-03	0.15726E-02	0.22890E-03
1124	-0.12017E-02	-0.25081E-02	-0.31388E-03	-0.80896E-04	-0.69541E-03	-0.20404E-03
1126	-0.80536E-03	-0.15760E-02	-0.40631E-03	-0.11678E-05	-0.98388E-03	-0.69146E-04

Fig. 10 PRNSOL window displaying node numbers and corresponding stresses

CONCLUSION

- The critical stress values are calculated for contact layer by the following Eqns by substitution of shear modulus in the range of 9000kg/cm2 to 12000kg/cm2 as x in order to obtain stress y
  - a) $y = 0.099\ln(x) - 9.323$ Logarithmic Eqn
  - b) $y = 1E{-}05x - 8.502$ Linear Eqn
  - c) $y = -3E{-}10x2 + 2E{-}05x - 8.538$ Polynomial Eqn
- Stress induced due to varying of shear modulus are in order of decreasing values which signifies better bonding characteristic of the contact layer with that of other layers.
- It was observed that the stress values for shear modulus below or above specified range showed no change.
- These are stresses are key factors for determining the bond strength of the layers of the flexible pavements.
- From study conclusion can be drawn that due to variation of shear modulus critical stresses are induced which has direct impact on bonding characteristics of the flexible pavement.
- A correlation of shear modulus with that of bond strength of the pavement is developed in order to determine the effect of the shear modulus on the performance of the flexible pavement.

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