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Modeling the response of ultra high performance fiber reinforced concrete beams

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Abstract

A finite element based numerical model is applied for tracing the response of Ultra High Performance Fiber Reinforced Concrete (UHPFRC) beams under the effects of flexural and shear dominant loading. The numerical model, developed in ABAQUS, accounts for superior strength properties of UHPFRC, including high compressive and tensile strength, and stain hardening effect in tension. The developed model can generate various response parameters including flexural and shear capacity, as well as load deflection response and propagation of cracks. Predictions from the model are compared with measured test data on UHPFRC beams, tested under dominant shear and flexure loading. The comparisons indicate that the model is capable of capturing the response of UHPFRC beams in the entire range of loading from preloading stage to failure through crushing of concrete or rupture of rebars.

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Keywords: Ultra High Performance Concrete; Finite Element Analysis; Concrete Damage Plasticity Model; Flexure, Shear.

1. Introduction

Extensive research and development efforts, over the past three decades, to improve properties of concrete have led to the emergence of ultra high performance concrete (UHPC). UHPC possesses very high compressive strength, good tensile strength, enhanced toughness, and durability properties [1]. However one of the main drawbacks of

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UHPC is its brittleness property. To overcome brittleness of UHPC, fibers are often added to UHPC and this type of concrete is referred to as ultrahigh performance fiber reinforced concrete (UHPFRC). Addition of fibers to UHPC can significantly improve its ductility, fracture toughness, and energy absorption capacity [1–3].

A number of experimental studies has been reported in literature on the response of UHPFRC beams [4–10]. Results from these studies indicate that increasing steel fiber content in UHPFRC enhance post cracking stiffness and thus improve load flexural capacity of UHPFRC beams. The reported test results also indicate that a higher shear capacity can be obtained by using a higher fiber volume content in UHPFRC and a lower shear span to depth ratio.

However only limited numerical studies are reported on the structural behavior of UHPFRC beams. Much of the reported numerical studies focused on applying sectional analysis approach to trace moment curvature response of UHPFRC beams under flexural loading [4,5]. There are limited finite element based numerical studies that simulated UHPFRC members. Mahmud et al [11] conducted two dimensional plane stress finite element analysis of unreinforced notched UHPFRC beams to study size effects on flexural capacity. Tysmans et al. [12] simulated the behavior of high performance fiber reinforced concrete under biaxial tension. Chen et al [13] focused on predicting load deflection (strain) response of UHPFRC girders subjected to shear and flexure. The authors showed that finite element model adopting concrete damage plasticity can accurately predict the load carrying capacity of the UHPFRC members. However, majority of these studies relied upon small-scale experiments for validation and focused on global response of UHPFRC structural members with no attention to local response (crack propagation).

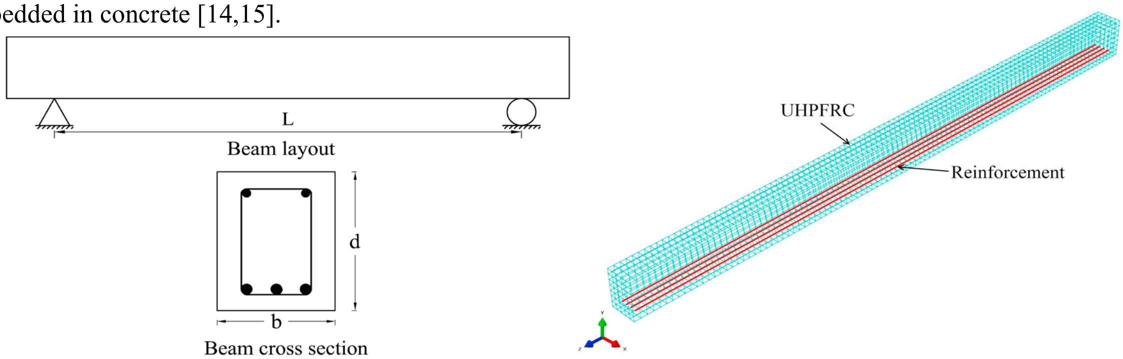
To address lack of numerical studies on UHPFRC at member level, a finite element based numerical model is developed. This paper presents the details of the numerical model to trace the structural response of UHPFRC beams. The model is validated against measured response parameters from full scale tests on UHPFRC beams under flexural and shear loading.

2. Numerical model

A numerical model for tracing structural behavior of UHPFRC beams under shear and flexural loading is developed in ABAQUS. The analysis carried out through load control technique by incrementing load on the beam in steps till failure occurs. Details of the numerical model including discretization details and material models are presented below.

2.1. Discretization of the beams

UHPFRC beams are discretized using eight-noded reduced integration brick elements (C3D8R) and two-noded link elements (T3D2) for concrete and reinforcing steel, respectively. C3D8 element has eight nodes with three degrees of freedom. This element can be used for 3D modeling of solids with or without reinforcement and it is capable of accounting for cracking of concrete in tension, crushing of concrete in compression, creep effects and large strains [14,15]. T3D2 elements are used to model one-dimensional reinforcing bars that are assumed to deform by axial stretching only. Discretization of a typical UHPFRC beam is shown in Fig. 1. The interaction between concrete and reinforcement is achieved by using the embedded region constraint, i.e. defining reinforcement to be embedded in concrete [14,15].



(a) Typical beam (b) Discretized beam