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Analysis And Design of Pavements in Submerged Condition

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Abstract
Stagnation of road structures because of flooding or improper drainage conditions can cause huge expense for their rehabilitation and maintenance at present, design of flexible and rigid pavements is defined by an important empiricism phenomenon though it has been in practice from the evolution of art to science. By layered theory the flexible pavement is designed by assuming that there is an absence of discontinuities and the layers are infinite in a real practice. The olden design of Flexible pavement is depended on using California Bearing Ratio (CBR) values in 1970.Instead of Elastic modulus values, Resilient modulus values are fundamentally considered in the flexible pavement design. It is vital material property which is used to identify the unbound pavement materials. These resilient mean values are used to evaluate the stress and strain, material stiffness in a submerged condition. Stress and strain condition differs from initial condition of pavement and a period of submerged condition in sub grade and granular base layer of pavement. This analysis is carried out to evaluate the reaction on sub grade strength and its properties during pavement submergence period. Pavement analysis can be done through a software package called KENPAVE. In this software, the programs like KENLAYER, KENSLAB, LAYERINP, and SLABSINP are combined with addition of graphic programme. An existing pavement structure suggested by the Indian Roads Congress standard is analyzed and compared with its submerged condition. New pavement sections were designed using the material properties under submerged cases, and compared for stresses, strains, displacements, damage ratio, etc.

Keywords: *Pavement Analysis, Pavement Design, Submerged Condition, Kenpave, Damage Ratio.*

1. Introduction

In 1870, the first flexible pavement laid at Newyork. Flexible pavement is composed of bituminous and granular materials. The flexible pavement can be designed using mechanistic empirical method, by limiting shear value method, limiting deflection method, by implementing regression method and by empirical method. The flexible pavements cannot take up the tensile stresses caused by load. A flexible pavement is composed of four layers viz. soil sub grade, sub base course, base course and surface course. The layers are consisting of a kind of diverse materials by their specifications. Strength of sub grade is more important in flexible pavement. Under transient traffic loading condition, the behavior of the sub grade is elastic in nature with negligible deformation in a single pass. The elastic behavior of the pavement is measured by the resilient modulus factor from the results [1]. In order to design the flexible pavement and to measure the performance of the pavement, resilient modulus is an important criterion which is used in this study. The strength of the sub grade which is the road foundation is the vital parameter in the design of pavement structure. Thus, the compacted soil in the sub grade layer defines the strength of the flexible pavements. If the roads are exposed to submerged conditions, the different layers in flexible pavement get saturated then the real condition of the sub grade soil is negotiated [2]. In this paper, the analysis of the flexible pavement is carried out by using KENPAVE computer program for the study of flexible pavement without the rigid layers or joints. The KENLAYER computer program provides a solution for an elastic multi-layer system under circular loaded area. The results from KENLAYER program are superimposed for multiple wheels which are applied repetitively for nonlinear layers and accumulated at various times for the visco elastic layers [3]. Hence the KENLAYER computer program is used to layered systems under different vehicle loading conditions where the layers behave

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differently in visco elastic, nonlinear elastic or at the linear elastic stage. The damage analysis of flexible pavement is carried out dividing each year deformations in to twelve periods by using different set of the material properties. Finally, the deteriorations due to permanent deformations, fatigue cracking at each period are estimated over all loading groups to compute the design life of the flexible pavement.

2. Literature Review

2.1. Sub Grade Strength

In this paper, initially the study over the strength of the soil samples under different inundation conditions is carried out. Though the study decreases in CBR strength of the soaked and unsoaked soil sample is observed, when the pavement layer is submerged for many days. It is observed the strength of the soil in flexible pavement is decreased when they are in submerged state in longer period were found by Naser and Ghani [2].

2.2. Fatigue and Rutting Lives

Sub grade resilient modulus and base thickness were the primary elements which control the stability between fatigue and rutting lives. Flexible pavements should be designed to provide a reliable, skid resistance to surface under in-service Conditions. Moreover, it is essential to minimize cracking and rutting in flexible pavement layers. The increasing asphalt layer elastic modulus the fatigue and rutting damage decrease were authorize by Ebrahim and Behiry [3].

3. Objectives

The partial or full submersion of pavement structure due rainfall adversely affects the pavement performance. The main objectives of the current study are:

- To analyze a pavement structure under conventional case and under partial and complete submerged conditions.
- To design required thickness for pavement structure under submerged conditions considering stresses, strains, deformations etc.

4. Methodology

The study of existing pavement configuration and to analyze layer thickness and calculate resilient moduli of subgrade according to CBR value. Assigning the Sub-grade resilient moduli value to calculate granular sub-base, granular base and bitumen course of pavement. Analyzing the pavement responses which include stresses, strains and displacements using KENPAVE software. Damage Analysis in fatigue and rutting of pavement.

4.1. Study of Existing Pavement

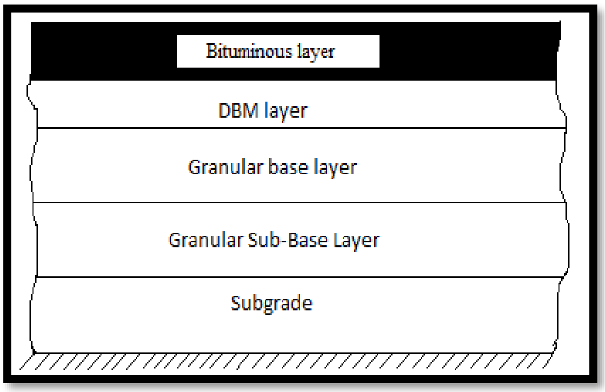

Figure 1 Pavement Layer

The flexible pavement layers are aligned as shown in Figure 1, which is as per Indian Road Congress (IRC) 37 standard. The sub grade is the bottom most portion of the pavement and the top 50 cm of the existing layer can be considered as subgrade. It is composed of the in-situ material, stabilized soil and suitable selected soil. It forms the foundation of the pavement, by providing the platform for the construction of traffic and to serve as drainage system, filter layer. The sub base layer protects the pavements from overstressing, and some cases it functions as a drainage layer. The design of sub-base, whether bound or unbound, should achieve these functional requirements. The base layer generally consists of wet mix macadam, water bound macadam, crusher run macadam, etc. which helps in the load distribution.

4.2. Analyze Layer Thickness

The layer thickness is obtained in IRC method by considering CBR value of subgrade and Traffic. In this analysis the design charts of flexible pavement is presented for different traffic combinations and material properties from IRC37:2012 as shown in Fig.2. There are different combinations of design charts considering CBR value and traffic conditions, using Granular Base and Granular Sub base materials. Sub-Grade of soaked CBR value 5% and Maximum Traffic

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of 100 msa (million standard axles) are considered in this case.

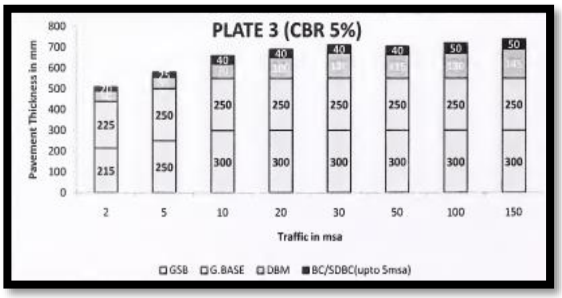

Figure 2 Design chart of flexible pavement of CBR 5 %

4.3. Resilient Modulus

Resilient modulus is an important property required for pavement design considering the dynamic loading conditions. This property can be determined by laboratory testing or by using correlation equations with some known material properties. Resilient modulus value is calculated for sub grade and equation of relation between resilient modulus and CBR is

$MR = 10 \times CBR$ for $CBR < 5\%$

$17 \times (CBR)^{0.64}$ for $CBR > 5\%$

M_R –Resilient modulus of sub grade soil.

After obtaining the resilient value for sub grade, the same for Granular sub base and granular base layers can be determined using the following expression.

$M_{Rgsb}=0.2 \times h^{0.45} \times M_R subgrade$

$M_{Rgb}=0.2 \times h^{0.45} \times M_R subgrade$

h - thickness of layer.

Resilient modulus of Bituminous layer is varies with different binders and viscosity grade of bitumen. From table 1 of IRC37:2012 for 30^0 temperature and VG30 bitumen the value is taken as $M_{Rbitumen}$=2500mpa.

4.4. Kenpave Inputs

For analysis all layers are assume to be linearly elastic with a constant elastic modulus for each layer. Stress strain analysis is conducted separately. Other input parameters are listed below:

General Inputs used are:

- Type of material is 1.
- The number of periods in a year is 1.
- The number of load groups is 1.
- The number of layers varies among 4.
- The number of Z- coordinates is calculated depending upon the number of interfaces and the intermediate points for analysis.
- The number of responses is 9, which are displacement, vertical stress, vertical strain, major principle stress, minor principle stress and intermediate stress in the output.
- All layer interfaces are simulated to be bonded.
- SI units are used for calculations.
- The contact radius of circular loaded area is provided as 30 cm for single axle with single wheel and contact pressure as 800 kPa.
- Analysis was conducted for radial distance = 0 (i.e., along the vertical plane of loading)
- The thickness of each layer is provided in cm.

4.5. Damage Analysis Inputs

For conducting damage analysis suitable option should be selected in software. For damage analysis, fatigue coefficients bottom tension is notated as FT1, FT2 and FT3, and the values are 0.0796, 3.291 and 0.854 respectively. In addition to permanent deformation coefficients of top compression FT4 and FT5, the values are 1.37E-09 and4.5337 are also provided [4-5].

5. Results

From KENPAVE software vertical stress, strain and displacements are calculated. In submerged condition sub grade properties will be affected or damage occurs in sub grade layer and granular base layer. This leads to the failure of pavement, indicated by the increase in stresses and strains at the corresponding layers. So by increasing the thickness of layers, the values of stress, strain, displacement should be within the limits as in the conventional case.

5.1. Case (1)

Table 1 Conventional Values Of 5% CBR and 100 msa Traffic

Vertical Coordinate (Cm)	Vertical Displacement (Cm)	Vertical Stress (Kpa)	Vertical Strain
0	0.245	800	-2.79E-04
18	0.25156	358.837	6.06E-04
43	0.21312	166.084	1.23E-03

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73	0.17957	72.822	1.00E-03

Table 2 50% Reduction of $M_{Rsubgrade}$ Submerged Condition

Vertical Coordinate (Cm)	Vertical Displacement (Cm)	Vertical Stress (Kpa)	Vertical Strain
0	0.43734	800	-4.78E-04
18	0.4453	262.941	8.15E-04
43	0.38729	129.324	1.93E-03
73	0.33279	6.16E+01	1.67E-03

Table 3 Depth Increase By 60cm (From Trial and Error Method) Submerged Condition

Vertical Coordinate (Cm)	Vertical Displacement (Cm)	Vertical Stress (Kpa)	Vertical Strain
0	0.21143	800	-1.14E-04
18	0.24588	362	6.04E-04
103	0.16327	54.3	4.95E-04
193	0.13158	11.2	2.81E-04

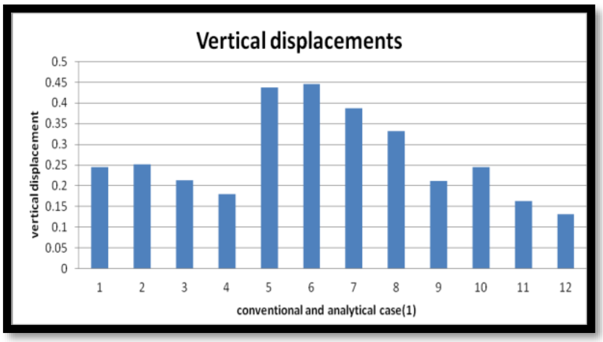

Figure 3 Vertical Displacements of Conventional Case Analytical Case (1)

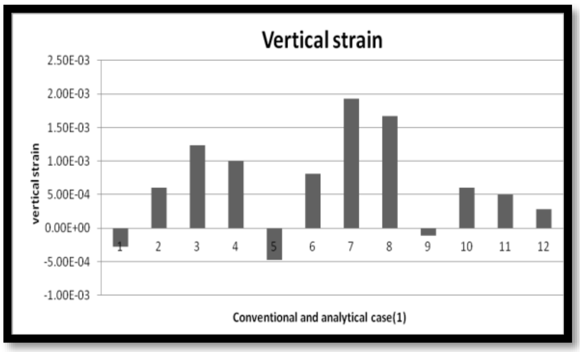

Figure 4 Vertical Strain of Conventional Case and Analytical Case (1)

5.2. Case (2)

Table 4 75% Reduction of $M_{Rsubgrade}$ Submerged Condition

Vertical Coordinate (Cm)	Vertical Displacement (Cm)	Vertical Stress (Kpa)	Vertical Strain
0	0.74807	800	-6.13E-04
18	0.77425	182.596	1.06E-03
43	0.69136	96.286	2.87E-03
73	0.60687	50.272	2.67E-03

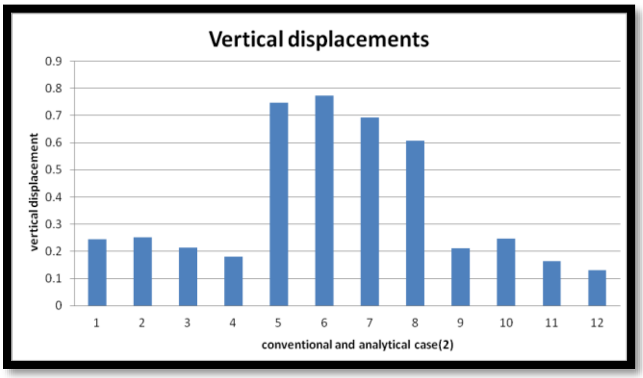

Figure 5 Vertical Displacements of Conventional Case Analytical Case (2)

Table 5 Depth Increase By 60cm (From Trial and Error Method) Submerged Condition

Vertical Coordinate (Cm)	Vertical Displacement (Cm)	Vertical Stress (Kpa)	Vertical Strain
0	0.21143	8.00E+02	-1.14E-04
18	0.24588	3.62E+02	6.04E-04
103	0.16327	5.43E+01	4.95E-04
193	0.13158	1.12E+01	2.81E-04

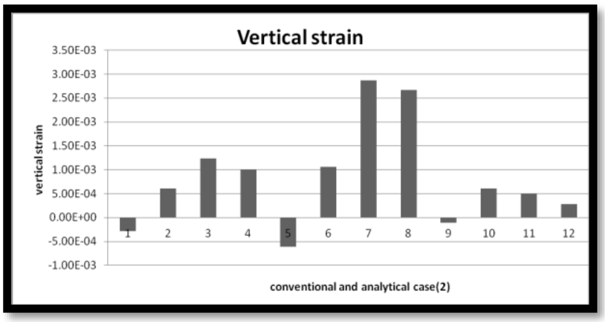

Figure 6 Vertical Strain of Conventional Case and Analytical Case (2)

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Table 6 Tensile Strain for Conventional and Analytical Cases

Cases	Tensile Strain
conventional	-5.82E-04
50%Reduction of M_R	-8.97E-04
50%Reduction of M_R 60cm	-5.79E-04
75%Reduction of M_R	-7.25E-04
75%Reduction of M_R 60cm	-5.80E-04

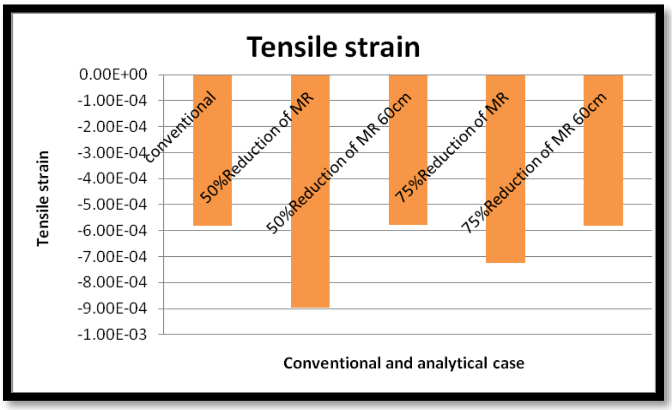

Figure 7 Tensile Strain of Conventional Case and Analytical Cases

Table 7 Compressive Strain for Conventional and Analytical Cases

Cases	Compressive Strain
conventional	1.49E-03
50%Reduction of M_R	2.53E-03
50%Reduction of M_R 60cm	4.76E-04
75%Reduction of M_R	4.05E-03
75%Reduction of M_R 60cm	5.95E-04

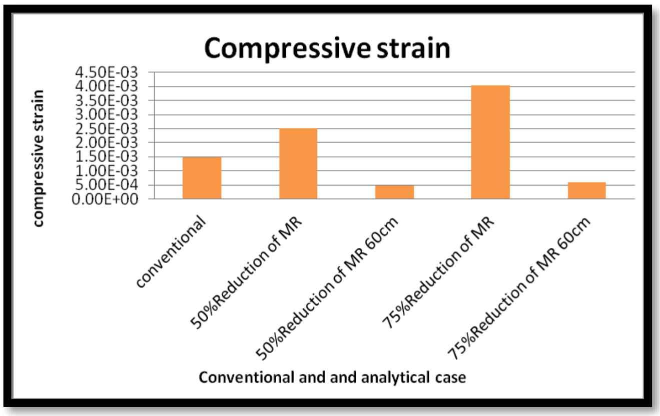

Figure 8 Compressive Strain of Conventional Case and Analytical Case

Table 8 Fatigue lives for Conventional and Analytical Cases

Cases	N_f
conventional	1.21E+04
50%Reduction of M_R	2.99E+03
50%Reduction of M_R 60cm	1.19E+04
75%Reduction of M_R	9.84E+02
75%Reduction of M_R 60cm	3.79E+03

Table 9 Rutting Lives for Conventional and Analytical Cases

Cases	N_r
conventional	6.25E+03
50%Reduction of M_R	5.77E+02
50%Reduction of M_R 60cm	4.58E+03
75%Reduction of M_R	7.05E+01
75%Reduction of M_R 60cm	6.06E+03

Table 10 Damage Ratio for Conventional and Analytical Cases

Cases	Damage ratio
conventional	1.60E+04
50%Reduction of M_R	1.73E+05
50%Reduction of M_R 60cm	8.90E+03
75%Reduction of M_R	1.92E+05
75%Reduction of M_R 60cm	2.64E+03

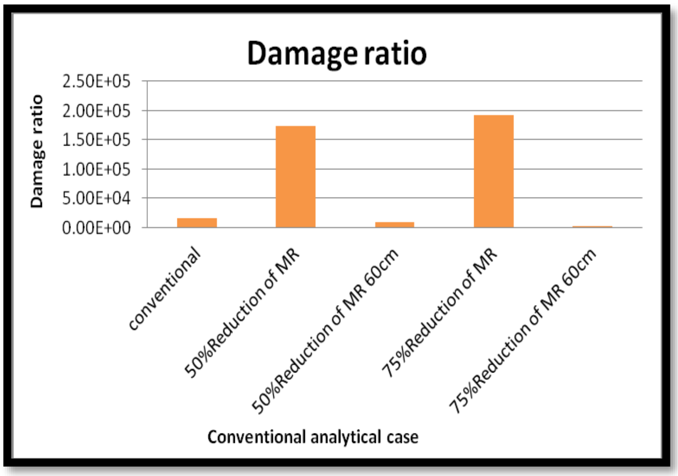

Figure 9 Damage Ratio of Conventional Case and Analytical Cases

For analytical cases, materials as in the conventional case were maintained and only the layer thickness material properties (MR values) were changed. In this study, the load was considered as the single axle single wheel load and analysis was done for the sub grade condition (CBR 5%). The submerged condition was introduced by reducing the resilient modulus values of subgrade, which in turn reduces the same for base and sub-base layers. The reduction was done through two cases of Case (1) 50% increase by depth and case (2) 75% reduction sub grade value increase by depth and using trial and error method the limit values will obtain. For conventional and analytical cases, vertical stress and vertical displacement values are presented in Tables 1, 2, 3, 4 and 5. Damage analysis gives the tensile and compressive strain values as shown in Tables 6 and 7. Fatigue lives (Nf), rutting (Nr) and damage ratio were also calculated from damage analysis and the results are presented in Tables 8, 9 and 10. The vertical displacements of conventional, reduced sub grade of 50 % and 75 % and increase in layer thickness is shown in Fig.3 and Fig.4. The vertical strain of conventional, reduced sub grade of 50 % and 75 % and increase in layer thickness is shown in Fig.5 and Fig.6. Damage analysis of tensile strain and compressive strain of conventional and analytical cases are presented in graph shown in Fig.7 and Fig.8. Damage ratio of conventional and analytical cases is shown in Fig.9.From graph presentation we can notice that there is increase in vertical displacements, vertical strain, tensile strain, compressive strain and damage ratio sub grade reduction than conventional case, when the trial-and-error method done layer thickness increases it remains same or less than conventional case.

Conclusions

Conclusions observed from the analysis of pavement structure for sub grade having 5% CBR and for reduced MR value conditions are as follows:

- There is minuscule change in vertical stress with the reduction in MR value, where the vertical displacement increased about 1.5 – 2 times from the conventional values.
- From damage analysis, Compressive and Tensile strain values were also observed to be 1.2 – 2 times higher for critical cases.
- For critical cases of reduced MR value, fatigue and rutting lives decreased drastically. The reduction was 30% for fatigue life and 50% for rutting life from the conventional value.
- Another change was observed in damage ratio, which increased about 10 times for 50% reduced MR value, whereas for 75% reduction it became 12.5 times the conventional value. This analytical increase in damage ratio indicates pavement failure.
- So to renew the strength of pavement reduction in MR, layer thickness is increased 60cm similar to conventional case values by repetition method. To withstand in submerged condition without damage of layer.

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