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FINITE ELEMENT ANALYSIS OF PRESTRESSED CONCRETE BEAM: A REVIEW

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Abstract—Pre-stressed concrete beam has been successfully modelled by nonlinear finite element analysis, allowing for plasticity and damage behaviour of concrete and slip-bond failure behaviour for strands. All the materials and bond models used are based on experimental data where the bond behaviour of pre-stress strands is first characterised in a small size beam model. The simulation results are validated with data from actual load testing and numerical model. Similarly, the main objectives of this research are the effective development of an updating process for nonlinear numerical modelling which is based on the information from different monitoring systems and code-based methods.

Keywords— Finite element analysis, pre -stressed concrete, beam, non linear numerical modelling, monitoring systems, code-based methods

INTRODUCTION

Finite element analysis is one the method where we can determine the static performance of structure for mainly increase the safety of the structure and cost effective in construction. It takes a complex problems and break down into finite number of simple problems. Similarly, by using the programs with interactive graphical facilities, we can generate finite element models of complex structures and obtain results in convenient, readily assimilated form. In addition it saves the valuable design time.

Prestressed concrete is used in a wide range of building and civil structures where its improved performance can allow for longer spans, reduced structural thicknesses, and material savings compared with simple reinforced concrete. Prestressed concrete is basically a concrete in which internal stresses of a suitable magnitude and distribution are introduced so that stresses resulting from external loads are counteracted to a desired degree. In reinforced concrete members, the prestress is commonly introduced by tensioning the steel reinforcement.

Many experimental studies on the behaviour of externally prestressed members with external tendons, bonded concrete beams, un-bonded concrete beams, using T beams have been undertaken so far. All these are done on several numerical models and analysis based on finite element method and the incremental deformation method which calculates the strain change in tendons by integrating the strain of concrete at the level of the tendons between the anchorages.

LITERATURE REVIEW

Diep *et. al,* (2019) investigated on non-linear analysis of externally prestressed beam. External prestressing is defined as prestress introduced by the high strength cable, which is placed outside the cross section and attached to the beam at some deviator points along the beam. It was found that the stress increase in an external cable depends mainly on the overall deformation of beam and cable friction at the deviators. There is a close relationship between the two curves of load vs. deflection of load vs. increase of cable stress. The proposed equation for the increment of cable strain of each segment at the certain loading stage is given in the Fig.1.

$$\begin{bmatrix} l_1 & l_2 & l_3 & \cdots\cdots\cdots & l_{n-1} & l_n \\ C_1+(-1)^{k_1}\mu S_1 & -C_2+(-1)^{k_1}\mu S_2 & 0 & \cdots\cdots\cdots & 0 & 0 \\ 0 & C_2+(-1)^{k_2}\mu S_2 & -C_3+(-1)^{k_2}\mu S_3 & \cdots\cdots\cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots\cdots\cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots\cdots\cdots & \cdots & \cdots \\ 0 & 0 & 0 & \cdots\cdots\cdots & -C_{n-1}+(-1)^{k_{n-2}}\mu S_{n-1} & 0 \\ 0 & 0 & 0 & \cdots\cdots\cdots & C_{n-1}+(-1)^{k_{n-1}}\mu S_{n-1} & -C_n+(-1)^{k_{n-1}}\mu S_n \end{bmatrix} \begin{Bmatrix} \Delta\varepsilon_1 \\ \Delta\varepsilon_2 \\ \Delta\varepsilon_3 \\ \cdots \\ \cdots \\ \Delta\varepsilon_{n-1} \\ \Delta\varepsilon_n \end{Bmatrix} = \begin{Bmatrix} \int_0^l \Delta\varepsilon_{cs}\,dx \\ 0 \\ 0 \\ \cdots \\ \cdots \\ 0 \\ 0 \end{Bmatrix}$$

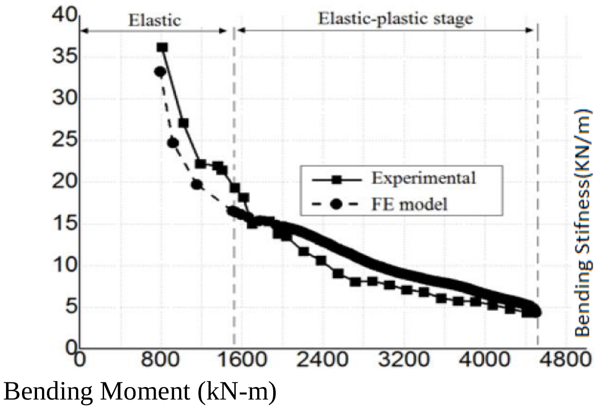
Fig.1: Proposed Equation of increment cable strain [1]

The letters *Ci* and *Si* are denoted as cosine and sine of the cable angle. The experimental and calculated value of different considered beam in ultimate load, stress increase in cable and ultimate deflection given in the Table no. 1 from which it is clear that numerical and experimental value are almost similar.

Table No. 1: The tested beam variables and their materials [1]

Beam No	Description of beam	Ultimate Load(KN)		Stress increase in cable(KN)		Ultimate deflection(MM)	
		Experimental	Calculated	Experimental	Calculated	Experimental	Calculated
T1	Simple Supported Box	58500	58253	0.0015	0.0015	350	358
T2	Two Span continuous flanged	73.3	72	230	185	50	48
T3	Two Span continuous Rectangular	308	310.8	370	366	48	50.2
T4	Three Span Continuous Box	375	377	319	307	40.6	40.3

Chengquan *et. al,* (2018) conducted an investigation of stiffness degradation characteristics of the pre stressed concrete T girder by destructive test and finite-element analysis. A test T-beam having length 20m, height 1m, width of wing 1m and width of web varying 30cm to 40 cm with grade of concrete C50 was selected. Two 100 ton hydraulic jacks are placed at two loading regions in the mid span and the distance between the loading regions is 2 m. T-beam three-dimensional finite element model is done by software ABAQUS. The finite element results are very much similar to the experimental results. The stiffness degradation slowed down significantly at the ultimate load. The beam bending stiffness of destructive test and FE model dropped from 36.19kN/m to 4.35 kN/m and 33.24 KN/m to 4.40 kN/m respectively. The Final difference between them was obtained as 1.15%. It is found that the stiffness degradation factor after concrete cracking and the position moving of the neutral axis showed a linear relationship.



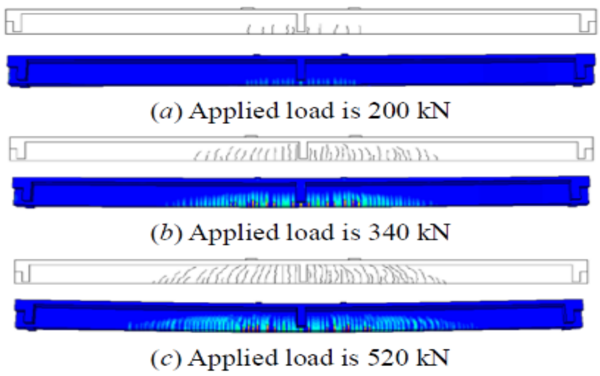


Fig.2: Stiffness degradation curves [2]

Fig.3: Tensile plastic strain cloud images of finite element model [2]

Leandro *et. al*, (2018) conducted Nonlinear finite element simulation of prestressed concrete beams under short term loading the RC beam is discretized using nonlinear Euler-Bernoulli frame elements based on the total Lagrangian approach, while the slipping tendon is modelled by a single cable element embedded in a specific subset of frame elements. The contribution of frame and tendon elements to the global internal force vector and stiffness matrix is evaluated in a consistent way, leading to a more robust and stable nonlinear solution. It was shown that if the nonlinear terms of the tendon stiffness matrix are not complete the convergence is slowed and may even not be reached.

Thoma *et. al*, (2018) conducted a thorough study of Nonlinear finite element (NLFE) analysis that takes into account material-dependent nonlinearities is an efficient way to calculate the load-deformation behaviour of reinforced concrete (RC) plates and beams, and prestressed concrete (PC) beams. In the FE model, the geometry of the prestressing cable is modelled as an open polygon of continuous members, and the anchor and friction forces due to prestressing are applied as external loads. Tension stiffening is taken into account. The interpretation of the results of the nonlinear FE analysis is made significantly easier by the graphical evaluation of mechanically based results specific to reinforced concrete, such as the steel stress at the cracks, the principal concrete compressive stress, and the direction of the principal concrete compressive stress.

Xie *et. al*, (2018) conducted experimental and numerical studies on prestressed concrete beams at low temperatures (+20 ºC to -100 ºC). Prestressed concrete (PC) members are widely used due to their improvements on the initial stiffness and cracking resistance. Twelve bonded PC beams in total were prepared in this test program. The investigated parameters contained the prestress levels (0 and 0.75fpu) and the temperature levels (20 ºC, 40 ºC, 70 ºC and 100 ºC). All the PC beams were under two-point loads and the displacement load from a hydraulic actuator was applied to the PC beams through a spread beam. The reaction forces at different loading levels were measured by a load cell that attached to the actuator.

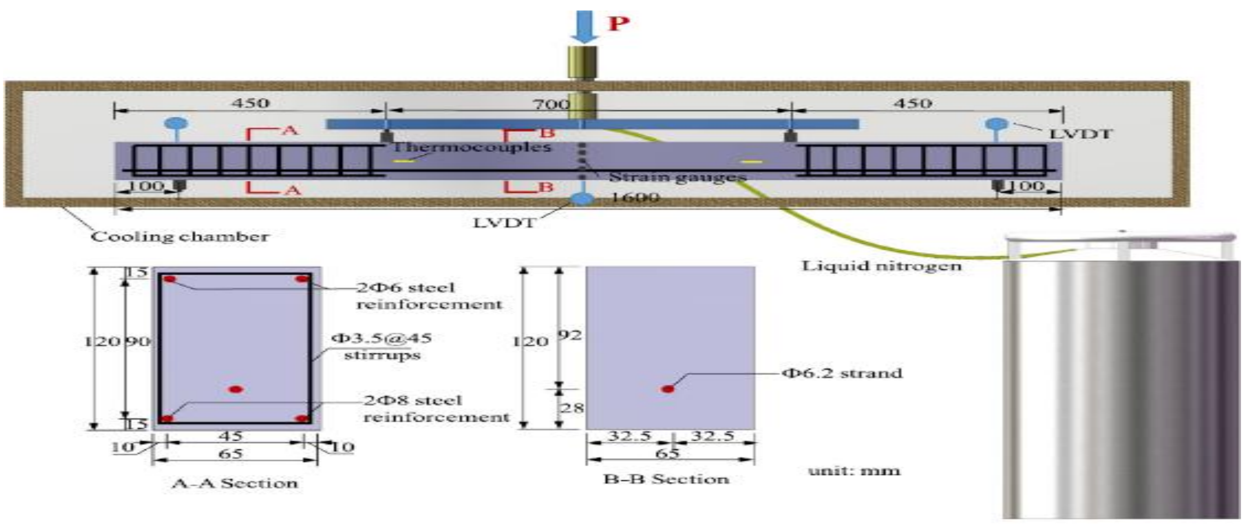


Fig. 4: Test setup and details of the bonded PC beams at low temperatures. [5]

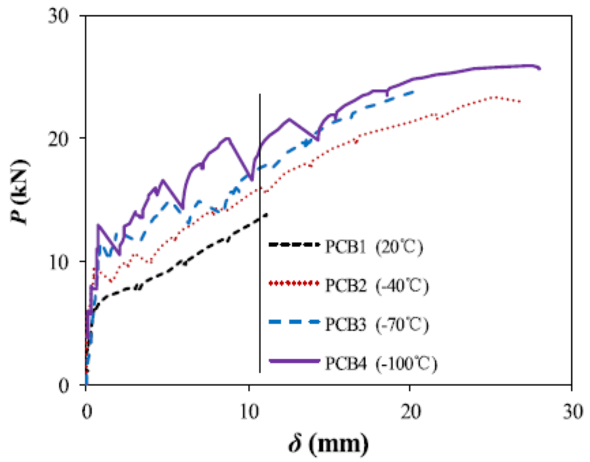


Fig. 5: Load-deflection curves of the PC beams at different low temperatures [5]

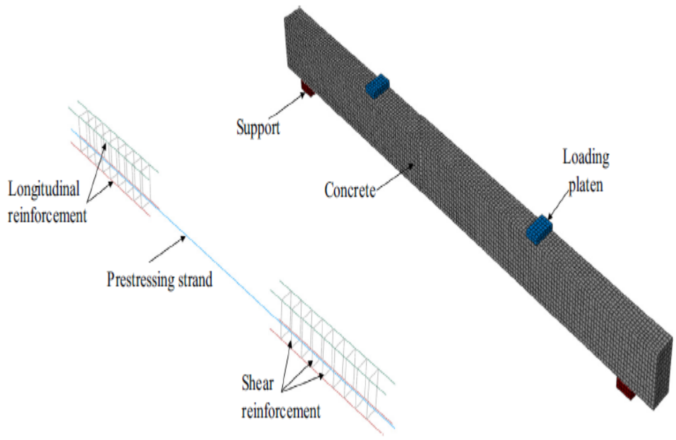


Fig. 6: FEM for PC beam [5]

The typical FEM for PC beams that contained the concrete block, loading platen, support, prestressing strand, and shear reinforcements was model in ABAQUS with mesh size for the concrete, loading platen and support were selected to be 10 x 10 x10 mm^3, 5 x 5 x 5mm^3 and 5 x 5 x5 mm^3 as shown in Fig. 4. The accuracy of the FEM was validated by test results, and it proved to be capable of simulating load-central deflection curves, cracking resistance, and ultimate resistance of the PC beams at low temperatures. It was found that FE model averagely overestimated the P_{cr} of the PC beams at low temperatures by 4% with the COV of 0.16 for 12 predictions whilst the model slightly overestimated P_u by 9% with a COV of 7% for 12 predictions. P_{cr}, P_u denotes resistances corresponding to first crack and ultimate resistance of PC beam.

Strauss *et. al,* (2017) focused their research on the combined ultimate shear and flexure capacity of the beams. The aim was to model the whole beam using hexahedral elements only with a ratio of edge lengths that is not higher than 3:1. The Prestressing strands were also modelled using 1D reinforcement material, but the stress–strain diagram of the tendons was idealized as a bilinear material with hardening. An FE mesh composed of 16,728 hexahedral finite elements was generated in the program GID. Here the nonlinear fracture mechanics FE 3D computational model showed good agreement with the performed experiment.

Yapar *et. al,* (2015) conducted research in nonlinear finite element analysis of plasticity and damage behavior of concrete and slip-bond failure behavior for strands. All material and bond models used are based on experimental data. The simulation results are validated with data from actual load testing. The modeling and simulation results showed good agreement with experimental results up to the collapse load as shown in Fig. 8. The simulation results gave a clear understanding of the true behavior of such beams.

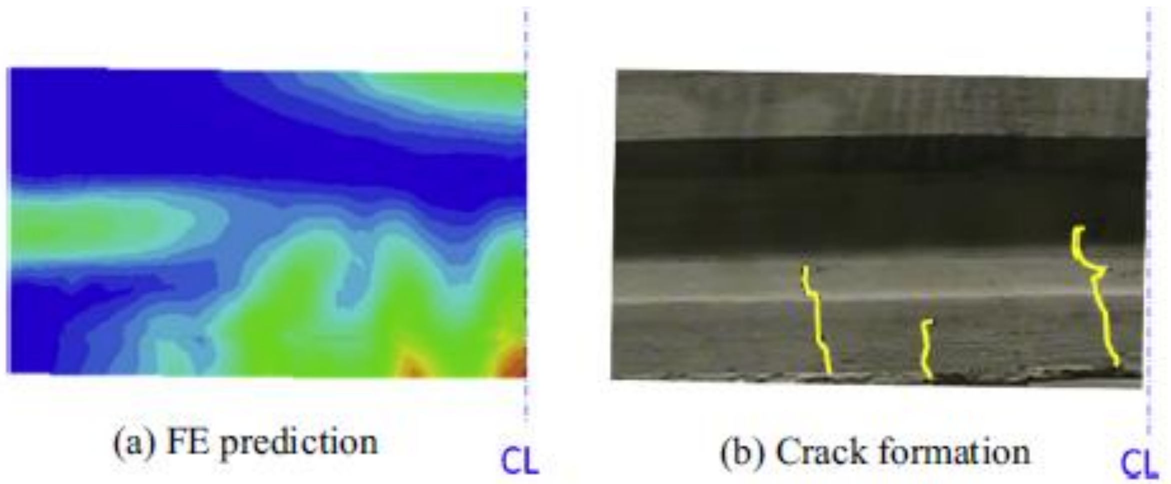


Fig. 7: Crack Predicted by FEM and Crack formation [7]

CONCLUSIONS

Based on the study done, it can be concluded that the experimental result and FEM analysis result are showing good arrangement. From the above research paper we look after different parameter of the prestressed concrete beam like ultimate strength, ultimate deflection, stiffness degradation curve, deflection of prestresssed concrete in low temperature, compressive stress, crack formation and found that actual test result and result from the FEM analysis software are in acceptance limit. So it is concluded that FEM analysis of prestressed concrete beam gives actual result and this result can be effectively used in research and practical field.

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