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3D FINITE ELEMENT MODELLING OF FRP CONFINED CONCRETE COLUMN

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Abstract: *Modelling concrete columns confined with fiber-reinforced polymer (FRP) using finite element (FEM) analysis is a difficult task due to the need for precise definition of material and interaction parameters. The inclusion of FRP confinement in composites introduces complexities in representing the volumetric behavior of concrete under triaxle stress conditions. The behavior of confined concrete differs from that of non-confined concrete due to the passive nature of FRP confinement, requiring consideration of flow rules, damage parameters, strain hardening/softening constitutive relationships, and a pressure-dependent yield criterion. This project aims to address these challenges by proposing a modified plastic damage model, a concrete dilation model, and a new set of concrete hardening/softening rules using the advanced FE program ABAQUS CAE. The FE model's strengths and limitations are evaluated by comparing it with experimental results from this project, as well as other findings from literature, including both experimental and analytical studies.*

Keywords: *Finite element, fiber-reinforced polymer, FE program ABAQUS CAE.*

1. INTRUDUCTION

During the last two decades, numerous stress-strain models have been developed to evaluate the behavior of concrete columns confined with fiber reinforced polymer (FRP) composites under monotonic axial compressive loading as illustarte in figure 1, based on experimental and analytical work [1][2]. The Finite Element (FE) method has been extensively utilized to model FRP-confined concrete columns, offering advantages in dealing with geometric non-linearity and material interactions. However, the complexity of FE modeling lies in accurately defining the properties of different materials, such as FRP sheets and concrete. FRP laminates are typically modeled as linear elastic materials, with the hoop properties being crucial when fibers are oriented in that direction. On the other hand, several constitutive models have been suggested to define concrete properties in FE software, particularly for confined concrete subjected to pressure. The theory of plasticity has been widely employed for modeling confined concrete, with the Drucker-Prager (D-P) type being commonly used and yielding good results for predicting the monotonic behavior of FRP-confined concrete [3]. Modifications to the D-P model have been proposed to address limitations, such as the modified damaged plasticity model by Yu et al. [1] and the improved version by Teng et al. [3]. However, the concrete damaged plasticity model (CDPM) available in ABAQUS, developed by Lubliner et al [4] and modified by Lee and Fenves [5], shows limitations when modeling concrete confined with constant pressure or FRP-confined concrete.

In a recent study by Hany et al [6], a modified CDPM (Concrete Damage Plasticity Model) is introduced to enhance the prediction accuracy of FRP (Fiber-Reinforced Polymer) confined concrete columns. This modified model aims to accurately estimate the monotonic axial stress-axial strain responses of the columns, as well as the lateral dilation of FRP confined concrete. The researchers incorporate new expressions for the dilation angle of FRP-confined concrete in circular sections, as well as the input hardening/softening rule of actively-confined concrete.

To account for non-circular sections, the dilation angle expression is generalized using the approach proposed by Yu et al [2]. This ensures the applicability of the model to various geometries beyond circular sections. Additionally, the compression hardening data utilized in the model is calibrated based on actively-confined concrete curves, which are used as input material properties dependent on the confining pressure for FRP-confined concrete.

To validate the accuracy of the presented model, experimental results of carbon fiber reinforced polymer (CFRP) confined concrete specimens with circular cross sections, conducted by the research group [7], are employed. These experimental results serve as a benchmark to assess the performance of the modified CDPM in predicting the behavior of FRP-confined concrete under different loading conditions.

By incorporating the new expressions for dilation angle and utilizing experimental data for validation, the modified CDPM presented by Hany et al. [6] offers a more precise approach to predict the behavior of FRP confined concrete columns. This advancement has the potential to enhance the design and analysis of FRP-confined concrete structures, contributing to safer and more efficient construction practices in the field of civil engineering.

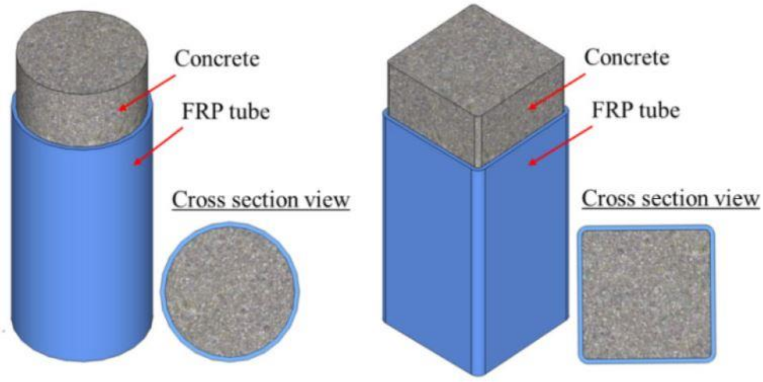


Figure 1 illustrate covered column plain concrete with FRP [15]

2. FE MODELING

Finite Element (FE) modeling is a computational technique widely used in engineering and scientific fields to analyze the behavior of complex structures and systems. ABAQUS CAE, a popular commercial software, provides a powerful platform for performing FE analysis [8]. In FE modeling, a complex geometry is divided into smaller, simpler elements called finite elements. These elements are interconnected at specific points called nodes, forming a mesh. By applying mathematical models and equations to these elements, the behavior of the entire structure can be accurately simulated and analyzed.

The process of creating an FE model in ABAQUS involves several steps. Firstly, the geometry of the structure is created or imported into ABAQUS. This can be done using CAD software or by directly defining the geometry within ABAQUS. Once the geometry is prepared, the next step is to generate a mesh. ABAQUS provides various meshing techniques, such as structured, unstructured, and adaptive meshing, to create an appropriate mesh for the given geometry [10].

After generating the mesh, material properties and boundary conditions need to be assigned to the model. Material properties, such as elastic modulus, Poisson's ratio, and yield strength, define the behavior of the material being simulated. Boundary conditions, including constraints and applied loads, represent the real-world conditions the structure will experience during analysis. ABAQUS offers a range of boundary condition options, such as fixed displacements, prescribed loads, and contact interactions [10].

With the mesh, material properties, and boundary conditions defined, the FE model is ready for analysis. ABAQUS employs numerical methods to solve the set of equations derived from the behavior of the finite elements. The software calculates the displacements, stresses, strains, and other relevant outputs based on the applied loads and material properties. ABAQUS also provides options for various types of analyses, including static, dynamic, thermal, and coupled field analyses, allowing engineers to explore different scenarios and study the response of the structure under different conditions [10].

FE modeling in ABAQUS has been extensively used in a wide range of engineering applications, including structural analysis, heat transfer analysis, fluid-structure interaction, and many more [9, 11]. It has proven to be a reliable tool for predicting the behavior of complex systems and optimizing designs. Numerous research papers, textbooks, and online resources are available that provide detailed information and examples on FE modeling in ABAQUS, guiding users through the process and helping them understand the underlying theory and best practices [12, 13].

3. MODIFIED CDPM FOR FRP CONFINED CONCRETE

The development of a modified CDPM (Concrete Damage Plasticity Model) for FRP-confined concrete is a significant advancement in accurately modeling the behavior of this composite material. FRP-confined concrete combines the strength and durability of concrete with the confinement and reinforcement provided by FRP. However, the presence of FRP confinement introduces complexities that require specialized modeling approaches. Parametric studies have been conducted to investigate the influence of various factors on the stress-strain behavior of FRP-confined concrete cylinders. Among these factors, the dilation angle (ψ) emerged as a critical parameter affecting both the stress-strain curve and the lateral strain-axial strain curve. By carefully varying the dilation angle, researchers gained valuable insights into the material's response and the interplay between axial and lateral strains.

In conventional modeling approaches, the definition of compression hardening data is instrumental in accurately capturing the stress-strain behavior of concrete under increasing compressive stress. However, when applying these approaches to FRP-confined concrete, using the stress-strain curve of unconfined concrete to define compression hardening proves inadequate. This limitation was recognized by Yu et al. [1, 2], who proposed incorporating the confining pressure as an additional parameter to define compression hardening. The confining pressure exerted on the concrete core in FRP-confined concrete columns is not constant during loading. As the concrete undergoes dilation, the confining pressure progressively increases, altering the material's response. To address this, the modified CDPM incorporates the varying confining pressure as a crucial parameter in defining the compression hardening behavior. By doing so, the model can more accurately capture the stress-strain curve and predict the material's behavior under different loading conditions, leading to improved simulations and more reliable design outcomes for FRP-confined concrete structures.

The hardening/softening rule is a fundamental concept in the behavior of FRP confined concrete columns. When subjected to loading, the confining pressure applied to the concrete core is not a constant value but rather increases in response to concrete dilation. Extensive research and literature have emphasized that the stress-strain relationship of FRP-confined concrete can be accurately represented by a collection of points situated on a sequence of curves corresponding to actively-confined concrete [7]. This phenomenon is illustrated in Figure 2, illustrating the dynamic nature of the confining pressure and its influence on the overall behavior of FRP-confined concrete columns.

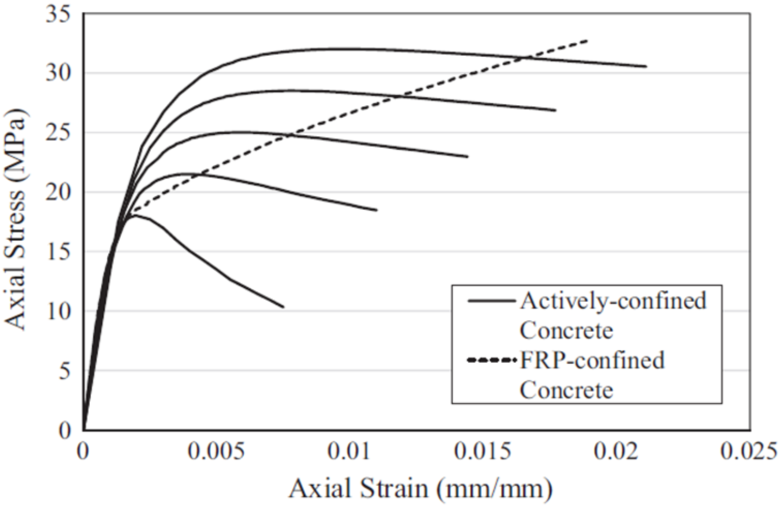


Figure 2 stress strain curve [6]

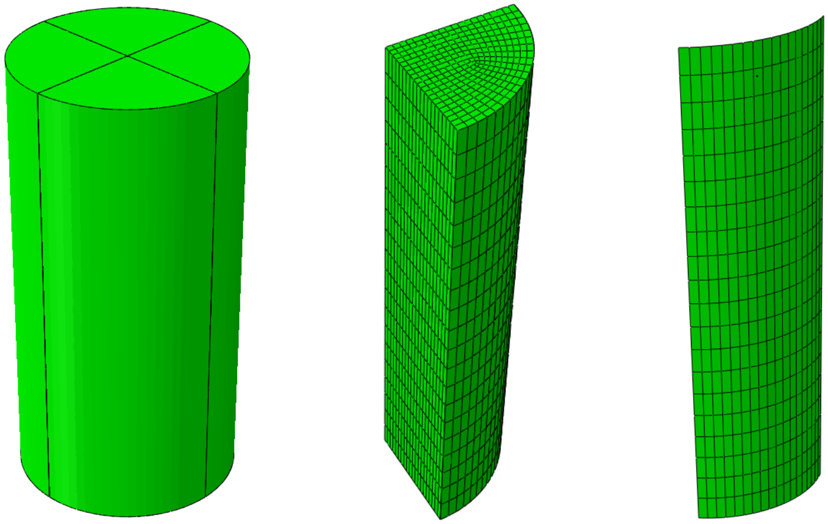
4. PROPOSED MODEL VERSUS EXPERIMENTAL RESULTS

In this study, the performance of a presented model using a modified Cyclic Degradation Plasticity Model (CDPM) for FRP confined concrete specimens is evaluated against experimental results found in existing literature. The presented model is designed to analyze FRP-confined concrete specimens with various cross-section shapes. The validation process involves comparing the predicted performance of the presented model with the actual experimental results.

Firstly, comparisons are made for the stress-strain response of the FRP-confined concrete specimens. The stress-strain behavior is a critical parameter that determines the structural response of the material under load. By analyzing the proposed model's predictions and comparing them to the experimental results, researchers can assess the model's accuracy and reliability in capturing the stress-strain response accurately.

Additionally, the lateral strain-axial strain response of the specimens is also compared. The lateral strain refers to the deformation occurring perpendicular to the applied load, while the axial strain refers to the deformation in the direction of the applied load. This comparison provides insights into the ability of the proposed model to capture the complex behavior of FRP-confined concrete under different loading conditions.

In the present work, experimental results obtained in monotonic uniaxial compression tests of cylindrical FRP-confined specimen, is compared with numerical predictions obtained with the suggested modified CDPM. The tested specimen was 100mm in diameter and 200mm in height, unconfined concrete compressive strength was 38 MPa, the thickness of FRP was 0.166mm and the specimen was wrapped with one layer of FRP. The details of the experimental results can be found in [14]. In the FE model, due to geometric and loading symmetry, only a quarter of cylinders was modelled, as illustrated in Fig. 3. Two different FE types (three dimensional 8-node linear bricks with reduced integration (C3D8R) and 4-node shell elements with reduced integration (S4R)) were used to discretize the concrete cylinders and the FRP jacket, respectively. Care was taken to ensure that the mesh had, as much as possible, a regular geometry. Several decreasing mesh sizes were studied to evaluate the convergence of the model.



(a) (b) (c)

Figure 3 Geometric representation of FE model: (a) full specimen, (b) mesh of 1/4 concrete specimen, and (c) mesh of 1/4 FRP jacket.

To visualize the comparisons, Figure 4 below presents the graphical representations of the Finite Element (FE) predictions using the presented model alongside the experimental results of Oliveira et al. [14]. Additionally, the analytical models developed by Teng et al. [7] are also included for reference. The figure provides a clear visual representation of the agreement or discrepancy between the presented model's predictions, experimental data, and other existing analytical models. Figure 5 how comparisons of the FE predictions with the test results of Oliveira et al. [14], Comparisons are shown for the lateral strain-axial strain response.

It can be seen from Figures. 4 and 5 that the FE results obtained using the proposed modified CDPM model are in close agreement with test results

Overall, this validation process is crucial for assessing the accuracy and effectiveness of the proposed model in predicting the behavior of FRP-confined concrete specimens. By comparing the stress-strain response and the lateral strain-axial strain response, researchers can gain insights into the model's performance and make any necessary adjustments or improvements to enhance its predictive capabilities.

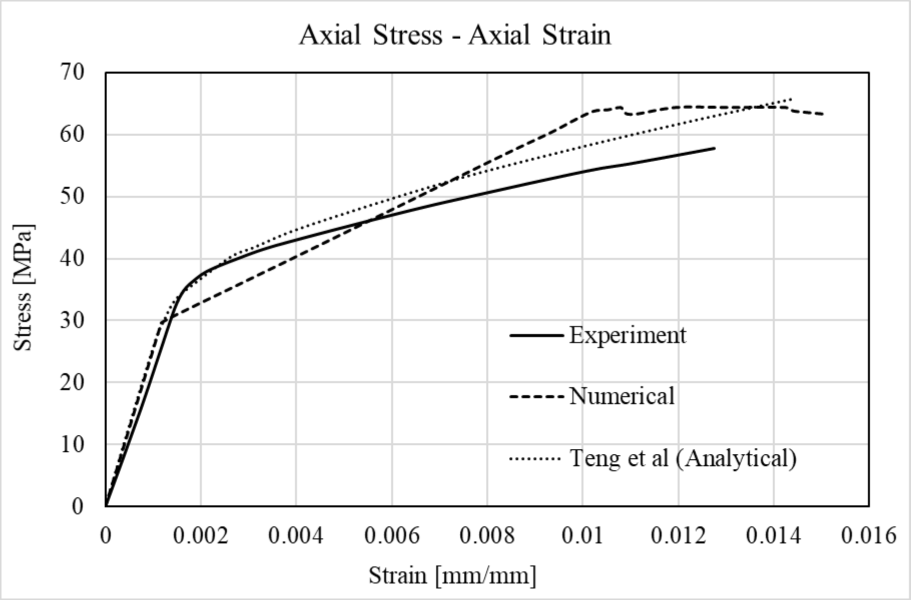


Figure 4 stress strain curve for expermental and numerical

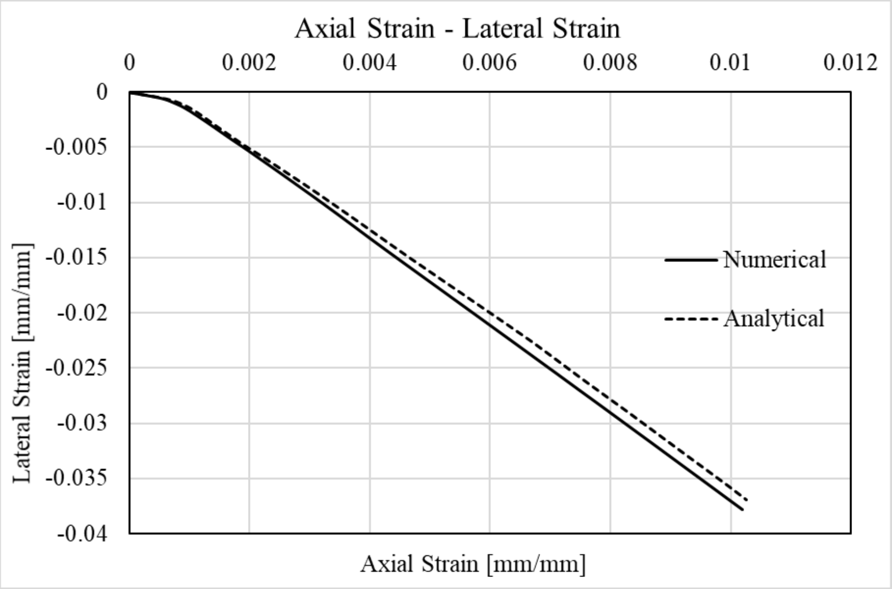


Figure 5 axial strain and latral starin

5. CONCLUSION

Tthis paper presented a 3D finite element modeling approach using the concrete damaged plasticity model in ABAQUS software for FRP-confined concrete columns under axial compression. A parametric study was conducted to assess the sensitivity of material parameters on the stress-strain and lateral strain-axial strain responses. Based on the results, modifications were proposed for the concrete damaged plasticity model, which demonstrated excellent agreement with experimental data from the literature. This research provides a reliable modeling method for predicting the behavior of FRP-confined concrete columns and contributes to safer and more efficient structural designs.

The outcomes of this study have practical implications for the design and analysis of FRP-confined concrete columns, leading to safer and more efficient structural solutions. This research opens avenues for further advancements in the understanding and utilization of FRP-confined concrete columns, ultimately benefiting the field of structural engineering.

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