Effects of Continuity between Steel Boundary Element and Concrete on Behavior of Shear Wall

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ABSTRACT: Structural walls are widely used in building structures as the major structural members to provide substantial lateral strength, stiffness and the inelastic deformation capacity needed to withstand earthquake ground motions. In this article the behavior of composite shear walls with continuous boundary elements are compared and contrasted with a state in which the wall's boundary elements are discontinuous and interrupted and the boundary steel columns are connected to the foundation through the column's baseplate and bolts; and these are all to assess and appraise some hypotheses by the structural designers in designing these walls. The finite element software is first calibrated and the accuracy of its results is validated through modeling the experimental samples. In this research, the concrete's nonlinear finite element analysis method and concrete damage plasticity model have been used for the concrete's behavior modeling. The results of this study indicate that the wall boundary elements' continuity improve the composite shear walls' behavior. Meanwhile, this effect increases by an increase in the number of the wall's floors.

1- Introduction

In recent years, steel reinforced concrete (SRC) walls have gained popularity for use in high-rise buildings in regions of high seismicity. SRC walls have additional structural steel embedded in the boundary elements of the reinforced concrete (RC) walls. Walls with additional shapes referred as composite steel-concrete shear walls, contain one or more encased steel shapes, usually located at the ends of the wall. Composite shear wall that now is being used in the world generally is consisted of steel composite shear wall and reinforced concrete composite shear wall with steel boundary element. Although these shear walls have been considered as an appropriate combined performance of steel and concrete in valid codes in the world, there are no certain criteria in Iranian codes for these walls. Reinforced concrete shear walls with steel boundary element being performed in Iran are joined to the foundation, in boundary element section, usually through bolts and baseplates. Most reliable codes of the world have nothing to say about the behavior of this type of shear walls, and no experimental studies or analyses have been conducted on the behavior of this type of shear walls. Alternative method for connection of steel columns to concrete is by directly embedding them, with or without end plates. In the past decade, great effort has been devoted to the study of seismic behavior of SRC walls, for design provisions for SRC walls have also been included in some leading design codes and specifications, for example, AISC 341-10, Eurocode 8, and JGJ 3-2010.

Previous researches, conducted by Ji et al. [1] to investigate the seismic behavior and modeling of steel reinforced concrete walls. Dan et al. [2] reported the test results of the RC shear wall with vertical steel encased profiles. Esaki and Ono compared the mechanical behavior of SRC–RC walls under two different loading rates, i.e. 0.01 cm/s for the static loading and 1 cm/s for the dynamic loading. Zhou et al. to investigate the Seismic behavior of composite shear walls with multi-embedded steel sections [3].

Significant failure of column baseplate connections has been reported in major earthquakes, emphasizing not only the importance of their function but also the lack of knowledge of their true behavior. Based on post-Kobe research, Hitaka et al. (2003), report that larger rotational stiffness is expected for embedded column base than the conventional baseplate connection. Further, they observed that anchor bolts had fractured or elongated severely in Kobe earthquake, whereas no damage was reported for the embedded column connections.

Investigation on technical essays by writers shows that there aren't specified criteria for designing composite shear walls with discontinuous steel boundary elements.

So this study is focused on the performance and behavior of shear walls with discontinuous bounder element with foundation, its comparison with a common type of implementation of these walls by using finite element method and also offering a suggestion for rational designing of walls with discontinuous boundary elements.

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2- Methodology

2- 1- FE model

ABAQUS software package was employed throughout the finite element analysis [4]. The I-shaped steel and the concrete were simulated by using 4-node shell elements and 8-node brick elements, respectively. The steel bars were simulated by using 2-node truss elements, with three translation degrees of freedom at each node.

2- 1- 1- Material model

The steel was simulated by an elastic–perfect plastic mode. The elastic modulus (E_s) and the Poisson ratio (ν_c) of steel were taken as 206,000 N/mm^2 and 0.3, respectively. In the current FE model, the damage plasticity model provided in the ABAQUS library was used for modelling concrete material. This model assumes non-associated potential flow rule and adopts a yield surface proposed by Lubliner et al. [5] and Lee and Fenves [6] to account for the different evolution of strength under tension and compression. The description of the plastic behavior comes from the equivalent stress–strain relationship of the concrete. The modulus of elasticity (E_c) of concrete was taken as $4730\sqrt{f'_c}$ according to ACI 318 [7] where f'_c is the cylinder compression strength of concrete, in the Poisson's ratio (ν_c) was taken as 0.2. In order to simulate the plastic behavior of the concrete under compression, an equivalent stress–strain model proposed by Attard and Setunge was adopted [8].

It is a common fact that the significant drop of the tensile strength after cracking makes it Behavior of concrete. The fracture energy (Gf) was assumed as 0.04 kN/mm and 0.12 kN/mm respectively for the concrete with a compressive strength of 20 MPa and 40 MPa as recommended in [9].

2- 2- Contact surfaces

It is assumed in this research that there is a full adhesion between steel columns and bars with confining concrete and the slippage between steel and concrete doesn't happen.

In shear wall with discontinuous boundary element it is assumed that at the time of detachment of the surface of tensional boundary element column from foundation, the bolts inside foundation won't be slip, and detachment will be the result of bolt elongation. Also the contact surface of concrete wall and foundation with baseplate is considered a "hard contact". Meaning that after stretching two surfaces can be detached.

2- 3- Verification of the FE model

The FE model described above was used to simulate the steel reinforced concrete (SRC) walls for the purpose of verification. The comparisons with test results reported by Tao et al. [10], It can be seen that a good agreement was achieved between the predictions and the test results in terms of load (F)–lateral displacement (Δ) curves.

3- Results and Discussion

In this study the performance of composite shear wall with continuous and discontinuous boundary element is compared with typical reinforced concrete shear wall. This comparison was made for walls that have one to four floors. The results show that presence of boundary steel columns increases the stiffness of the wall. Increasing the stiffness of composite walls with discontinuous boundary element is going down, relating to the reinforced concrete wall by increasing the ratio of height to length.

We can relate this downward trend to changing the performance of wall from shear mode to bending mode. The bending mode can result in axial force on the edge of the wall, acceleration in changing the length, and surrendering bolts. Moreover, fraction increases in greater part of tensile area of the wall.

Comparison between composite shear wall and reinforced concrete shear wall shows that the continuity of boundary elements wall, increases the maximum resistance of the wall than reinforced concrete wall considerably.

4- Conclusions

Due to the lack of certain criteria for designing shear walls with steel boundary element in our country, in this research shear walls with steel boundary element were analytically remodeled in two moods based on experimental validation, continuous and discontinuous boundary walls, so the effect of boundary elements continuity become clear. In summary we can present the results of this research as follows:

1. When the steel boundary columns were embedded in foundation, the resistance and difficulty of the wall were increased more than reinforced concrete shear walls. This increase raised according to the increase of the number of floors.
2. The results of the consideration showed that with existing amount of bolt and for walls with the ratio of height to length equals 3, the resistance of shear walls with continuous boundary element with foundation is not more than typical reinforced concrete shear walls.
3. Burying the foot of steel boundary columns in foundations increased their share of the impacts of maximum resistance of walls. So making the performance of both walls equals cannot be to ensure unless we do some tests and using some of the parameters in the codes of designing to relate the resistance and difficulty of these two walls.
4. According to the done remodeling and gained results it has been recommended that in case the steel columns with boundary elements discontinuously get detached, we suggest that when we are making a design, in order to make sure of it regardless of its effects on resistance and difficulty of the wall. It is also suggested that in order to increase the resistance and difficulty of the walls we bury the steel boundary element in foundation.

References

[1] Ji, Xiaodong, Ya Sun, Jiaru Qian, and Xinzheng Lu. "Seismic behavior and modeling of steel reinforced concrete (SRC) walls." Earthquake Eng Struct, 2014.

[2] Dan, D., Fabian, A., and Stoian,V.; "Theorical and experimental study on composite steel-concrete shear walls with vertical steel encased profiles"; Constructional Steel Research; 2011; pp. 800-813.

[3] Esaki, F, and M Ono. "Effect of loading rate on mechanical behavior of SRC shearwalls." Steel Compos struct, 2001: 1(2):201-12.

[4] ABAQUS, INC. ABAQUS/THeory User manual, Version 6.11. 2011.

[5] Lubliner, J., Oliver, J., Oller, S., and Oñate, E. "A plastic-

damage model for concrete"; Int J Solids Struct; 1989; pp. 299–326.

[6] Lee, J., and Fenves, G.L. "Plastic-damage model for cyclic loading of concrete structures"; J Eng Mec; ASCE; Vol. 124; No.8; 1998; pp. 892–900.

[7] ACI.318-08; "Building code Requirements for Structural Concrete and Commentary"; American Concrete Institute; 2008.

[8] Attard, M.M., and Setunge, S. "Stress–strain relationship of confined and unconfined concrete"; ACI Mater J; Vol. 93; No.5; 1996; pp. 432–42.

[9] Hillerborg, A., Modeer, M., and Petersson, P.E. "Analysis of crack formation and crack growth in concrete by means of fracture mechanics and finite elements"; Cem Concr Res; Vol. 6; No.6; 1976; pp. 773-82.

[10] Liao, Fei-Yu, Lin Hai Han, and Zhong Tao. "Performence of reinforced concrete shear walls with steel reinforced concrete boundary columns." Engineering Structures, 2012: 186-209.