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A Comparative Study on Non-Linear Analysis of Frame with and without Structural Wall System

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Abstract

Earthquake is an unexpected and expensive disaster for both livelihood and economy. In the present day construction, there has been a lot of importance to make the structure resistance against lateral loads for multi storied building, Structural walls are an option of lateral loads resisting system (LLRS) in buildings. They attract lateral loads due to their high-in-plane stiffness as compared to other members in the structure. The presence of structural wall allows the designers to design other members to take gravity load only. A well designed and detailed shear wall can provide the required strength as well as sufficient ductility for resisting lateral loads and can prevent high damages. The increased use of shear wall in buildings has triggered the necessity to study the behaviour of the wall under various modelling conditions. In the present study a typical low rise building is considered with two types of modelling the structural wall, one with multi-layer shell element and other with equivalent column element. The results obtained were compared with a normal frame building designed to with stand lateral loads without shear wall. The building was analysed using SAP2000 (V-17.3). From the analysis, it was observed the pushover curves observed for multi-layered shell element and equivalent column elements are almost equal. Hence, the modelling of structural wall as a column element can predict the behaviour similar to multi-layered shell element.

Keywords — *Shear wall, lateral loads resisting system, structural wall, multilayered shell element, equivalent column element.*

I. INTRODUCTION

Recent earthquakes have demonstrated the importance of selecting a good seismic structural system to provide life safety and economic protection. Even though in previous days structural frames were over designed called as Lateral Load Resisting Structures (LLRS) to withstand all these kind of lateral loads, now a days structural walls have been a common and cost effective way of providing lateral load resistance to buildings in seismic areas throughout the world. They attract large amount of lateral loads due to their high in-plane stiffness as compared to other frame members in a building. A well designed and detailed shear wall can provide the required stiffness, strength as well as sufficient ductility for resisting lateral load.

Walls can be classified based on their aspect ratio (height-to- width or height-to-length) as tall walls and squat walls. The tall walls are primarily governed by flexural action and are usually casted in site. The squat walls are primarily governed by the shear. The squat walls can be precast or built along with other frame members. A structure of shear wall in the centre of a large building often encases an elevator shaft and is called a core wall.

The increased use of shear wall in buildings has necessitated the study for better understanding the modelling aspect of a wall and its behaviour under lateral loads. Linear analysis is the first step that is usually carried out to verify the model for stiffness. For seismic evaluation and retrofit of buildings, a performance-based non-linear analysis is recommended.

A non-linear static analysis such as the push over analysis helps us in understanding the ductility and performance levels of these kind of wall. The present study involves the modelling of regular building with only frame and building with different kinds of shear walls

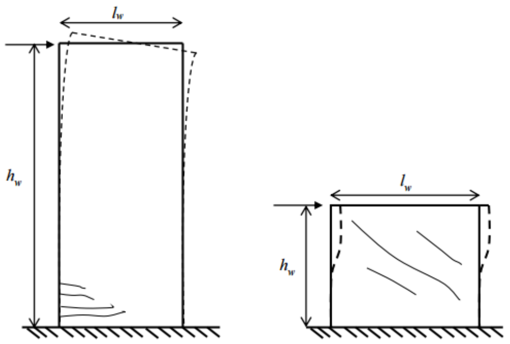
II. OVERVIEW OF STRUCTURAL WALLS

A. Lateral Load Resisting System

In this type of structures the members (beams and columns) are designed to withstand the lateral loads as well as dead load of the structure. As this structure has no structural walls, the dimensions and reinforcement in both beams and columns is high. This makes the building capable to resistant the lateral loads.

B. Structural Walls

Depending on the height-to-width ratio structural walls can be classified as tall wall (h_w/l_w substantially more than 2), squat wall (h_w/l_w less than 2), or transition of the two. The deformations of a tall wall and a squat wall are governed by flexure and shear, respectively. Fig. 1 represents the possible deflected shapes of an isolated tall wall and squat wall, respectively



a) Tall wall b) Squat wall

Fig.1 Types of Structural Walls Based on Height to Length Ratio

III.MODELLING OF STRUCTURAL WALLS

A. Modelling of Hinge in Beams or Columns.

Park and Paulay (1975) explained the behaviour of tall walls based on the mechanics of reinforced concrete. This theory predicts the moment versus curvature behaviour of a tall wall subjected to simultaneous in-plane moment and axial load. This is based on equilibrium of vertical forces, compatibility of strains in concrete and steel, and the constitutive relationships of the materials. This approach can be used to calculate the flexural hinge property for a tall wall for pushover analysis. But in the present study auto hinges option provided in the software (SAP 2000) are used.

B. Modelling of Structural Wall

The structural walls can be modelled by using multi-layered shell elements or equivalent columns. In multi-layered shell element concrete and reinforcement is modelled as separate layers. An equivalent column member is modelled as a column with the dimensions and reinforcement of structural wall. Rigid beams are used to connect the equivalent columns to the others members

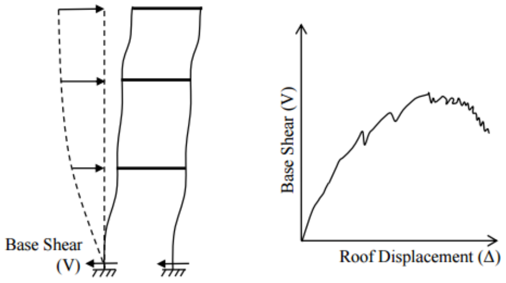
IV. NON LINEAR ANALYSIS OF RC BULIDINGS

A. Monotonic Pushover Analysis (POA)

Pushover analysis is a static, non-linear analysis in which the loads are incrementally increased according to a predefined pattern. To model the non-linear in-elastic behaviour in flexure, shear or axial compression hinges were used at potential plastic hinge locations. As the magnitude of load is increased, hinge-formation takes place.

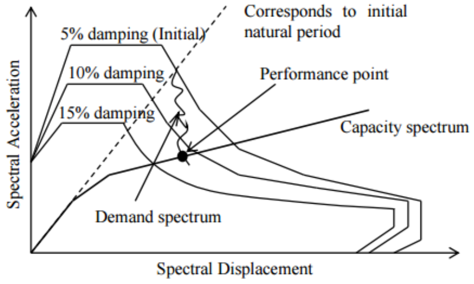
The pushover analysis of a building model can be studied under force controlled push or displacement controlled push. In force controlled push, the building is pushed till the target load value is reached. The gravity loads are usually applied under a force controlled push. In displacement controlled push, the building is laterally pushed till a target displacement value of the control node is reached or the building has reached a collapse mechanism. The base shear versus roof displacement is recorded at each step, and the curve between the two is called the pushover curve. The displacement controlled push can determine the lateral strength of the building and maximum inelastic drift.

To determine the performance point capacity spectrum and demand spectrum were used. The capacity spectrum is a curve between spectral acceleration to spectral displacement. It is plotted in the acceleration displacement response spectrum (ADRS) format. The locus of the demand points in the ADRS plot is referred to as the demand spectrum. The point at which the capacity curve crosses the demand curve is called the performance point and is shown in fig.3. If the states of damage of the members at this stage are acceptable, then the structure is considered to be satisfactory. Fig. 2 explains basic pushover analysis for a building.



a) Building Model b) Pushover Curve

Fig.2 Push over Analysis for a Building



c) Demand Curve and Capacity Spectra

Fig.3 Demand Curve and Capacity Spectra
Courtesy: Manual for Seismic Evaluation and Retrofit of Reinforced Concrete Buildings (2005)

V. COMPUTATIONAL MODELLING

The building considered for the analysis was a regular low-rise building, rectangular in- plan with orthogonal moment resisting frames and a centrally located structural wall adopted from Bulusu Suryateja (2014). Since the main objective of the study was to understand the modelling of the behaviour of structural wall, a single wall was provided in the centre of the structure only in the direction of investigation. The sizing of the structural members and other building information are given in Table 1. The building plan and elevation are shown in Fig. 4.

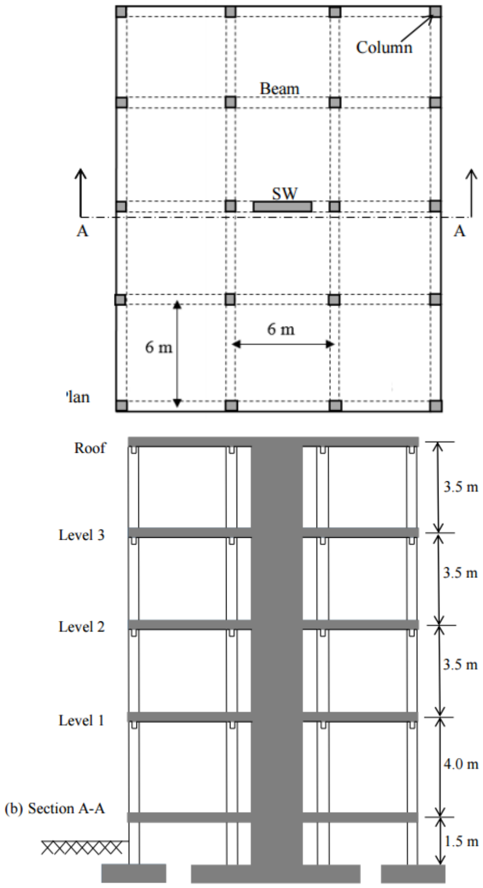


Fig.4. Floor Plan and Sectional Elevation of Building

A. *Sizing of Structural Members*

The depth of the slab was calculated based on the provision of span-to-depth ratio given in Cl.24.1 of IS 456:2000. The depth of the beam was based on the span-to-effective depth ratio of 26 as per Cl.23.2.1 of IS 456:2000. The cross-sectional dimensions of columns were selected based on the factored gravity loads from the tributary areas of the floors supported above. The design of the members were based on the internal forces calculated using equivalent static method of analysis as per IS 1893: 2002.

For dual system, ACT 318:11 recommends that the frame member can be designed for gravity loading only and provided with ductile detailing. The lateral load is resisted entirely by the structural wall. In the considered building, the framed structural wall along with the adjacent boundary columns were designed to resist gravity loads only

Table.1 Building Model Specification

S.No	Description	Information
1.	Plan dimensions	24m × 18m
2.	Slab thickness	200mm
3.	Beam size	250 mm × 400 mm
4.	Beam size in lateral load resisting system	250 mm × 500 mm
5.	Column size	350 mm × 350mm
6.	Column size in lateral load resisting system	450 mm × 450mm
7.	Thickness of wall panel	150mm
8.	Grade of concrete	M30
9.	Grade of reinforced steel	Fe415
10.	Live load	3kN/ 2 for floors, 2kN/ 2 for roof
11.	Finish load	0.75kN/ 2 for floors, 2kN/ 2 for roof
12.	Seismic zone	V, Z=0.36
13.	Importance factor	1
14.	Response reduction factor	5
15.	Type of soil	Medium (Type II)

The computational model of the building was developed using SAP2000 (V.17).

B. *Beams and Columns*

The beams and columns were modelled using 1D elastic frame elements with point plastic hinges. The beam-column joints were treated as rigid. The finite dimension of a joint was simulated by assigning end offsets to the connected members with a rigid zone factor equal to 1.

C. *Structural Wall*

A wall panel was modelled using multi-layered shell element with fine meshing. The size of the mesh adopted was 0.5m × 0.5m. In a multi-layered shell element the overall layer is of concrete and two rebar layers were modelled, as shown in Fig. 5

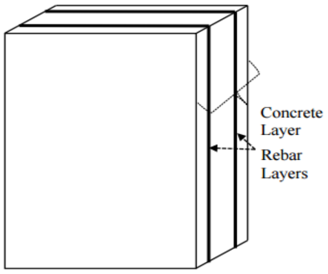


Fig.5. Multilayered Shell Element

D. *Slabs*

The slabs in the model were not explicitly modelled. The loads on the slabs were distributed to the supporting beams as triangular loads based on their tributary areas. The effect of the in-plane stiffness of the slabs was modelled by assigning the diaphragm constraint to all the nodes at each floor levels.

E. Modelling of Flexural Hinges

The flexural hinges were developed using piece-wise moment versus curvature curves. For a typical beam, the flexural hinges were assigned at the ends since the maximum moment was expected to occur at these locations. The hinge assignment for typical beam and column is shown in Fig 6. The corresponding hinges for all the beams and column was assigned separately from the auto hinge command found in SAP 2000. Fig.7, 8 and 9 shows the SAP modelling of LLRS building, building with shear wall modelled as multilayered shell element and building with shear wall modelled with equivalent column respectively.

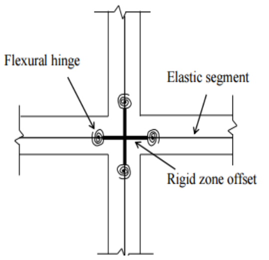


Fig. 6 Typical beam column joints with assigned hinges

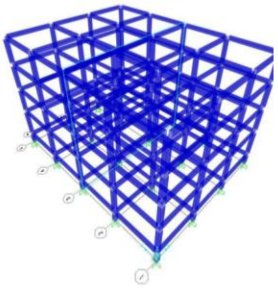


Fig. 7 Extruded 3 D view of LLRS building

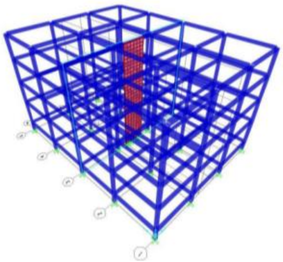


Fig.8 Extruded 3D view of frame with multi layered shell element

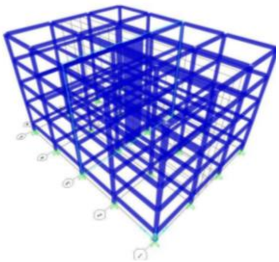


Fig.9 Extruded 3 D view of frame with equivalent column

VI.RESULTS AND DISCUSSIONS

Monotonic Pushover analyses were conducted for the three computational models. The response parameters like pushover curve, and sequence of hinge formations are discussed below.

A. LLRS Frame Models

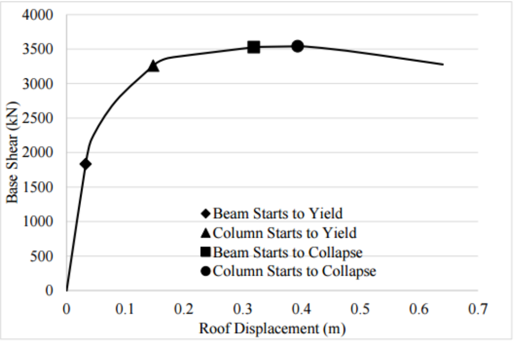
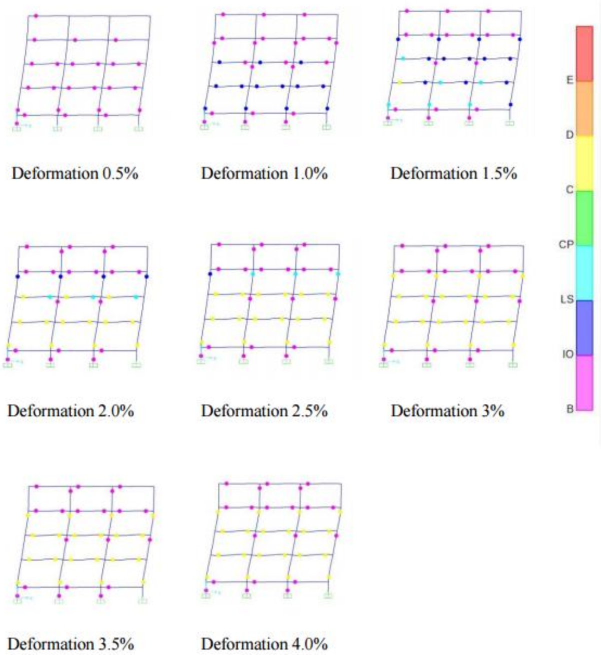


Fig.10. Push Over Curve for LLRS Building

From Fig.10 it is inferred that, the LLRS structure showed maximum base shear of 3540 kN at a displacement of 0.39 m (2.4% of drift) after which the collapse mechanism in columns were observed. The formation of hinges at periodic intervals are shown in Fig 11.

The yielding of beam was started at a roof displacement of 0.0325 m and column at 0.147 m. The formation of collapse mechanism in beams were observed at a roof displacement of 0.3187 m. The whole structure undergoes collapses mechanism at a roof displacement of 0.3934 m (2.4% of drift).



Deformation 0.5% Deformation 1.0% Deformation 1.5%

Deformation 2.0% Deformation 2.5% Deformation 3%

Deformation 3.5% Deformation 4.0%

Fig. 11 Hinge Formation of LLRS Building

B. Building with Multi-Layered Shear Wall:

This beams and columns of this building was designed to take the dead load and the shear wall was designed to take the lateral loads. Fig 12 shows the pushover curve with location of yielding and collapse of beams and columns, respectively.

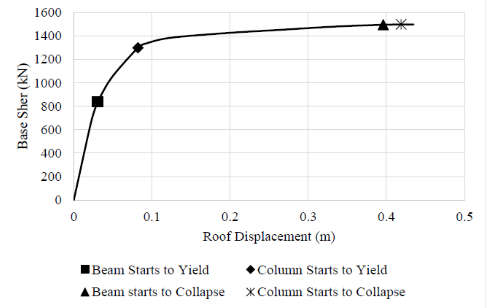


Fig.12. Push Over Curve For Multilayered Shell Element Shear Wall Building

Due to the presence of shear wall less lateral displacement was observed in comparison to LLRS building. The yielding of the beams and columns were started at a roof displacement of 0.031 m and

0.082 m, respectively. The collapse mechanism in beam and columns were observed at a roof displacement of 0.39 m and 0.42 m, respectively. The formation of hinges in beams and column for multilayered shear wall building is shown in Fig 13 and Fig 14 shows the vertical stress distribution in shear wall.

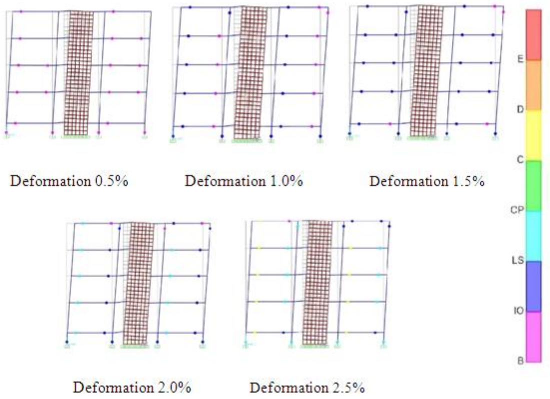


Fig.13 Formation of Hinges in Beams and Column for Multilayered Shear Wall Building

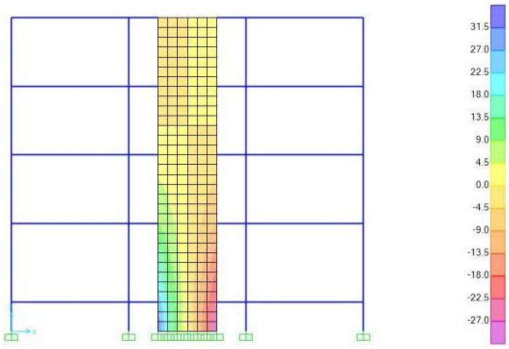


Fig.14 Vertical Stress Distribution in Concrete

C. *Building with Equivalent shear wall*

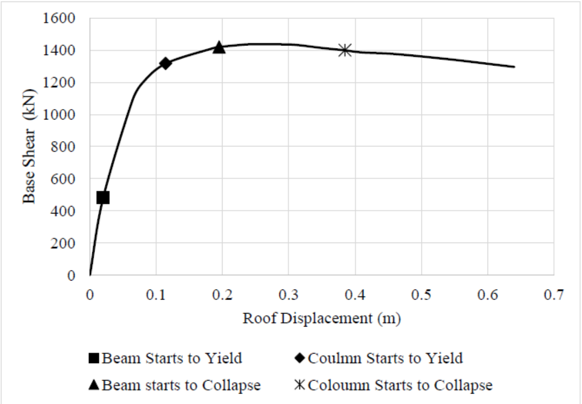


Fig. 15 Push Over Curve for Shear Wall Modelled with Equivalent Column.

Fig.15 shows the push over curve for shear wall modelled using equivalent column. The first beam starts to yield at a displacement of 0.063 m then followed by the column at a drift of 0.115 m then beam moves to collapse mechanism at a drift at 0.195 m then column at drift at 0.384 m hinge formation of the structure under lateral load in beams and column are shown in Fig 16.

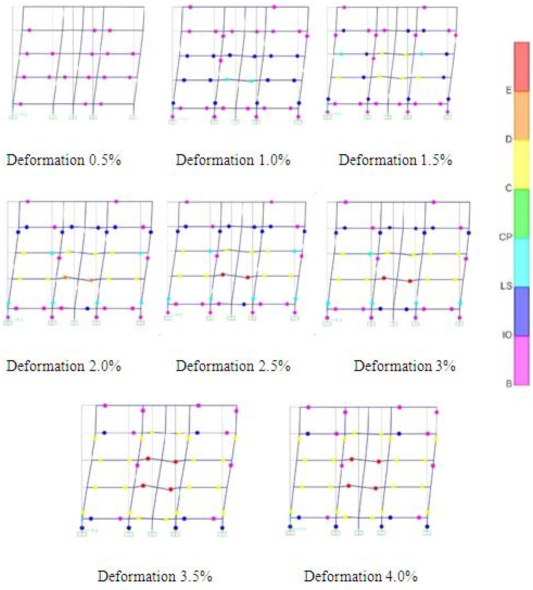


Fig.16 Hinge Formation in Beams and Columns for Equivalent Column Shear Wall Building

D. *Comparison of Multi-Layered Shell Element and Equivalent Column Shear Wall*

Figure 17 shows the comparative pushover behaviour curves observed for shear wall buildings modelled by using multi-layered shell element and equivalent column. It is observed that both the models showed equal initial stiffness. For the shear wall modelled as equivalent column drop in capacity was observe after roof displacement of 0.25 m. Whereas no drop in capacity was observed for shear wall modelled as multi-layered shell element.

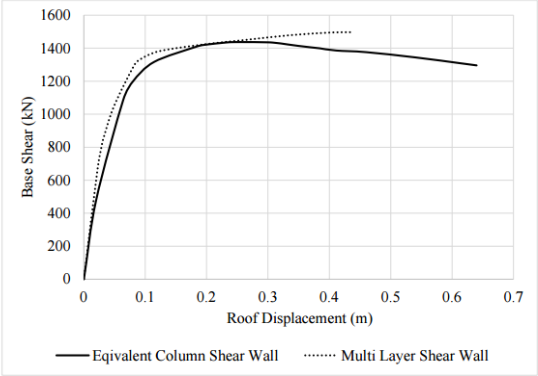


Fig.17 Push over Curve for Shell Element And Equivalent Column Element Shear Wall Buildings

VII.CONCLUSIONS

Based on the observation form numerical analysis, the following conclusions were drawn.

- In comparison with LLRS building, building with structural walls can with stand lateral loads without much deformation.

- The monotonic pushover curves for the Shear wall modelled using multi-layered shell element and by equivalent column were almost similar.
- Any one of the method can be used for modelling the shear wall. But for equivalent column provision of proper hinges property is required.

ACKNOWLEDGEMENT

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