International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 /doi:10.14445/22315381/IJETT-V69I2P203

Volume 69 Issue 2, 19-24, February 2021

Repercussion on Plastic Zones Formed in Vertically Oriented Planar Wall

Vikram S. Singh[1*], Keshav K. Sangle[2]

[1]*Research Scholar, Department of Structural Engineering, Veermata Jijabai Technological Institute, Mumbai, 400019, India*
[2]*Professor, Department of Structural Engineering, Veermata Jijabai Technological Institute, Mumbai, 400019, India*

Abstract - *Vertically oriented planar wall has become very popular worldwide for stabilizing the high-rise structures against the lateral forces. In contrast, very little research, primarily lead to problems in accurately modelling the complicated behaviour of concrete, has indeed been concerned with simulation. A simple yet versatile finite element (FE) model for the simulation of shear wall behaviour with varying mesh sizes is presented in this paper. To capture the concrete-to-reinforcement relationship behaviour, a concrete damage plasticity model is proposed. Also, for carrying out effective simulation of concrete structures, much more important constitutive model available in ABAQUS is Concrete Damaged Plasticity (CDP). It only needs the specific material parameters (i.e. no arbitrary user specified parameter is needed, like that of the shear retention factor) as well can be implemented directly in the ABAQUS CAE software. These are two additional advantages in conjunction to accuracy that model has. Model predictions are contrasted with actual experimental data on shear walls subject to monotonous loading conditions. Further investigation was carried out by simulating the wall with varying mesh sizes for observing the effect of mesh sizes on to the plastic zone which is formed at the base of shear wall under extreme loading condition***.***

Keywords — *ABAQUS CAE, Nonlinear Analysis, Plastic Zone, Plastic Hinge, Vertically Oriented Planar Shear Wall.*

I. INTRODUCTION

In several software that are based on the Finite Element Methods, various mathematical models are developed as well as enforced for carrying out simulation of reinforced concrete to observe its nonlinearity. In analyzes, nonlinearity of the material is being applied through models with the so-called localized as well as distributed plasticity. The simplest are concentrated plasticity models where formation of plastic joints takes place leading to nonlinear behavior. The most commonly defined behavior is the relationship of moment-rotation or force-displacement. Distributed plasticity models more efficiently simulate non-linear behavior in relation to concentrated plasticity [1] and [2]. That can be formed by the application of fibrous cross sections for simulating distributed plasticity on the cross-sectional surface and by the element length in the integration points respectively. Deployment of a distributed plastic model may be portrayed either with the formulations of the displacement-based model or with force-based [3] and [4]. There are also known continuum mechanics-based models, in which discretization of concrete with 3-D solid elements and its reinforcing is discretized with rods and beam elements, in addition to the modelling of the reinforced concrete structure in the case of nonlinearity as described earlier. The major benefit of these models has been that the triaxial stress are being implemented in the analysis in different varieties of reinforced concrete structures and various fracture regimes (e.g. cracks, shear fracture, concrete crushing etc.). The interaction of different kinds of element degradation (e.g. effects of reinforcement and damage to cement) is taken into account. In this paper, the RC wall is exposed to monotonically increasing static load, for observing its nonlinearity. Concrete Damaged Plasticity (CDP) model, implemented in the software know as Abaqus CAE [5], for simulation of the concrete part of the member under nonlinearity. The model was concrete damage model based on continuum plasticity that offers concrete a general modelling capability as well as the trusses, beams, solids and shells (quasi-brittle materials). The research was conducted on the basis of a state of plane stress. The 3-dimensional finite elements C3D8 were applied to discretize the concrete component. A comparable evaluation was carried using a fibrous model in accordance with linear finite elements having force-based formulations implemented in the software. In this article, two models were introduced to simulate the nonlinear behaviour of the RC wall, monotonically subjected to static load. The very first approach is the so-called continuum mechanics-based model, where the CDP principle is used and applied in the Abaqus software for simulating the model and the comparative model used had fibrous cross- sections with distributed plasticity that was analyzed in the SeismoStruct software [6]. Esfahani et. al. proposed a simplified concrete damage plasticity model along with the strain-based damage mechanics model based on a tabular structure for four different concrete grades for the unconfined prestressed concrete structure merged a stress-based plasticity function [7]. The theory of the Sidiroff energy equivalent as well as strain equivalent, and the method for evaluating plastic-damage variables in the CDP model, was introduced by the comparative study of the CDP model and the special concrete model under this framework

[8]. Research investigated the experimental as well as numerical properties of the shear walls and also illustrated parametric influence on the lateral resisting capabilities of the various steel thicknesses of the walls [9]. 8-noded solid elements with relax stiffness hourglass control and reduced integration for concrete element is used in ABAQUS CAE. Concrete's plastic stress strain relationship using some default parameters in the concrete damaged plasticity (CDP) model is generally used for analyzing concrete behaviour [10].

II. MODELLING APPROACHES

The model implemented in this paper to simulate nonlinear concrete behavior which, portrays a plasticity-based, damage model is called as Concrete Damaged Plasticity (CDP). That can be used for any model under static as well as dynamic loads. In Abaqus the plastic-damage model is inspired by the approach developed by Lee and Fenves [11] and Lubliner et al. [12]. For this model, fracture mechanisms are generally the cracks caused by tensile and crushing of concrete under pressure. Concrete behavior in cracked state is represented by dt and dc (scalar variables), used to correct the section's elastic stiffness and are dependent on plastic dilation, temperature and other parameters [5]. Concrete behavior in pressure and uniaxial tension is shown in Fig. 3. It aslo shows the failure envelope in plane stress state and in the deviator plan. In this model, the parameter used are (with usual values in brackets): “Kc - proportion of the distance between the hydrostatic axis and the compression meridian and the tension meridian in the deviatoric cross section, respectively” (usually 2/3), ψ – frictional material observes dilation which is the inelastic volume transition phenomenon due to plastic deviation (13 °,[13]), fbo / fco – ratio of the uniaxial and biaxial compressive strengths (1.16), ϵ –plastic potential surface’s eccentricity (0.1) and μ – viscosity parameter which represents the viscoplastic relaxation time (0). Table 1. displays the model parameters implemented in this paper. On the given recommendations [14], values of scalar dt and dc variables for regulating concrete behavior in a cracked state are set. Within this article a comparative study of the reinforced concrete wall member is carried out, based on the fibrous cross sections that is an element typical of the RC is discretized. The concrete portion of the cross section is designed as unconfined (concrete cover to reinforcement layer) and confined (section core) using the Mander model for stress-strain relationship. Distributed frame elements of inelasticity are implemented with power-based formulations of finite elements, with five integration points per unit length (Gauss-Lobatto integration).

III. TEST SPECIMEN

Structural wall (SW21) which was previously tested by Lefas et al. [15] is regarded with simplified approach in this article. SW21 was tested with the upper beam subjected to static horizontal load. Wall measuring as 650 mm wall length, 1300 mm wall height and 65 mm as the wall thickness having aspect ratio of 2. Wall is subjected to horizontal load, with beam dimension as 1150 mm on the upper beam, 150 mm long and 200 mm deep. Perhaps it served as an enclosure for vertical bar anchorages. The wall is connected to both a lower beam and an upper beam that behaves monolithically. The lower beam is engineered with fixed constraints having length, width and depth as respectively 1150 mm, 300 mm and 200 mm as showcased in Fig. 1. Along with the reinforcement descriptions the model with dimension is shown in Fig. 1. The 8 mm diameter vertical and 6.25 mm horizontal reinforcement is made of high yielding strength deformed bars.

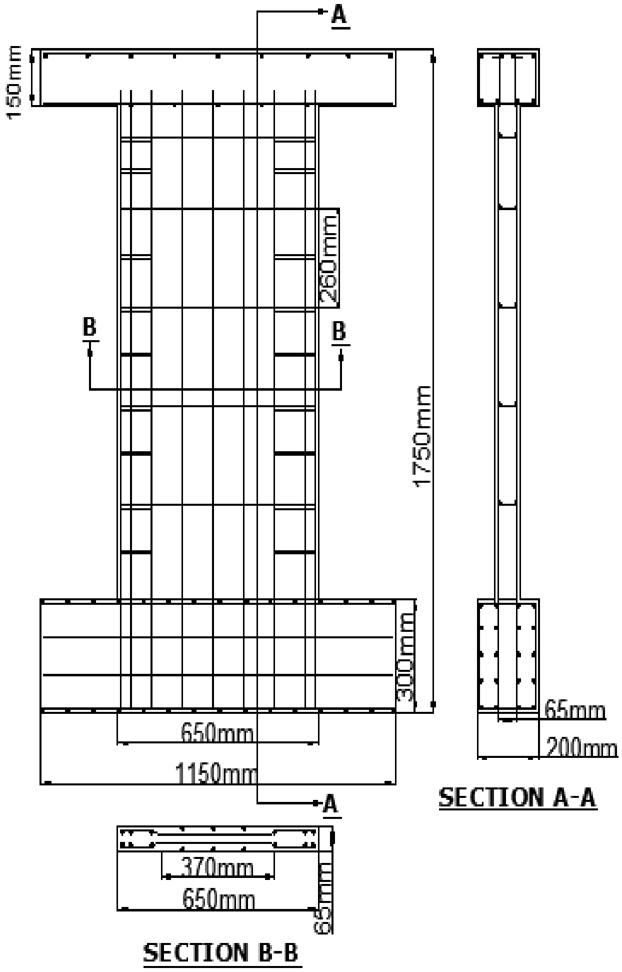


Fig. 1. Dimension and reinforcement pattern of SW21 [10]

The wall edges were restricted by adding more horizontal reinforcement by means of stirrups. Both the concrete as well as steel characteristics are summarized in Table 1. Laboratory model SW21 deformed 20.61 mm at a charge of 127 kN. Fig. 2. shows how the test result and the analytical result for a vertically oriented planar shear wall are compared using the load-displacement curve.

Table 1. Material properties of structural wall specimen (All dimensions in Mpa)

Wall Properties	Steel		Concrete	
	E_s	F_y	E_c	F_c
SW21	200000	415	33541	45

IV. VALIDATION

The average displacement of 19.52 mm was perceived under lateral load of 127 kN on the top of the SW21. Along with the variance of about 5 per cent, these analytical results are in full compliance with the test results. Fig. 2. signifies that, at the beginning of the simulation until the load of 127 kN, the displacement at the top was seen as predicted, the load-deflection response of the vertically oriented planar wall is in near agreement with the experimental response. For model SW21 a parametric investigation is considered based on different parameters that could be used to explain the effect of mesh sizes on formation of plastic hinges zones in vertically oriented planar shear walls. In this study, the value of the Equivalent Plastic Strain (PEEQ) is also discussed with detailed comparison of models with different mesh sizes (M1, M2 and M3).

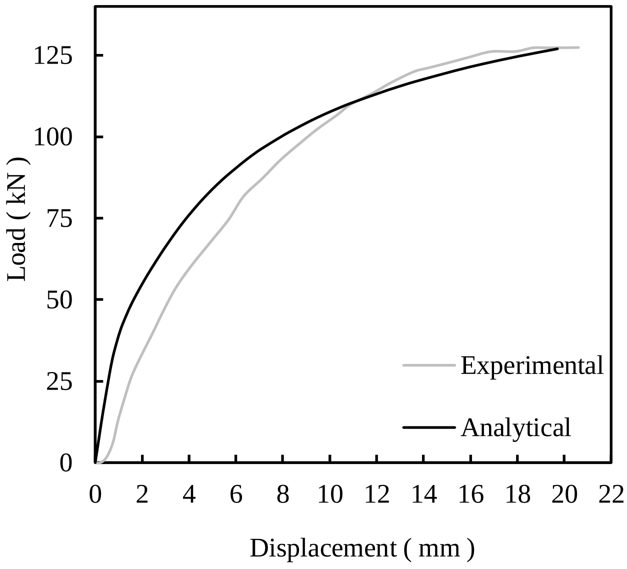


Fig. 2. Comparison of load vs displacement curve obtained analytically with the experimental result

V. CONCRETE DAMAGED PLASTICITY MODEL

For simulating the concrete's behaviour, tensile plasticity as well as isotropic compressive together with isotropic damaged elasticity is the base of CDP. The equivalent plastic strain in tension as well as compression, in connection with tensile cracking and compressive crushing failure mechanisms respectively controls the advancement of yield surface. Modulus of elasticity, Eo and poisson's ratio, v is what required for the elastic behaviour. For tension and compression, the development of damage and post yield stress must be well-defined as a function of cracking strain and inelastic strain, respectively. Flow potential eccentricity, dilatancy angle, ratio of second stress invariant on the compressive meridian and tensile meridian and ratio of initial equibiaxial to uniaxial compressive yield stress, all these defines yield function.

A. Compression and Tension Behaviour

The material in compression until the initial yield stress is grasped is linear and hardened, accompanied with strain softening, before the full stress is achieved. When tension is exerted, the stress increases linearly until micro-cracks are initiated in material and after which the stress strain behaviour softens.

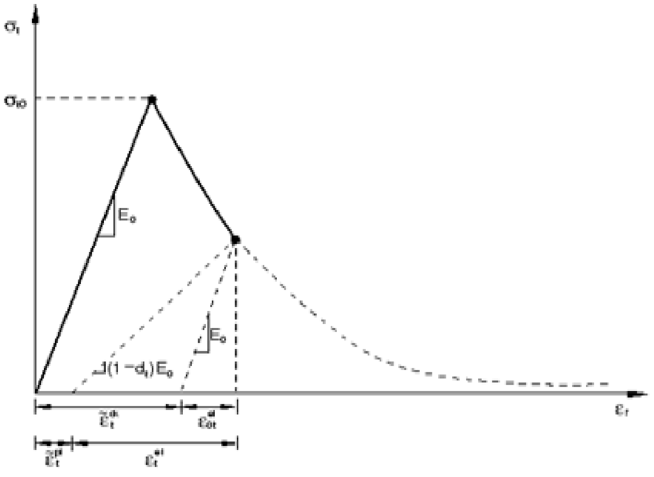


Fig. 3. Concrete's response to uniaxial loading - Tension curve [5]

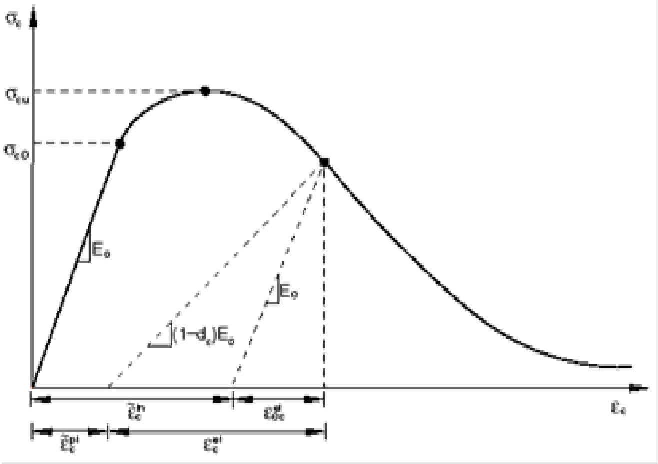


Fig. 4. Concrete's response to uniaxial loading - Compression curve [5]

To describe the post-yield behavior, stresses be expressed by function of cracking strain in tension and inelastic strain in compression that are obtained by deducting elastic strain from overall strain. Depending on damage's evolution, it is automatically converted into a stress plastic stress relationship by ABAQUS. Fig. 3. and Fig. 4. shows the constitutive concrete's response under uniaxial loading as tension curve and compression curve respectively.

B. Damage Parameters

Undamaged material will exhibit same initial elastic stiffness as that of material during unloading. When unloaded from a point further than the yield in compression or tension, concrete showcases a relatively weak response. The above weak response during unloading, stiffness is called as degraded stiffness or damaged stiffness, that is a portion of the initial elastic stiffness. Therefore, the defining the degradation of stiffness is of special importance for analyses that involve reversible stresses, such as dynamic loading or quasi-static cyclic loading. (1-dt) and (1-dc) in CDP model are the variables that describe the damaged stiffness in tension and compression respectively. dc and dt are given by,

$$d_c = 1 - \frac{\sigma_c E_o^{-1}}{\varepsilon_c - \tilde{\varepsilon}_c^{pl}} \; ; \; d_t = 1 - \frac{\sigma_t E_o^{-1}}{\varepsilon_t - \tilde{\varepsilon}_t^{pl}}$$

VI. FINITE ELEMENT ANALYSIS

As per the previously described formulation of damage plasticity, three separate mesh sizes 20, 40 and 80 mm have been introduced within the simulating system. Design of the variable scalar compression and tension damage for meshes of 20, 40 and 80 mm has been defined as M1, M2 and M3 respectively throughout. The general structure for the formulation of plasticity damage has been defined and evaluated and it can be widened to many other grades of concrete with compatible mesh sizes as required. Simulation was carried out by creating a nodal displacement boundary condition on the top beam with a maximum displacement of 52 mm (4 % of wall height).

A. Load-Deflection Response

When a vertically oriented planar shear wall deforms every element produces certain deformation. The impact of the deformation of the element is superimposed jointly to show an overall load-displacement curve for the vertically oriented planar shear wall. Fig. 5. displays the load-displacement curve for all models with different mesh sizes, as discussed earlier. It has been clearly observed that the maximum deformation of 103.50 kN for M3, 101.95 kN for M2 and 99.42 kN for M1. Difference between the mesh sizes have no impacted much to the load, yet it is found to be around 1-2% of the overall load with maximum deflection of 52 mm.

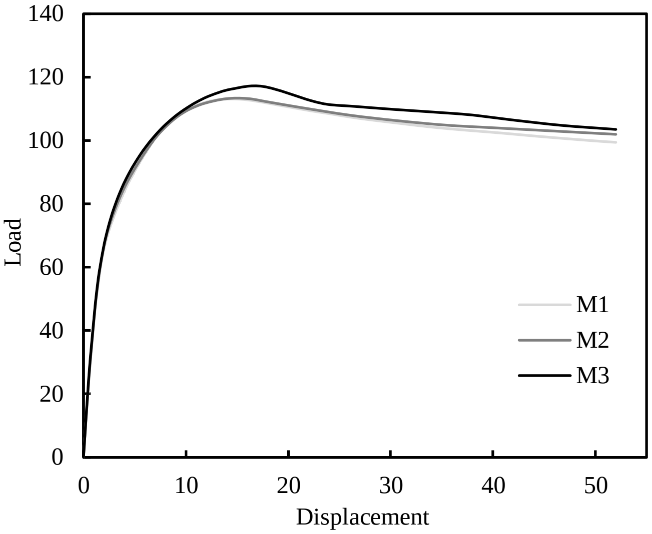


Fig. 5. Load vs displacement comparison of models with varying mesh size

B. Plastic Strain

A state of yield formulated within the effective stress space is being used by the plastic portion which is generally local in behaviour. Through the model's damage part softening is buildup. Damage is related to plastic strain evolution and it is known to be isotropic. A special group of integral-type non-local damage-plastic models, for which the damage part is driven by a non-local measure of the plastic strains, was studied analytically. In the finite element method, a discontinuous strain rate usually corresponds to a fully localized zone of plastic strains, which is related to the finite element mesh sizes [16].

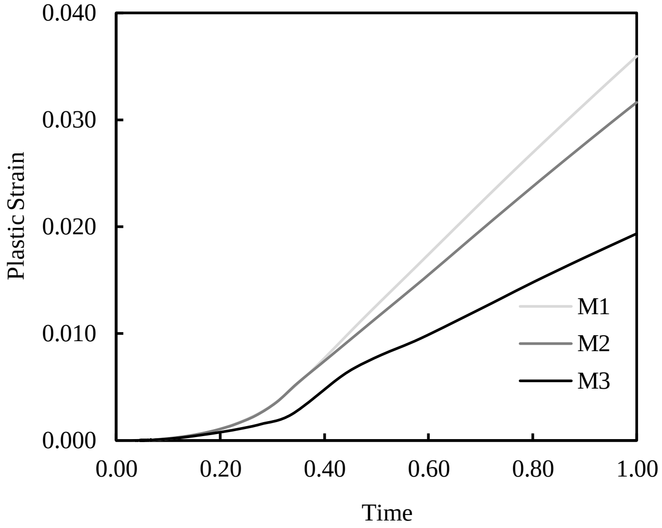
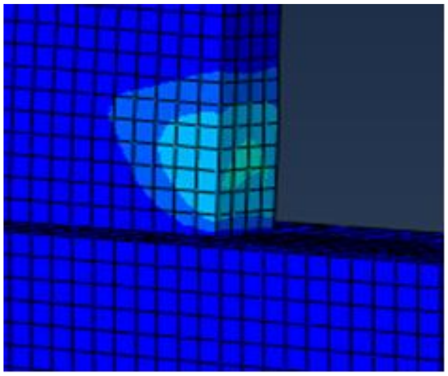


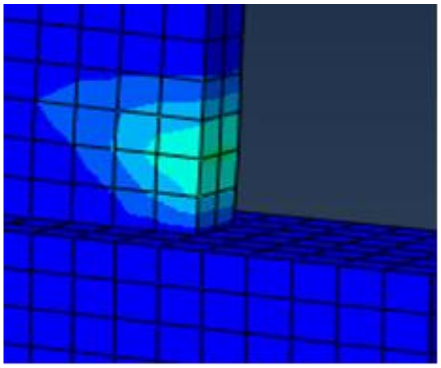
Fig. 6. Incrementation of the plastic strains at three different mesh sizes

C. Plastic Hinge Zone

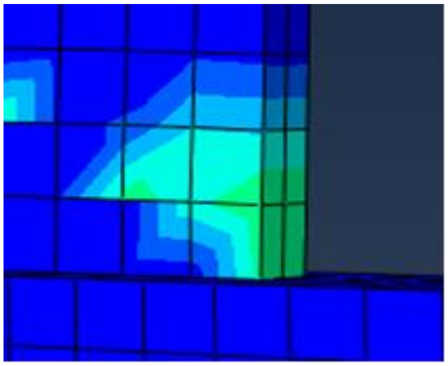
Creation of plastic hinge in regions with plastic behavior in a shear wall depends on multiple factors. The actual physical range, the distribution of plasticity, is bigger and more so called as a plastic hinge zone. It is hypothesized that the wall sections have non-uniformly distributed plastic strains, particularly at the bottom one third in the wall as shown in Fig. 7. Throughout nonlinear methods of analysis, the nonlinear material model of the shear wall is usually predicated on the plastic zones through the plastic hinge in the structural wall.



(a) M1



(b) M2



(c) M3

Fig. 7. Plastic zone observed on compression side of wall

with different mesh sizes

VII. CONCLUSION

This article presents the results of a detailed evaluation of the analytically expected plastic hinge zone of a vertically oriented planar shear wall obtained using modeling approaches with different mesh sizes specified in ABAQUS. For understanding the structural failure, it is of utmost importance to locate the plastic hinge zone. These days codal requirement makes it mandatory to conduct nonlinear structure analysis to make the system safer. In this article, the significance of the analysis is to find the exact position and shape of the plastic hinge zone in a vertically oriented planar structure with different mesh sizes and to determine the best compatible mesh size along with concrete plasticity parameters for damage. Finding the plastic hinge location would also help the designer basically stabilize the portion where the hinges are present. These shear wall with more reinforcement can help to make structure stiffer. Equivalent plastic strain formation at the base of the shear wall also predicts where plastic hinge is located. Finite element (FE) technique was introduced to investigate the failure pattern at the base of the shear wall structure. Best mesh size helped monitor the plastic hinge zone as the load applied increases before it reaches the full displacement. It portrays that the equivalent mesh sizes of the unit in a structure plays a significant role in predicting and evaluating the vertically oriented planar wall plastic hinge region.

NOMENCLATURE

d_c	Damaged stiffness in compression
E_o	Modulus of elasticity
E_c	Compressive strain
σ_c	Compressive stress
d_t	Damaged stiffness in tension
E^{pl}	Equivalent plastic strain
E_t	Tensile strain
σ_t	Tensile strain
ϵ	Plastic potential surface’s eccentricity
μ	Viscosity parameter

ACKNOWLEDGMENT

This research work has not received any funding from any agencies/boards. The authors are grateful to the authorities of Veermata Jijabai Technological Institute and AICTE for their continuous support and encouragement for the smooth conduction of the research work.

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