PARAMETRIC STUDY OF PRESTRESSED COMPOSITE BEAM UNDER POSITIVE MOMENT

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Abstract: Cost effective and economical construction are the essential part of the modern construction. Economy in the construction can be achieved by the efficient utilization of the materials. Now a days prestressed composite structures are widely used in the bridges and multi – storey buildings. In the steel – concrete composite structures the compressive strength of the concrete is utilized along with the tensile strength of steel. The major problem in the composite structure is the large deflection due to dead weight, live load, shrinkage and creep of concrete. Prestressing improves the load carrying capacity and deflection limit of the structures. Hence, this technique is adopted for the rehabilitation of existing bridges and buildings. This research work mainly focuses on the parametric study of the prestressed steel – concrete composite beam under positive bending moment. In this paper simply-supported composite beam is considered and prestressing tendon is connected at the bottom flange of the steel section. Further the nonlinear finite element analysis is performed to study the effect of the different parameters on the behavior of the prestressed composite beam. ANSYS16.0 computer software has been used to analyze the three dimensional finite element model. The nonlinear material and geometrical analysis is performed by changing the different parameters. These parameters includes tendon length, prestressing force, steel beam section (NPB400x200 and NPB500x200), concrete grade and thickness to width ratio of the concrete.

Index Terms **- ANSYS16.0, Deflection limit, Finite element model, Prestressing tendon, Steel – concrete composite beam.**

I. INTRODUCTION

Steel – concrete composite beams have been widely used in multi-storey buildings and bridges. Composite beams are subjected to the bending and shear. Concrete is stronger in compression but weak in tension and steel is strong in tension but susceptible to buckling in compression. In composite beam, concrete and steel are connected together with the help of shear connector in such a manner that they act monolithically. In case of simply – supported beam which is subjected to positive moment the compressive stresses at the top fiber and tensile stresses at the bottom fiber are developed and these stresses are resisted by the concrete and steel, respectively. The use of composite beams in the modern construction are very common because of the following advantages. (a) The most effective utilization of steel and concrete is achieved. (b) Higher stiffness is achieved in composite sections compared to corresponding steel sections thus bending stress as well as deflection are lesser. (c) Required depth of the beam for composite section is lesser than steel sections. (d) In composite construction cost of formwork is lower than the RCC construction. The major problem in the composite structure is the large deflection due to dead weight, live load, shrinkage and creep of concrete.

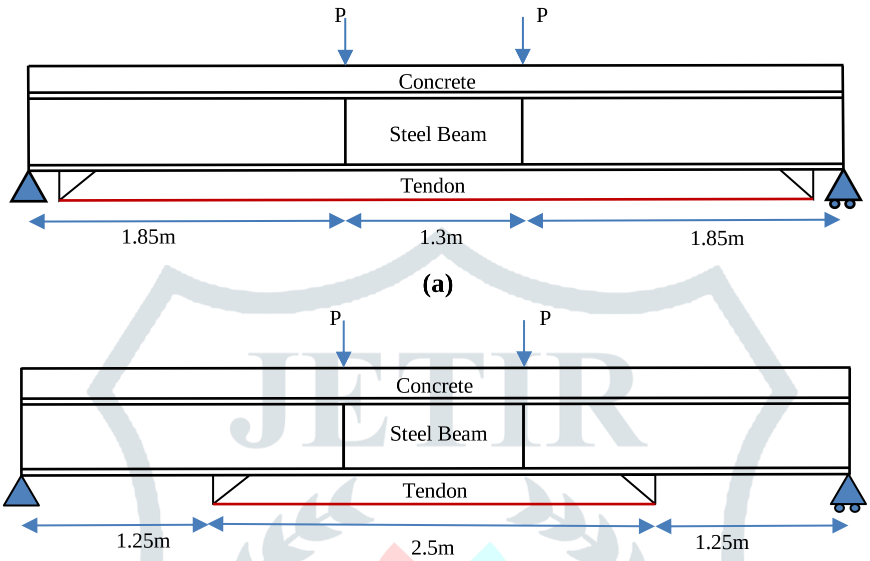
The prestressing technique is one of the most effective solution for the improvement of the deflection limit of the structures. This method is very commonly used for the rehabilitation of the bridges. Basic concept of the prestress is to apply the opposite stress to the structure so that its ultimate carrying capacity can be improved. In the case of simply-supported beam subjected to positive bending moment, the tensile stresses and compressive stress are generated at the bottom and top fiber of the beam, respectively. Hence, initial stresses opposite to the external loading can be created by using the prestressing tendon. These initial stresses will be countered by the stresses developed because of the external loadings. Saadatmanesh, H. et al. (1989) [7] have explained some advantages of the prestressing based on their research on analysis of prestressed composite beam. The prestressing technique can be used. (a) To enlarge the elastic range of behavior. (b) To increase the ultimate capacity. (c) To reduce the structural steel weight. (d) To improve the fatigue and fracture strength. (e) To improve the deflection.

There are many available achievements and research work on the prestressing of composite beam. Ayyub, B. M. et al. (1990) [1] examined the behavior of prestressed composite steel concrete beams under positive bending moment by experiments as well as two different analytical methods. They have also studied the various aspects such as tendon type and tendon profile. The nonlinear analysis of the prestressed composite girder was done by two different analytical methods. It had been concluded that higher ultimate load was achieved for beam prestressing with strands and straight tendon profile is more advantageous than draped profile. Ronghe, G. N. and Gupta, L. M. (1999) [6] had also studied the different tendon profile of the prestress steel girder. The advantages and the analysis procedure for different tendon profile had been explained. The conclusions given by the authors are very much useful to decide the tendon profile for the present study. Korkess, I. N. et al. (2009) [5] had been compared the available experimental results by the nonlinear finite element analysis using ANSYS software. The detailed modeling procedure for composite beam had also been explained by the authors. Saadatmanesh, H. et al. (1989) [8] had given the guidelines for the design of prestressed composite beam by working stress method as well as load factor method.

In the present study, simply-supported composite beam is considered for the analysis and the prestressing tendon is connected at the bottom flange of the steel section. The connection between concrete and steel section is assumed as full shear connection. Full shear connection can be achieved by providing sufficient number of shear connectors by using IS: 11384 (1985) [2]. The prestressing force is applied to neutralize the dead load stresses when the concrete is only placed on the steel beam but composite action is not achieved. Straight tendon profile is considered for the analysis. Further in this study the nonlinear finite element analysis is also performed to study the effect of the different parameters on the behavior of the prestressed composite beam. The nonlinear material and geometrical analysis is performed by using ANSYS 16.0 software. The parameters considered for the study are prestressing force, tendon length, steel beam section i.e. NPB400x200 and NPB500x200, concrete grade and thickness to width ratio of the concrete.

II. Model Description

Simply-supported composite beam of 5m span with two point load has been considered in this study. Parallel flange steel section (NPB400x200 and NPB500x200) with concrete slab at the top of steel beam have been modeled. Parameters such as prestressing force, tendon length, steel beam section, thickness to width ratio of concrete slab and grade of concrete (M30, M40 and M50) have been considered for the comparative study. The connection between the concrete and steel is assumed as full shear connection which is modeled in ANSYS by coupling the coincident nodes of steel top flange and the bottom nodes of the concrete slab. The prestressing forces have been applied in the form of initial strain in the tendon. To study the effect of tendon length two models i.e. tendon connected to full length of the beam and tendon connected in the middle half portion of the beam have been considered which is shown in Fig.1 (a) and (b). The prestressing tendon connected at the bottom of the beam with 100mm eccentricity from bottom flange with the help of stiffener. Three triangular steel plates have been connected with one rectangular steel plate to model the stiffener which connects the tendon to the bottom flange of the beam. Vertical stiffeners are also provided just below the point loads and at the supports to avoid the web buckling.



(b)

Fig.1 Simply-supported prestressed composite beam with two point load

III. Finite Element Analysis

Nonlinear finite element analysis of the simply-supported prestressed composite beam have been performed using ANSYS 16.0 computer software. Number of models are analyzed to study the effects of the parameters on the prestressing composite beam. The material properties required and elements used to model the prestressed composite beam in ANSYS are explained below.

3.1 Material Properties

In the prestressed composite beam two different materials steel and concrete are connected by the shear connectors. And external prestressing tendon is connected at the bottom flange of the steel beam. High tensile strength steel is used to model tendon and E250 grade of steel is used for steel beam. Material properties of the high tensile strength steel are different from the normal steel (E250 grade). Hence three different material properties have been modeled for the numerical analysis. Nonlinear parabolic stress-strain curve for concrete as in IS 1343:2012 [3] is used for the finite element analysis of composite beam. The stress – strain relationship is shown in the Equation 3.1 and Fig.2. The other properties required to model concrete are shown in Table 1.

$$\left.\begin{aligned} \sigma &= f_{ck}\left(2\left(\frac{\epsilon}{0.002}\right)-\left(\frac{\epsilon}{0.002}\right)^2\right) && 0<\epsilon\le 0.002 \\ &= f_{ck} && 0.002<\epsilon\le 0.0035 \end{aligned}\right\} \quad (3.1)$$

Where, σ and ϵ = Stress and strain of the concrete and f_{ck} = Characteristic strength of concrete.

Stress-strain curve for steel beam is assumed as bilinear elastic perfectly plastic curve and multi-linear stress strain curve for prestressing wire as in IS 1343:2012 [3] has been used for the tendon. The stress strain curve for steel beam and tendon are shown in Fig.3 and 4 respectively. Other properties of the steel beam and the tendon are shown in Table 2.

Table 1 Properties of concrete used in the modeling (Ref. Joshuva, N. R. et al. (2014) [4])

Properties	**Concrete**
Grade	M30, M40, M50
Modulus of elasticity	29300, 39000, 48800 MPa
Density	$25\ kN/m^3$
Poison's ratio	0.2
Uniaxial cracking stress	$0.7\sqrt{f_{ck}}$
Open shear transfer coefficient	0.2
Closed shear transfer coefficient	1
Uniaxial crushing stress	-1
Biaxial crushing stress	0

Hydrostatic pressure	0
Hydrostatic biaxial crushing stress	0
Hydrostatic uniaxial crushing stress	0
Tensile crack factor	0.6

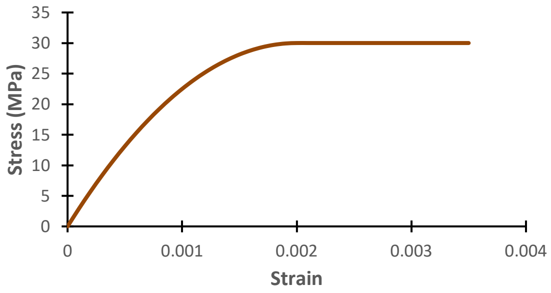


Fig.2 Stress-strain curve of M30 concrete (Ref. IS 1343:2012)

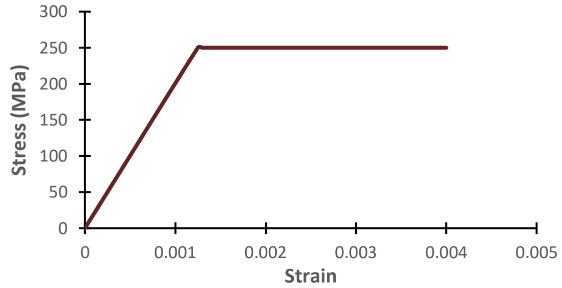


Fig.3 Stress-strain curve of steel beam (E250)

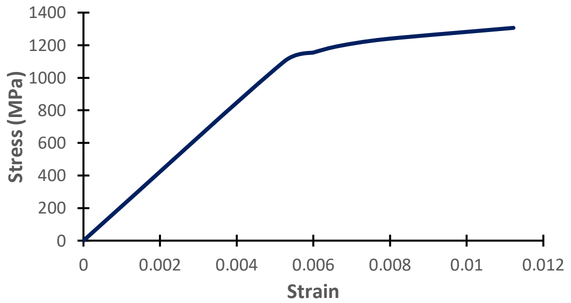


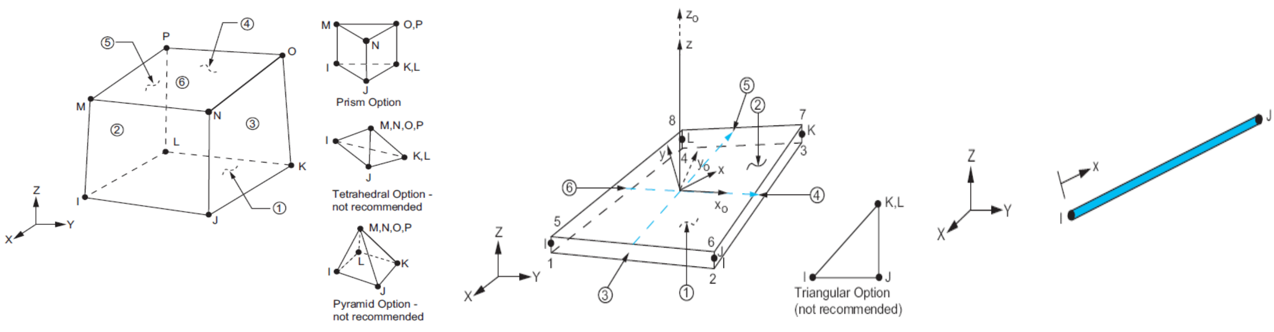
Fig.4 Stress-strain curve of steel wire (Ref. IS 1343:2012)

Table 2 Properties of steel beam and tendon

Properties	**Steel Beam**	**Tendon**
Yield Strength (f_y)	250 MPa	1375 MPa
Modulus of elasticity (E)	200 GPa	210 GPa
Poison's ratio (μ)	0.3	0.3
Cross Section	NPB400x200 and NPB500x200	200.96 mm^2

3.2 Element Details

ANSYS16.0 had been used for the finite element analysis. To model the prestressed composite beam SHELL181, SOLID65, and LINK180 elements were used for the steel beam, concrete slab and prestressing tendon, respectively. The details of the elements are shown in the Fig.5. SOLID 65 can be used for the 3-D modeling of solids with or without reinforcing bars (rebar). The solid is capable of cracking in tension and crushing in compression. In concrete applications, for example, the solid capability of the element may be used to model the concrete while the rebar capability is available for modeling reinforcement behavior. These properties of the SOLID65 are suitable for the concrete. SHELL181 is suitable for analysing thin to moderately-thick shell structures. It is a four-node element with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes. The properties required for the tendon are very much similar to the properties of LINK180 element. LINK180 is a 3-D spar that is useful in a variety of engineering applications. This element can be used to model trusses, sagging cables, links, springs, and so on. This element is a uniaxial tension-compression element with three degrees of freedom at each node: translations in the nodal x, y, and z directions. Tension-only (cable) and compression-only (gap) options are supported. In the present study tension only property is used for the prestressing tendon. The assumption had been made that there is a full shear connection between concrete slab and steel beam. Hence, the connection between the steel beam and concrete slab had been modeled by using the coupling of coincident nodes. Coupling of nodes means it does not allow the relative motion between two nodes.



(a) SOLID65 element for concrete (b) SHELL181 element for steel beam (c) LINK180 element for tendon

Fig.5 Different elements used to model prestressed composite beam (Ref. ANSYS user manual)

IV. RESULTS AND DISCUSSION

The main objective of this paper is to study the effects of different parameters such as prestressing force, tendon length, steel beam section, grade of concrete and thickness to width ratio of the concrete slab. The finite element models had been analyzed using ANSYS computer software by changing the above parameters. The results obtained are shown in the form of load versus mid span deflection curves and it is discussed below.

4.1 Effect of Prestressing

The prestressing force had been applied in the form of initial strain in tendon. To study the effect of prestressing four different models non-prestressed composite beam, composite beam with tendon without initial strain, composite beam with initial strain 0.002 and 0.0055 had been considered. After the analysis the load versus mid span deflection curves had been plotted which is shown in the Fig.6. It is observed that curves are linear up to the yielding of bottom flange of the steel beam after that large deformation occurs with small increase in the loading. The results shows that adding the prestressing tendon significantly increases the yield load as well as ultimate load and it continuously increases with increase in the prestressing forces. The load deflection curves also illustrates that the deformation of the prestressed composite beam is lesser than the non-prestressed composite beam. The tangents of the curves for composite beam with tendon and the prestressed composite beam are slightly greater than the non-prestressed composite beam before the yielding of the bottom flange of steel beam. The reason should be the incremental prestressing in tendon which is small but develops linearly with increment in loading. It is noted that 10.55% increase in the ultimate load is achieved when tendon connected. Further when 0.002 and 0.0055 initial strain are applied 16.94% and 21.59% increase in ultimate load is achieved, respectively.

4.2 Effect of Tendon Length

In this section the effect of the tendon length on the load deflection behavior of the prestressed composite beam were studied. For that two different models were considered. In the first model tendon was connected to full length of the beam and in second model tendon was connected only in the middle half portion of the beam. The analysis results are shown in the Fig.7. From the load deflection curves it is observed that before the yield load first model deforms lesser than the second model. After the yielding of the bottom flange the behavior of both the beams are similar. In both the cases significant increase in yield and ultimate load is observed. The increment of 12.19% in yield load and 21.59% in ultimate load are noted for first model. In case of the second model the increment of 15.04% in yield load and 21.89% in ultimate load are observed.

4.3 Effect of Different Steel Beam

Parallel flange section (NPB400x200 and NPB500x200) had been considered to study the effect of different steel beam section on the behavior of prestressed composite beam. The stiffness of the beam depends on the cross sectional properties. Hence stiffness can be increased by using the higher depth steel section. The overall stiffness of the prestressed composite beam with NPB500x200 is very high compare to NPB400x200. Analysis was performed and the load deflection curve for both cases are plotted (shown in Fig.8) and the same results i.e. the increase in the stiffness is observed also from the load deflection curves. The maximum deflections had been decreased and yield and ultimate load had been significantly increased in case of NPB500x200 because of the higher stiffness.

4.4 Effect of Grade of Concrete

To study the effect of concrete compressive strength of the concrete slab on the behavior of prestressed composite steel-concrete beam, M30, M40 and M50 grades of concrete were considered. Fig.9 shows the effect of compressive strength of concrete slab on the load-deflection behavior of the prestressed composite beam. The Fig.9 indicates that the stiffness of beam increases slightly with the increase in the compressive strength. Also it is seen that the maximum predicated deflection increases as the concrete compressive strength is increased.

4.5 Effect of Thickness to Width Ratio of Concrete Slab

In this section effect of thickness to width ratio (t/B) of the concrete slab on the load deflection behavior of the prestressed composite beam had been studied. Three different thickness to width ratio (0.064, 0.1, 0.156) had been considered by making the concrete slab area constant i.e. 100000 mm^2. Fig.10 shows the load against mid span deflection curves for the different models with different (t/B) ratios. From the Fig.10 it can be seen that as the (t/B) ratio increases the stiffness of the beam also increases. Hence the loading capacity increases for the particular deflection value. Improvement in the yield and ultimate load is observed for the higher (t/B) ratio and the maximum predicted deflection increases significantly as the (t/B) ratio increases.

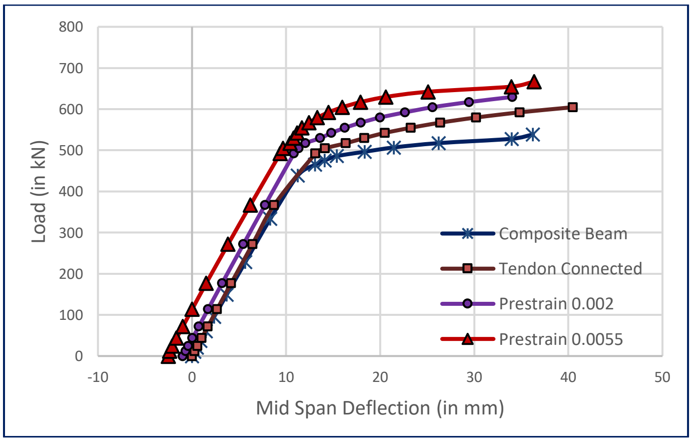


Fig.6 Effect of prestress on load deflection behavior of prestressed composite beam

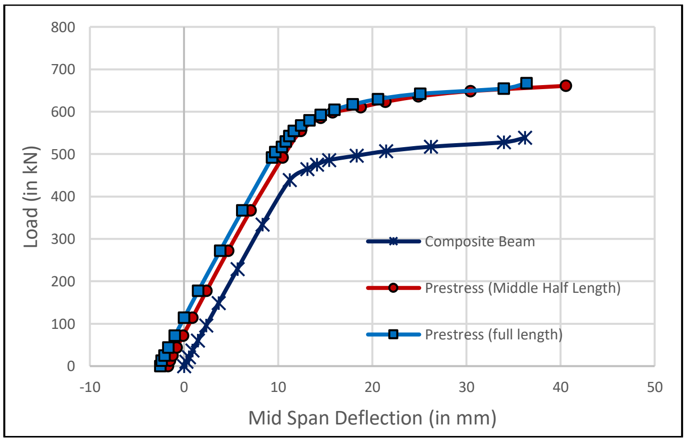


Fig.7 Effect of tendon length on load deflection behavior of prestressed composite beam

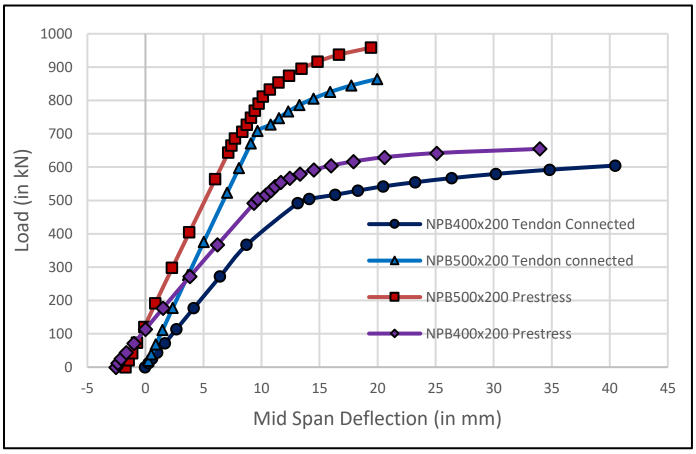


Fig.8 Effect of steel beam on load deflection behavior of prestressed composite beam

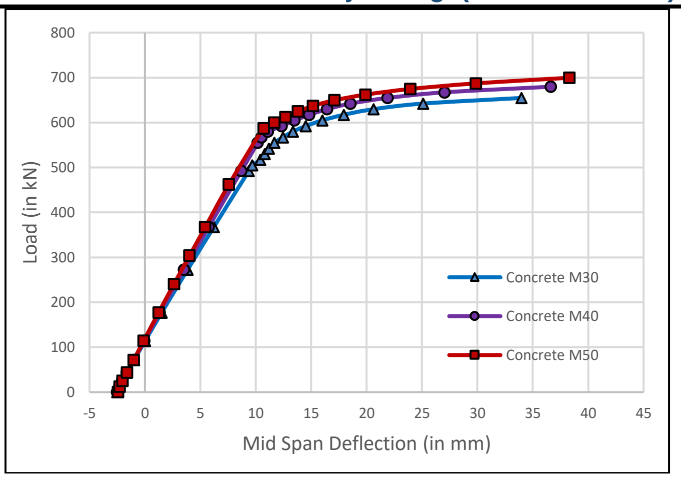


Fig.9 Effect of grade of concrete on load deflection behavior of prestressed composite beam

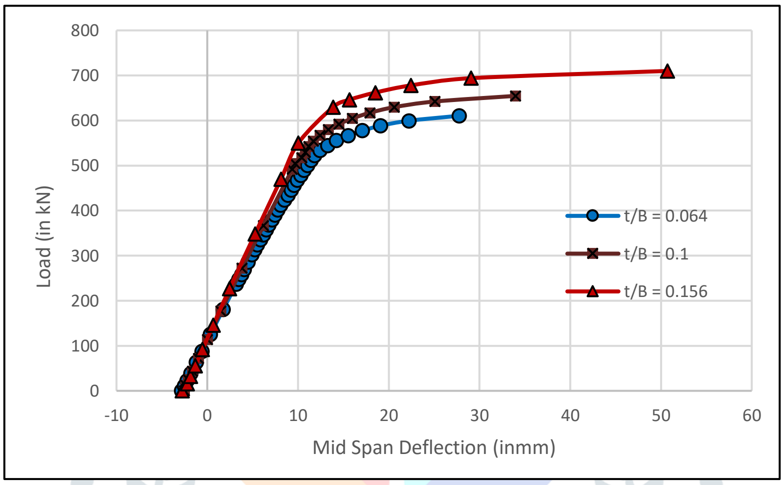


Fig.10 Effect of thickness to width ratio (t/B) of concrete slab on load deflection behavior of prestressed composite beam

V. CONCLUSIONS

The behavior of the prestressed composite beam depends on the various parameters. Parametric study had been performed by finite element method using ANSYS 16.0 computer software. Five different parameters i.e. prestressing force, tendon length, depth of steel beam, grade of concrete and thickness to width ratio of the concrete slab had been selected for the present study. Results obtained from the analysis are explained in the previous section. From those results the following conclusions can be drawn:

1. From the finite element analysis carried out to study the effect of prestressing, it was observed that the deformation is lesser in prestressed composite beam compare to non-prestressed composite beam. It was also noted that 10.55% increase in the ultimate load is achieved when tendon connected. Further when 0.002 and 0.0055 initial strain are applied 16.94% and 21.59% increase in ultimate load is achieved, respectively. Hence, the advantages of the prestressing explained above are verified.
2. When the effect of tendon length on prestressed composite beam was studied it was found that percentage increase in yield load is higher when tendon connected to full length of the beam. It was also observed that after the yield point the behavior of both models i.e. tendon connected full length and tendon connected middle half-length are similar. The increment of 12.19% in yield load and 21.59% in ultimate load are noted for first model and the increment of 15.04% in yield load and 21.89% in ultimate load are noted for second model. There is only 2.85% difference in the yield load increment and 0.3% difference in the ultimate load increment.
3. The stiffness of composite beam with NPB500x200 is very high compare to composite beam with NPB400x200 since the cross sectional properties of NPB500x200 are larger than the NPB400x200. Hence 46.39% higher ultimate load is achieved in case of prestressed composite beam with NPB500x200. The maximum mid span deflection is decreased from 33.97 mm to 19.44 mm.
4. From the numerical analysis carried out to study the effect of compressive strength of concrete on the strength behavior, it was found that as the compressive strength of concrete is increased from 30 N/mm^2 to 50 N/mm^2 the ultimate load is increased by about 6.86%.
5. The strength of composite beams are increased by increasing the ratio of the thickness to width of concrete slab (t/B), with keeping the total area of concrete slab constant. It was found that as the (t/B) ratio is increased from 0.064 to 0.156 the ultimate load increases by about 16.29%.

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