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Three-dimensional finite element analysis of circular reinforced concrete column confined with FRP using plasticity model

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Abstract

A prediction of reinforced concrete column capacity confined with FRP remains one of the challenging research area. One of the challenges are the inaccuracy of the effective confinement area of the concrete core which is used to estimate the reinforced concrete (RC) columns capacity. Considering these challenges, the use of plasticity model to predict the behavior of FRP wrapped RC column is a very attractive solution. In this study, a three dimensional non-linear finite element analysis based on plasticity formulation is presented. The proposed flow rule is able to automatically adjust the dilation rate of concrete from the state of active to passive confinement and vice versa. The flow rule has a specific dilation rate formulation that includes the lateral modulus (E_L) parameter to observe the confinement effectiveness. This study focuses on the modelling of circular reinforced concrete column confined with FRP using FEM. The steel rebar is modelled as a truss element with elastic-perfectly plastic material behavior. Both the concrete and FRP elements are modelled as 8-noded hexahedral element. FRP elements are considered as transversally isotropic material with determined fibers orientation. The non-linear analysis performed using the finite element code developed by the authors. For comparisons, a validation of the predicted stress-strain responses with the experimental results are presented.

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1. Introduction

In high seismic region, the building structure must have sufficient ductility to withstand the loads during the earthquake. However, many buildings may not be properly design based on the building codes. This will increase the possibility of structural failures and can cause loss of life. One of the efforts to prevent the structural failures is to enforce new building structures to meet the minimum requirements based on the building codes. However, for old buildings, strengthening the structures may be required. The strengthening could be done in slabs, beams or columns. In this study, the focus is on the modeling of RC columns strengthened with fiber reinforced polymer (FRP) wrap.

In recent years, there has been lots of effort to predict the responses of concrete confined with FRP. These research has been carried out due to the inaccuracy of the models obtained using actively confined concrete [1]. Generally, the response predicted using active model will overestimate the responses obtained from experimental results. The error is more pronounce in FRP with extremely high elastic modulus or when the multiple layers of FRP wrap were used. This finding has led into the development in new empirical [2-7] and plasticity models for FRP wrapped concrete columns [8,9]. However, different researchers have different methods to deal with this problem. These methods can be summarized as: a) adjusting the failure surfaces from the state of active to passive confinement, b) adjusting the lateral strain prediction of the constitutive law, c) introducing the effective confining pressure.

Most of these models were carried out at the constitutive level. At this level, the deformation compatibility between concrete core and the external confining device (such as FRP wraps) are determined from the compatibility equation. Perfect bond between both materials were assumed. The challenges in the modeling of RC column at the constitutive level with and without FRP are located in the estimation of the effective confinement area, the calculation of the exerted lateral pressure, the prediction of the peak stress and the residual stress. This issues can be eliminated using FEA. The works using finite element analysis (FEA) based on plasticity model formulation have been carried out by several researchers. However, in this study, only few of them were highlighted. Lo et. al. [10] used two dimensional (sectional method) finite element analysis with triangular elements which is not able to capture the confining area in longitudinal direction. Luccioni's [11] used axisymmetric elements with plasticity damage model. Teng et. al. [8,9,12] used a simplified three dimensional model which may not give complete information in comparison to full 3D FEA. However, full three dimensional analysis of RC columns confined with FRP in the literature are found to be rare.

In this paper, a full three-dimensional finite element analysis was carried out. A plasticity based constitutive model for concrete developed by the author's [13,14] were used. The failure surface is based on Menetrey and Willam's [15] model. The failure surface was further enhanced with additional frictional driver parameter. This frictional driver parameter will enforce any type of empirical formulation that defines the peak and residual failure surfaces into the plasticity format. The empirical formulations used to define the failure surfaces are based on [16,17]. The proposed flow rule has a plastic dilation rate control parameter that is able to distinguish between active and passive confinement during the analysis. The plastic dilation rate is governed by the stiffness of confining devices and calculated at each finite step. The proposed model is implemented in finite element code developed by the authors.

Finally, in order to validate the accuracy of the proposed model, the model is compared with the available experimental results in the literature. Matthys's [18] experimental results are used for comparisons which consist of reinforced concrete columns being strengthened with various FRP wraps. In order to see the performance of the proposed model in comparison with other plasticity models, Papanikolau et. al.'s [19] and Bao et. al.'s [20] were included in the comparisons.

2. Plasticity Model

The proposed model formulation is based on modified Menetrey and Willam's (See [15]) which can be categorized as three parameter failure surfaces. An additional parameter called the frictional driver parameter (α) is introduced to adjust the peak and residual failure surfaces. The general equation of the failure surface is written in three cylindrical coordinates, the hydrostatic length (ξ), the deviatoric length (ρ) and the lode angle (θ). The general

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