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Simulation of reinforced concrete short shear wall subjected to cyclic loading

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HIGHLIGHTS

- Prediction of the capacity of squat shear wall using tests and analysis.
- Modification of model of concrete in the softening part.
- Pushover analysis using softened truss theory and FE analysis is performed.
- Modified concrete model gives reasonable accurate peak load and displacement.
- The ductility, ultimate load and also crack pattern can be accurately predicted.

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ABSTRACT

This paper addresses the strength and deformation capacity of stiff squat shear wall subjected to monotonic and pseudo-static cyclic loading using experiments and analysis. Reinforced concrete squat shear walls offer great potential for lateral load resistance and the failure mode of these shear walls is brittle shear mode. Shear strength of these shear walls depend strongly on softening of concrete struts in principal compression direction due to principal tension in other direction. In this work simulation of the behavior of a squat shear wall is accurately predicted by finite element modeling by incorporating the appropriate softening model in the program. Modification of model of concrete in the softening part is suggested and reduction factor given by Vecchio et al. (1994) is used in the model. The accuracy of modeling is confirmed by comparing the simulated response with experimental one. The crack pattern generated from the 3D model is compared with that obtained from experiments. The load deflection for monotonic loads is also obtained using softened truss theory and compared with experimental one.

1. Introduction

Shear walls are the reinforced concrete elements that provide substantial strength and stiffness as well as the deformation capacity needed to meet the demands of strong earthquake ground motions. Due to the role they play as a structure's horizontal force resisting system, the ability to accurately predict and model shear wall behavior is of utmost importance. Use of realistic concrete models will therefore, improve the evaluation of these lateral load resisting components.

In nuclear power plants, massive low rise and squat shear walls are present. For these low rise shear walls, designed with proper boundary elements, flexure and sliding shear failure does not occur. These shear walls generally fail in shear. When these shear walls are subjected to cyclic loading diagonal cracks are formed in two directions; following the formation of the diagonal cracks, either the concrete crushes or the reinforcement yields extensively. Earlier, lot of experiments have been carried out by researchers (Lefas et al., 1990; Lopes, 2001a,b) on low rise shear walls. Another work is based on path dependent constitutive model of RC elements and the dynamic equilibrium (Kazaz et al., 2006). Also predictions of the behavior of the shear walls for monotonic static and cyclic loading using finite element analysis and simplified approaches has been carried out (Vecchio et al., 1994; Palermo and Vecchio, 2002; Lopes, 2001a,b). The models used were able to predict the maximum load more accurately than the displacements at the peak load. The ductility of the walls could not be accurately predicted and

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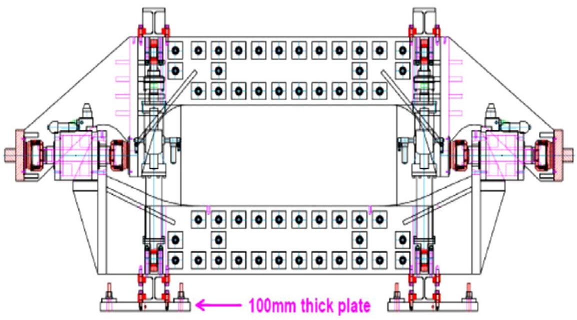

Fig. 1. Test setup.

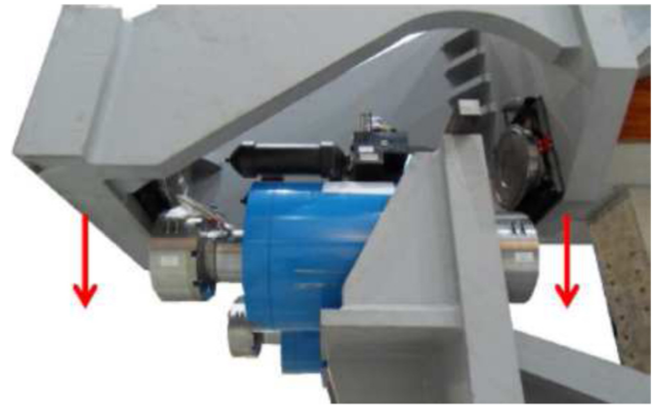

Fig. 2. Mounting of actuator.

also accurate prediction of crack pattern from FE analysis was difficult. From the literature available it is found that improvement in the ductility model and hysteretic response of the shear walls was needed. More realistic unloading–reloading curves in compression and tension and damage to the concrete upon reloading have to be precisely incorporated in the analytical models.

Experiments were performed on stiff shear wall of 3 m width, 1.2 m height and 0.4 m thick in an ongoing experimental program at JRC, Italy in IRIS project. The shear wall with axial load of 60 tons was subjected to pseudo-static cyclic loading and the important parameters like load, displacements, reinforcement strains were monitored. The main objective of this paper is to present the analytical work for the pseudo-static cyclic test carried out on this stiff shear wall and compare the force displacement characteristics obtained from analysis with that obtained from test. Modification of model of concrete in the softening part is suggested and reduction factor given by Vecchio et al. (1994) is used in the model. Appropriate constitutive model is formulated on the basis of nonlinearity of concrete and reinforcement and using these models, FE analysis is performed. The model considers tension stiffening in tension and degradation of stiffness and strength in compression based on Collin's theory. Reinforcement is modeled by bi-linear relationship. In this paper FE 3D analysis is also carried out using the above model. Moreover, the backbone curve is estimated using softened truss theory. The comparison of analysis and test results is presented explicitly.

2. Experimental program

A squat short shear wall of width 3 m, 1.2 m height and 0.4 m thick was tested at JRC, Italy the test program was called TESSH (TEsts on Strong SHear wall). Vertical reinforcement consisted of 22 bars of 16 mm ϕ arranged in 2 layers and horizontal reinforcement consisted of 6 bars of 16 mm ϕ arranged in 2 layers. Top and bottom beams were 4 m long, 0.8 m deep and 1.25 m thick. The schematic test setup is shown in Fig. 1. Vertically 60 tons of load was applied by vertical actuators. There was control of rotation of the shear wall during testing however vertical displacements were allowed. Rigid loading device was designed such that it should transfer the load and should be easily mountable. The shear wall is loaded in pure shear with no rotations allowed and the structure was connected to reaction wall. There were four horizontal actuators each actuator having capacity of 300 tons with total capacity 1200 tons. The mounting of the actuator is shown in Fig. 2. Instrumentation was carried out using optical measurements to measure the crack width and crack pattern. Two cameras were arranged on either side of shear wall. The cameras were kept 3.3 m away from the shear wall. Cyclic loading was applied initially starting with 3 cycles of 50 tons. Then 2 cycles each of 100, 200, 300, 400, 500, 600, 650, 700 and 750 tons were applied. The ultimate load of the wall at cyclic horizontal load of amplitude 750 tons was obtained. Finally monotonic loading test was conducted till failure of the wall. The force deformation relation obtained from the tests is shown in Fig. 9.

3. FE model and material constitutive law

3.1. FE model

In complex 3D-RC shear wall slab structures, concrete with material nonlinearity is modeled using 4 noded iso-parametric 2D plane quadrilateral elements for wall, top and bottom beams. Steel is modeled in discrete form of truss element for wall and smeared form in the top and bottom beams. The FE model of shear wall 3 m width, 1.2 m height and 0.4 m thick is shown in Fig. 3. The RC wall has been investigated through 2D non-linear FE analyses. Concrete strength f_{ck} is 54 MPa. Steel strength is 500 MPa. During the experiment, the wall was fixed at the base and the test was conducted for pure shear case however vertical deformations were allowed to take place. Also the axial load applied on the wall was 60 tons.

3.2. Concrete material constitutive model

The constitutive model is formulated on the basis of nonlinearity of concrete. Concrete model is a damaged-based model in which a smeared approach is used to model both cracks. This model comprises non-linear compressive behavior that is capable of modeling, hardening and softening. The pre-peak relation is based on

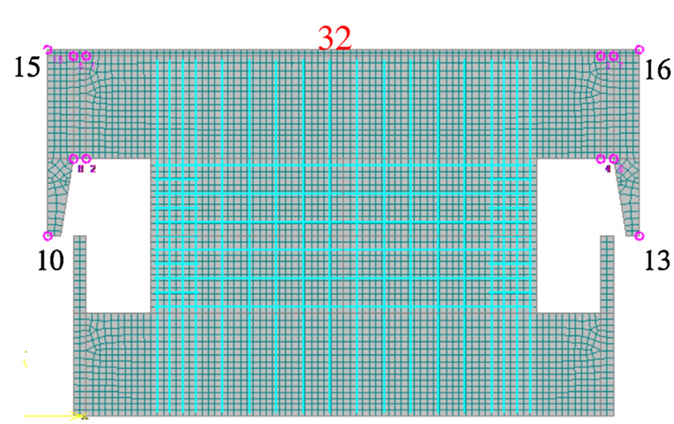

Fig. 3. FE model.