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Analysis, Design and Development of U-Shaped Precast Panel for Serviceability Improvement of Flexible Pavements

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Abstract: The flexible roads have many advantages as compared to the rigid pavement. In India, the flexible pavements are deteriorated quickly due to heavy loads of the vehicles. Thus, it is important to find out cost effective structural solution for serviceabilityimprovement of flexible pavement. Currently, Precast Concrete panels are being increasingly used for rapid construction and repair of various types of pavements. The concept of using U-shaped Precast Concrete Panel is expected to be a solution in strengthening the bearing capacity of the sub-grade. The U-shaped precast panel is a open ended rectangular precast panel with a couple of webs at top end of the panel. The main objective of this paper is to carry out the analysis on the precast panel and appraise the advantages and benefits of innovative approach in contrast to traditional flexible pavements, and to come up with the conclusion and recommendations for the regular practices. The stress analysis carried on the pavement with and without using precast panel concluded that the stress gets reduced on the application of precast panel, and thus serviceability of pavement improves.
Keywords: U-shaped precast panel, stress analysis, CBR method, modeling, ANSYS software, a couple of web.

I. INTRODUCTION

The performance of pavements in India until today is not to be ideal. The constructions of flexible or rigid pavement usually don't reach designed service lives, either because of the actual fact that the development doesn't meet specifications or inevitable excessive load (Ackroyd 1985).Technical difficulties such as shortage in asphalt delivery in flexible pavement case, highway obstructions in case of typical rigid pavement (jointed plain concrete pavement, JPCP), inability to satisfy quality specification in case of rigid pavements are usually faced during the construction of the pavements. If the pavement deteriorates faster than its design life period, the maintenance or repair would be expensive and hinder highway users. Additionally, the system is not addressed properly (Nurjaman et al. 2017). The major flexible pavement failures are fatigue cracking, rutting, and thermal cracking. Sub-grade rutting may occur due to insufficient compaction during construction where secondary settlement takes place in the long period (Wibowo, 1989). The fatigue cracking of flexible pavement is due to horizontal tensile strain at the bottom of the asphaltic concrete. Pavement construction has several types; the two broad categories of pavement construction are (i) precast construction and (ii) cast-in-situ construction (Olidis et al. 2010). Cast in place concrete pavements are used for over 20 years and represent an economical solution for the development of rigid pavement which offer adequate support for loads exerted by vehicle(L.P. Priddy, P.G. Bly 2013). Long-term traffic restrictions as a result of intensive and extended lane closures, long curing period needed to achieve sufficient strength and also the inability to put a material in all weather conditions increased pressure on the use of systems with enhanced construction technology (Novak et al. 2017). Such problems would possibly cause delays and consequently increase the cost associated with extended construction time. As a consequence, various precast concrete technology are developed till now and used for the development of technical structures, significantly for the repair and rehabilitation of roads, parking yards and airfield pavements. Precast concrete system are the system that are primarily fabricated or assembled off-site, transported to the project site and placed on a existing foundation (Tayabji, Ye, and Buch 2013). Precast panels may be casted in an exceedingly controlled manner with less demanding environmental constraints which give better standard concreting practices to be followed. Panels created may be reserved and hold on off-site for later use whenever required. Another prevalence is that the utilization of standard Precast Technology with native materials is also additional economical than victimization the expensive proprietary materials for cast-in-place repairs (Bly et al. 2013). Each of those benefits need further exploration to know the installation time necessities and therefore the cost needed to use this repair technology compared to current expedient and permanent repair strategies already used for various types of pavements (L.P. Priddy et al. 2013).

II. DESIGN OF U-SHAPED PRECAST PANEL

The precast concrete panels which are developed till now were more suitable for the repair works of pavement. But, it was found to be more complicate for the new pavement constructions. Thus, there is a need of development of new precast panel that will be preferable for the construction of new pavement and can also be suitable for repair works without any complication related to site.

In precast concrete system, each panel is casted separately and cured in a casting yard. Since, these panels are casted in a supervised environment, higher grade of concrete may be used for the casting of panels. The optimum size of pavement panel should not be more than 4.5 m in order to have a perfect balance between temperature stresses and the thickness of pavements (PPCP).Thus the panel size considered for the analysis is 3.5m x 4.0m. Each panel is having a single lane width of 3.5m as per the clause no. 6.4 of IRC 73:1980. The main aim of our project is to reduce the use of cement in pavement because the cement is harmful to the environment as well as the human. Hence, the thickness of 100 mm is adopted for the panel. The panel is designed as the U-shaped open ended rectangular panel by providing a couple of web at the top end of the panel. This U-shaped concrete panel (USCP) will help up in the strengthening of sub-grade by providing a platform to receive load transferred from the upper most layer of the flexible pavement structure. This panel will perform as a divided between undisturbed soil and the pavement structure above it (USCP).

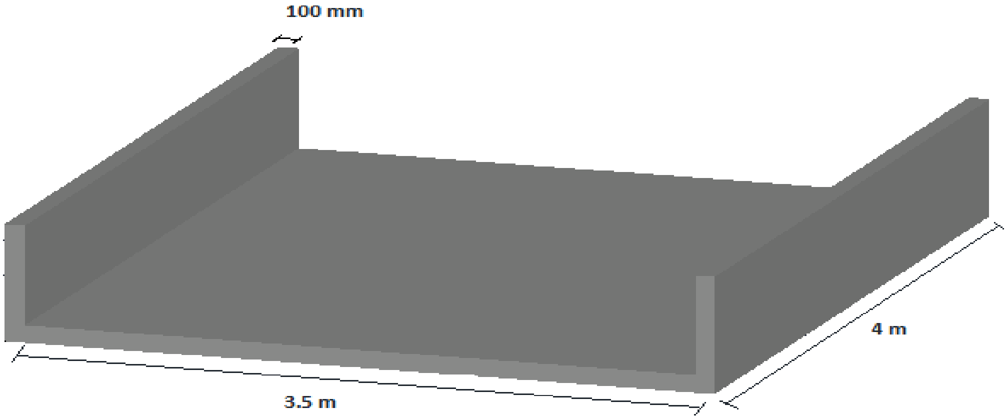

Fig.1. Conceptual U-shaped rectangulat precast panel

III. RESEARCH METHODOLOGY

A. *Calculation of Layer Thickness Reduction by CBR Method*

The CBR method is generally used to design the Flexible pavement i.e. to calculate the total thickness of pavement. In this paper, CBR method recommended by IRC is used, which consists of a chart showing different curves (A, B, C, D, E, F, & G) that are based on different traffic intensities. The curve is selected from classification table after calculating the traffic intensities. The curve is selected from classification table after calculating the traffic intensities.

The CBR value of sub-grade soil gives the total thickness of the pavement (T) with respect to the selected curve. The thickness of sub-base course (tsb) and base course (tb) is calculated by using the CBR values of sub-base and base course resxectively.

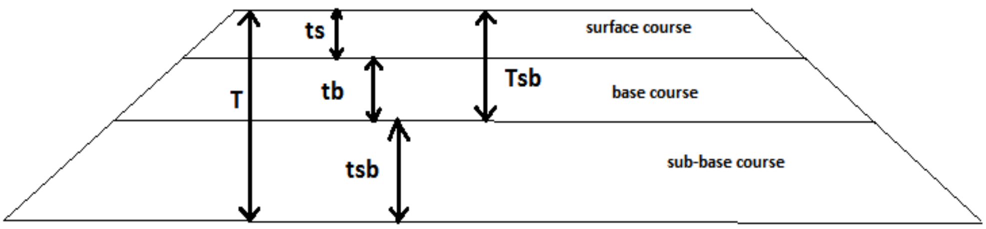

Fig.2. CBR Method

From the chart showing the curves, for the given CBR value of the sub-base and the traffic intensities, the thickness of pavement above the sub-base layer i.e. Tsb is obtained. Then, the thickness of sub-base course can be calculated as tsb = T – Tsb. Similarly, from CBR of the base course, the thickness of pavement above the base course i.e. ts is obtained, Thus, the thickness of base course is calculated as tb = Tsb – ts. Hence, the thicknesses of all the layers of pavements are obtained from the curve of CBR method.

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To find the reduction in the thicknesses of layers by improving the CBR value of sub-grade, the above procedure is followed with different values of CBR taking original CBR of sub-grade as 3%. Considering the 100% improvement in the sub-grade of CBR 3%, then for this improved CBR of 6 %, calculation of layer thicknesses using the same method as above is done. As per IRC 50, the CBR of sub-grade can be improve up to the 45 % by the soil stabilization technique, thus for the improved CBR of 45 %, the calculation of layer thicknesses by the CBR method is done and values obtained are tabulated as shown in the table no. 1.

Table no. 1. Comparison of layer thicknesses with different CBR values

Sr. no.	Description	Thickness of sub-base layer	Thickness of base layer	Thickness of bituminous layer
1.	For Original CBR value of sub-grade i.e. 3 %	400 mm	150 mm	70 mm
2.	After 100 % improvement in original CBR i.e. 6 %	200 mm	150 mm	70 mm
3.	After improvement of CBR by cement stabilization i.e. 45 % as per IRC-50	Total thickness of Pavement = 100 mm		

B. FEM Modeling of Precast panel

In this study, the commercially available finite element software ANSYS is used to develop the model shown in fig. 3 and fig. 4. The model is composed of a U-shaped open ended rectangular precast panel and the three layers of flexible pavement placed on it. The following figures show the respective parameters of the modeling of panel.

In the geometry of pavement, the four different sketches are added to draw the four parts of the model i.e. precast panel and three layers of pavements. All this sketching is done in the XY plane. To make the sketch in the solid form, extrude is done up to the proposed dimension. The extrude is done separately for these four different sketches. The material properties for the various layers of the pavement are assigned as per recommendations of IRC 37:2001. These properties are shown in fig.5.In this analysis, the type of contact between the layers of pavement is assigned as the frictional contact as shown in fig.6.

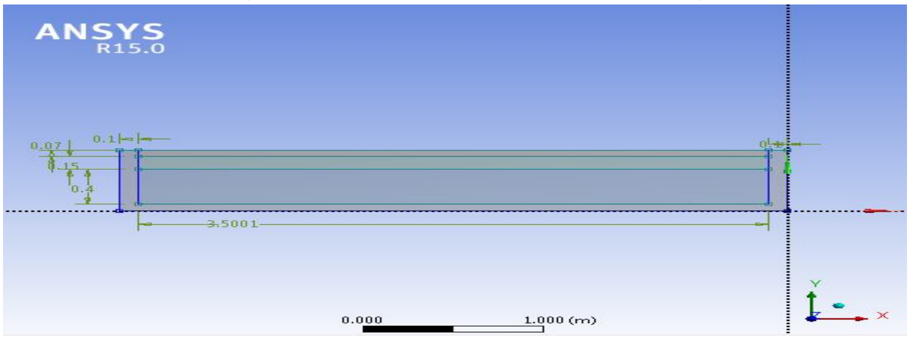

Fig.3. Front view of model

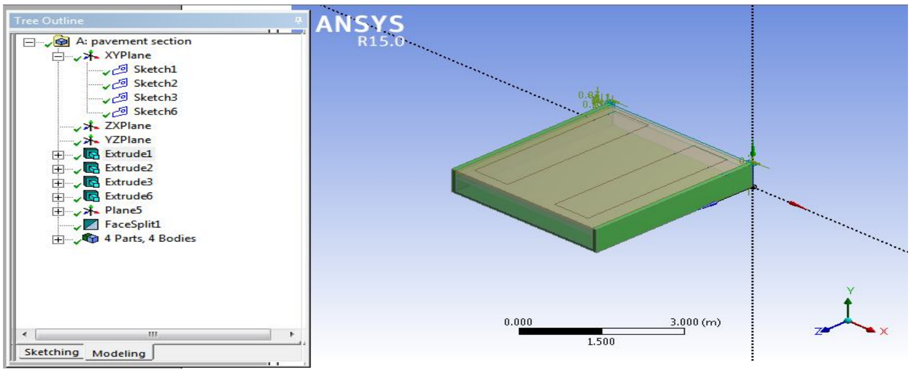

Fig.4. Isometric view of model

Material Data

concrete

TABLE 25
concrete > Constants

Density	2400 kg m^-3

TABLE 26
concrete > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.5e+010	0.15	1.1905e+010	1.087e+010

sub-base -gravel

TABLE 27
sub-base -gravel > Constants

Density	2000 kg m^-3

TABLE 28
sub-base -gravel > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	5.9638e+009	0.35	6.6265e+009	2.2088e+009

base

TABLE 29
base > Constants

Density	1120 kg m^-3

TABLE 30
base > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	5.9638e+009	0.35	6.6265e+009	2.2088e+009

BM

TABLE 31
BM > Constants

Density	1.01 kg m^-3

TABLE 32
BM > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	7.e+008	0.4	1.1667e+009	2.5e+008

Fig.5. Material properties assigned as per IRC 37: 2012

Model (A4) > Connections > Contacts > Contact Regions

Object Name	*Frictional - Solid To Solid*	*Frictional - Solid To Solid*	*Frictional - Solid To Solid*	*Frictional - panel To BM*	*Frictional - base To BM*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	3 Faces	2 Faces	1 Face	2 Faces	1 Face
Target	3 Faces	2 Faces	1 Face	2 Faces	1 Face
Contact Bodies	panel		SUB-BASE	panel	base
Target Bodies	SUB-BASE	base		BM	
Definition					
Type	Frictional				
Friction Coeficient	0.55		0.15	0.3	
Scope Mode	Automatic				

Fig.6. Layer to layer contact details

Model (A4) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	On: Curvature
Relevance Center	Medium
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse

Fig.7. Details of mesh sizing

C. Loads And Boundary Conditions

The wheel load is applied in the form of pressure i.e. 114379.08 Pa on the contact area of wheel i.e. 0.85m x 3.6 m on the topmost layer of the pavement as per the IRC 6:2010. Thus to apply the wheel pressure, the contact area of 0.85m x 3.6 m is get splitted from the top layer of pavement as shown in fig.8. To maintain the fixity of pavement with the existing ground surface, the bottommost layer of the pavement is assigned as the fixed support. The self wt of 9.8066 m/s² is assigned for the whole model.

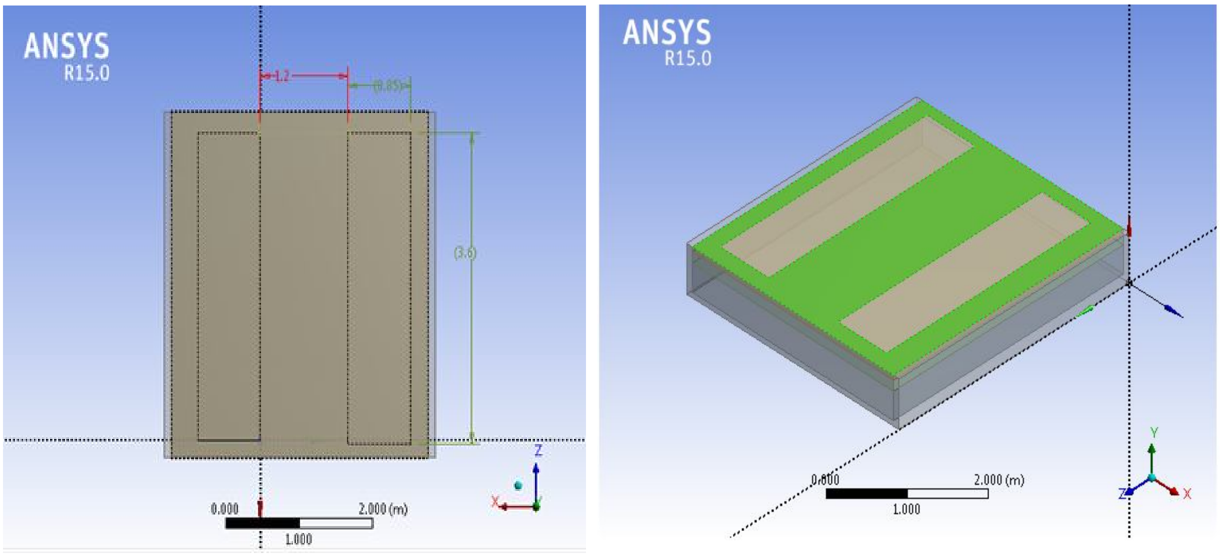

Fig.8. Details of face split

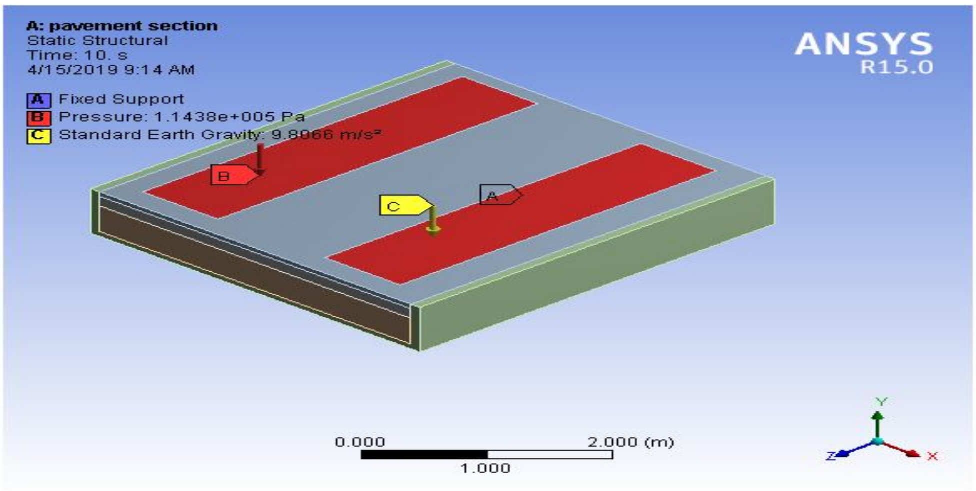

Fig.9. Static structural details

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D. Stress Analysis Of Panel At Centre Line Of Bottommost Layer

To find the equivalent stress values at the bottom most layer of the panel, the stress analysis is carried out for the path. The path is assigned at the centre of the bottom face of the panel as shown in fig.10. The result of equivalent stress obtained is then compared with the equivalent stress values of traditional flexible pavement by plotting the graph between length and stress values. The comparison of graphs is shown in the fig.11.

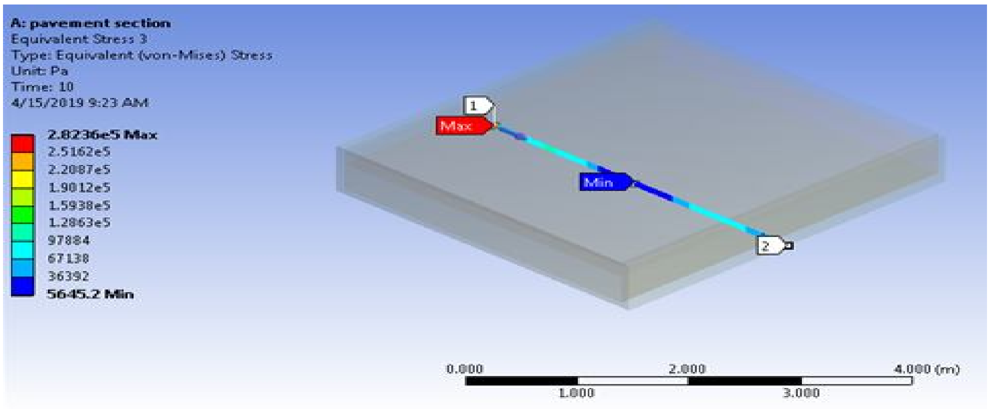

Fig.10. Equivalent stress results

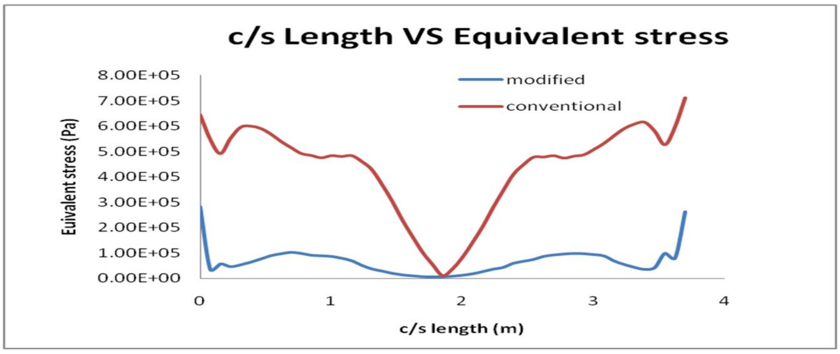

Fig.11. Comparison of the graph

IV. CONCLUSIONS

This paper has demonstrated the following conclusions after the full study:

A. From the literature study done in this project, it is concluded that precast concrete panels were determined to be the most practical type of pavement to apply for the pavement construction. Also, precast panel effectively reduces thickness of the pavement and improves the durability of the pavement, which is particularly important for handling operations.

B. With the proposed dimension and shape adopted while designing U-shaped precast panel, the precast panel improves the CBR value of sub-grade by placing it over the existing the soil.

C. In this project, CBR method is carried out for the different values of CBR of sub-grade. From the result of this method, it is concluded that there is reduction in the total thickness of the pavement as the CBR of sub-grade improves. Hence, from above observation it is concluded that by improving the CBR of sub-grade up to 45%, there is reduction of 17% in the total thickness of pavement.

D. Due to reduction in the total thickness of flexible pavement, material requirements also get reduced which solves the problems of less availability of materials.

E. The stress analysis carried on the pavements with and without using precast panel shows that maximum stress is occurred at wheel contact area of vehicle and the minimum stress is occurred at the centre of the panel.

F. By plotting the results of equivalent stress with respect to the cross-sectional length of panel for the pavement with and without using precast panel, it is concluded that stress get reduced up to 30-40% on the application of precast panel.

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