



Nonlinear and Experimental modelling of

Prestressed SCC Bridge girders

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ABSTRACT

To achieve acceptance for use self consolidating concrete, SCC in prestressed concrete bridge girders, this study was conducted on T-beams fully prestressed SCC of 9m length. The girders were designed based on the Iranian bridge code of practice. Different types of electrical gauges were attached on the steel, prestressed strands and concrete surface at different sections. In the numerical study, 3-D ANSYS modelling was performed. The load-deflection and load strain diagrams for transfer and service conditions of two methods were plotted for different sections. The comparison of experimental and numerical results is performed and a very good agreement is available.

Keywords: Prestressed Concrete, Bridge, Self-consolidating-concrete, Finite Element, ANSYS.

INTRODUCTION

Concrete structural components require the understanding into the responses of those components to a variety of loading. There are a number of methods for modeling the concrete structures through both analytical and numerical approaches. Finite element analysis (FEA) is a numerical one widely applied to the concrete structures based on the use of the nonlinear behavior of materials. FEA provides a tool that can simulate and predict the responses of reinforced and prestressed concrete members. The use of FEA has increased because of progressing knowledge and capability of computer package and hardware. Any attempts for engineering analyses can be done conveniently and fast using such versatile FEA packages.

Self compacting concrete, SCC is a new type of concrete, which has generated tremendous interest since initial development in Japan by Okamura [1] in the 1980s in order to reach durable concrete structures. Since that time, Japanese contractors have used SCC in different applications. In contrast with the Japan research in Europe and American started latter [2]. The advantageous of SCC offers many benefits to the construction practice; the elimination of the compaction work results in reduced costs of placement, equipment needed on construction time and improved quality control.

With the rapid development of concrete technology in recent decats to enhanced durability of conventional concrete, the high strength concrete, HSC can be produced much more easily than before. However, considering SCC, reaching high strength self consolidating concrete, HSSCC is a new type of concrete introduced in more recent years preferred. HSSCC is less liable to shrinkage crack, has a higher modulus of elasticity and a reduced creep strain [3], resulting in smaller losses in the initial prestress. Thus the major emphasis of the present study was to determine flexural strength of high strength SCC prestressed bridge girders.

For modeling purpose, the prestressing wires (with initial pre-strain), ordinary reinforced steel and stirrups were been modeled as truss element. Tension stiffening and bond slip between concrete and reinforcement steel (prestressing wire, and rebar) were considered in the model by drawing truss element between concrete meshing. The main obstacle to finite element analysis of reinforced concrete structures is the difficulty in characterizing the material properties. Much effort has been spent in search of a realistic model predict the behavior of reinforced concrete structures [4].

By applying HSSCC in prestressed elements, it is possible to reduce the total amount of prestress losses. The theoretical and experimental research is required to understand the effect of concrete strength on SCC High-strength concrete is preferred in prestressed concrete members, as the material offers high resistance in compression. In the anchorage zone the bearing stresses being higher, high strength concrete is invariably [5].

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This report evaluates the experimental results of prestressed T-bridge girders using SCC reported by [6, 7], with the numerical non linear modeling of F.E. Also, the results are compared theoretically by the available British standard, B.S [8].

EXPERIMENTAL PROGERAM

The T-girders were cast at laboratory selected from base beam of T- bridges' deck ($L=900\text{cm}$, $b_f=53.5\text{cm}$, $b_w=19.5\text{cm}$, $t_f=12\text{cm}$, $h=71\text{cm}$) with HSSCC (cubic compressive strength more than 500 kg/cm^2). Each beam was reinforced longitudinally by two types of steel bars (ordinary bars and prestressing strands) for tension and only ordinary steel bars for compression along, with 10-mm-diameter bars at spacing of 90 mm for shear reinforcement, eight 11mm tendons, each composed of $7*3.5\text{mm}$ diameter wires were used to prestress each beams, each load bearing was about 11 ton. The loading arrangement and sections of beams that show dimensions, steel bars, strands and shear reinforcement, is illustrated in (Figures 1, 2).

Beams were loaded in four-point bending to failure with a clear span of 8.7m, and one loading point was located at 140cm on left side of the mid-span location and another load point was located at mid span of the beam. Fig. 1 shows the locations of load points and the location of measuring sensors including strain gauges and linear variable differential transducers (LVDT). Exact equipment was used on prestressed strands, ordinary bars and concrete to obtain strain before and after loading, Electrical resistance disposable strain gauges, manufactured by TML measurements group (Japan), was pasted on the internal reinforced bars and wire and concrete surface at different locations. The demec and electrical gauges were also attached along the height of beams to measure the concrete strains. The load was applied step-by-step (with notation to critical mode by influence line theory under 40ton track load according to the Iranian bridge code of practice [9]) to service load in a load control manner of test beams. Load-deflection and load-strain curves are illustrated in reference [7] as experimental results.



Figure 1- Loading arrangement and position of gauges on beam[7]

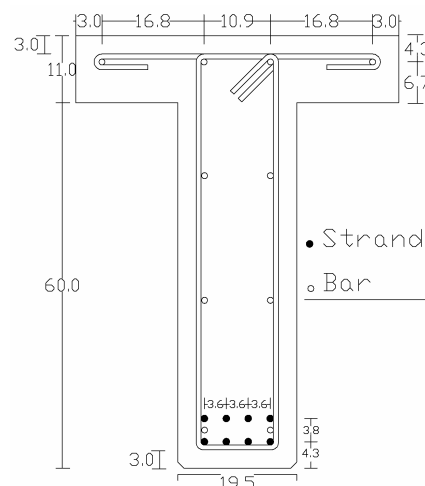
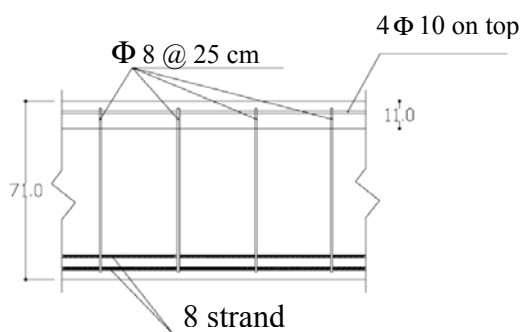


Figure 2- T girder sections[6].

NONLINEAR MATERIALS BEHAVIOR

Nonlinear elastic behaviors of concrete can be defined by the multi-linear stress-strain relationships. The modulus of elasticity of concrete (E_c) can be calculated based on ACI [10] as given by $0.135w^{1.5}\sqrt{f_c'}$ and considering the tensile strength of concrete as $1.78\sqrt{f_c'}$. In this study, the multi-linear isotropic stress-strain for concrete was introduced and defined by results of experimental compressive test as shown in Figure 3. The value of f_c' equal to 55 Mpa and Poisson's ratio was assumed to be 0.3. For prestressing wire, the bi-linear elasto-plastic material models were used as well as the multi-linear isotropic model from the manufacturer's data and laboratorial tensile test, shown in Figure 4. The modulus of elasticity of prestressing wire is $1.99 \times 10^6 \text{ kg/cm}^2$. Here, the stress-strain curve for steel reinforcement used in concrete beams was obtained from steel bars tested in tension

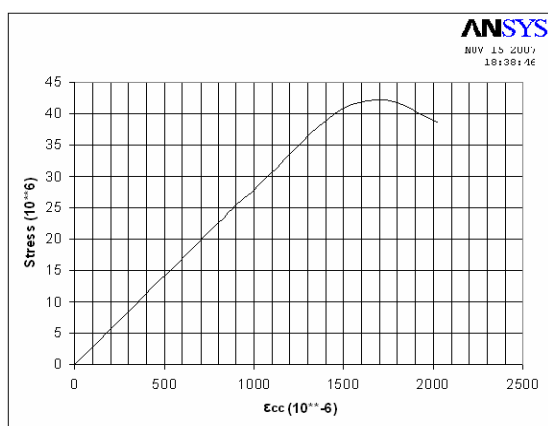


Figure 3- Stress-strain diagram for concrete core

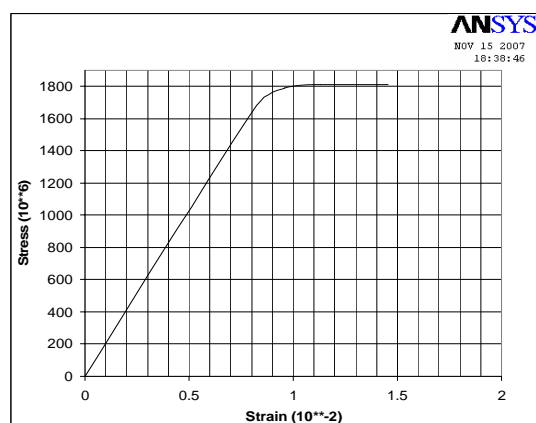


Figure 4- Stress-strain diagram for prestressed wire

FINITE ELEMENT MODELLING

The three dimensional model of prestressed SCC T-girders was developed by using ANSYS software [11] and the model is illustrated in (Figures 5-7). The SCC was modeled using a three-dimensional solid element, SOLID65, which has the material model to predict the failure of brittle elements. SOLID65 is defined with eight nodes, each with three degrees of freedom: translation in nodal x, y and z directions. This element is capable of cracking in tension and crushing in compression. Plastic large deformation and creep can also be captured. To simulate the behaviors of prestressing wire and ordinary rebar, a truss element, LINK8, were used to withstand the initial strain attributed to prestressing force, by assuming perfect bond between these elements and concrete. The bond between concrete and rebars is important at all concrete structures specially for prestressed concrete, because tensile cable's force had to transfer to concrete, thus rebars element was modeled between concrete



elements, so they are joint at nodes. According to this, meshing of concrete lead to position of rebars and wires. In addition, at joint point don't reduce rebars from concrete volume. Meshing is one of the most important issues in modeling, since the accuracy of the results largely depends on it. Finer mesh means better accuracy, but it should be kept in mind that in order to accelerate the solution the number of elements used should be reasonable. Link8 requires users to input 'real constant' to define reinforcement geometry as area of rebars and wires, material behavior and prestressing strain. According to tensile force in wires and after first (instantaneous) losses primitive strain equal to 0.00576 m/m allocated to wires. This element cannot resist neither bending moments nor shear forces [12]. Because software cannot accept two elements between two nodes, use different element with twice area. For best distribution of load, loading was considered superficial on elements, this surface selected to show loading is like point loading (Figure6). To harmonious with experimental model accurate boundary conditions is prescribed in the model along the relate nodes as shown in (Figure 7).

There were three steps towards service load. First, no load was applied since the initial strain was defined, and cause to uphill deflection on beam. Second, the self-weight was added in a load step, which is done by applying gravitational acceleration of 9.81 m/s^2 in the negative global Y direction. The typical mass density of concrete, 2400 kg/m^3 as entered in as a function of the gravitational acceleration. The last step was defined as external loading.

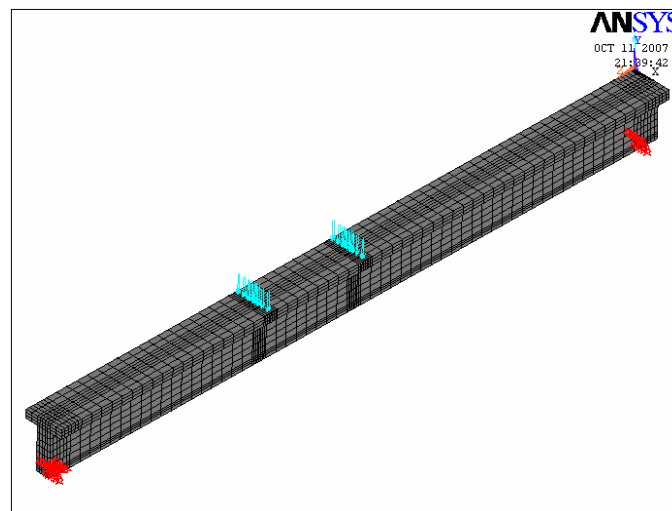


Figure 5- Three-dimensional full-scale model

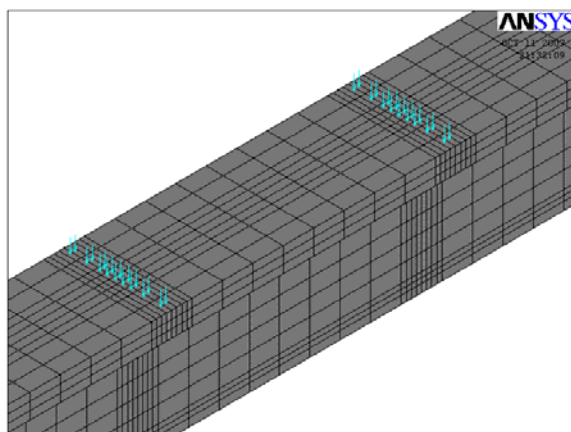


Figure 6- External loading (on mid-span and 140 cm away towards left)

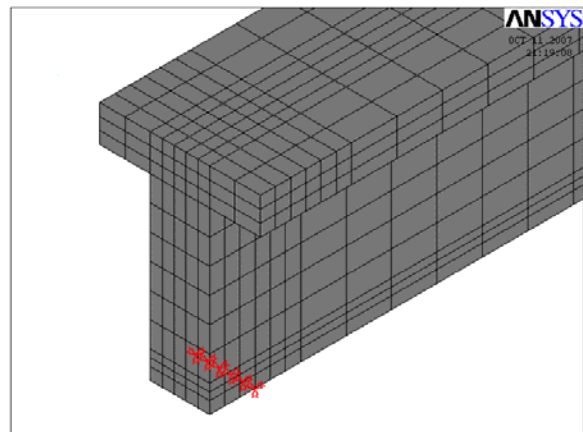


Figure 7- Boundary conditions



NUMERICAL RESULTS

The numerical analysis of T-bridges girders at transfer of prestressing force is performed and the result is presented in Figure 8. The effect of member self weight is very low as compared with prestressing force result.

The Comparing of F.E analysis and experimental values of load-deflection, strain in wires, rebars and concrete and crack interface were performed and the results are shown in Figures 9-20. The calculated service load was 14 ton however, the LVDTs reading indicated that when the load reached 15.4 ton, the deflection get zero. By comparison of the experimental and numerical results, it was found that using F.E.M results in order to estimate the behavior of prestressed self-consolidating reinforced concrete beams are reliable. It is reminded that the experimental results reported by [7], are based on the value of load cell readings however, in this paper the weights of beam and spreader beam are also considered.

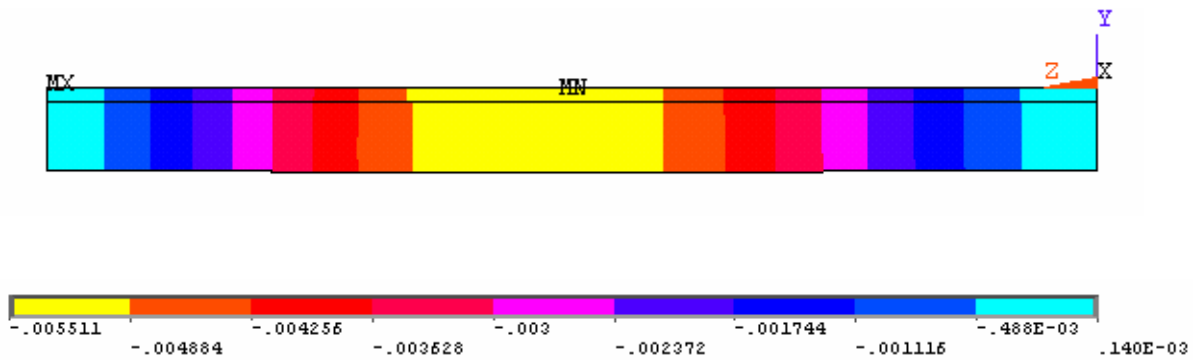


Figure 8- Zero deflection after external loading.

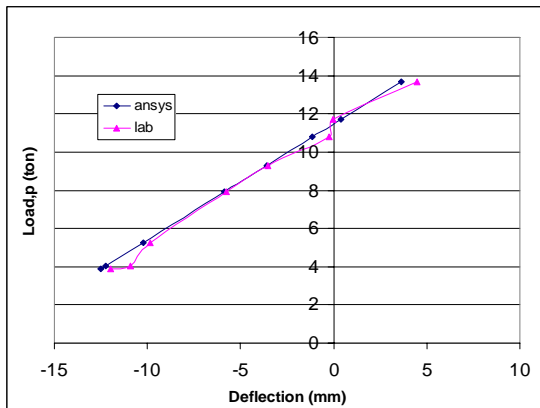


Figure 9- Load-deflection at midspan (B1)

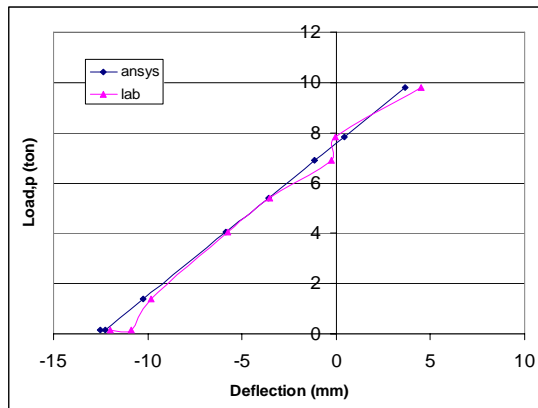


Figure 10- Load-deflection at midspan (B1)

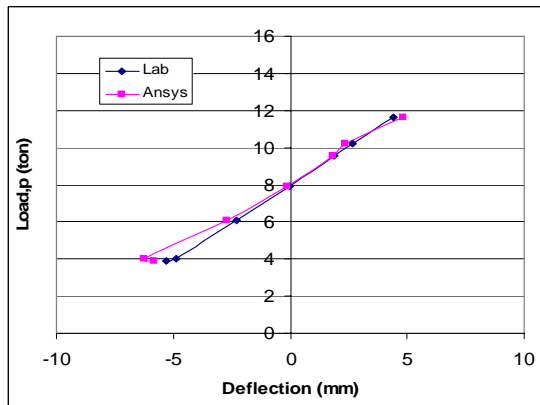


Figure 11- Load-deflection at midspan (B2)

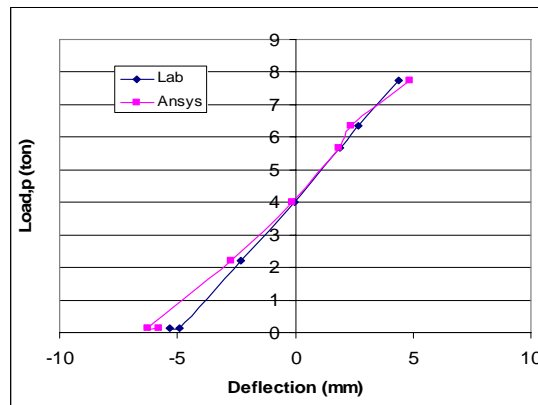


Figure 12- Load-deflection at midspan (B2)

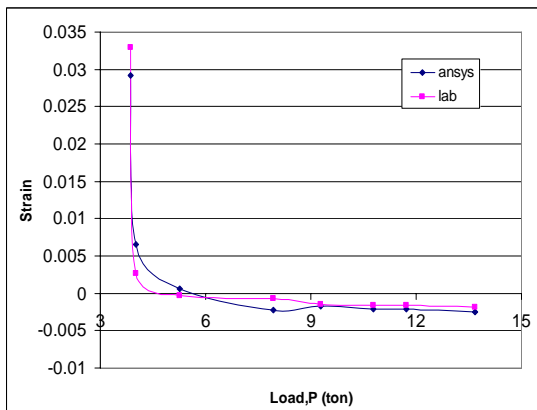


Figure 13- Load-top concrete strain (B1)

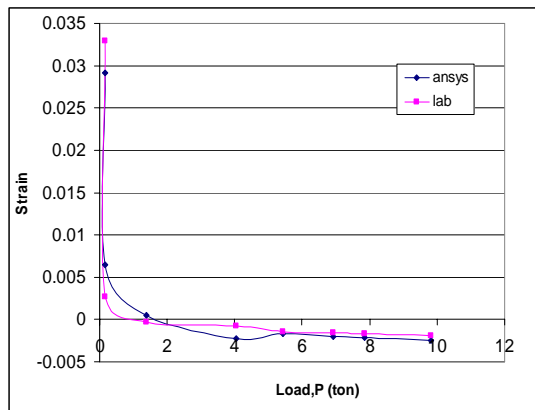


Figure 14- Load-top concrete strain (B1)

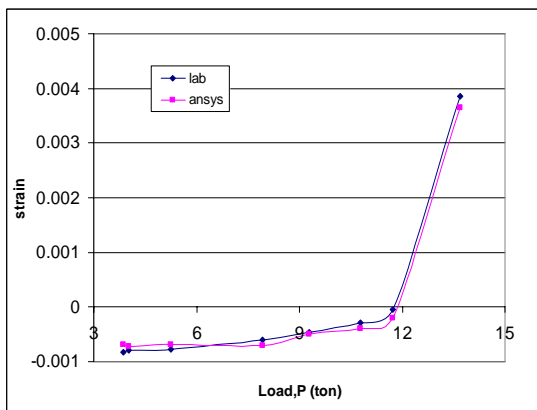


Figure 15- Load-Bottom concrete strain (B1)

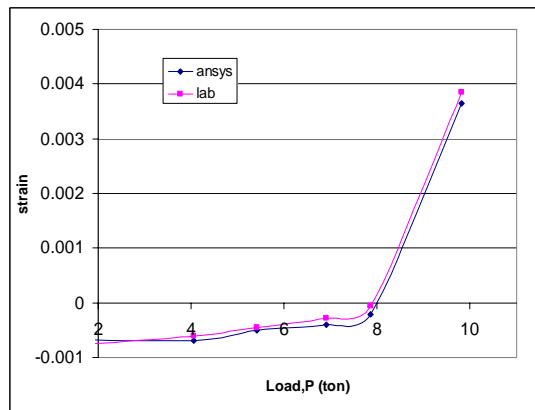


Figure 16- Load-Bottom concrete strain (B1)

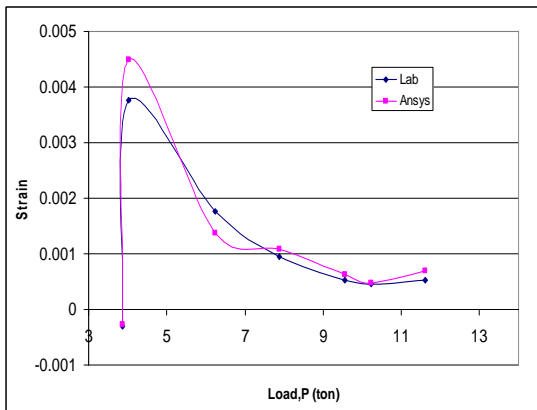


Figure 17- Load- top concrete strain (B2)

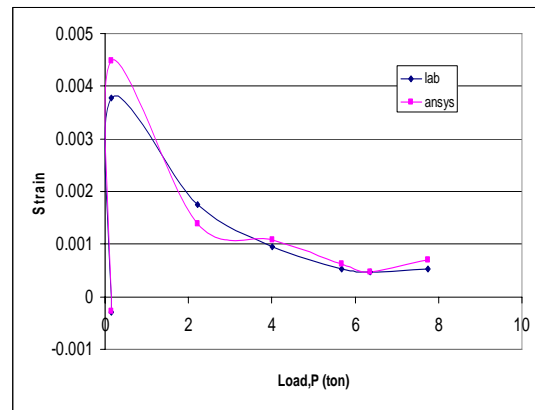


Figure 18- Load- top concrete strain (B2)

The above right hand side curves are based on applied load at 140 cm away towards the left and the left hand side curves are based on applied load at mid point of prestressed beam. The curves show that, loads at mid point are of higher values which are due to the weights of beam and spreader beam.

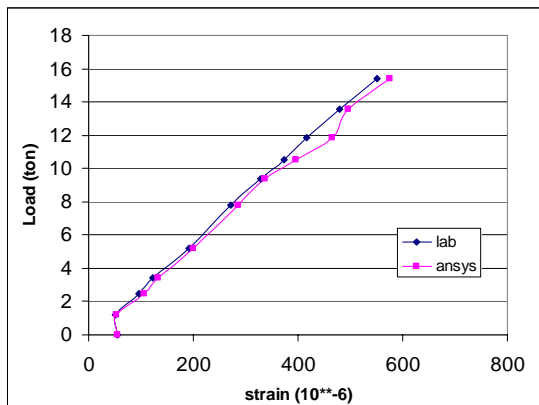


Figure 19- Load-wire strain at midspan(B1)

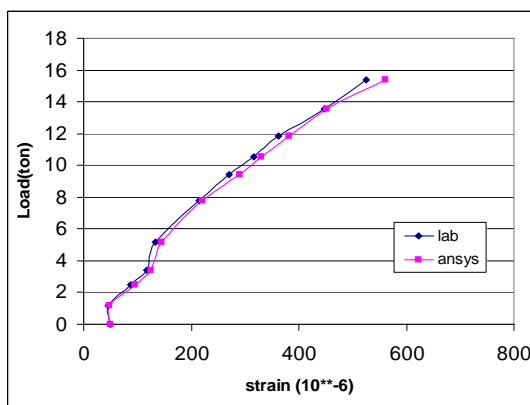


Figure 20- Load-wire strain at 1.4 from midspan (B1)

Table 1-comparison of Experimental and Numerical deflection results

Beam No.	Experimental results (cm)		Numerical Results (cm)	
	Δ at transfer	Δ at service	Δ at transfer	Δ at service
B1	-1.20	+0.27	-1.25	+0.32
B2	-0.53	+0.439	-0.58	+0.483

The negative sign show upward and the positive sign show downward deflection.

Table 2- comparison of Experimental and Numerical concrete compressive strain at transfer and service load

Beam No.	Experimental results		Numerical Results	
	ε _{cc} at transfer	ε _{cc} at service	ε _{cc} at transfer	ε _{cc} at service
B1	0.03289	-0.001630	2.92E-02	-2.16E-03
B2	0.003768	-0.000528	2.52E-03	-4.52E-04

BEAMS DEFLECTION

The upward calculations for beams deflection under transfer load using Eq. (1) are performed and the comparisons with the numerical results are given in Table 3. The downward deflection under self weight of beam is calculated based on Eq. (2). Also the deflection calculations for service load are given in Table 3.

$$\Delta = -\frac{5 P_t e l^2}{48 EI} \quad (1)$$

$$\Delta = \frac{5 W_{self} l^4}{384 EI} \quad (2)$$

Where E is the modulus of elasticity and I is the moment of inertia of sections.

Table 3- comparison of theoretical upward and Numerical deflection under transfer load

Beam No.	Calculated results(cm)		Numerical Results(cm)	
	Δ at transfer	Δ at service	Δ at transfer	Δ at service
B1	-0.91	+0.09	-1.25	+0.32
B2	-0.91	+0.09	-0.58	+0.483

The negative sign show upward and the positive sign show downward deflection.

CONCLUSIONS

This paper demonstrates the finite element modeling and experimental test results to investigate the behavior of prestressed T beam SCC with the use of nonlinear material properties.

The F.E.M results are compared with the experimental results and the following conclusions are drawn:

i) The load-deflection curves by both methods are in good agreement i.e., the numerical results are differed by 8% with the experimental results.



- ii) The load-strain curves for concrete and wires show that the maximum difference between two methods is 12%.
- iii) This comparison between modeling and experimental results shows good agreement and maximum difference between them is 12%.
- iv) The comparison of load-deflection curves of both methods are almost coincide each other except at transfer and at zero deflection. It shows that, it is due to practical losses occurred, where as for F.E.M these losses are not considered.
- v) The comparison of theoretical and Numerical deflection under service load indicates that, deflection reached zero for 14.3 ton load (nearly service load) but at laboratory this events get at 15.4 ton.

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