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Analytical Study on Seismic Behavior of Rectangular Shear Wall Connected to Floor Slabs

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Abstract

For construction of reinforced concrete buildings over four stories, structural walls are the predominant form for lateral load resistance under earthquakes. Current Indian seismic code for design of frame shear wall buildings (FSWB) do not explicitly consider the forces transferred from the floor slabs to the shear wall for seismic design. To assess stress concentration at the wall-slab junction region of the building and to observe the extent of possible damages in wall, slab and their junction region, nonlinear static analyses is carried out using ABAQUS program. Further, a wall-slab sub-assemblage is also analyzed to stimulate the observed behavior of the walls in the multistoried buildings and the behavior is compared with the isolated cantilever shear wall. The main intention of the study carried out is to study the behavior of the junction region between the shear wall and the floor slab and to develop a simplified but efficient analytical model to analyse a shear wall - floor slab junction. It is observed that the presence of floor slab at different levels along the height of slender shear wall tends to partition the wall into squat wall panels between two consecutive floors. Thus, an overall seismic design methodology for damage avoidance behavior of floor slabs in multistoried RC frame-wall building needs to be evolved.

Keywords: Concrete Shear wall, floor slab, seismic behavior, wall-slab junction, damage pattern, strut action.

1. Introduction

Reinforced concrete structural walls are commonly used for resisting lateral forces imposed by earthquakes. Therefore, RC structural walls are widely used in new structures as well as in rehabilitating existing RC buildings with inadequate lateral force resisting systems. In RC buildings, the junction between the floor slabs and the shear walls plays a major role in determining the transfer of forces into the walls and finally to the foundation. From the past experimental research, it is observed that the junction between the shear wall and the slab is subjected to severe stress concentration [1]. The shear wall considered for analysis is squat in nature, and no study has been carried out on slender shear wall partitioned by floor slabs. Although various studies have been carried out on coupling action of beam and floor slab in building with shear walls, the behavior of shear wall-floor slab junction has not been studied extensively. Using finite element modelling and experimental studies, the bending stiffness of floor slab and its effects on the distribution of bending moments and stresses in slab have been investigated [2-5]. None of the past studies has focused on detailed investigation of the behavior of floor slab and shear wall junction under earthquake shaking.

Conventionally, design of a slender RC wall is carried out against combined axial compression and bending moment at the base of the wall. Past research has focused on determination of various failure modes in slender walls by both analytical methods [6-7] and experiments [8-11]. Different approaches of shear wall modelling have been attempted to simulate the most realistic behavior. The RC shear wall without boundary element can be modeled using four-noded plane elements considering the top slab to be rigid [12]. Kim et al. [13] developed a three-dimensional super element for shear walls and floor slabs and a substructure was formed by assembling the super element to reduce the time required for modeling and analysis.

In the past, research has been carried out using vertical stirrups as shear reinforcement in the coupling slabs along the periphery of wall to enhance the strength of the slab. It was proposed that the design of slab-wall connection must be done considering the stress concentration to avoid redistribution of forces from walls to other elements not necessarily designed for lateral load resistance [14]. Apart from monolithic slab-wall junctions, behavior of precast slab-wall junction has been investigated experimentally. The mathematical models, strut and tie model and modified

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stiffness matrix method are proposed in order to analyze both monolithic and precast type of connections [15]. Experiments have been carried out on RC slab-squat wall panel under monotonic and cyclic lateral forces to obtain the inelastic behavior in the members. It was observed that RC slab can undergo significant damage which gets initiated from wall-slab junction [16]. However, in none of the studies seismic design of slab-wall junction in light of damages in slab and wall, has been considered. Also, the effects of possible earthquake ground motions have not been investigated.

Considering the limited research on seismic behavior of shear wall-slab junction, nonlinear static analysis is carried out to study the behavior of three different models namely, (a) one five storied frame-wall building, (b) exterior shear wall-floor slab assemblage, and (c) isolated slender shear wall, under lateral loading. The main aim of this study is to investigate the damage pattern at the wall-slab junction region under in-plane loading and possible implication on the seismic design of wall and slab members. Stresses and damage pattern are monitored in wall, slab and at the shear wall-slab junction to see the possible failure modes in both wall and slab. The results highlight the requirement of changes in seismic design methodology of RC wall, slab, and slab-wall junction.

2. Modelling Details and Parameters

Concrete Damage Plasticity (CDP) model is considered to assign the concrete properties to all the model considered. The CDP model present in the finite element program ABAQUS [17] uses the concepts of isotropic damaged elasticity and hardening plasticity to represent the behavior of plain and reinforced concrete. The model uses the yield function of Lubliner et al. [18] with the modifications proposed by Lee and Fenves [19] to account for the multiple damage states (compression and tension damage). The flow potential is defined using a Drucker-Prager function of the hyperbolic type. The model is a continuum, plasticity-based, damage model for concrete with the two principal failure mechanisms as tensile cracking and compressive crushing of concrete. The evolution of the yield (or failure) surface is controlled by two hardening variables, tensile and compressive equivalent plastic strains, linked to failure mechanisms under tension and compression loading.

Among the input parameters for CDP, the modulus of elasticity, Poisson's ratio, yield stresses in compression and tension are considered as 25,000 MPa, 0.2, 25 MPa and 3.5 MPa respectively. The assumed parameters are, dilation angle = 55º, eccentricity = 0.1 [20], viscosity parameter = 0.01, shape factor (K_c) = 0.667 and σ_{b0}/σ_{c0}, the ratio of initial equibiaxial compressive yield stress to initial uniaxial compressive yield stress is taken as 1.16. The details of the reinforcement used in the analysis are provided in Table 1.

Table-1. Material Properties for Concrete and Steel

	Density (kg/m^3)	Elastic Modulus (MPa)	Poisson's Ratio	Compressive Strength (MPa)	Tensile Strength (MPa)	Yield Stress (MPa)	Ultimate Stress (MPa)
Concrete	2,500	25,000	0.2	25	3.5	-	-
Steel	7,800	2,00,000	0.3	-	-	415	527

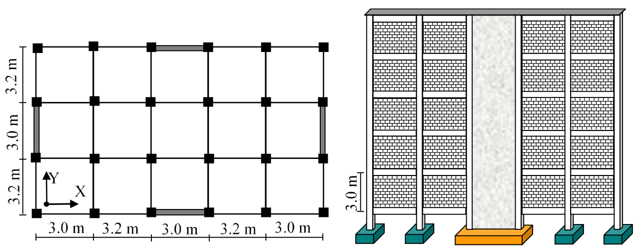
Steel reinforcement is modelled with plasticity model in ABAQUS for both tension and compression. Most materials that exhibit ductile behavior (large inelastic strains) yield at stress levels that are orders of magnitude less than the elastic modulus of the material, which implies that the relevant stress and strain measures are "true" stress (Cauchy stress) and logarithmic strain [17]. Material data for all of these models need to be given in these measures.

3. Validation

For any detailed finite element study, the material parameters and the modelling methodology need to be validated for judging the consistency, reliability and accuracy of the obtained results. In the past, several analytical and numerical studies have been carried out on the behavior of floor slab in shear wall. However, very few experimental works are available on this topic. A series of experiments for investigation of the behavior of slab-wall connection were carried out by Pantazopoulou and Imran (1992) at the University of Toronto. In the present study, the experimental specimen was analysed using ABAQUS considering CDP concrete model and the results are compared with the available experimental results. It was observed that the cracking started at the junction of the shear wall and slab and propagated in the slab. Damage in the slab was mostly concentrated within the region adjacent to the shear wall [23]. Also, the finite element analysis results are in good agreement with the experimental results. All the observations indicate that the simulation of the experimental results could be carried out with reasonable accuracy. Thus, the material modelling parameters of ABAQUS are established for use in further finite element simulations.

4. Detail of Specimens

Displacement based nonlinear static analyses are performed under monotonic loading for a hypothetical wall-frame building (Figure 1) [21-23] considered to be located in seismic zone V as per Indian Seismic Code [24]. Using finite element program ABAQUS, the beams, columns, shear walls and slabs are modelled with eight noded linear hexahedral 3D solid continuum elements with reduced integration (C3D8R). Two noded linear truss element (T3D2) is used to model the steel reinforcement. Figure 2 gives details regarding the geometry and the boundary conditions of the specimens that are used for the simulations.



(a) (b)

Fig. 1. Details of buildings considered in the analysis: (a) plan (b) elevation.

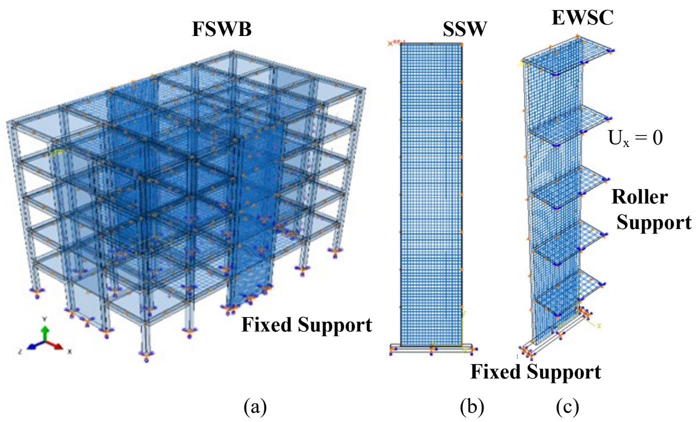


Fig. 2. Geometry and boundary conditions of specimens used for pushover analysis: (a) five storied building; (b) isolated slender wall and (c) exterior wall-slab assemblage.

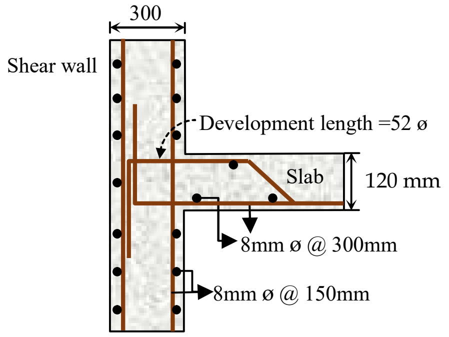


Fig. 3. Detailing of reinforcement at shear wall - slab junction.

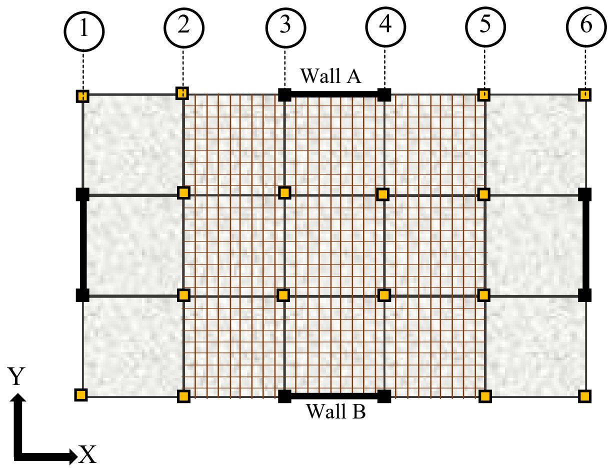


Fig. 4. Plan of FSWB with reinforcement mesh.

The concrete and reinforcement are modelled using CDP characteristics and elasto-plastic properties respectively. The validated material parameters are assigned to the models. For FSWB model, the building is of 5 stories with the storey height as 3 m with reinforcement embedded in the structural elements. In this model all the structural elements are modelled using CDP concrete model and has embedded reinforcement in shear wall and in floor slabs. As the study is intended to investigate the behavior of the slab-wall junction region, linear elastic behavior of concrete is considered for the beams and the columns of the model.

Next analyzed specimens are the exterior shear wall-slab connection (EWSC) considered from the five storied FSWB model and isolated slender shear wall (SSW). The intention of analyzing EWSC model is to find out whether the wall and slab-wall junction behave in a similar way as observed in the FSWB model and how the behavior differs from the SSW model. The total target lateral displacements of 500 mm for EWSC and SSW models and 750 mm for all models of five storied frame - shear wall building (FSWB) are applied at the top level in the plane of the wall.

In this simulation, the embedded technique is used to constrain the two-node truss elements (steel reinforcement) with solid element (shear wall and floor slab) in order to create proper bond between steel and concrete. The translational and rotational degree of freedoms are restrained at the bottom nodes for all the specimens. The outer edges of slabs are supported on rollers in case of EWSC model. The out of plane bending of the shear wall and the vertical bending of slab are restrained along the roller supported edges. The gravity loads (both dead and live loads) on slab are assigned as pressure loads on the surface of solid elements. The total intensity of loading on slab including live load and floor finish is considered as 4 kN/m^2.

5. Reinforcement Detailing

HYSD Fe415 steel reinforcing bars are used to model the reinforcement in the specimens described in the previous section. The reinforcement is obtained in the wall and slab by considering the design load combinations provided as per Indian seismic code [24]. The detailing of reinforcement in shear wall and continuous floor slabs is done as per Indian Standard, SP: 34 - 1987 [25]. The detailing of steel reinforcement at the shear wall-slab junction for both EWSC and FSWB models is explained in Figure 3.

A typical reinforcement mesh in the floor slab is shown in Figure 4, which is used to simulate FSWB model. The reinforcement is embedded in the slabs panels which are located between grid lines 2 and 5. These slab panels are expected to be influenced by the behavior of wall-slab junctions for wall A and wall B for earthquake force acting along X-direction. The other slab panels are analyzed without reinforcing steel embedded in them, as the main intention of the study is to check the behavior at the wall-slab junction region (Figure 4).

6. Response of Finite Element Model

The response of nonlinear static analysis of the five storied frame - shear walls building (FSWB) is compared with the analysis results of exterior wall-slab assemblage (EWSB) and isolated slender shear wall to understand the behavior of the wall and the wall-slab junction. For comparing the behavior of the different finite element models, tensile damage patterns are extracted. These represent the extent of cracking. Different drift levels are chosen to compare the propagation of tensile damage corresponding to the results obtained at drift levels of model FSWB and EWSB. Figure 5 represent the propagation of tensile damage at different drift levels, namely (a) 0.04% (development of first crack at the base of the wall); (b) 0.48% (tension yielding of vertical reinforcement at the bottom of wall); (c) 1.22% (yielding of reinforcement of slab at junction region) and (d) 5% for FSWB (final stage). The damage starts from the base of the shear wall and propagates to the wall-slab junctions at different floor levels. Also, the slab which is connected to the shear wall undergoes maximum damage. At the same drift level, similar damage patterns are observed in the wall panels and wall-slab junctions.

6.1 Behavior of FSWB Model

Nonlinear static analysis of FSWB model is carried out along X-direction, and the salient points on the capacity curve are shown in Figure 6. The base shear is normalized with respect to the weight of the model and plotted against lateral drift. The peak shear strength of FSWB model is reached at a lateral drift of 1.65% along X direction. The propagation of cracks in FSWB model is presented in Figure 5 at different drift levels. At the lateral drift of 0.03%, the concrete in the slab region near the slab-wall junction at first floor starts cracking. The development of cracks at the bottom of the shear wall starts at a drift of 0.04%. The onset of cracks at first floor level is due to the development of diagonal tension, from strut action, in the squat wall panel between two floor slabs. Tension yielding of vertical bar at the bottom of the wall starts at 0.48% lateral drift. This shows the onset of material nonlinearity well before the code specified elastic drift limit. The peak strength of concrete is reached at a lateral drift of 0.76%.

At a drift of 1.22%, the longitudinal reinforcement in the slab near the junction region of floor slab and shear wall starts yielding. The vertical reinforcement at the base of the wall reaches its ultimate strain value at a lateral drift of 3.30%, leading to rupture of vertical bar in tension. The first crushing of concrete occurs at the toe region of the wall at

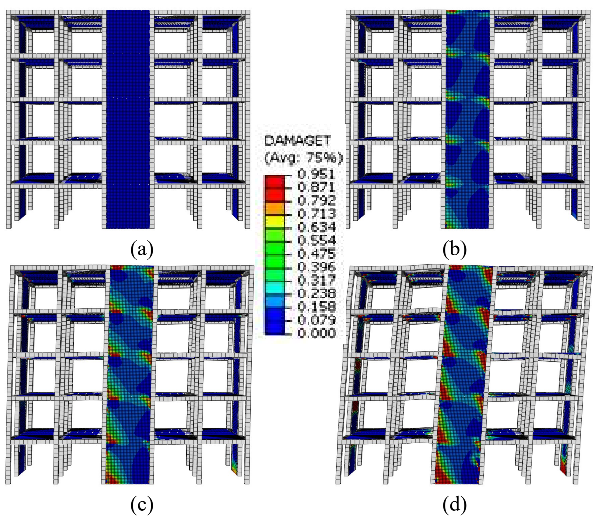


Fig. 5. Propagation of tensile damage in FSWB model at different drift levels: (a) 0.04%, (b) 0.48%, (c) 1.22% and (d) 5% (Final stage).

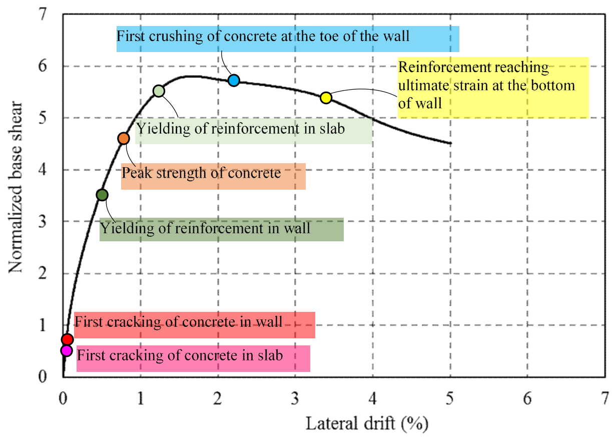


Fig. 6. Variation of normalized base shear during nonlinear static behavior of FSWB model.

2.20% lateral drift. This is due to the very high concentration of compressive stress at the toe of the wall under the combined effect of diagonal compression (from the bottom wall panel) and flexural compression. At the slab-wall junctions in the upper floors, the combined effect reduces due to lesser flexural compression.

The equivalent plastic strain in concrete at the shear wall - slab junction along the length of the wall signifies the possibility of crushing of concrete. This may lead to the development of a major sliding shear crack across the wall-slab junction in the plane of the wall. The sliding cracks can further result in the formation of compressive strut in wall panel between the floor slabs. Yielding of the slab and wall reinforcement adjacent to the wall-slab junction region, occurs simultaneously. It is observed that the reinforcement in the floor slab, which is connected to the shear wall yields first, while the reinforcement in the unconnected slab remains unyielded. The vertical reinforcement in the shear wall region yields mostly at the slab-wall junction region.

6.2 Behavior of EWSC Model

Displacement controlled nonlinear static analysis is carried out on a five storied exterior shear wall - floor slab assemblage (EWSC model) from FSWB model for detailed study of the wall-slab junction region. The target lateral displacement is applied in the plane of the shear wall. Figure 7 shows salient point for the global response of the EWSC model. The nature of capacity curve for EWSC model is the same as that obtained for FSWB model with expectedly less lateral strength. Figure 8 shows the propagation of cracks from the initial cracking with subsequent local crushing of concrete up to the final displacement stage.

First cracking starts at the first-floor slab at a drift of 0.01%. The cracking of concrete in the shear wall starts at 0.014% drift from the bottom and propagates to the shear wall-slab junction region. The vertical bars on the tension side at the bottom of the wall start yielding at a lateral drift of 0.136%. Also, at the same displacement, some of the vertical reinforcement at the first-floor shear wall-slab junction region start yielding. The reinforcement in the slab starts yielding at 0.245% drift. Thus, significant nonlinear

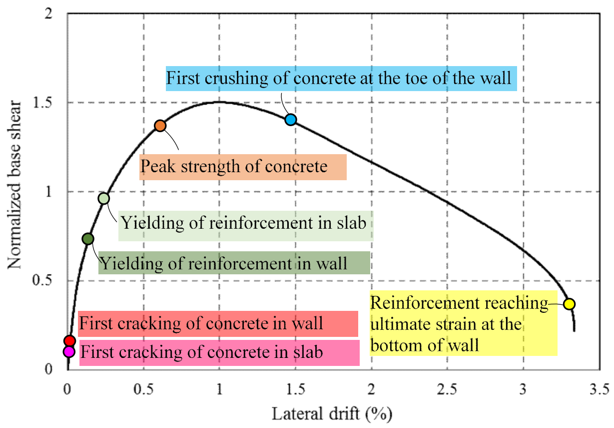


Fig. 7. Variation of normalized base shear during nonlinear static behavior of EWSC model.

behavior is observed in wall and slab well before the code specified elastic drift of 0.4%. The crushing of concrete starts in slab-wall junction at a lateral drift of 1.47%.

Due to the presence of floor slab, a diagonal compressive strut develops in the wall panel between two successive floor slabs. Thus, the wall panels between the floor slabs behave similar to squat walls. The floor slab significantly modifies the behavior of the slender wall by partitioning it into squat wall panels. The diagonal struts tend to concentrate the damage at the wall-slab junction regions. As the floor slabs provide diaphragm action in actual buildings, EWSC model aims to investigate possible damages in such slab diaphragm. The peak lateral strength of EWSC model is reached at a lateral drift of 1%. The behavior of the junction between the shear wall and floor slab has been studied by observing the stresses in the steel reinforcement, equivalent plastic strain and tensile damage pattern. Concentration of compressive stresses is observed to be higher at the slab-wall junction as compared to that at the base of the wall. Similar results were observed in the experimental study carried by Ile and Reynouard (2004) [26]. Deformation in individual bar at wall-slab junction also leads to concentration of stresses. Stresses in the longitudinal reinforcement of the slab start reaching the yield values from the face of the wall and extend linearly to the edge support. The stresses in the longitudinal reinforcement of shear wall remain constant over the wall panels along the height of the wall except in the junction region. In the shear wall – slab junction region, most of the vertical reinforcing bars are yielded. The maximum tensile damage is observed in the shear wall-slab junction region and spreads diagonally between the two adjacent floor slabs concentrating the stresses at the corners. Flexural shear cracks are formed in the slab at the junction with the shear wall [1]. In addition, major cracks develop on the tension side of the slab from the face of the shear wall.

6.3 Comparison of EWSC and SSW Models

In practice, the shear wall in a multistoried building is analyzed and designed as an isolated slender wall. To investigate the influence of slab on the behavior of shear wall, the behavior of SSW model is compared with that of EWSC model. For SSW model, displacement-controlled nonlinear static analysis is carried out with the total target displacement applied at the top level. Although the overall capacity curve has the same trend as that of EWSC model (Figure 9), the salient points are discussed. It is observed that after achieving the peak strength, the model exhibits a gradual loss of lateral strength. The peak lateral strength of the entire wall is achieved at a lateral drift of 0.77% whereas, for EWSC model it is at a lateral drift of 1%. First cracking of concrete started at the early drift of 0.05% whereas, in case of EWSC model the cracking of concrete in the shear wall starts at 0.014% drift due to the presence of slab at each floor level. The vertical bar on the tension side of the wall started yielding at a lateral drift of 0.31% at the top. The peak compressive strength of concrete in wall is achieved at 0.66% lateral drift for SSW model. The vertical reinforcement of the wall does not reach its ultimate strain value; thus, some reserve capacity remains in reinforcement. The first crushing of concrete occurs at the toe region of the wall when the lateral drift is 1.66% and 1.47% for SSW and EWSC models respectively.

The maximum plastic equivalent principal strains also represent the onset of possible cracks in finite element analysis. The comparison of tensile damage pattern for SSW and EWSC models are shown in Figure 10a. The reduction in the lateral strength of the wall is mainly due to compressive crushing of concrete at the toe of the wall. The

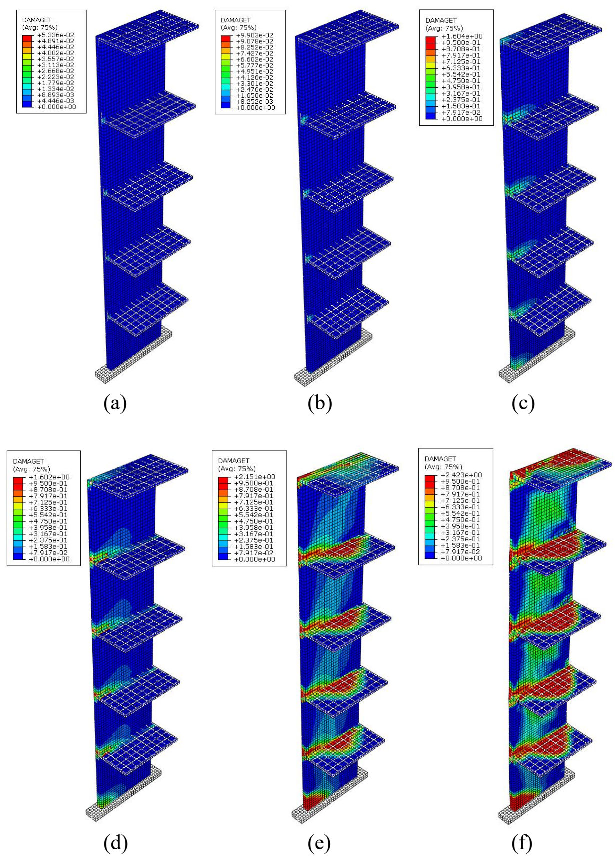


Fig. 8. Tensile damage pattern for EWSC model at: (a) first cracking in slab, (b) first cracking in wall, (c) yielding of reinforcement in wall, (d) yielding of reinforcement in slab, (e) crushing of core concrete at slab-wall junction and (f) final stage.

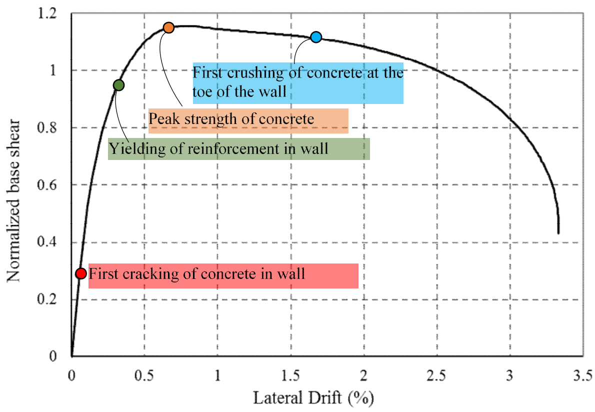


Fig. 9. Variation of normalized base shear during nonlinear static behavior of SSW model.

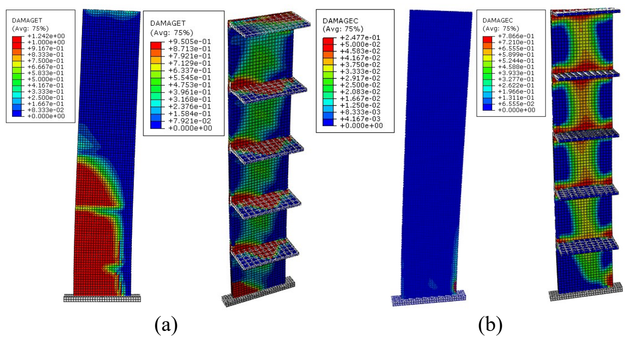


Fig. 10. Comparison of response of SSW and EWSC models at maximum drift level: (a) tensile damage pattern and (b) compressive damage pattern.

compressive damage pattern for both SSW and EWSC is shown in the Figure 10b. The tensile damage pattern follows the same trend as that of cracking pattern. The face of the shear wall which is under tension experiences the tensile damage first. The damage starts from the base of the wall and propagates vertically upward until the maximum displacement is reached. Longitudinal stresses in horizontal reinforcement are not significant.

Conclusions

To predict the behavior of shear wall - floor slab junction, the finite element analysis of three different models are carried out under lateral loading. The findings and conclusions are summarized as follows:

1. The design methodology should consider strut formation and associated failure modes for slender walls in multistoried buildings with floor slabs. The strut formation leads to further propagation of damage in the floor slab.
2. The portion of the floor slab connected to the walls undergoes significant damage at higher levels of lateral displacement. Significant damage at slab-wall junction may also lead to formation of sliding shear crack across the wall. Thus, a new design methodology involving prevention or reduction of damage in slab needs to be evolved.
3. The finite element analysis results confirm that the maximum stress concentration develops at the base of the shear wall (EWSC) first and then propagates to the upper floor level at the junction. Also, the developed tensile damage and the stresses are higher in the portion of the slab connected to the shear walls which are oriented in the direction of the pushover analysis.
4. As per the current provision of the Indian earthquake code IS: 1893 (Part-1) - 2016, RC buildings are expected to show linear elastic behavior till the lateral drift limit of 0.4%. However, for all the studied models, nonlinearity in concrete starts at much lower drift levels. Also, yielding of vertical reinforcement in wall is observed at lower or comparable drift levels. Thus, the existing codal prescription needs to be relooked at for RC wall buildings considering the realistic behavior.

Disclosures

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References

1. Pantazopoulou S. and Imran I. Slab-wall connections under lateral forces. ACI Structural Journal, 1992; 89 (5): 515-527.
2. Coull A and Wong YC. Effect of local elastic wall deformations on the interaction between floor slabs and flanged shear wall. Journal of Building and Environment, 1985; 20: 169-179.
3. Qadeer A and Smit, BS. The bending stiffness of slabs connecting shear walls. ACI Structural Journal, 1969; 66(6): 464-473.
4. Schwaighofer J and Collins MP. Experimental study of the behavior of reinforced concrete coupling slabs. ACI Structural Journal, 1977; 74(3): 123-127.
5. Paulay T and Taylor RG. Slab coupling of earthquake-resisting shearwalls. ACI Structural Journal, 1981; 78(2): 130-140.
6. Medhekar MS and Jain SK. Seismic behaviour design and detailing of R.C. shear walls Part I: behaviour and strength. The Indian Concrete Journal, 1993; 67(7): 311-318.
7. Paulay T and Priestley MJN. Seismic design of reinforced concrete and masonry buildings. 1992; John Wiley and Sons Inc., New York.
8. Kabeyasawa T, Shiohara H, Otani S, and Aoyama H. Analysis of the full-scale seven-storey reinforced concrete test structure. Journal of the Faculty of Engineering University of Tokyo, Tokyo Japan, 1983; 37(2): 431-478.
9. Elnashai AS, Pilakoutas K, and Ambraseys NN. Experimental behaviour of reinforced concrete walls under earthquake loading. Earthquake Engineering and Structural Dynamics, 1990; 19: 389-407.
10. Cardenas AE and Magura DD. Strength of high rise shear walls rectangular cross sections. ACI Special Publication, 1973; 119-150.
11. Orakcal K and Wallacem JW. Flexural modeling of reinforced concrete walls-experimental verification. ACI Structural Journal, 2006; 103(2): 196-206.

12. Kwak, HG and Kim DY. Material nonlinear analysis of RC shear walls subject to cyclic loadings. Engineering Structures, 2004; 26: 1423-1436.

13. Kim HS, Lee DG, and Kim CK. Efficient three-dimensional seismic analysis of a high-rise building structure with shear walls. Engineering Structures, 2005; 27(6): 963–976.

14. Bari MS. Nonlinear finite element study of shear wall-floor slab connections. Journal of Civil Engineering, The Institution of Engineers Bangladesh CE, 1996; 24(2): 137-145.

15. Zenunovic D and Folic R. Models for behaviour analysis of monolithic wall and precast or monolithic floor slab connections. Engineering Structures, 2012; 40: 466-478.

16. Li ZJ, Balendra T, Tan TKH, and Kong KH. Finite element modeling of cyclic behavior of shear wall structure retrofitted using GFRP SP-230. Seventh International Symposium on Fiber-Reinforced (FRP) Polymer Reinforcement for Concrete Structures, ACI, 2005.

17. Hibbit Karlsson and Sorensen Inc. Abaqus/Standard user's manual (Version 6.11-3). Pawtucket RI, 2010.

18. Lubliner J, Oliver J, Oller S, and Onate E. A plastic-damage model for concrete. International Journal of Solids and Structures, 1989; 25(3): 299-326.

19. Lee J, and Fenves GL. Plastic-damage model for cyclic loading of reinforced concrete structures. Journal of Engineering Mechanics, ASCE, 1998; 124(8): 892-900.

20. Gulec CK and Whittaker AS. Performance-based assessment and design of squat reinforced concrete shear walls. MCEER Technical Report-09-0010. MCEER, Buffalo, 2009.

21. Kaushik S and Dasgupta K. Seismic behavior of slab-structural wall junction in RC building. International Conference on Structural Engineering and Mechanics. Rourkela, India. 2013; Paper No. 054.

22. Kaushik S and Dasgupta K. Seismic damages in shear wall-slab junction in RC buildings. Procedia Engineering Elsevier, 2016; 144: 1332-1339.

23. Kaushik S and Dasgupta K. Seismic behavior of slab-structural wall junction of RC building. Earthquake Engineering and Engineering Vibration, 2019; 18(2): 331-349.

24. Bureau of Indian Standards (BIS). Indian standard criteria for earthquake resistant design of structures. Part 1: General provisions and buildings. IS 1893. New Delhi, India, 2016.

25. Bureau of Indian Standards (BIS). Handbook of concrete reinforcement and detailing. SP: 34. New Delhi, India, 1987.

26. Ile N and Reynouard J. Seismic behaviour of R/C walls subjected to multidirectional seismic loading. Thirteenth World Conference on Earthquake Engineering. Vancouver, Canada, 2004.