MODELLING OF SHEAR WALLS FOR NON-LINEAR AND PUSH OVER ANALYSIS OF TALL BUILDINGS

Naveed Anwar[1], Thaung Htut Aung[2]

ABSTRACT: The Performance Based Analysis and design of buildings and structures, especially for seismic resistance is becoming widely accepted as an alternative and more realistic approach. The Pushover method for analysis was initially developed for frame structures modeled in 2D. Gradually it was extended to 3D frame models comprising mostly of beams and columns. The shear walls which are often modeled by using shell or membrane elements did not participate in the non-linear analysis and were considered to remain elastic. However in case of tall buildings some non-linearity or hinging is expected in shear walls as well especially near the base. In such cases it is difficult to convert a large shear wall core into an equivalent column and beam system.

This paper presents various approaches to model the shear walls for non-linear and Pushover analysis including a simple frame model, an equivalent fiber model and equivalent strut and tie model. The question of the hinge length and its estimation is discussed in the context of various types of models. The paper also describes the new developments in direct non-linearity in layered shell elements, which can be used to model shear walls.

KEYWORDS: Seismic Resistance; Pushover Method; Shear Walls; Non- linear analysis; Strut and Tie Model

1. ISSUES IN MODELLING OF SHEAR WALL

The proper modeling of shear walls and other forms of structural walls has been a matter of concern for the structural engineers for a long time. In the early days of computer aided analysis, and before the wide spread availability of finite element based programs, the forces on the shear walls were typically determined by an approximate division between frames and walls. However, at present, the response of shear walls and frame structures is determined through proper modeling of the shear walls and structural walls for finite element based analysis. Some of the important considerations for the linear elastic and non-linear modeling are discussed before presenting various modeling techniques.

1.1 Consideration for Linear Elastic Modeling

While modeling shear walls and other types of walls to capture the response with the assumed linear elastic range, the primary concerns are;

(1) The elastic stiffness is modeled correctly, both in terms of absolute value, needed for proper estimation of modal properties, and drift ratios, but also correct estimation with respect to the frame elements for proper determination of relative lateral load sharing. This means that the estimation of the gross or cracked section properties should be done carefully and consistently.

(2) Use of appropriate techniques and elements that capture the response of the particular type of walls
(3) The modeling of the connections between the shear wall elements and the rest of the structural elements to avoid orphan degrees of freedom or deformation or force locking.

1.2 Considerations for Nonlinear Modeling

The purpose of the nonlinear modeling is to capture or to estimate the capacity of the structure to deform and the corresponding force demand.

(1) This requires that the materials properties as used are modeled correctly throughout their entire loading history, including the effects if confinement etc.
(2) That the cross-section dimensions and reinforcement distribution is correctly represented while determining the action-deformation relationships
(3) The effects of hysteresis and degradation are included either explicitly or at least indirectly.
(4) The assumptions about hinge locations and yield zones or hinge lengths are realistic.

2. MODELLING TECHNIQUES

2.1 Single Column Model

The simplest model of the shear wall is of course, representing it by an equivalent column at the center line of the wall section. The connecting beams within the wall are replaced by rigid links to make the deformation compatible with the actual wall width. Non-linear axial-flexural hinges are located at the bottom and top of the column, where as optional shear hinges can be located at the mid height. The moment rotation of the entire wall section is assigned to the column line. This approach is reasonable and suitable for walls of small proportions. For very wide and complex cellular wall arrangement, this may not be able to correctly model the 3D response. Also this model may not be appropriate for the walls portions close to the footings or large beams and outriggers. This model may be used in preliminary models and for quick assessment of the building performance curve. This model can also be used as a reference model for the comparison of various wall models when analysis is carried out independently of the rest of the structure. One of the difficulties is to handle cellular core walls or walls with openings. In such cases, the link beams above the opening will be neglected in the model as shown in Fig 4.

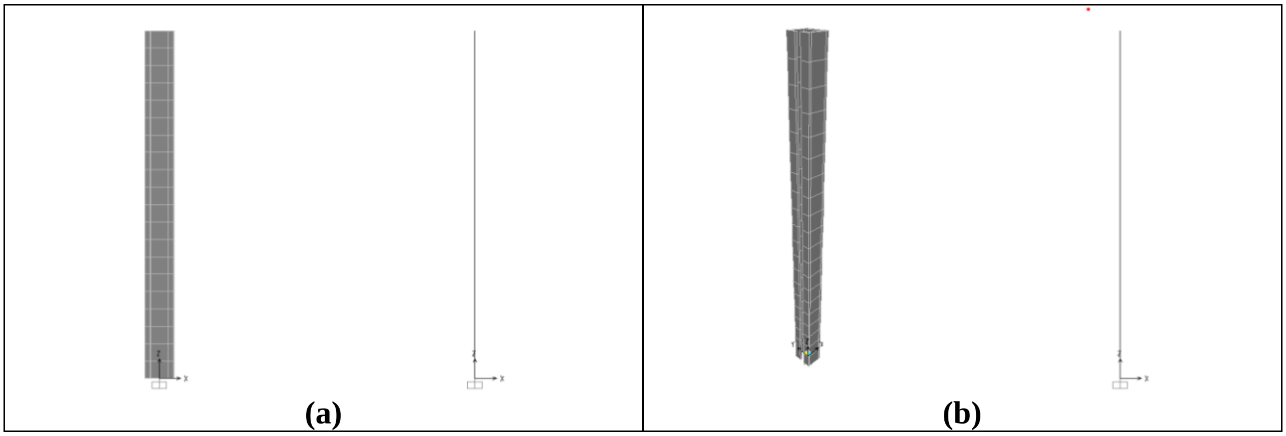
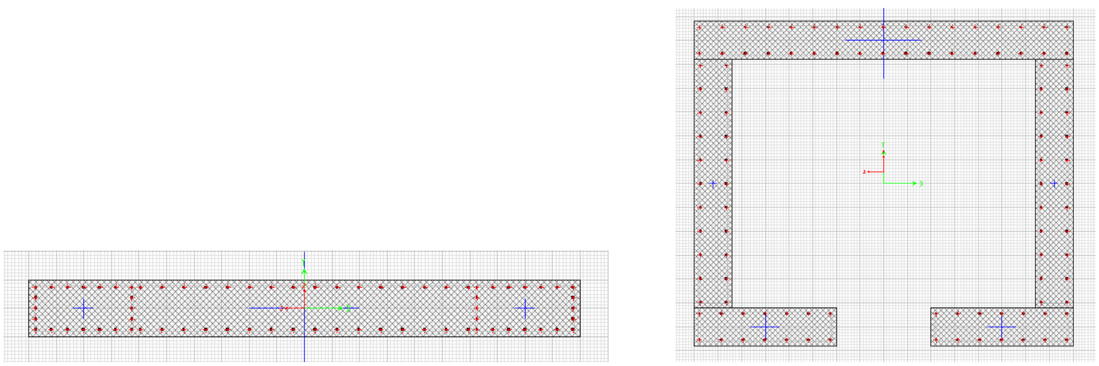


Figure 1. (a)Single column model of planner wall; (b) Single column model of core wall with opening



(a) (b)

Figure 2. (a) Frame section of planner wall; (b) Frame section of core wall with opening (link beam above the opening is not considered)

2.2 Fiber or Frame Model

For the shear walls in tall building, primarily the flexural deformation mode governs, except may be for the lower floors near the base. An equivalent frame discretized model can be used to determine the non-linear response. In this approach closely spaced column representing portions of the wall in the section can be used, connected at the floor level by rigid link to enforce deformation compatibility, without causing local bending. This approach is based on the fiber modeling of the wall sections in PEER Report 2006/2007 (Orakcal, K., Massone, L. M. and Wallace, J. W., 2006). The nonlinear hinges can be added in each column at arbitrary level, representing the axial response of the corresponding portion of the wall. Care should be taken in handling of confined and un-confined portion of the wall as well as the corner and junctions of cellular walls. This model, when properly defined can help to identify the extent of yielding in the wall and eliminates the need to predefine the hinge length, needed in single element models, or to determine this length through analysis. This model can not directly represent the shear stiffness of deformation. The shear strength is assumed to be sufficient is to be checked separately at the control points, typically for each panel.

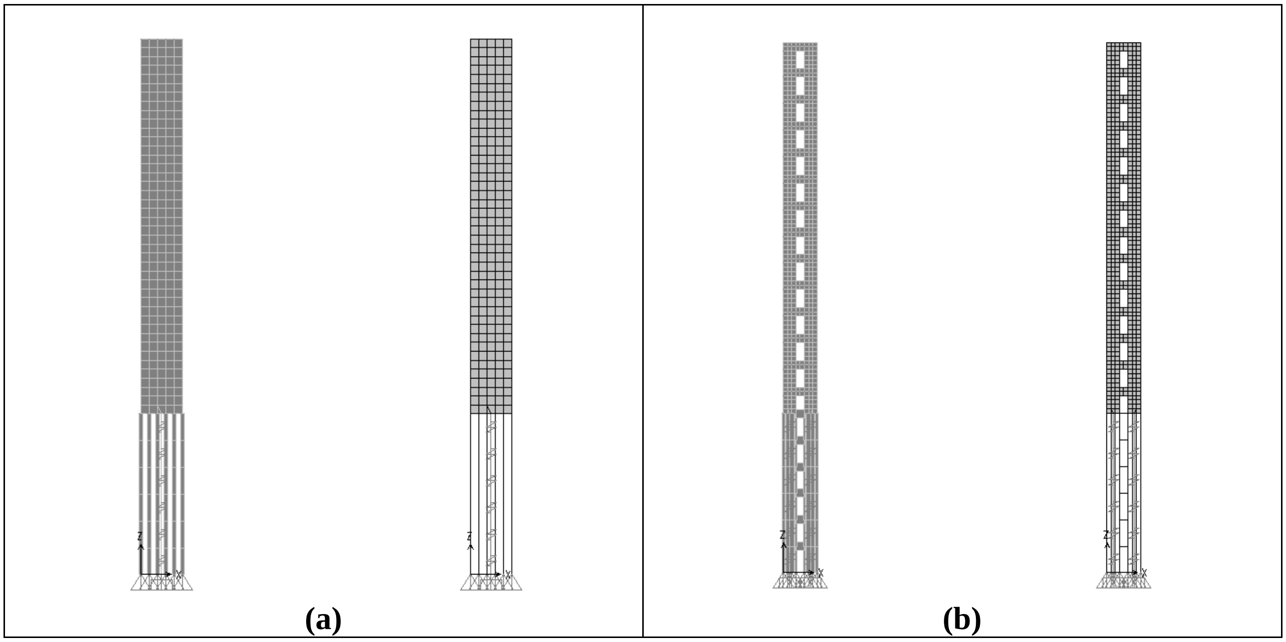


Figure 3. (a) Fiber or frame model of planner wall; (b) Fiber or frame model of core wall with opening

2.3 The Strut and Tie Model

The Strut and Tie Model has been used extensively for the modeling of deep beams, shear walls and other similar members, for elastic analysis, as well as for post-cracking plastic analysis. The basic assumptions of the strut and tie makes this approach also suitable for the nonlinear analysis. The shear wall is assumed to resist the lateral loads through tension-compression couple and diagonal shear elements. Nonlinear hinges can be introduced in these members representing the axial load-deformation response. The vertical members are typically easier to represent in most cases due to presence of boundary element. However, the size and reinforcement considered in the diagonal element(s) is more difficult and subjective. While the truss model for a narrow and single panel wall is rather simple and obvious as shown in Fig. 7, for a wider wall or multi-panel wall cores, the truss model may be more difficult to conceive and construct. Some sample models for various wall geometries and configurations are shown in Fig. 8. Generation of the load deformation curves for the axial member needs special attention as the response in tension and compression is significantly different. The tension side is represented directly by the stress-strain curve of the rebars. However, on the compression side the load deformation curve must take into account the stress-strain curve of concrete and steel, including the effect of confinement, loss of strength due to cyclic degradation. There are several software that can generate the moment-curvature relationship, but not many have the capability to generate proper axial load-deformation curves. For the diagonal members, representing shear, generally, non-linearity or plasticity is not acceptable and the strut must be based on elastic properties. However, if hinges are used in the diagonal struts, they should represent somewhat brittle behavior using force control to check the capacity and detect shear failure. For the diagonal struts, it is preferable that they are aligned approximately with the main diagonals between floors.

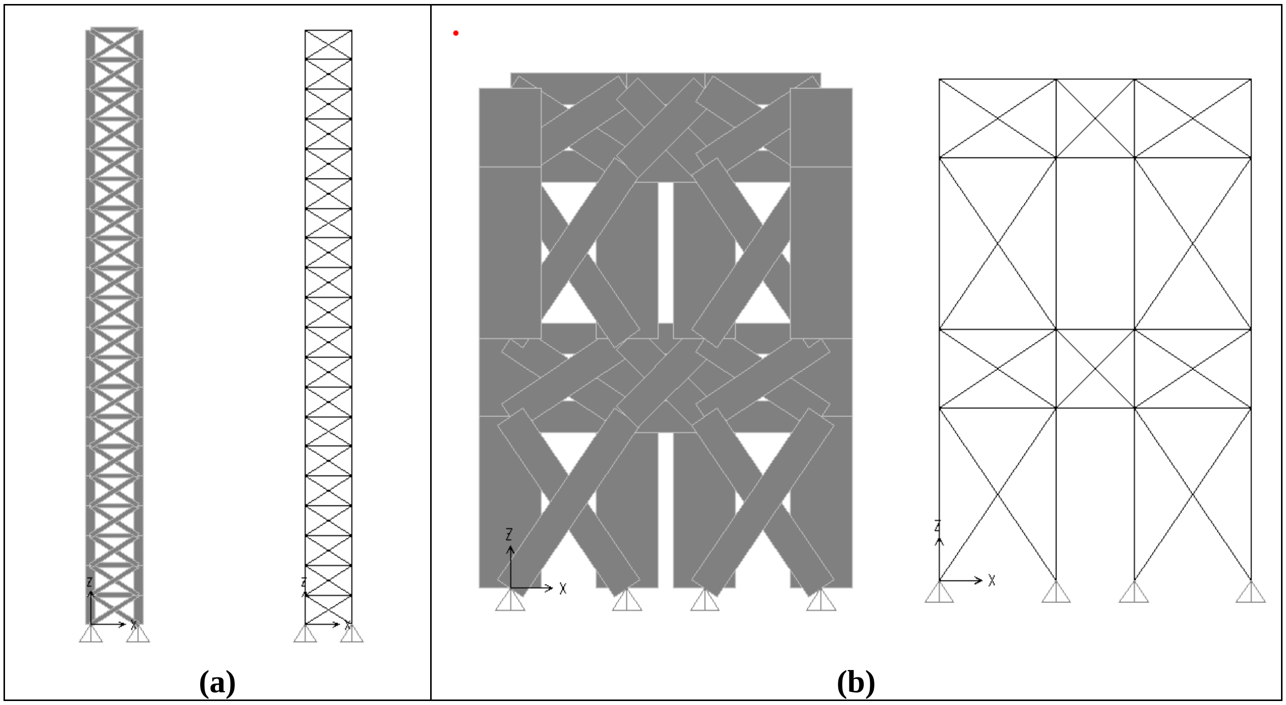


Figure 4. (a) Strut and tie model of planner wall; (b) Strut and tie model of core wall with opening

2.4 Shell Model

There are not many software that have the capability to analyze the nonlinear response of shell element, especially when subjected to in-plane stresses and deformation. The complex stress state, and presence of reinforcement in possible arbitrary direction with respect to the shell elements natural coordinates, posses significant difficulties in generating nonlinear force-deformation relationship. The coupling of in-plane direct and shear stress, some software handles the nonlinearity in the shell elements by using the fiber model internally to generate model hinges. However, if this capability is available then this may be used with appropriate representation of reinforcement and concrete material properties.

2.5 Special Considerations for NLTH Analysis

The Static pushover analysis is typically unidirectional, single pattern load analysis, in which most hinges will deform monotonically. In this case the material and section hysterics can not be considered directly. The hinge properties therefore typically will be based on the envelop curve from the expected hysteresis curves. The material or section degradation due to cyclic response is not explicitly considered. However, for a detailed nonlinear time history analysis, the effective of material as well as section level hysterics and degradation for cyclic response needs to be considered. Although the basic modeling approaches presented for the static pushover analysis are also suitable for the NLTH, the hinge properties as well as modeling should represent the hysteric descending on the software this may be explicitly specified on a hysteric loops, or be based on some established models, such as talked.

2.6 Software Suitable for Nonlinear Analysis of Walls

The software used for the nonlinear analysis of buildings with shear walls should have the capability to handle, Nonlinear Hinges for Axial, P-M-M, Shear DOF, including the effects of Hysteretic. Capability to handle the nonlinearity in shell elements would be an advantage.

3. COMPARITIVE STUDY

Two walls are selected to compare the non linear pushover curves generated by various modeling technique. Pushover analysis is performed by displacement control (top displacement of 5% drift). Inverted triangular loading is used. Axial hinges are assigned in the mid length of the member for fiber or frame model and strut and tie models. For the cracked section models, 50% bending stiffness and 40% shear stiffness of gross section are used.

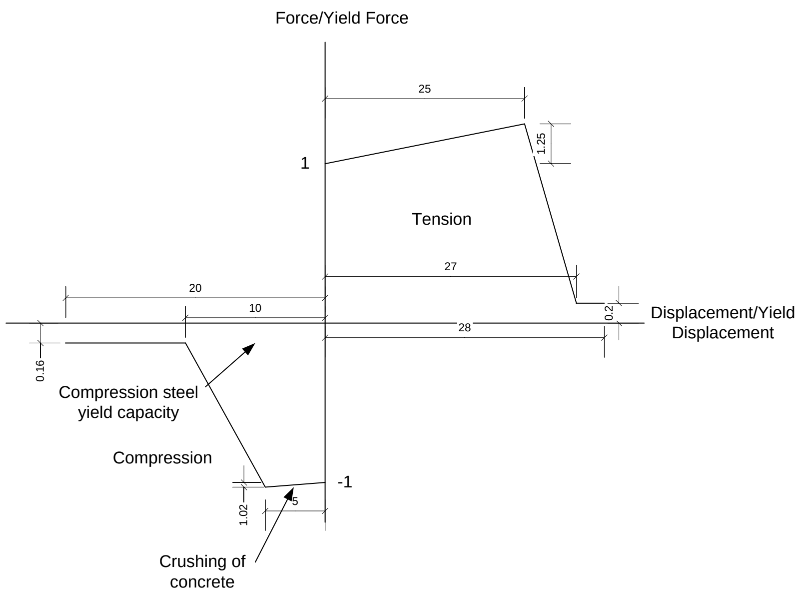
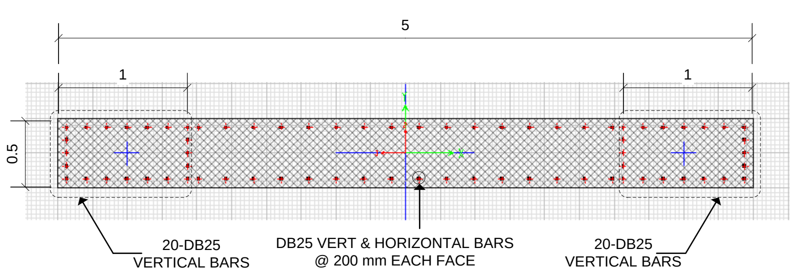


Figure 5. Axial hinge property

3.1 Planner Wall



20 STORIES @ 3.2 m = 64 m

ALL UNITS ARE IN METER

Figure 6. Rebar layout in planner wall

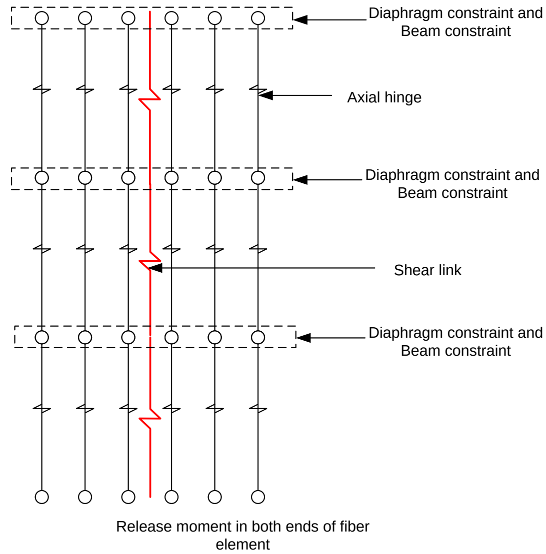


Figure 7. Fiber or frame modeling in planner wall

Table 1 Comparison of Time Period (sec) in Planner Wall

Mode	*Single Column (Cracked)*	*Full Shell (Gross)*	*Full Shell (Cracked)*	*Fiber or Frame*	*Strut and Tie*
1	2.24	1.58	1.59	1.49	1.42
2	0.37	0.26	0.27	0.25	0.25
3	0.14	0.10	0.10	0.09	0.12
4	0.08	0.08	0.08	0.08	0.10

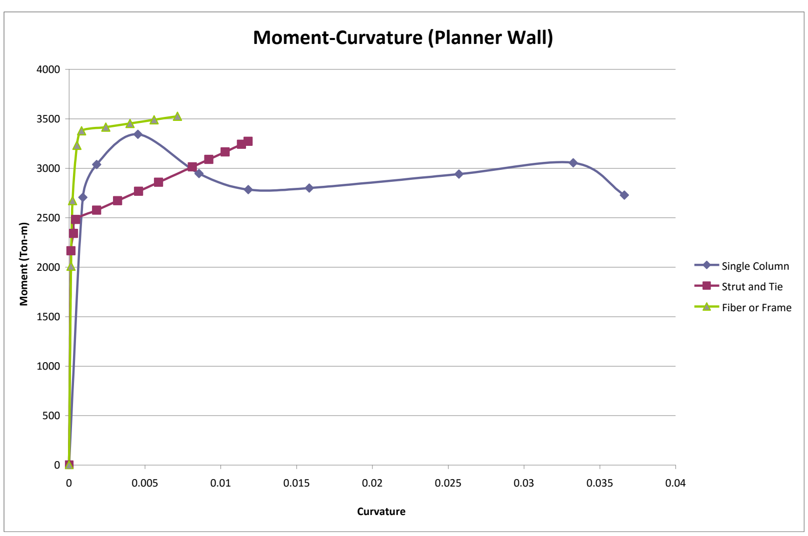


Figure 8. Comparison of moment-curvature curves in planner wall

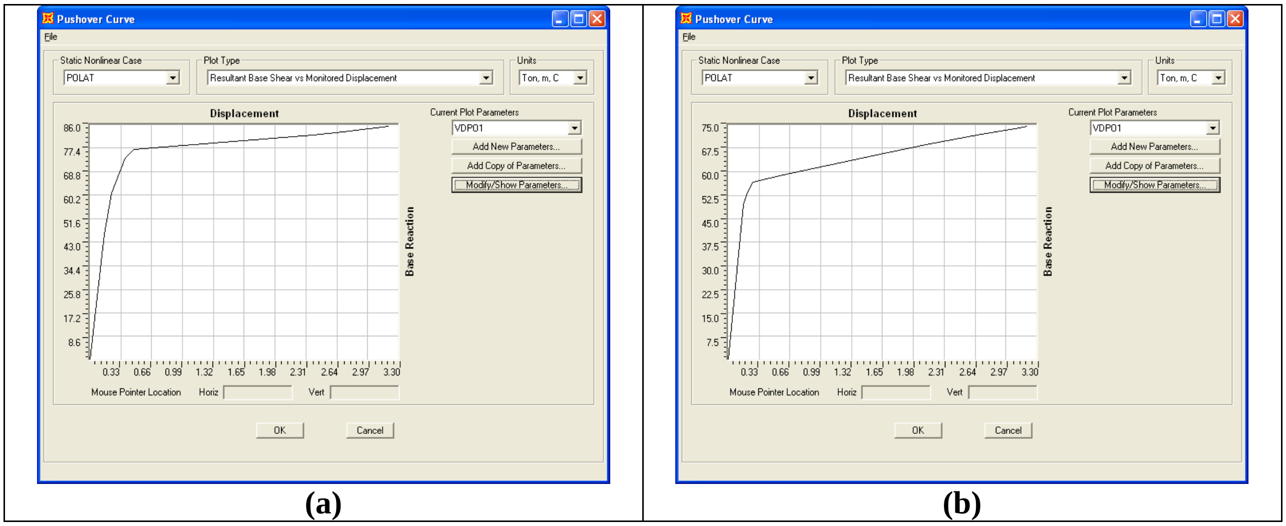


Figure 9. (a) Base shear and top displacement of planner wall (Fiber or frame model); (b) Base shear and top displacement of planner wall (Strut and tie model) Unit: Ton-m

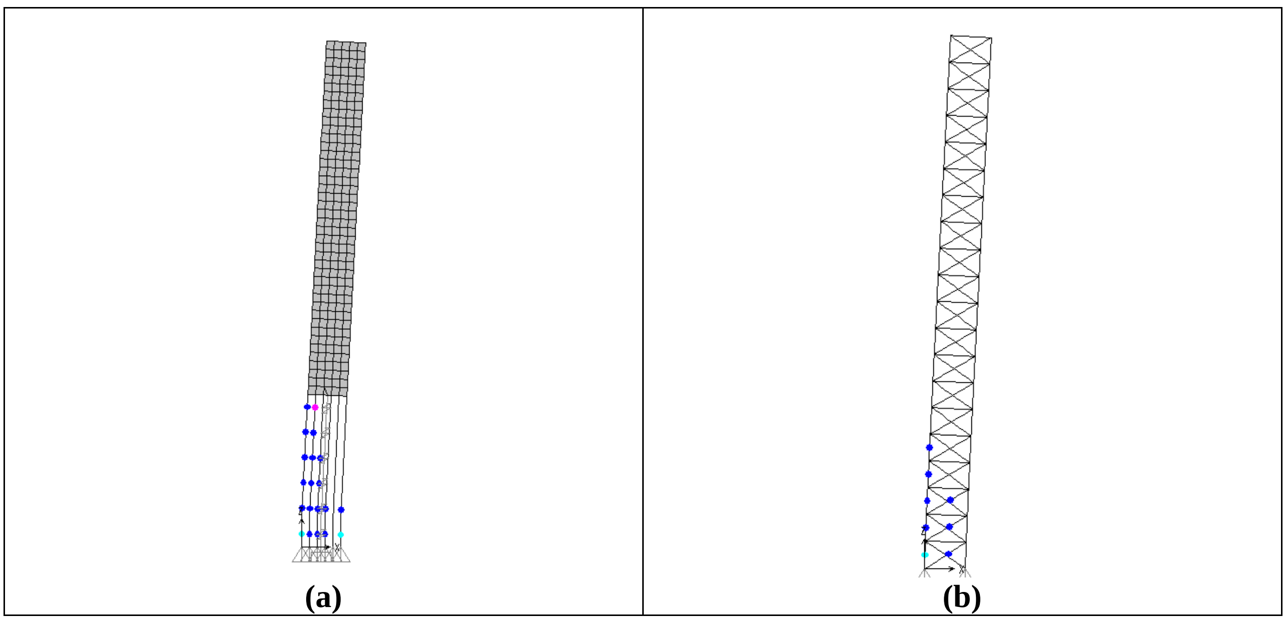
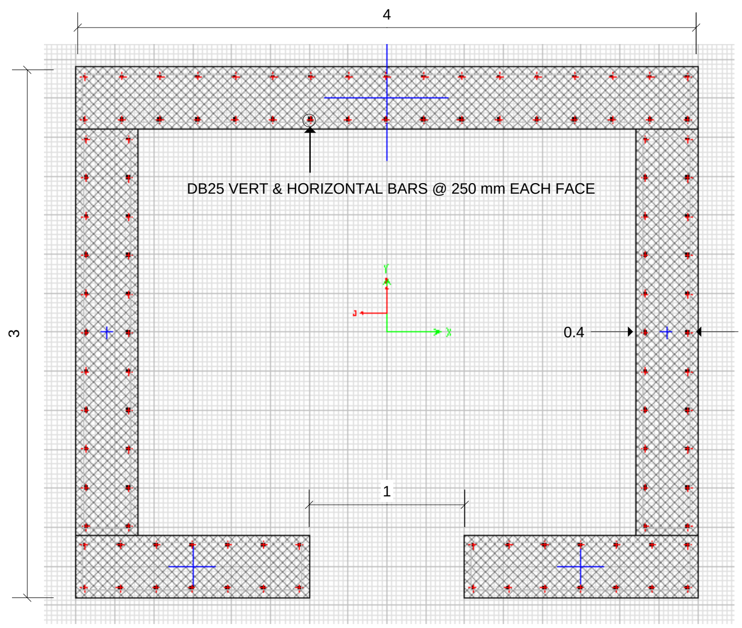


Figure 10. (a) Hinge formation in planner wall (Fiber or frame model); (b) Hinge formation in planner wall (Strut and tie model)

3.2 Core Wall



For Link Beam above opening, Top Rebar = 8-DB25, Bottom Rebar = 8-DB25

Figure 11. Rebar layout in core wall

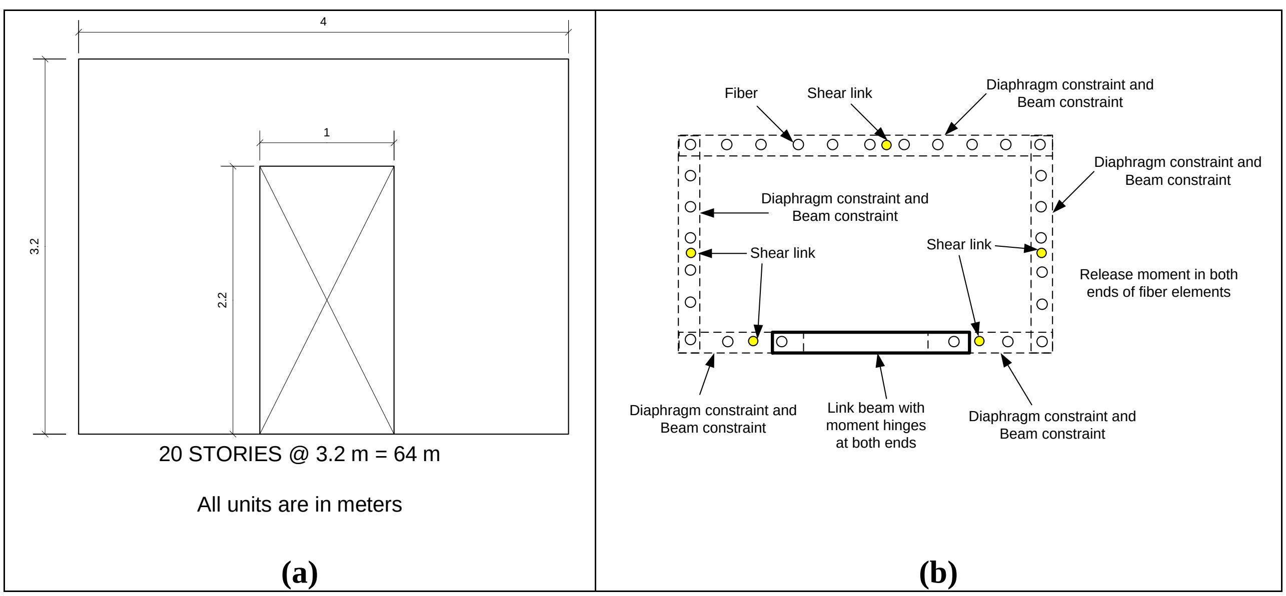


Figure 12. (a) Elevation of opening in core wall; (b) Fiber or frame modeling in core wall

Table 2. Comparison of Time Period (sec) in Core Wall

Mode	*Single Column (Cracked)*	*Full Shell (Gross)*	*Full Shell (Cracked)*	*Fiber or Frame*	*Strut and Tie*
1	2.85	1.85	1.87	1.83	2.16
2	2.06	1.43	1.45	1.41	1.61
3	0.47	0.31	0.32	0.30	0.38
4	0.35	0.25	0.27	0.24	0.31

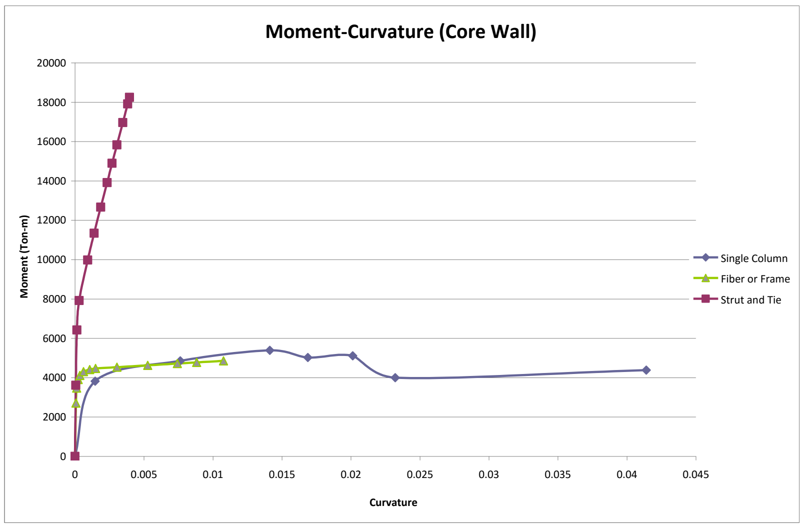


Figure 13. Comparison of moment-curvature curves in core wall

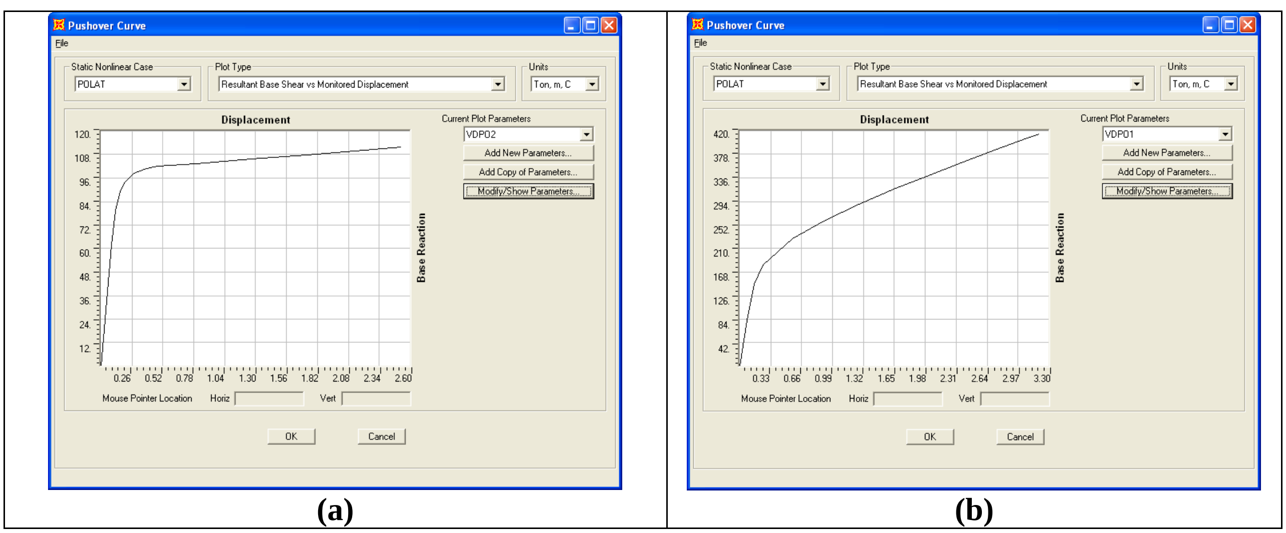


Figure 14. (a) Base shear and top displacement of core wall (Fiber or frame model); (b) Base shear and top displacement of core wall (Strut and tie model) Unit: Ton-m

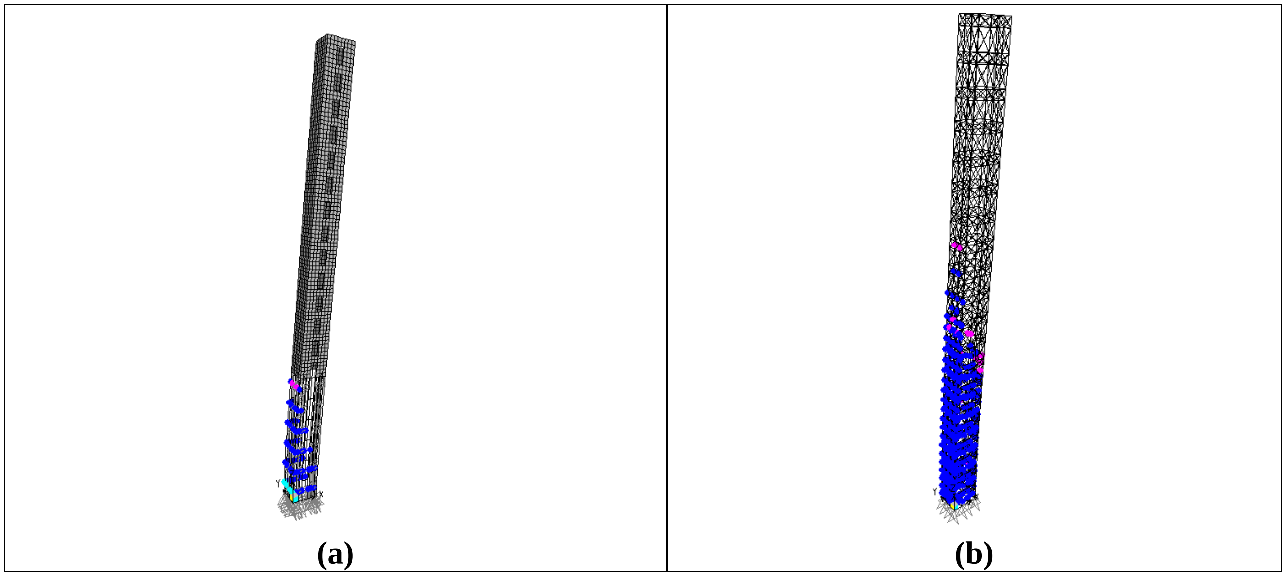


Figure 15. (a) Hinge formation in core wall (Fiber or frame model); (b) Hinge formation in core wall (Strut and tie model)

4. CONCLUSIONS

The objective of this study was to investigate the various approaches of nonlinear modeling of shear walls to predict their inelastic response by pushover analysis. For this purpose, the planner wall and core were modeled via implementing refined fiber or frame model and strut and tie model. Regarding the efficiency of various modeling approaches, it is concluded that the refined fiber or frame model has the capability to present the nonlinear flexural behavior more reliable than strut and tie model. The fiber model can be used to estimate the extent of yielding in the shear walls and can be used to determine the hinge length more realistically than based on single or double story concept. However both models lack the proper representation nonlinear shear behavior and shear flexural interaction behavior. Nonlinear analysis using the nonlinear shell elements directly is not compared in this study and may prove to represent the response more realistically.

REFERENCES

ACI 318-05. 2005. Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary (ACI 318R-05). **American Concrete Institute: Farmington Hills, MI**.

Orakcal, K., Massone, L. M. and Wallace, J. W. (2006) Analytical modeling of reinforced concrete walls for predicting flexural and coupled shear-flexural responses. **PEER Report 2006/2007, Pacific Earthquake Engineering Research Center, University of California, Berkeley**, October 2006, 213 pp.

Wallace, J. W. (2007) Modeling issues for tall reinforced concrete core wall buildings. **The Structural Design of Tall and Special Buildings**, Vol. 16, 2007, 615-632.

Park, R. and Paulay, T. (1975) **Reinforced concrete structures**, John Wiley and Sons.

ABOUT THE AUTHORS

[1] Director, Asian Center for Engineering Computations and Software, Asian Institute of Technology, Thailand

[2] Research Associate, Asian Center for Engineering Computations and Software, Asian Institute of Technology, Thailand

ACKNOWLEDGEMENTS

Some of the modeling techniques presented were referenced from the paper of Orakcal, K., Massone, L. M. and Wallace, J. W. All the analyses were done in SAP2000 V12 and Computers and Structures Inc., Berkeley, USA is gratefully appreciated for allowing using the SAP2000 V12 and generating some graphics and output. Any opinions, findings and conclusions or recommendations expressed in this paper are those of the author and do not necessarily reflect those of the organization or other people acknowledged herein.

The Support provided by the Asian Center for Engineering Computations and Software, ACECOMS at the Asian Institute of Technology, Thailand is greatly appreciated.