

Seismic Evaluation of RC Tall Shear Wall Building Using Nonlinear Dynamic Analysis

*Seung Yong Jeong¹⁾ and Thomas Kang²⁾

^{1), 2)} *Department of Architecture & Architectural Engineering, Seoul National University,
Seoul, Korea*

²⁾ tkang@snu.ac.kr

ABSTRACT

Recently, construction of tall buildings with reinforced concrete (RC) shear walls as a seismic-force-resisting system has been increased. According to ASCE 7-10, there is a strict height limitation of 49 m for special RC shear walls assigned to Seismic Design Category D or E. To overcome the limitation, seismic evaluation of designed tall buildings by nonlinear dynamic analysis is necessary to confirm their performance, which is also called as performance-based seismic design. In this study, a performance based seismic design is carried out in comparison with conventional analysis and design method that incorporates the response modification coefficient for special RC walls.

1. INTRODUCTION

As one of the lateral load resisting systems, shear wall system has been commonly used for residential buildings. Following the trend of construction of tall residential buildings, construction of tall RC shear wall building also increased. However, conventional design codes such as ASCE 7-10 (American Society of Civil Engineers 2010) do not specifically deal with the design of high-rise buildings. The design criteria using response spectrum analysis with the response modification coefficient, R , are mainly for low to mid-rise buildings. According to ASCE 7-10, there is a strict height limitation of 49 m for special RC shear walls assigned to the seismic design category D or E. However, the structural design should be possible that ensures satisfactory seismic performance, even if the height of a building exceeds the limitation, which is called performance based seismic design (PBSD). Because the PBSD is not based on prescriptive codes, the engineer should provide reliable bases. ASCE 41-13 (American Society of Civil Engineers 2014) is one of the commonly used guidelines for PBSD.

¹⁾ Graduate Student

²⁾ Associate Professor

Comparison between the linear and nonlinear analysis of RC structures were conducted by many researchers, and most of the previous studies dealt with moment frame or dual systems (Hagen G.R. 2012, Leng K. 2014). Thus in this study, nonlinear dynamic analysis of a 25-story shear wall building for the performance based seismic design is carried out by using a nonlinear finite element analysis program, ETABS 2015. The results of linear response spectrum analysis by ASCE 7-10 and nonlinear dynamic analysis based on ASCE 41-13 and other guidelines are compared.

2. Analysis Model

2.1 Plan

A 25-story apartment building with the typical plan shown in Fig. 1 is used for the analysis model. It consists of RC shear walls, coupling beams and slabs. The dimensions of elements are assumed to be the same over the height. The adopted structural system is the special shear wall system.

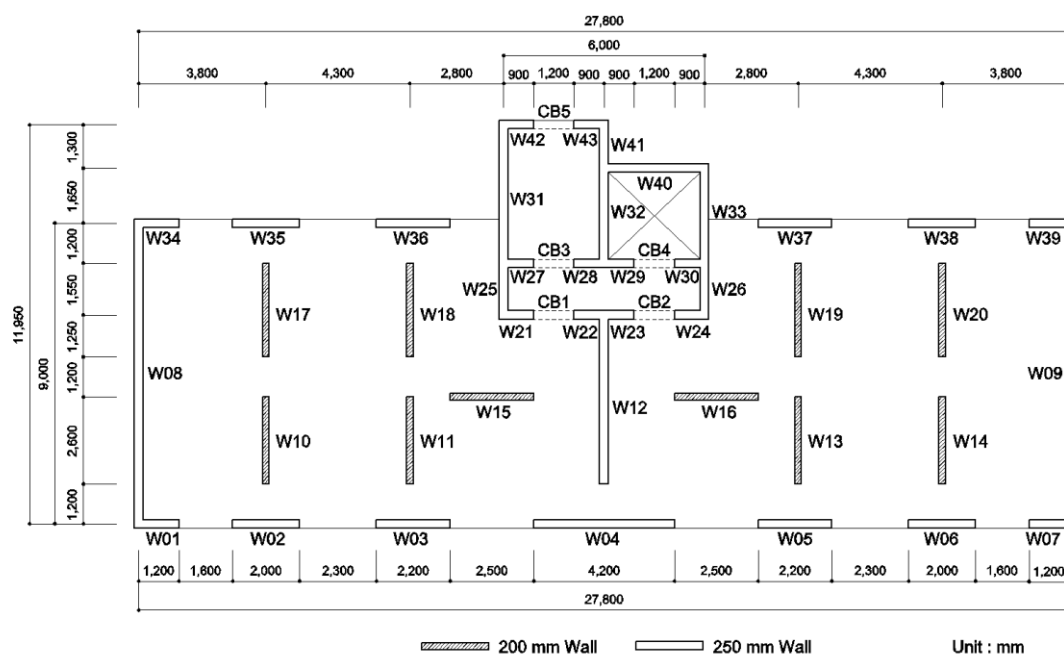


Fig. 1 Typical plan

2.2 Material

The properties of materials are indicated in Tables 1 and 2. The modulus elasticity is determined in accordance with ACI 318-14 (American Concrete Institute 2014). The expected strengths for nonlinear analysis are from Table 10-1 in ASCE 41-13.

Table 1 Properties of reinforcement

Material	Yield Strength (F_y)	Tensile Strength (F_u)	Modulus of Elasticity (E_s)	Expected Yield Strength (F_y)	Expected Tensile Strength (F_u)
Reinforcement	500 MPa	620 MPa	200,000 MPa	625 MPa	775 MPa

Table 2 Properties of concrete

Material	Compressive Strength (f_c')	Modulus of Elasticity (E_c)	Expected Strength (f_c')
Unconfined Concrete	27 MPa	24,422 MPa	40.5 MPa
Confined Concrete	34 MPa	24,422 MPa	47.4 MPa

2.3 Shear Wall Modeling

Shear walls are modeled as shell elements. In seismic design, cracking of concrete elements should be accounted for, so their effective stiffness should be used. Because shear walls of 1/6 to 1/8 of the total building height are generally assumed to be cracked, the stiffness of shear walls of 1st to 5th floors is reduced. The effective stiffness of $0.35I_g$ for cracked walls and $0.7I_g$ for uncracked walls suggested by ACI 318-14 are used for the linear analysis.

The fiber models for shear walls are used in the nonlinear analysis. Nonlinear behavior of the fiber model is determined by the stress-strain relationship of materials.

2.4 Coupling Beam Modeling

Coupling beams of 600 mm depth and 250 mm width are used at the core of the building. ACI 318-14 suggests effective stiffness of $0.35I_g$ for beams. However, this value is not appropriate for coupling beams according to the recent research of PEER/ATC 72-1 (PEER/ATC 2010), which suggests $0.15I_g$ for coupling beams. Thus, the value of $0.15I_g$ is adopted in this study.

2.5 Slab Modeling

Generally, some analysis techniques are used to simplify the analysis of slabs. First, a rigid diaphragm model excluding slabs from the lateral resisting system is used to transfer the lateral forces to the vertical resisting elements in direct proportion to the stiffness of vertical elements. When slabs are included in the lateral resisting system, the equivalent frame method or effective beam width method is used. These techniques can reduce the analysis time, but can lead to wrong estimation of the lateral stiffness of the building. Hence, membrane elements with out-of-plane bending stiffness, so called shell elements are used for slabs.

ACI 318-14 suggests the effective stiffness value of $0.25I_g$ for bending stiffness of slabs. Because ETABS 2015 does not provide nonlinear analysis of slab, so a conservative value of $0.2I_g$ is used for effective stiffness of slabs in both the linear and nonlinear analyses.

3. LINEAR RESPONSE SPECTRUM ANALYSIS (LRSA)

The LSRA is a design method confirming the safety by linear behavior of a structure against the response spectrum with consideration of response modification coefficient. The R factor reflects the ductility of the structure, and allows for the reduction of design earthquake load in LRSA. However, the R factor is determined based on the entire structural system, not each element and connection. ASCE 41-13 proposes the performance evaluation method for linear system using m-factor which takes into account the nonlinear behavior of each member. It can be directly compared with the result of nonlinear analysis by performance levels. In this study, this method is not used, as the paper focuses the comparison between conventional linear design and nonlinear dynamic design.

3.1 Design Response Spectrum

The design response spectrum is determined according to ASCE 7-10, as shown in Fig. 2. The used building system is the special shear wall system, the R factor of 5 is used, and the important factor of 1.25 is used. The input earthquake load is determined from the design spectrum that is multiplied by the important factor and divided by R factor.

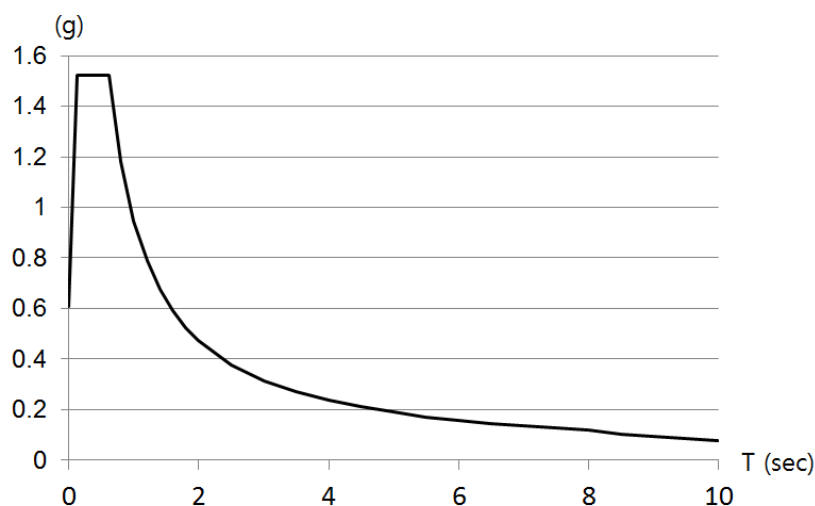


Fig. 2 Design response spectrum

3.2 Damping for LRSA

There is a decreasing tendency for the damping of high-rise buildings, and thus Tall Building Initiative (TBI) suggests 2~3% of damping ratio for high-rise buildings. The analysis model is not considered tall enough to match up to the high-rise building criteria of TBI; hence, the general value of 5% is used for viscous damping ratio.

3.3 Linear Static Analysis

Before LRSA, the linear static analysis is conducted to compare the base shear. If the base shear of LRSA is less than 85% of that of the linear static analysis, the modification factor should be applied. The base shear forces of the linear static analysis and LRSA, and the modification factors for X and Y directions are shown in Table 3.

Table 3 Base Shear and Modification Factor

	Linear Static (kN)	LRSA (kN)	Modification Factor
X-dir. Base Shear	9599.5	6611.7	1.23
Y-dir. Base Shear	9599.5	9097.3	Not Needed

3.4 Analysis Result

The purpose of this study is not to obtain the exact design, but for the comparison between the linear and nonlinear design. Thus, the safety check of whole members is not conducted. Demand capacity ratios (D/C ratio) for only five critical parts of shear walls with specified steel ratios are checked.

The D/C ratios from LRSA are calculated by using P-M diagrams in ETABS 2015 as shown in Fig. 3 (Computers & Structures, Inc. 2014). The point *L* indicates the demand of (P_u and M_u), and Point *C* denotes the point where the extension line of *OL* and P-M diagram meet. The D/C ratio is the length of *OL* divided by that of *OC*.

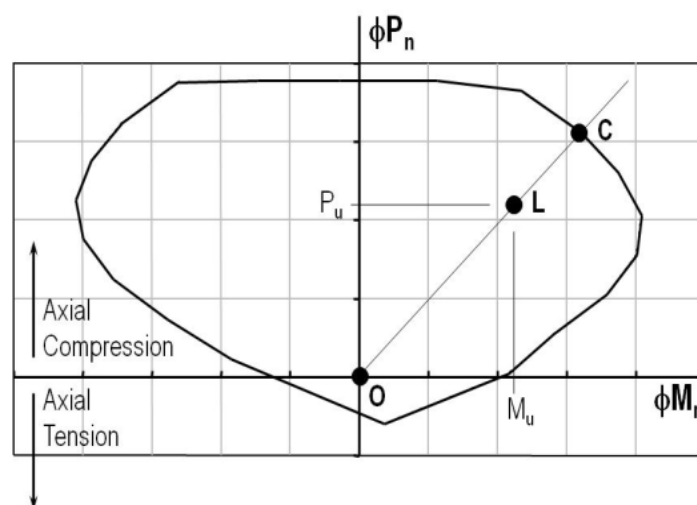


Fig. 3 D/C ratio calculation from P-M diagram

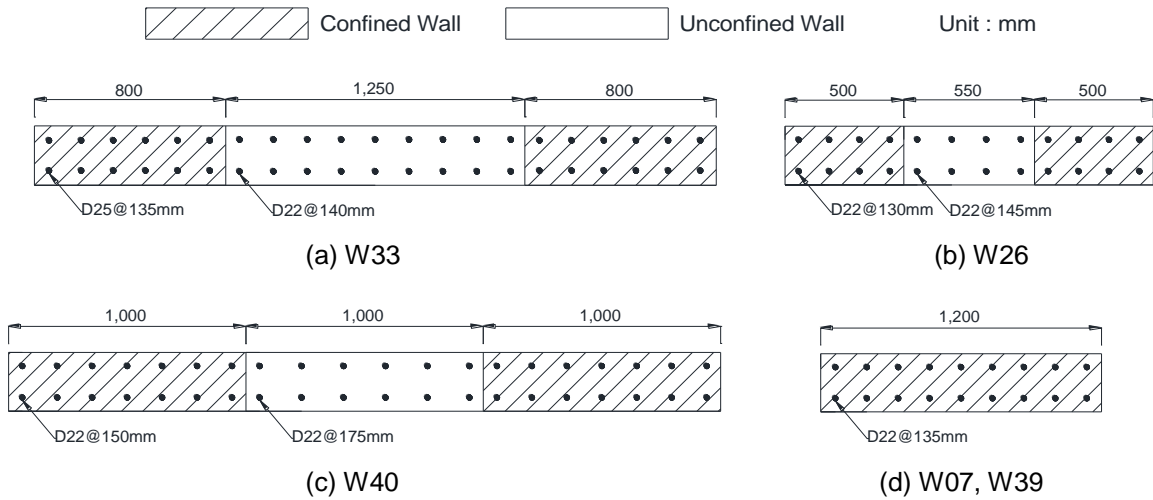


Fig. 4 Shear wall sections

4. NONLINEAR TIME HISTORY ANALYSIS (NTHA)

4.1 Nonlinear Material Model for Fiber Elements

For nonlinear time history analysis (NTHA), the same expected strengths in Table 1 and Table 2 are used. Mander's model implemented in ETABS 2015 is used for both unconfined and confined concrete. The stress-strain curves of concrete and steel are shown in Figs. 5 and 6, respectively.

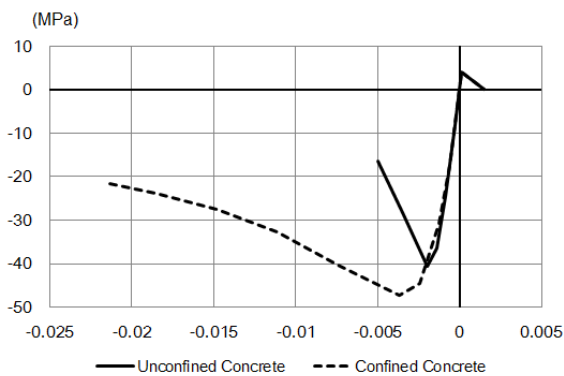


Fig. 5 Stress-strain curve of concrete

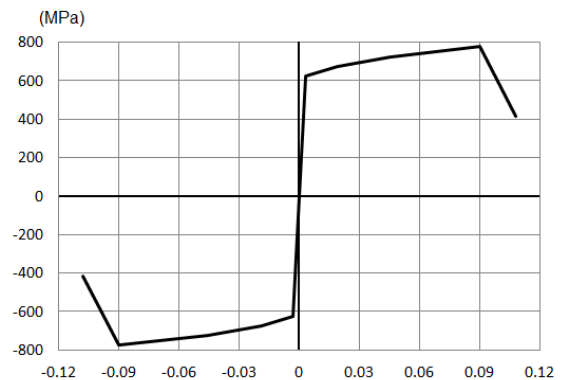


Fig. 6 Stress-strain curve of reinforcement

4.2 Nonlinear Behavior of Members

The nonlinear behavior of shear walls is generally governed by the stress-strain curves of materials, while the nonlinear behavior of coupling beams is affected mostly by plastic hinges at the each end of the beam. The properties of plastic hinges are

