ISSN: 0974-5823 Vol. 7 No. 1 January, 2022

International Journal of Mechanical Engineering

Nonlinear 3D Finite Element Modeling of Continuous Prestressed HSC Girders

Hawra Mohamed Ali M. Taher [1], Mustafa B Dawood[2]

1-Ph.D. candidate, Civil Engineering Department, College of Engineering, University of Babylon, Babylon, Iraq.

2-Professor, Civil Engineering Department, College of Engineering, University of Babylon, Babylon, Iraq.

Abstract

For modelling concrete structural members, a variety of analytical and numerical techniques are available. Finiteelement analysis is a numerical process which is frequently used to analyze the structures of concrete. It is established on the utilization of materials'nonlinear behaviour and is widely used in the design of concrete structures. The most difficult aspect of modelling prestressed concrete structures is how to deal with the contact between the concrete and the prestressing tendons and tendons. The finite-element modelling mechanism addressed in this work is based on finite-element packages that are suitable for a variety of applications.The current research describes the FEA of continuous high strength concrete, post-tensioned rectangular girders and its comparison between two methods of loadings two points and distributed loading. Two 4.3 m length partial post-tensioned girders. It is necessary to simulate girders and their bonding circumstances in order to evaluate the accuracy of the FEA. The software package ABAQUS was utilized for this purpose. It is possible to get excellent agreement between computational and experimental crack patterns. The comparison of finite-element modelling (FEM) and experimental results of load-deflection revealed that the beams' load histories were consistent throughout their service lives till failure. When the FEM and experimental findings were compared, it was found that there was a reasonable agreement between the two ways of ductility indices. When applied to prestressed tendons in their final state, finite-element modelling has a tendency to overstate the amount of stress in the tendons. The results obtained utilizing the 3D finite element models generated in this work were consistent with the experimental and numerical data acquired from the prior studies, indicating that the models were effective."

Keywords: HSC, post-tensioned, FEA, continuous.

1.Introduction

In recent years, civil engineers have been faced with the job of determining the load capacity of existing post-tensioned bridges, which has grown increasingly common. When it comes to the structural evaluation of these constructions [1].When compressed, concrete is extremely strong; but, when tensioned, it is weak: its tensile strength ranges from 8 to 14 percent of its compressive strength. Because of the low tensile strength of the material, flexural cracks appear during the early phases of stress. In order to decrease or avoid the development of such cracks, a concentric or eccentric force is applied to the structural element in the longitudinal direction of the element. Because this force eliminates or significantly reduces the tensile stresses at the key mid-span and support sections under service load, the fractures are prevented from emerging. This results in increases in the bending, shear, and torsion capabilities of the sections. The portions are then capable of exhibiting elastic behaviour. When all loads operating on the structure are considered, almost the complete capacity of the concrete in compression can be efficiently utilized across the entire depth of the concrete sections[2].

Partially prestressed concrete members are concrete elements that are constructed with a mixing of prestressed tendons andconventional reinforcing. The notion is becoming ignificantly popular as an alternative to fully prestressed concrete structures or reinforced concrete. The majorityof design codes for the structures of concrete (as ACI 318) have detailed provisions and units for fully prestressed concrete elements and reinforced concrete. However, provisions or even directly tackles the partially prestressed concrete elements were nt included, which is a significant oversight. Although partially prestressed elements are utilised in practice, the design of partially prestressed elements is relies on ultimate strength criteria, the satisfaction of serviceability rational and analysis, and lastly on the technical judgment of those who are involved in the project[3].

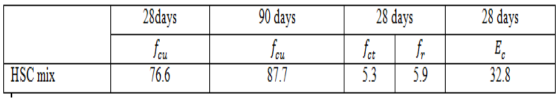
High-strength concrete (HSC) production in the construction industry has seen a significant increase in recent years, owing to the increased demand for HSC in modern construction projects. Improving the performance of concrete structures will, in the end, increase the total efficacy of modern concrete structures. When compared to the typical concrete system, HSC has much better strength in concrete media, with greater than 40 MPa[4]If you are looking for a modified kind of concrete, go no further than high strength concrete (HSC). It is a dense and homogenous concrete with exceptionally high strength and greater durability features when compared to ordinary concrete, making it extremely useful in the construction business. Examples include high-rise skyscrapers, long-span bridges, piers, and other structures with a lot of spans. According to the American Concrete Institute (ACI), high-strength concrete (HSC) is "concrete that meets special operating requirements that are not achievable with regular concrete."[4]

2. Experimental set-up

The two-point load, each one concentrated at the mid-span of a continuous beam. Was conducted up to failure on continuous post-tensioned high strength concrete bridge girders. Girder construction, prestressed jacking operations, loading, and beam failure are all examples of laboratory work processes. A tension and compression ordinary steel bars 10 mm diameter bars, stirrups 10 mm diameter at a spacing of 100 mm centre-to-centre were used to reinforce a post-tensioned concrete rectangular form girder longitudinally (i.e., ordinary bars and prestressed strands). Stirrup spacing and reinforcing ratios are in conformity with ACI-318 requirementsTested beam detailsare shown in figures (1), (2) and (3).

At each mid-span, vertical deflections were measured using linear variable deflection transducers, or LVDTs. Table (1) shows the details of the concrete mechanical properties test beams as well as the primary variables that were evaluated. Properties of prestressed strands with seven wires (Grade 270).[5]

Table (1) concrete properties



	28days	90 days	28 days		28 days
	f_{cu}	f_{cu}	f_{ct}	f_r	E_c
HSC mix	76.6	87.7	5.3	5.9	32.8

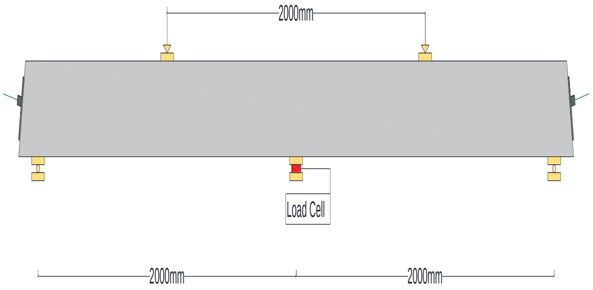
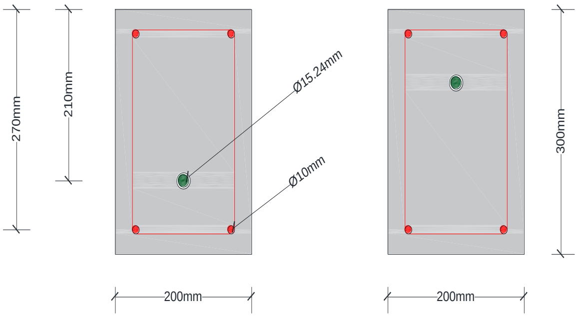


Figure (1)Geometry of beam



a- Beam section of sagging region b - Beam section of hogging region

Figure(2) Cross section dimensions

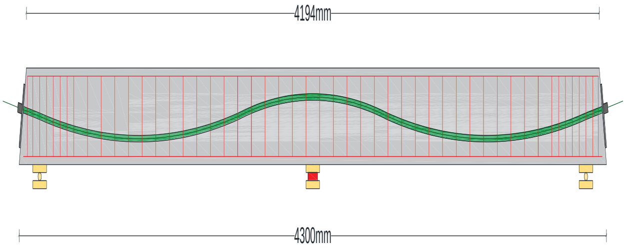


Figure (3) Reinforcement details

3. Finite element modelling with ABAQUS

Abaqus is a finite element simulation software that has a wide population in various civil engineering applications, especially for structural engineering. It is necessary to define material models to get the desired behaviour of the overall structure, as shall be described in the next subsections. In the modelling of the concrete, steel plate, prestressed steel and shaft at the support and loading point a three-dimensional eight-node element (C3D8) with three degrees of freedom at each node is used as shown in Figure (4).

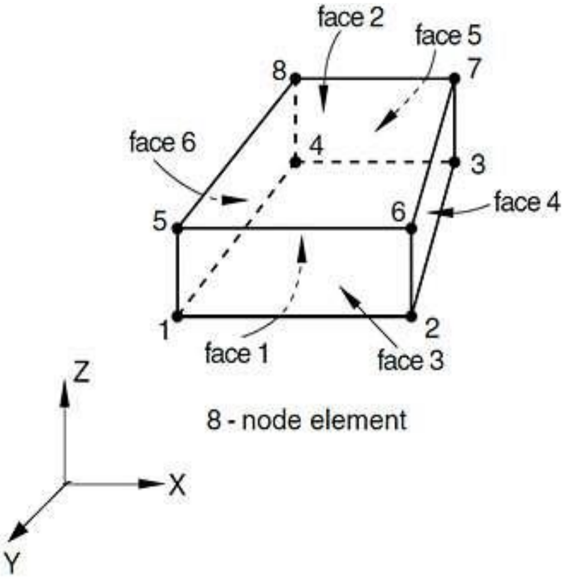


Figure (4) 8-Node 3D Element

Three variousmodels of constitutive are available in ABAQUS for concrete analysis under small confining pressures: the model of smeared crack concrete in Standard /ABAQUS; the model of brittle cracking in Explicit/ABAQUS; and the model of concrete damaged plasticity in both Explicit/ABAQUS and Standard/ABAQUS. Every model is intended to offer a generic ability for reinforced concrete and modelling plain (and the other comparable materials of quasi-brittle) in a variety of structural configurations, including solids, shells, trusses, and beams , as well as other comparable materials like quasi-brittle, in various structures. Material points showing either tensile cracking or compressive crushing at the material point are created using smeared crack concrete in applications where the concrete is subjected to essentially monotonic stress. When plastic is compressed, plastic straining is controlled by a yield surface known as the "compression" yield surface, which is located on the yield surface. Given that cracking is claimed to be the most critical behaviour of the component, cracking representation and the behaviour ofpost cracking anisotropic takes precedence over all other parts of the modelling. When tensile cracking dominates the concrete behaviour and compressive failure is not a significant influence, brittle cracking is the preferred method of failure. It is taken into consideration throughout the modelling phase the anisotropy induced by cracking. This suggests that compression will result inelastic behavior, according to the model. Removal of pieces from a mesh is made possible by a simple brittle failure criterion, which is simple to implement. This model of concrete damaged plasticity has been constructed on the basis of the premise that scalar (isotropic) damage has occurred. It may be used in applications where the concrete is exposed to randomloading conditions, such as monotonic and cyclic loading. When plastic straining occurs in both the tension and compression directions, the model consideres the elastic stiffness deterioration that happens as a result of the straining. During cyclic loading, it also takes into account the effects of stiffness recovery on the system.[6]

It has a greater chance of convergence than the smeared crack model. As a result, elastic stiffness can degrade at different rates in tension and compression, as well as different yield strengths in compression andtension. Moreover,it accounts for the response of true post-yield, likethe behaviour of softening in tension rather than initial hardening preceeded by compression softening. The element of three-dimensional two-node truss (T3D2) with 3 degrees of freedom at the nodeswas utilised to simulate the reinforcing bars, as illustrated in Figure (5).

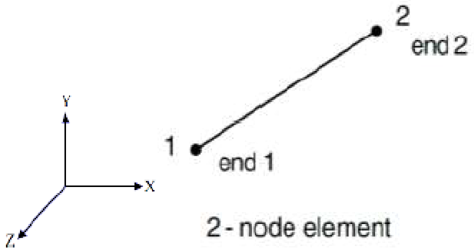


Figure (5) 2-Node 3-D Truss Element

Reinforcing steel is regarded as a homogenous material since it exhibits a consistent stress-strain relationship in both compression and tension, and because its qualities are well defined and predictable. Axi-symmetrical force transmission is thought to be possible solely through steel reinforcement. However, in the current study, the stress-strain relationship corresponding to steel is determined through the use of a tensile test method.

The anchorage steel plates that were given at the jacking and prestressing of the specimens ends were determined in terms of materials and geometry that are similar to the ones utilised in the real-world tests. Nodal restrictions can be used to simplify and model the intricate anchorage of post-tensioned prestressing systems, which otherwise would be impossible. The limitations ensure that the tendon nodes are properly "anchored" in the concrete at the anchorage zones by preventing them from moving about. Multi-point Constraints (MPCs), which are available in ABAQUS, are used to satisfy the constraint. A specific rigid beam MPC is an excellent choice for anchoring the tendon end nodes in the surrounding concrete nodes because of its rigidity. They are modelled (C3D8).

Mesh In finite element modelling, the selection of the mesh density is a critical step that must be completed. A suitable number of elements is utilized in a structure to ensure that the results are in close proximity to one another. This is achieved in practice when an increase in the mesh density has a negligible influence on the outcomes of the analysis. To identify anappropriate mesh density for the finite element modelling, in thi situation , a convergence analyses weredone to identify the appropriate mesh density. According to Figure 1, the convergence study was carried out by increasing the number of components (mesh) in each of the three directions (z, y, and x). As a result, displacement boundary conditions must be applied to models in areas where support beams are present in order to verify that they behave identically to the experimental beams. The loading and support dimensions of the plates and shafts used in the experimental test were (10015020) mm and (30150) mm, respectively, in the experimental test. Additionally, they are modelled using C3D8 elements, which were added at the support and loading sites in order to avoid difficulties with stress concentrations. This resulted in a more even distribution of stress throughout the support area. The supporting shafts nodes located at the bottom surface are constrained in all freedom degrees, except for the first degree of freedom. In the ABAQUS software, the externally applied load was represented as pressure by dividing the total load on the top surface of the loading shaft by the number of times the load was applied. The boundary conditions and applied loads are depicted in further detail in Figure (6).

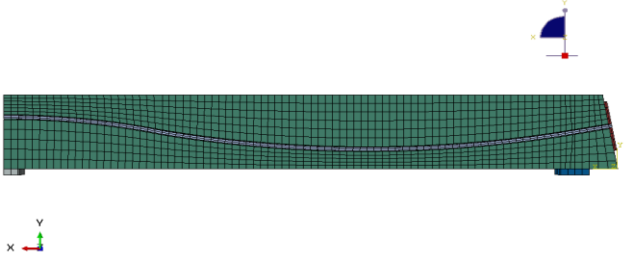


Figure (6)Mesh of beam

4.Numerical results and validations

As shown in Figure (8), a comparison of the beam's experimental crack pattern at failure with the FEA damage patterns at the final stage is shown. It was found that the computational and experimental crack patterns were in excellent agreement. In Figure(9), the results of the FEA and the experiments on the load and deflections are shown. As shown, the beams' load histories are in great agreement up until the point of failure. According to the table (2), simulated and experimental results for applied loads and vertical deflections at cracking, yield, and failure are shown.

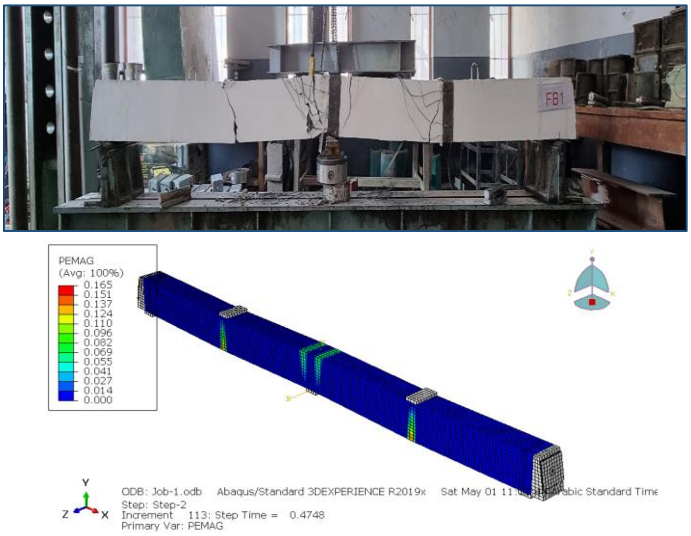


Figure (7)Comparison of numerical and experimental crack patterns

Experimentative, as well as Figure (8), shows the findings of the FEA as well as the experimental findings of deflections and load (9). Overall, the great agreement is attained using the beams load history until they fail, as previously mentioned. Table (2) shows the comparisons of vertical deflection and applied load at cracking, yielding, and failure between experimental results and numerical simulations at various stages of the cracking, yielding, and failure process.

Table (2) FEA and experimental results

Ultimate load capacity (kN)			**Max. deflection (mm)**		
Exp.	**Num.**	**Num./Exp.**	**Exp.**	**Num.**	**Num./Exp.**
438.2	446.0	1.017	17.8	18.0	1.012

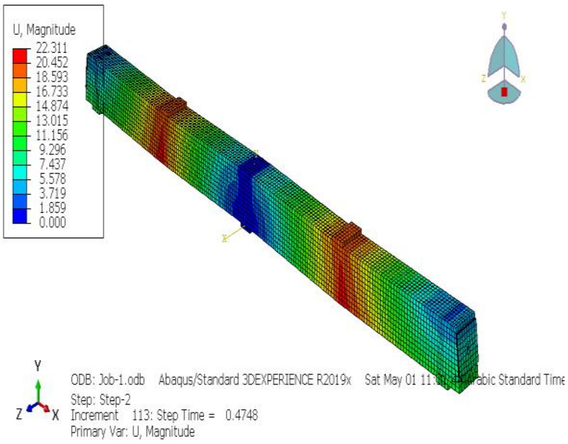


Figure (8) vertical load deflection

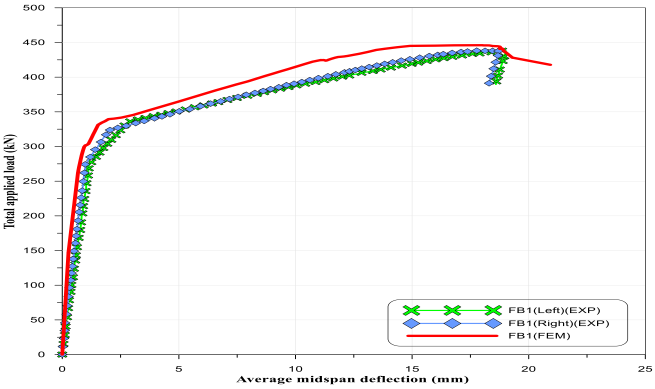


Figure (9) load-deflection curve of experimental and numerical

5. Effective of distributed loads

The impact of different load types is highlighted through the use of the model that was simulated in the ABAQUS program. Comparing the load-deflection responses of the two loading types is shown in Figures (10). According to elastic analysis, when the applied load is distributed uniformly over the beam, the continuous beam capacity will rise as compared to the case of two-point concentrated loading. This enhanced reach (120.2 %) was accompanied by an increase in the ultimate deflection reach as well (59 %).

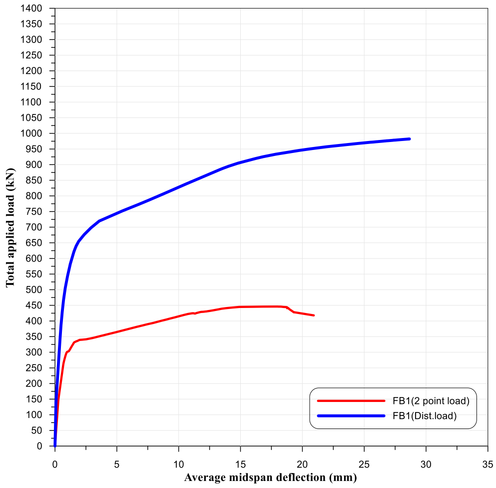


Figure (10) load-deflection curve of the two types of loading

5.Conclusions

The finite element modelling of a prestressed concrete beam was carried out using ABAQUS and CDPM.This technique was utilized to represent the binding between the 3D-element strand, steel bars, and concrete using the surface-based cohesive interaction technique. Based on the outcomes of the present investigation, the following inferences may be withdrawn:

- It has been discovered that the damage-plasticity simulation for concrete in the FE program ABAQUS accurately models the behaviour of the prestressed beam in this study.
- The suggested 3D finite element modelling was validated using both experimental and numerical data, and the results revealed a very excellent match between the experimental and projected data.
- The alternative strategy of applying the cohesive surface bonding method to mimic the bond between the steel bars and concrete may accurately forecast the behaviour of prestressed beams with a high degree of accuracy, as demonstrated in this study.

6.References

[1] P. Huber, T. Huber, and J. Kollegger, “Experimental and theoretical study on the shear behavior of single- and multi-span T- and I-shaped post-tensioned beams,” *Struct. Concr.*, vol. 21, no. 1, pp. 393–408, 2020, doi: 10.1002/suco.201900085.

[2] H. M. A. M. T. Mustafa B Dawood, “Various methods for retrofitting prestressed concrete members : A critical review,” vol. 9, no. 2, pp. 657–666, 2021.

[3] C. G. Karayannis and C. E. Chalioris, “Design of partially prestressed concrete beams based on the cracking control provisions,” *Eng. Struct.*, vol. 48, pp. 402–416, 2013, doi: 10.1016/j.engstruct.2012.09.020.

[4] H. J. Yim, J. H. Kim, and S. H. Kwon, “Effect of admixtures on the yield stresses of cement pastes under high hydrostatic pressures,” *Materials (Basel).*, vol. 9, no. 3, pp. 1–11, 2016, doi: 10.3390/ma9030147.

[5] M. B. Dawood, H. Mohamed, and A. M. Taher, “Flexural strengthening of the continuous unbonded post -tensioned HSC beams by precast SIFCON laminates,” vol. 9, no. 4, pp. 948–955, 2021.

[6] ABAQUS, “Abaqus 6.14,” *Abaqus 6.14 Anal. User’s Guid.*, p. 14, 2014.