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Analysis of rigid pavement stresses by Finite Element Method & Westergaard's Method by varying sub-grade soil properties

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ABSTRACT: *The Project involves design and mechanistic analysis of a rigid pavement and further reveals the disparity and contrast between the Empirical and Finite Element Analysis techniques on an empirically designed rigid pavement. Where both the mentioned procedures were conducted, the results were plotted so that the deviation is pronounced. Since, the use of Empirical Analysis is eminently laborious; hence in order to execute several iterations with diverse material properties, locations of applied load and load combinations, we have endeavored to appreciate the convenient use of FEA, for which, software EverFE 2.25 is being used as a tool to operate the Finite Element Analysis.*

The response of the pavement was observed and the results compared with the Westergaard's manual calculations were satisfying and encouraging. The model was then gradually enhanced so to meet the most realistic conditions.

More and more parameters were involved and a model with optimum meshing, most suitable elements with self-defined complex properties, appropriate material properties, realistic boundary conditions and load applications was achieved. With single tyre configurations, the model will be then subjected to number of varying input parameters like the change in the thickness of pavement slab, sub-grade material to rigid foundation, and position and intensity of loads.

Keywords: *Finite element analysis, rigid pavements, stresses analysis etc.*

I. INTRODUCTION

Finite Element Method is defined as a numerical technique for finding approximate solutions to partial differential equations (PDE) and their systems, as well as integral equations. In simple terms, FEM is a method for dividing up a very complicated problem into small elements that can be solved in relation to each other. Its practical application is often known as **finite element analysis** (FEA). A rigid pavement is modeled as a flat slab along with the base and sub-grade beneath the slab. Wheel load stresses at critical points on the pavements i.e. the interior, edge, corner region of the pavement are taken into consideration while analyzing the stresses developed in the pavement. So from the literature review we aim to analyze the following objectives:

- Finite Element Analysis of Rigid Concrete Pavements using EverFE software.
- Comparison of results with Westergaard's equation and Finite Element Analysis.
- Execute several iterations with diverse material properties, locations of applied load and load combinations, we shall perform FEA, for which, EverFE will be used as a tool to operate the Finite Element Analysis.
- Temperature differentials across the various layers of the slab, base, and subgrade will be taken into account and optimum results will be obtained.
- Design and mechanistic analysis of a rigid pavement and shall reveal the disparity and contrast between the Empirical Westergaard's Analysis and Finite Element Analysis techniques on an empirically designed rigid pavement.
- An analytical investigation of the above-mentioned rigid pavement is made for finite element analysis by using suitable meshing and discretization with the aid of the software EverFE 2.25 developed by Bill Davids, University of Maine, United States of America.
- The response of the above-mentioned rigid pavement model is examined for the critical stresses in the regions as indicated by Westergaard's empirical stress analysis.

Stabilization of soil sub-grade is an important procedure to ensure the proper construction of a rigid pavement as the component layers of the rigid pavement system i.e. the slab, aggregate-base and soil-subgrade are in close contact with each other and bear the vehicular loads simultaneously. So in order to ensure the stabilization of unstable soil sample sawdust is added as a stabilizer in increasing proportions and the stress response in the unstable as well as stabilized soil samples is indicated. Principal objectives in undertaking this line of action are as follows:

- Taking into consideration the structural safety of rigid pavements of location of unstable soil it is necessary to consider the change in the geotechnical properties due to such a soil.
- In order to ensure further contamination of soil so as to reflect its unstable properties a secondary contaminant is added to the soil and its effects on the stress is observed
- Soil samples prevailing in the Nagpur region have been analyzed for the stress response of a rigid pavement under the respective wheel load stresses at the critical points.
- The rigid pavement model is subjected to analysis with subsequent stabilized soil samples to the same parameters of load and temperature differentials as in the original soil samples in the Ever FE 2.25 software and the stress response is recorded.
- The thickness of the slab is varied in increasing order as per the respective limits stated in IRC codes and the model is analyzed for the same.
- The stress analysis thus includes a wide spectrum of parameters in each case such as the soil properties, wheel loads and proportion of stabilizer and location of loads.

II. DETAILS OF THE RIGID PAVEMENT MODEL

1. Type of pavement : - Rigid pavement
2. Dowel joints: Not considered in the single-slab model
3. Width of the slab :- 4600 mm
4. Length of the slab :- 3600 mm
5. Load type considered :- Single axle load
6. Load acting on slab : - 126 KN
7. Points of application of load :-Interior, Edge and Corner
8. Temperature zone :- $17.5^0 – 19.5^0$ according to IRC 58:2002
9. Thickness of slab:- 15 cm ,16 cm ,17 cm, 18 cm,19 cm,20 cm
10. Type of original soil :- Black Cotton soil
11. Pavement model system: - 3 layer pavement: slab (M-25), aggregate base and soil sub-grade.
12. Stresses computed on structure: - wheel load stresses, temperature stresses, and warping stresses.

III. SAMPLE REPRESENTATION OF FINITE ELEMENT STRESSES

I. Stresses developed in rigid pavement with series of unstable soils thickness of slab=15 cm:

	Interior	**Edge**	**Corner**
Virgin BC soil	**3.73 Mpa**	**4.42 Mpa**	**2.04 Mpa**
5% castor oil impurity	**4.35 Mpa**	**4.64 Mpa**	**6.68 Mpa**
7.5 % castor oil impurity	**4.77 Mpa**	**5.23 Mpa**	**7.18 Mpa**
10 % castor oil impurity	**4.79 Mpa**	**5.99 Mpa**	**6.04 Mpa**

II. Stresses developed in rigid pavement after stabilizing the soil with 10 % castor oil impurity thickness of slab=15 cm:

	Interior	**Edge**	**Corner**
10% oil	**4.79 Mpa**	**8.38 Mpa**	**5.04 Mpa**
5 % sawdust stabilizer	**6.2 Mpa**	**10.6 Mpa**	**6.96 Mpa**
7.5 % sawdust stabilizer	**3.84 Mpa**	**1.85 Mpa**	**2.54 Mpa**
10 % sawdust stabilizer	**3.62 Mpa**	**5.49 Mpa**	**2.04 Mpa**

IV. SAMPLE REPRESENTATION OF WESTERGAARD METHOD STRESSES

Stresses developed in rigid pavement with series of unstable soils thickness of slab=15 cm**:**

	Interior	Edge	Corner
Virgin BC soil	**3.51 Mpa**	**5.73 Mpa**	**6.57 Mpa**
5% castor oil impurity	**3.54 Mpa**	**5.87 Mpa**	**6.61 Mpa**
7.5 % castor oil impurity	**3.57 Mpa**	**5.93 Mpa**	**6.65 Mpa**
10 % castor oil impurity	**3.59 Mpa**	**5.97 Mpa**	**6.67 Mpa**

Stresses developed in rigid pavement after stabilizing the soil with 10 % castor oil impurity thickness of slab=15 cm:

	Interior	Edge	Corner
10% oil	**3.59 Mpa**	**5.97 Mpa**	**6.67 Mpa**
5 % sawdust stabilizer	**3.65 Mpa**	**6.07 Mpa**	**6.77 Mpa**
7.5 % sawdust stabilizer	**3.63 Mpa**	**6.05 Mpa**	**6.57 Mpa**
10 % sawdust stabilizer	**3.61 `Mpa**	**6.01 Mpa**	**6.61 Mpa**

V. DISCUSSIONS

The results as expressed in the above page, similar results are available for pavement slab of thicknesses ranging from 15cm, 16 cm, 17 cm, 18 cm, 19 cm, and 20 cm.

1. The stress analysis shows a comparison between the rigid pavement stresses developed by Finite element method and Westergaard's empirical method.
2. Maximum stresses are developed in the edge region in case of finite element analysis and corner region in case of empirical analysis.
3. Sawdust when used as a stabilizer in increasing proportions gives away a spectrum of stresses which will be reviewed as per their face value in each case.
4. Oil when used as an impurity in the original in-situ soil decreases the stability of the soil.
5. Finite Element Method is suggested as an alternative method to calculate the rigid pavement stresses and is not the only method.

VI. CONCLUSIONS

Westergaard's empirical method is not the only method to calculate rigid pavement stresses and stresses can be as effectively calculated by Finite Element Method.

1. Finite Element Stresses when used in the design of rigid pavements as suggested can provide an optimum and economical design in practice because of the procedure of FEM to discretize each element under consideration and calculate stresses at each node.
2. Estimation of the behavior of the rigid pavement critical points under the applied load can be more accurately described by Finite Element Method stresses.
3. The lower value of the Finite Element Stresses as compared to the Westergaard's stresses ensures that the design of the pavement and its further manipulations by trial and error method can be easily done with constraints of design look-up minimized.
4. The lifetime of the pavement can be considerably increased by the application of Finite Element Method Analysis and the fatigue and distress can be accurately ascertained.
5. According to the analysis done by us it is found that the rigid pavement model exhibits minimum value of the stresses when the sub-grade layer is treated with 10 % sawdust as a stabilizer

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