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Research Paper

EFFECT OF DECK THICKNESS IN RCC T-BEAM BRIDGE

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The increased traffic demand, material ageing, cracking of bridge components, physical damages incurred by concrete, corrosion of reinforcement and inadequate maintenance of bridges necessitate the assessment of bridges periodically for their performances. The accuracy of analytical assessment of bridges depends on the ability of the tool to simulate the problem. The nonlinear analysis is one such tool to simulate the exact material behavior, to evaluate strength in inelastic range and to identify the potential of high load carrying capacity through redistribution, tensile and shear strength. An attempt has been made to perform nonlinear finite element analysis to analyze the component of a selected road bridge. The aim of this dissertation is to study the effects of deck thickness of RCC T-Beam bridge on the properties like Arching action by varying the thickness of the bridge and keeping all the other parameters same. Linear analysis using SAP and nonlinear analysis of the structural element using ANSYS is carried out. Linear analysis is used for the identification of critical component. A single panel of the RCC T-Beam bridge has been chosen for detailed 3D nonlinear analysis. The Solid 65 element is used for modeling the concrete and Beam 188 element is used for modeling the reinforcement. The magnitude of the gravity loads are obtained from the linear analysis. From the present study, it is concluded that decrease in the deck slab thickness by a small value decreases the bending stiffness by about 40% to 50%. Analysis yields deck stresses far in excess of permissible stresses. The cracking propensity increases with decrease in the deck thickness by about 45%.

Keywords: Arching action, Flat dome, Cracks, SAP-2000, Displacements, ANSYS

INTRODUCTION

An important area of research in the field of structural engineering is that of concrete slab behavior. Bridge decks must withstand one of the most damaging types of live load forces—i.e., the concentrated and direct pounding of truck wheels. A primary function of the deck is to distribute these forces in a favorable manner to the support elements below. The ratio of live to total load stresses is high in bridge decks—usually much higher than in most of the other components of the bridge and such fatigue

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producing stresses tend to aggravate any defects that might be present in the deck. Additionally, because of their exposed location, temperature variations are large in bridge decks and restraints to the resulting volume changes tend to cause early cracking of the concrete as well as fatigue producing stresses. In recent years, the understanding of a phenomenon known as “Arching Action” has changed the way designers think of concrete bridge decks. Arching action is the formation of compressive and tensile membrane forces after a slab has undergone flexural cracking. This structural action can be visualized as similar to that found in a very flat dome, in which a compression ring forms in the loaded region and a tension ring forms in the surrounding structure. The principal effect of these membrane forces is to increase the flexural capacity of the cracked slab.

This paper summarizes the “Development of Predictive Model for Bridge Deck Cracking”. Specifically, this paper presents a concise summary of the study performed related to volume changes in concrete, resultant stresses and deflections in bridge decks. Bridge deck cracking has been found to be a serious threat to aging infrastructure. The multi-mechanistic nature of bridge deck cracking and the fact that the mechanisms interact and influence each other makes bridge deck cracking a difficult issue to understand or predict. The current study restricts to analytical method of performance evaluation. In analytical method the accuracy of the result depends upon the ability to simulate the problem. In reality, most of the problems are nonlinear in nature. Hence nonlinear analysis is an effective tool to simulate the exact problem. Nonlinearity may be geometric or material nonlinearity. A structure could encounter either one of the above or combination of both. The material nonlinearity includes nonlinear stress-strain relationship of material and as a result the modulus of elasticity is not a unique value. There are a number of numerical methods available such as fourth order Runge Kutta method, Newton Rapson method, Finite difference method, etc., but all the above are iterative and approximate methods. It involves huge computational efforts and are time consuming. Nowadays we have a number of software packages which are computationally faster and could be used with ease.

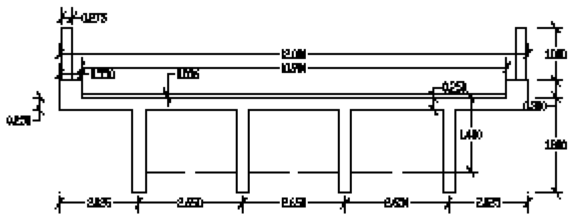
In this study, nonlinear finite element analysis is carried out using ANSYS which employs Newton Rapson technique to solve the higher order differential equation. Karwar bridge, built across river Kali is chosen for the present study. The study is restricted to know the development of the cracking pattern by decreasing the thickness of the bridge deck. The loads are arrived as per IRC 6-2000 standards and the responses are obtained by modeling the bridge superstructure in SAP2000 v-14. The dynamic effects of seismic loading are not considered in the study.

DESCRIPTION OF THE BRIDGE

As per the standard drawing number SD 232, prepared by the Ministry of Surface Transport, Government of India, the data is obtained for the proposed 18 m span T-Beam RCC bridge in Karwar across river Kali. The global method of analysis for T-beam girder bridges involves the analysis and design of the interior deck panel and the exterior cantilever portion. Also it does include the longitudinal and cross girders. Interior deck panels are designed using Peigaud's curves and the cantilever portion by the cantilever moments. Girders can be designed either by Courbon's method.

Of all these methods the Finite Element technique is the most general and comprehensive technique for static and dynamic analysis capturing all the aspects affecting the structural response. In the present study, a T-beam RCC bridge deck is modeled and analyzed in SAP 2000 v14 software which is principally based on Finite Element techniques. The bridge superstructure is 18 m simply supported, cross sectional dimensions of the bridge is as shown in the Figure 1. Materials used are of M30 concrete and Fe 415 steel.

Figure 1: Cross-Sectional Dimensions of Bridge



COMPUTER MODELING

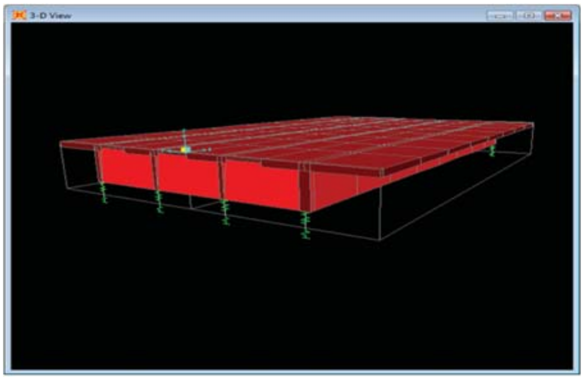
Modeling the complex behavior of reinforced concrete, which is both non homogeneous and anisotropic, is a difficult challenge in the finite element analysis of civil engineering structures. A smeared cracking approach was introduced using isoparametric formulations to represent the cracked concrete as an orthotropic material (Nilson, 1968). In the smeared cracking approach, cracking of the concrete occurs when the principal tensile stress exceeds the ultimate tensile strength. The elastic modulus of the material is then assumed to be zero in the direction parallel to the principal tensile stress direction (Suidan and Schnobrich, 1973).

A smeared cracking idea is employed in ANSYS, where a special three-dimensional eight noded solid isoparametric element, Solid 65 is developed. It models the nonlinear response of brittle materials and is based on a constitutive model for the triaxial behavior of concrete by Williams and Warnke (1975). Solid 65 allows the presence of four different materials within each element; one matrix material (e.g., concrete) and a maximum of three independent reinforcing materials. The concrete material is capable of directional integration point cracking and crushing besides incorporating plastic and creep behavior. The reinforcement (which also incorporates creep and plasticity) has uniaxial stiffness only and is assumed to be smeared throughout the element. In the current study, Solid 65 element available in ANSYS is employed for obtaining the ultimate load carrying capacity and for determining the behavior of deck under service load.

LINEAR ANALYSIS

Before performing the nonlinear analysis of the bridge deck a linear analysis of the entire bridge model is performed using SAP2000 v-14. A 3D model of the entire bridge is created using bridge modeler wizard. The material properties are assigned to the components as concrete and the modulus of elasticity is calculated as per IS-456(2000). The supports are considered as simple supports at both ends. Figure 2 shows the 3D model of the

Figure 2: 3-D View of the Bridge Deck



bridge created using SAP2000.

The linear analysis for dead and live load (gravity loading) has been performed. The moving loads are generated by defining standard vehicles in SAP environment. The live load considered for our analysis is IRC Class A train of vehicles. It is found that the maximum moment is obtained for the factored dead load and live load combination. Responses at the supports are found and the interior deck panel is chosen for a detailed 3-D non linear analysis.

NONLINEAR ANALYSIS

From the responses obtained from the linear analysis performed in SAP 2000 v-14 the detailed non linear analysis is done using ANSYS. Nonlinear analysis (the most advanced form of structural analysis) covers the complete loading process, from the initial "stress-free" state, through the weakly nonlinear behavior under service loading, up to the strongly nonlinear behavior leading to collapse.

Element Description

Solid 65 is used for the 3-D modeling of solids with reinforcing bars (rebar). The solid is capable of cracking in tension and crushing in compression. The solid capability of the element may be used to model the concrete while the rebar capability is available for modeling reinforcement behavior. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. Up to three different rebar specifications may be defined.

The most important aspect of this element is the treatment of nonlinear material properties. The concrete is capable of cracking (in three orthogonal directions), crushing, plastic deformation, and creep. The rebar are capable of tension and compression, but not shear. They are also capable of plastic deformation and creep.

Material Properties

Concrete

For concrete, ANSYS requires input data for material properties as follows: Elastic modulus (Ec), Ultimate uniaxial compressive strength (f'c), Ultimate uniaxial tensile strength (modulus of rupture, fr), Poisson's ratio (v), Shear transfer coefficient (βt) and Compressive uniaxial stress-strain relationship for concrete. M30 grade of concrete has been used for the bridge superstructure; the elastic modulus and cracking strength have been obtained from the expression given as below:

$$E = 5000\sqrt{fck}$$

$$ft = 0.7\sqrt{fck}$$

where, fck is the characteristic compressive strength of concrete. Poisson's ratio of 0.2 has been used. The value of βt ranges from 0.0 to 1.0, with 0.0 representing a smooth crack (complete loss of shear transfer) and 1.0

representing a rough crack (no loss of shear transfer). The value of αt used in many studies of reinforced concrete structures, however, varied between 0.05 and 0.25 (Bangash, 1989; Huyse *et al.,* 1994; Hemmaty, 1998). However studies indicated that the value less than 0.2 give convergence problem. Hence the open shear coefficient of 0.3 and closed shear coefficient of 0.95 indicating good interlocking between the aggregates has been adapted in the present work.

The uniaxial stress-strain relationship for concrete in compression is obtained from the numerical expressions (Desayi and Krishnan, 1964), given in Equations (1) and (2) along with Equation (3) (Gere and Timoshenko, 1997).

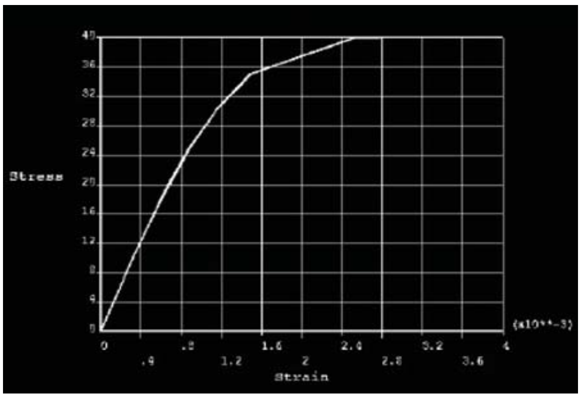
$$f = \frac{E_c \varepsilon}{1 + \left\{ \frac{\varepsilon}{\varepsilon 0} \right\}^2}$$

$$E_c = \frac{f}{\varepsilon}$$

$$\varepsilon 0 = \frac{2fc}{Ec}$$

where, f = stress at any strain ε, ε = strain at stress f, ε0 = strain at the ultimate compressive strength fc. Hence concrete is modeled as multilinear isotropic material with the stress-strain curve as shown in Figure 3 obtained from the above equations.

Figure 3: Stress-Strain Curve for Concrete

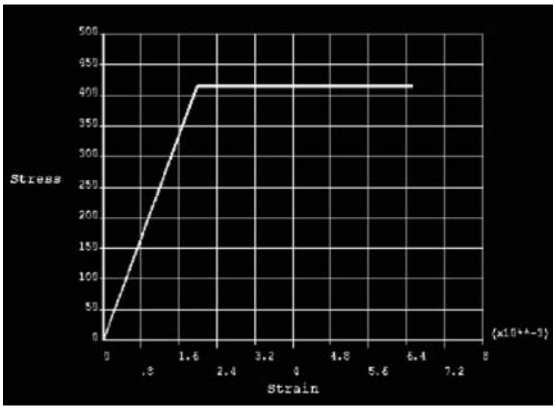


The model is capable of predicting failures in concrete. Both cracking and crushing failure modes are accounted for. The two input strength parameters, i.e., ultimate uniaxial tensile and compressive strengths are needed to define a failure surface for the concrete.

Steel

The steel used is of grade Fe415 with a yield stress of 415 N/mm^2. Steel is modeled as bilinear kinematic hardening material with stress-strain curve as shown below in Figure 4.

Figure 4: Stress-Strain Curve for Steel



Serviceability

The bridge deck should be serviceable under working load without showing excessive deflection or cracking. In order to ensure the serviceability of the bridge a smeared model was developed with one set of real constants in ANSYS representing Concrete modeled as Solid 65 element and main reinforcement and the distribution bars modeled using Beam 188 element. The model is loaded with the vehicle loading that produced critical bending moment in linear analysis and with the impact allowance as per the IRC 6-2000. The bridge deck is modeled with the deck thickness as the only variable and the stresses induced and deflections in the decks with varying thickness is studied. The models also showed the predictive development of the crack patterns in the deck. In this study the bridge deck thickness is reduced from an initial deck thickness of 280 mm to 150 mm. The model with deck thickness of 280 mm along with stress distribution, deflection and the cracking patterns is as shown in the Figures 5, 6, 7 and 8, respectively.

Figure 5: Model of Bridge Deck with 280 mm Deck Thickness

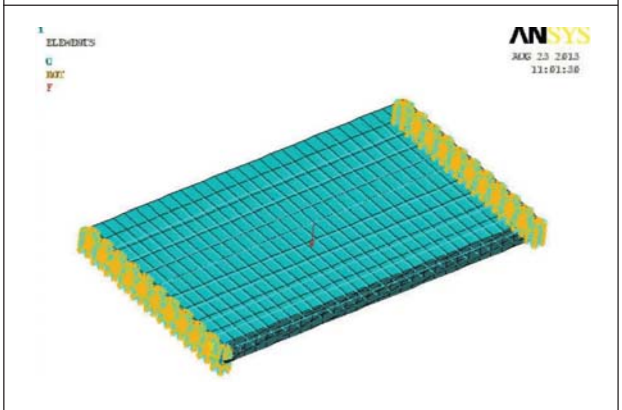


Figure 6: Stress Contour

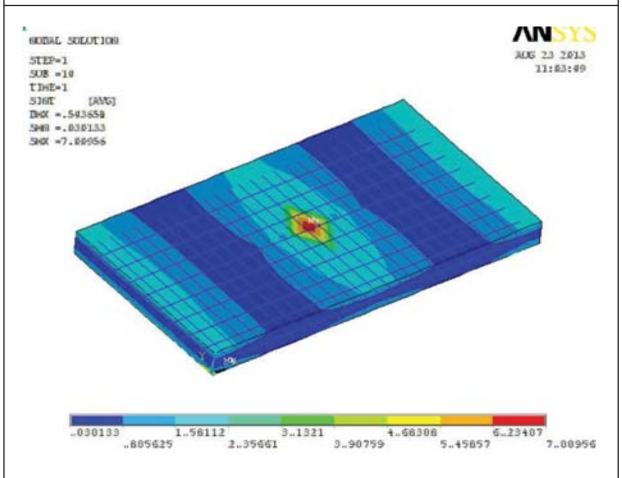


Figure 7: Deflection Contour

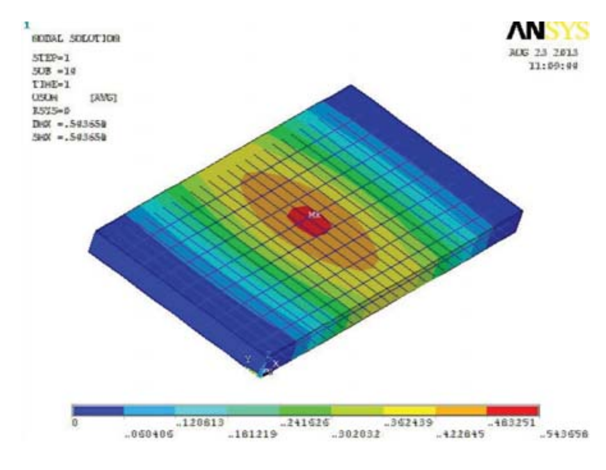
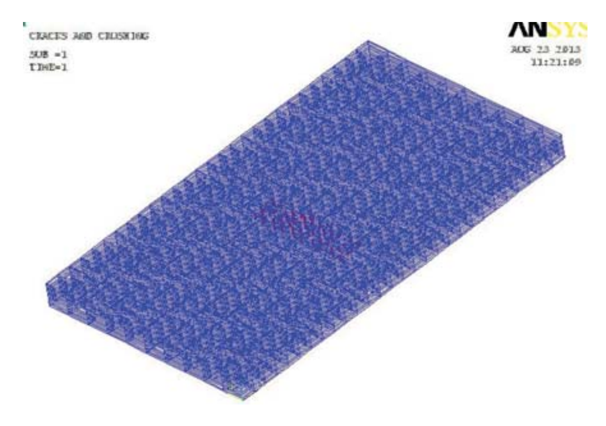


Figure 8: Cracking Pattern Developed Under Service Load



The distribution of cracks is studied and Arching force for different deck thickness is calculated manually, using the equation.

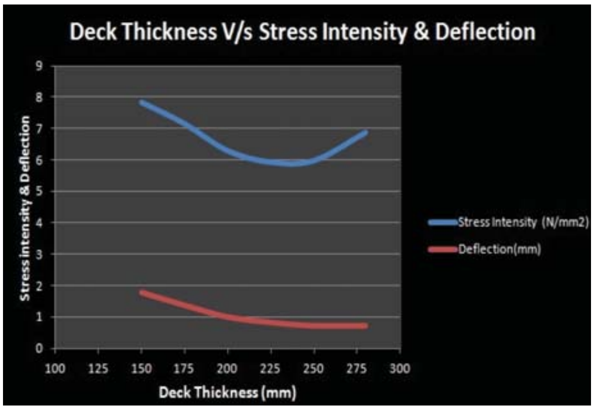
$$F_{arch} = \frac{P}{2}\sqrt{1+\left\{\frac{\left(\frac{S}{2}\right)}{(D-2)}\right\}^2}$$

The results obtained by varying the deck

Table 1: Stress Intensity and Deflections for Different Deck Thicknesses

S. No.	Deck Thickness(mm)	Stress Intensity(N/mm^2)	Deflection(mm)
1	150	7.82	1.77
2	175	7.14	1.37
3	200	6.28	1.006
4	225	5.92	0.837
5	250	5.97	0.735
6	280	6.86	0.734

Figure 9: Deck Thickness V/s Stress Intensity and Deflection



thickness for stress intensity and deflection are presented in Table 1. The graph for the same is presented in Figure 9.

This paper presents an overview of arching action in concrete slabs, when an un-cracked bridge deck undergoes loading, it acts primarily as a one-way system, resisting the load with transverse flexure. In-plane action remains insignificant in bridge decks before flexural cracking. However, once the deck cracks near the point of loading and above the supports, it acts as a at dome. Arching action is the formation of compressive and tensile membrane forces after a slab has undergone flexural cracking. This structural action can be visualized as similar to that found in a very flat dome, in which a compression ring forms in the loaded region and a tension ring forms in the surrounding structure. The principle effect of these membrane forces is to increase the flexural capacity of the cracked slab.

CONCLUSION

The following inferences can be concluded from the present study on the effects of deck thickness in RCC T-beam bridge. For every decrement in deck slab thickness decreases the bending stiffness by about 40% to 50%. The analysis yields the deck stresses far in excess of the permissible stresses. Stresses acting in the deck under truck wheel load are about 55 times greater than the permissible stresses. For every decrement in the deck slab thickness from 280 mm to 150 mm would drastically increase the cracking propensity by about 31% under the wheel load. The uncracked moment of inertia decreases by about 45% for every decrement in the deck slab thickness from 280 mm to 150 mm subjected to IRC Class A truck loading. The Arch force developed in the deck slab decreases by about 0.43% for every decrement in the deck slab thickness.

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