Finite element modeling of reinforced concrete shear wall subjected to static loading

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Abstract

This paper presents a numerical modeling of RC shear walls using SSI3D finite element program. The objective of this research is to develop the full-scale model lab test of reinforced concrete (RC) shear wall. The wall is subjected to axially and laterally monotonic loading up to failure. The concrete performance is represented by 20-node solid elements that have ability of modeling the cracking in tension and failure in compression. The main steel reinforcing bars and stirrup are modeled by nonlinear bar elements that only axial stress-strain behavior is considered. The analysis results show that the concrete reaches to failure states in both tension and compression while the rebars only yield in tension.

Key words: *concrete shear wall, finite element model, nonlinear material, model lab test*

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Date of receipt: 15/4/2022
Editing date: 6/5/2022
Post approval date: 5/9/2022

1. Introduction

Reinforced concrete (RC) shear walls are considered as most effective elements of the lateral resisting force systems against the lateral forces of earthquake and wind loads in high-rise and mid-rise multi-story buildings due to their high lateral stiffness and strength. The RC walls also carry the vertical loads including both dead and live loads transferred from beams and slabs. Wall-frame systems provide the necessary strength and stiffness to satisfy the demands produced by both vertical and lateral loads.

Several researchers [1-4] reported that improperly designed RC shear walls may suffer severe damage, and some even collapsed during strong earthquakes such as in the recent Chile earthquake on February 27, 2010 and the Christchurch earthquake on February 22, 2011 in New Zealand. The walls were the lack of boundary transverse reinforcement, thin, and relatively high levels of axial force that suffered great damages [4]. To control the performance level of RC shear walls effectively, the earthquake-induced behavior of RC shear walls is necessary to investigate based on both model tests and nonlinear analyses.

Previous experimental studies on shear walls were focused on the load carrying capacity, hysteretic characteristics, and deformation ductility [1,5]. Wang and Jiang [1] conducted seven tests of shear wall with different geometries with aspect ratio of two and reinforcement configurations to assess the damage behavior of shear wall members under horizontal cyclic loading. Deng et al. [5] carried out four quasi-static tests of RC shear walls with low concrete strength and reinforcement ratio to investigate large axial compression ratio, stiffness, strength and energy dissipation capacity.

The current design standards for structures [6,7], the shell element that combines a membrane element with a plate element is widely used in modeling the elastic behavior of reinforced concrete wall system. The nonlinear analyses of structures with RC shear walls are very computationally expensive and not appropriate in practical but it still can be used in special purposes such as model test design and model test verification, etc. In this study, model tests of RC shear wall are analyzed using nonlinear finite element method to serve for the design of the model tests. The results of the model tests will be used to develop and calibrate a new nonlinear finite element that combining both concrete and reinforcements in one element and verify the behavior factor (q) of the current design code of earthquake resistances in Vietnam [7].

2. Finite element analyses

2.1. Preliminary design

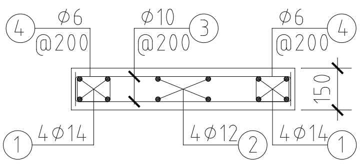
The RC shear wall in the model test has dimensions of 3.0mx0.8mx0.15m (Height x Width x Thickness). The cross section and vertical section of the RC

Table 1: Concrete material

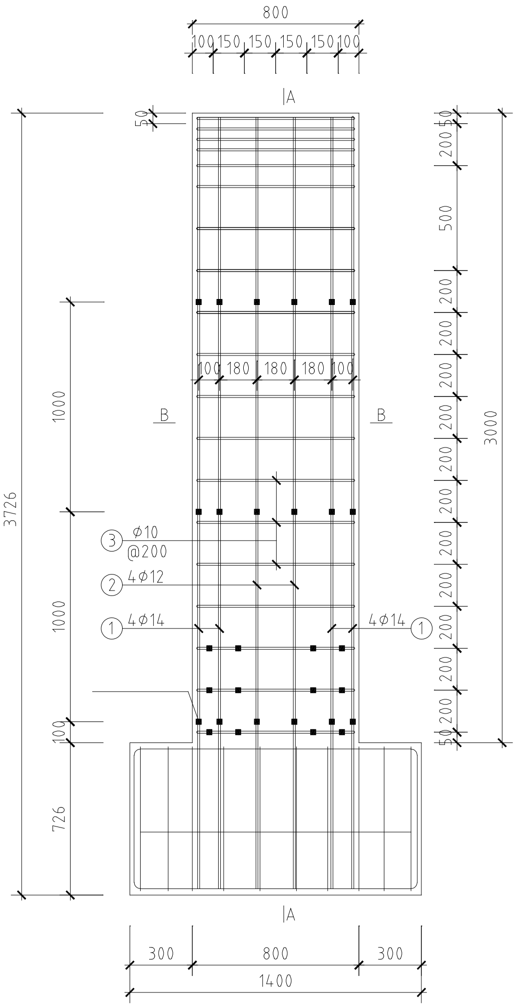
Parameter	Unit	Value
Young's modulus	MPa	27000
Poisson's ratio	-	0.2
Compressive strength	MPa	25
Tensile strength	MPa	1

Table 2: Steel reinforcement material

Parameter	Unit	Value
Young's modulus	MPa	200000
Poisson's ratio	-	0.3
Yield strength	MPa	360a



a) Cross section



b) Vertical section

Figure 1: Details of RC shear wall

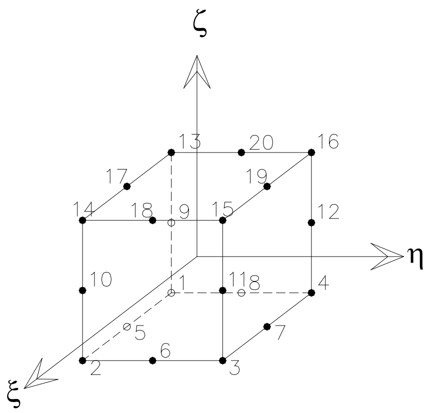


Figure 2: Twenty-node solid element

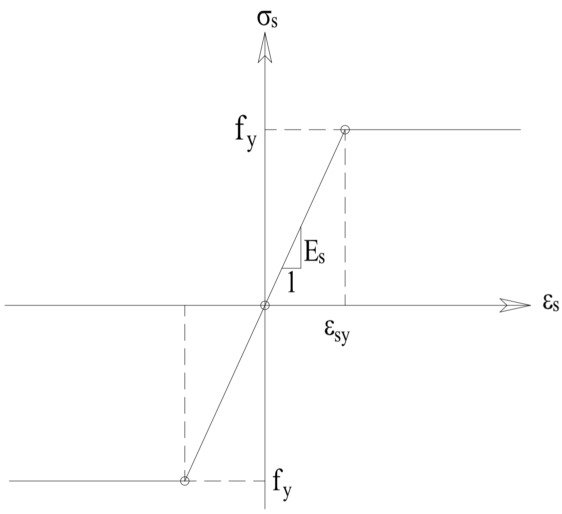


Figure 3: The stress-strain relationship for steel reinforcement

shear wall are shown in Figure 1. The material parameters of the concrete and reinforcement are presented in Table 1 and Table 2.

2.2. Element type

The finite element computer code SSI3D is used in the analyses [8]. A twenty-node solid element is used to model the RC shear wall. The solid element has twenty nodes with three degrees of freedom at each node. Figure 2 shows the twenty-node solid element in the local coordinate system. The element is capable of plastic deformation, cracking in three orthogonal directions. The nonlinear bar element is adopted to model the longitudinal rebars and stirrups. An assumption can be made that rebars and concrete are fully bonded at their interface.

2.3. The behavior of steel reinforcements

The stress-strain relationship of steel material, both in tension and in compression, is assumed to be elastic-perfectly plastic, and the strain hardening of steel is neglected, as shown in Figure 3. The normal stress in the section is calculated as:

$$\sigma_s = E_s \varepsilon_s \tag{1}$$

where ε_s is Young's modulus of steel; ε_s is axial strain of steel.

The normal stress should not be greater than the yield strength of the steel material, :

$$-f_y \le \sigma_s \le f_y \tag{2}$$

The yield strength is determined as:

$$f_y = E_s \varepsilon_{sy} \tag{3}$$

where ε_y is yield axial strain.

2.4. The behavior of concrete in compression

Many mathematical models of concrete are currently used in the analysis of reinforced concrete structures. For the nonlinear analysis, the stress-strain relation of concrete should be considered in both compression and tension.

In this study, elastic perfectly plastic model is adopted. The concrete stress-strain relation exhibits a linear elastic

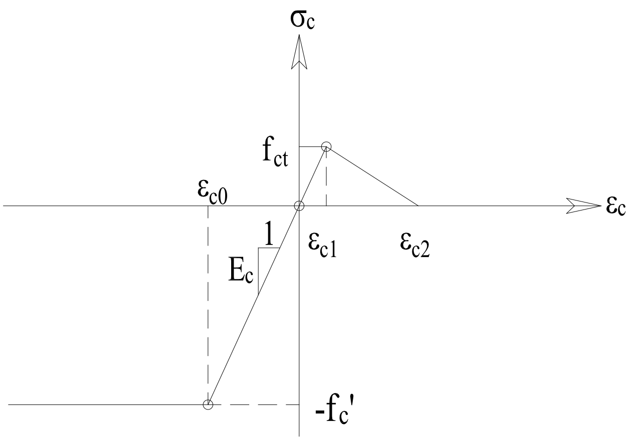


Figure 4: The stress-strain relationship for concrete

response up to the compressive strength. Beyond the compressive strength, the concrete stress-strain relation exhibits perfectly-plastic. The model can be represented by Tresca model in three-dimensional (3D) finite analyses that is already existed in the SSI3D software [8]. The behavior of the concrete represents the monotonic stress-strain relation for concrete under compression as depicted in Figure 4 and Eq. (4):

$$\begin{aligned} &\sigma_c = E_c \varepsilon_c \quad if \;\; \varepsilon_c \geq \varepsilon_{c0} \\ &\sigma_c = -f_c' \quad\;\; if \;\; \varepsilon_c < \varepsilon_{c0} \end{aligned} \tag{4}$$

where f_c' is ultimate compressive strength; ε_c is strain (positive in tension and negative in compression); f_c' is a corresponding strain to f_c'; E_c is Young's modulus of concrete.

2.5. The behavior of concrete in tension

This study also accounted for the stress-strain relationship of concrete in tension. Idealized stress-strain curves for concrete in tension are shown in Figure 4. For plain concrete, the curve is linear up to cracking stress f_{ct} then gradually reduced to zero [9]. The stress-strain relationship of concrete in tension can be given in the following forms:

$$\begin{cases} \sigma_c = E_{ct}\varepsilon_c & if \;\; \varepsilon_c \leq \varepsilon_{c1} \\ \sigma_c = f_{ct} - E_{cr}(\varepsilon_c - \varepsilon_{c1}) & if \;\; \varepsilon_{c1} \leq \varepsilon_c \leq \varepsilon_{c2} \\ \sigma_c = 0 & if \;\; \varepsilon_c > \varepsilon_{c2} \end{cases} \tag{5}$$

where f_{ct} is tensile strength; f_{ct} is a corresponding strain to f_{ct}; E_{ct} is Young's modulus of concrete in tension; and E_{cr} is slope of the stress-strain curve beyond the tensile strength.

2.6. Analysis results

Four analyses are performed to determine the maximum lateral load at different axial loads as presented in Table 3. Based on the lateral load-displacement curves at the top of the wall as shown in Figure 5, the maximum lateral loads are corresponding to the load values at the end of the curves that the shear wall cannot suffer more load. The highest lateral load is corresponding to the axial load of 250kN.

Table 3: Maximum lateral load

Axial load, P (kN)	Maximum lateral load, F_{max} (kN)
0	115
125	147
250	168
500	143

The maximum tensile and compressive stresses occur in the rebars at the boundaries. The tensile stress reach to the yield stress while compressive stress is much lower the yield stress. Figure 6 shows the plastic points in the RC shear wall. The concrete reaches to both failure states, tension or cracking indicated by blue color areas and compression failure illustrated by red color areas.

3. Conclusions

The three-dimension finite element analyses of the RC shear wall are performed to determine the maximum lateral load and failure states of the concrete and rebars for design purpose of the full-scale model tests. The RC shear wall is subjected to axially and laterally monotonic loading up to failure. The concrete performance is represented by

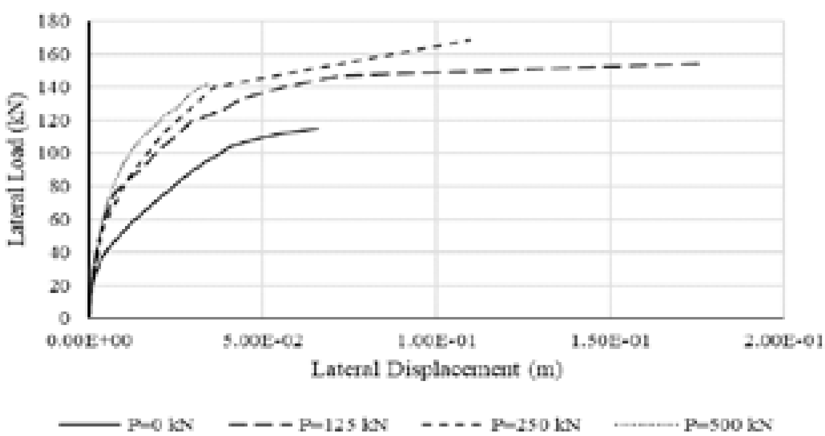


Figure 5: Lateral load-displacement curves at the top of the wall

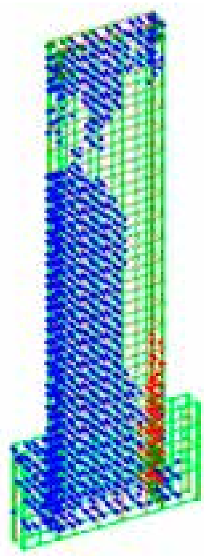


Figure 6: Plastic points in the RC shear wall

twenty-node solid elements that have ability of modeling the cracking in tension and failure in compression. The main steel reinforcing bars and stirrup are modeled by nonlinear bar elements that only axial stress-strain behavior is considered. The analysis results show that the concrete reaches to failure states in both tension and compression while the rebars are only yield in tension. Based on the analysis results, two model tests of the shear walls with different configurations of rebars will be manufactured. The tests will be carried out to verify the new finite element the behavior factor of the current design code of earthquake resistant in Vietnam that the shear walls will be subjected to lateral dynamic and axial static loads simultaneously./.

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Experimental and numerical investigation...

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properties of wood as a function of temperature (density and thermal conductivity) suggested by the Eurocode 5 for native (virgin) wood were applied to both uncompressed and compressed samples. It can be seen that the results from the developed FE-model match well the experiments in both cases, while the Eurocode 5 model is accurate in the case of uncompressed wood for which it is dedicated.

The mean experimental and simulated charring depths for both uncompressed and compressed spruce are summarized in Table 2 for the different heat flux values. It can be observed a fairly good correlation between experimental and numerical values.

Table 2: Comparison between experimental and numerical charring depths (mm)

	Heat flux (kW/m^2)	Exposed time (min)	Charring depth (Experiment)	Charring depth (Present Model)
Virgin spruce	20	20	12	13
	75	10	15	16
Densified spruce	20	20	3	3,5
	75	10	7	7

The mass loss for the heated square plates (compressed and uncompressed) was simulated and compared to the experimentally measured loss masses during the cone calorimeter tests (Figure 9). It can be seen as a fairly good correlation.

4. Conclusion

The thermal behavior and degradation of uncompressed (virgin) and thermomechanically-compressed spruce have been studied experimentally and numerically. Several square samples measuring 100 mm x 100 mm and 19 mm thick, have been exposed to fire under a cone calorimeter using two different heat fluxes. In addition, a predictive three-steps pyrolysis finite element model has been developed and successfully implemented in the Abaqus software via the user-subroutine UMATHT. Based on the obtained results, the following conclusions can be drawn:

- Densified wood exhibits reduced charring rate and masse loss as compared to the normal (uncompressed) wood.

- An extension of Blasi's multi-reactions pyrolysis model has been proposed to deal with the temperature profile of wet wood exposed to fire. Kinetic multi-reactions pyrolysis finite element models are more general, predictive, and accurate, while the Eurocode 5 approach is not accurate to predict the thermal behavior of densified wood as it is not calibrated and validated./.