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# Pushover analysis of G +7 residential building with & without shear wall

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***Abstract*---**Shear wall is applied to counter the effects of lateral load acting on a structure. Wind and seismic loads are the most common loads that shear walls are designed to carry in high rise building. This project used four models of 7 floors building with three variations of shear wall position. The dimension of each floor is 15 m x 15 m. In this study the seismic response of a seven storied reinforced concrete building is analysed by displacement-controlled pushover analysis. It is assumed to be located in seismic zone 5. The building frame is simulated and analysed using the structural analysis and design software ETABS 19. In non-linear analysis, moment-curvature relationship is used to model plastic hinge behaviour. Thus, it was developed for modelling the user defined hinges for beam and column sections. The lateral forces were obtained as per IS 1893 (Part1):2002 and applied to the building. Top node displacement is incremented step by step up to the limiting displacement to obtain the pushover curve and the sequence of formation of plastic hinges and failure of beams and columns were recorded. The analysis results including the pushover curve and hinge formation are discussed. The maximum base shear


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capacity was found to be higher than the design base shear and hinges were formed in beams prior to columns.

***Keywords*---**seismic waves, earthquake, structural analysis, time history analysis, pushover analysis, response spectrum analysis, shear wall.

## Introduction

Seismic loading on any structure needs detailed data of its behaviour underneath large inelastic deformations. The behaviour of seismic loads isn't the same as wind loads or gravity loads. Structural behaviour under seismic loading calls for an expertise of inelastic deformation behaviour. Pushover analysis (Non-linear Static analysis) is a manner this is used to evaluate the building loaded beyond elastic range. The latest introduction of performance-primarily based design has introduced the non-linear static push over analysis procedure to the leading edge. Pushover analysis is a static non-linear process wherein the value of the structural loading is incrementally expanded alongside the lateral direction in predefined pattern. It is assumed that the behaviour of the structure is managed by using fundamental mode and the predefined pattern is expressed in phrases of story shear or in phrases of fundamental mode form. With the growth in of lateral load, the non-linear behaviour of different structural factors is captured, and their vulnerable links and failure modes of the structure are determined. further, pushover analysis is also used to examine the efficiency of a structure and many other types of structures as well to resist certain stage of input movement in phrases of a response spectrum. lately, changes to push over methods were proposed to capture contribution of higher modes of vibration. Push over technique is being famous now due to the availability of the analytical gear including SAP-2000, ETABS, MIDAS, and many others.

## Pushover analysis

### Description

Federal Emergency Management Agency (FEMA) and Applied Technical Council (ATC) are the two agencies which formulated and suggested the Non-linear Static Analysis or Pushover Analysis under seismic rehabilitation programs and guidelines. This included documents FEMA-440, FEMA-356, and ATC-40.

### Types of pushover analysis

Presently, there are two non-linear static analysis procedures available, Displacement Coefficient Method (DCM), documented FEMA-440 and Capacity Spectrum Method (CSM) documented in ATC-40. Both methods depend on lateral load-deformation variation obtained by non-linear static analysis under the gravity loading and idealized lateral loading due to the seismic action. This analysis is called Pushover Analysis.

**Capacity spectrum method**

Capacity Spectrum Method is a non-linear static analysis procedure which provides a graphical representation of the expected seismic performance of the structure by intersecting the structure's capacity spectrum with the response spectrum (demand spectrum) of the earthquake. The intersection point is called as the performance point, and the displacement coordinate dp of performance point is the estimated displacement demand on structure for the specified level of seismic hazard.

**Displacement coefficient method**

Displacement Coefficient Method is a non-linear static analysis procedure which provides a numerical process for estimating the displacement demand on structure using a bilinear representation of the capacity curve and a series of modification factors to calculate a target displacement. The point on capacity curve at target displacement is the equivalent of performance point in the capacity spectrum method.

**Building performance level**

Building performance is the combined performance of both structural and non-structural components of the building. Different performance levels are used to describe the building performance using the pushover analyses, which are described below.

**Operational level (OL)**

As per this performance level building are expected to sustain no permanent damages. Structure retains original strength and stiffness. Major cracking is seen in partition walls and ceilings as well as in the structural elements.

**Immediate occupancy level (IO)**

Buildings meting this performance level are expected to sustain no drift and structure retains original strength and stiffness. Minor cracking in partition walls and structural elements is observed. Elevators can be restarted. Fire protection is operable.

**Life safety level (LS)**

This level is indicated when some residual strength and stiffness is left available in the structure. Gravity load bearing elements function, no out of plane failure of walls and tripping of parapet is seen. Some drift can be observed with some failure to the partition walls and the building is beyond economical repair. Among the non-structural elements failing hazard mitigates but many architectural and mechanical and mechanical systems get damaged.

**Collapse prevention level (CP)**

Buildings meeting this performance level are expected to have little residual strength and stiffness, but the load bearing structural elements function such as load bearing walls and columns. Building is expected to sustain large permanent drifts, failure of partitions infill and parapets and extensive damage to non-structural elements. At this level the building remains in collapse level.

**Methodology**

**Assignment of hinges for pushover analysis**

Location of inelastic action of the structural member is called as plastic hinge. For nonlinear static, and nonlinear direct-integration, users may simulate post-yield behaviour by assigning concentrated plastic hinges to frame and tendon objects. Elastic behaviour occurs over member length, and then deformation beyond the elastic limit occurs entirely within hinges, which are modelled in discrete locations. Inelastic behaviour is obtained through integration of the plastic strain and plastic curvature within a user-defined hinge length. To capture plasticity distributed along member length, a series of hinges can be modelled. Multiple hinges may also coincide at the same location. Plasticity may be associated with force-displacement behaviour or moment-rotation. Hinges can be assigned (uncoupled) to any of the six DOF. The modelling of strength loss is discouraged, to mitigate load redistribution and to ensure numerical c onvergence .

**Pushover analysis procedure**

The use of the nonlinear static analysis pushover analysis came into practice in 1970's but the potential of pushover analysis has been recognised for last 10 to 15 years. Pushover analysis can be performed as either force control or displacement controlled depending on the physical nature of the Lateral load and behaviour expected from the structure force. Controlled procedure is useful when the load is already known and the structure is expected to support the load. Displacement controlled procedure should be used where the magnitude of the applied load is not known in advance (such as seismic loading) or when the structure can be expected to lose strength or become unstable. The nonlinear pushover analysis of a structure is an iterative procedure. It depends on final displacement, as the effective damping depends on the hysteretic energy loss due to inelastic deformation which in turn depends on the final displacement. This makes the analysis procedure iterative. Steps for Pushover Analysis:

- Modelling
- Static Analysis
- Design
- Pushover Analysis

**Aim of the study**

- To understand the applications the pushover analysis
- To understand the usage of shear walls
- To develop serviceable and safe structures by carrying out pushover analysis to find out best position to apply shear wall to a given building

**Literature review**

Various literature reviewed on pushover analysis is presented in this section. A review of literatures is presented in brief summarizing the work done by different scholars and researchers on pushover analysis of building structures.

**Joheb Ahmed and Syed Ahamad Raza (2014)** carried out study on seismic vulnerability of RC buildings by considering plan irregularities using pushover analysis. Various models were considered in order to identify the performance of the structures to withstand against disaster for building structures. They have conducted study on „G+9" storey building situated in zone V having plan irregularities like, rectangular, diaphragm discontinuity, and Y-shaped building. Pushover analysis has been performed using FEM based analytical software ETABS 9.7.4 version. They have presented their results in terms of pushover demand, capacity spectrum and plastic hinges. They have concluded that base shear for rectangular model is greater than diaphragm discontinuity and Y-shaped models. Point displacements are greater for diaphragm discontinuity model as there is an opening in the centre for that model. Finally, they concluded that among the three models considered for study purposes, rectangular model is most vulnerable to seismic effect.

**Mr. A. Vijay, Mr. K. Vijayakumar (2013)** performed a study which concentrates on a computer based push-over analysis technique for performance-based design of steelbuilding frame works subjected to earthquake loading. 2-D frames were modeled for solid and hollow sections, for various stories with constant bay width and storey height which was analyzed and concluded that :

- When the number of stories decreases then the corresponding base shear increases and also when the number of stories increases then the corresponding displacement increases.
- Drift to height ratio is limited to thirty-five stories.
- On comparing the results of solid and hollow sections base shear versus displacement curve, it is shown that the hollow sections are far better than solid ones.

**Modelling**

Pushover Analysis is carried out on four different RC models with and without shear wall at different locations. All the models are of G+7 storey and having a floor area of 15 m x15 m.

- Model 1: Bare Frame model
- Model 2: Frame with Shear wall at External mid-span
- Model 3: Frame with Shear wall at Corners
- Model 4: Frame with Core Shear wall

The models are designed for Zone V and for type II soil

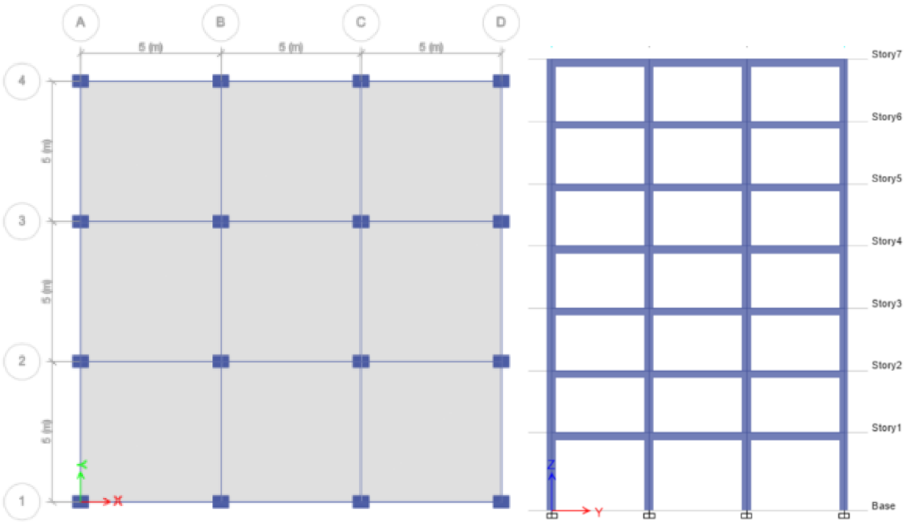



Fig 1. Plan and elevation view of bare frame model

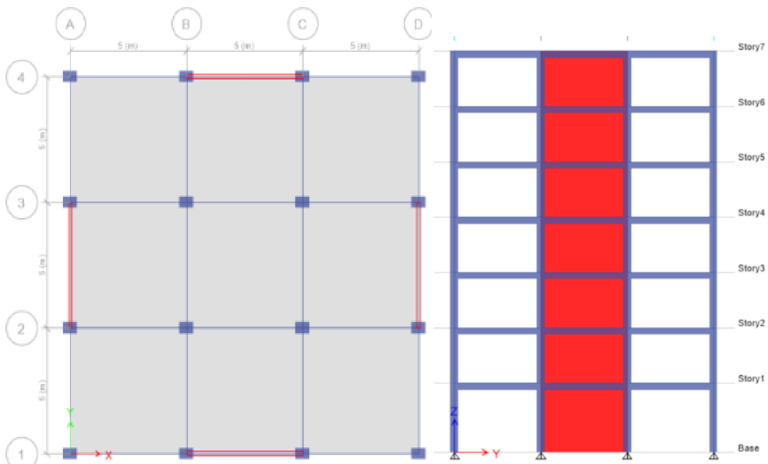



Fig 2. Plan and elevation view of model with shear wall at external centre

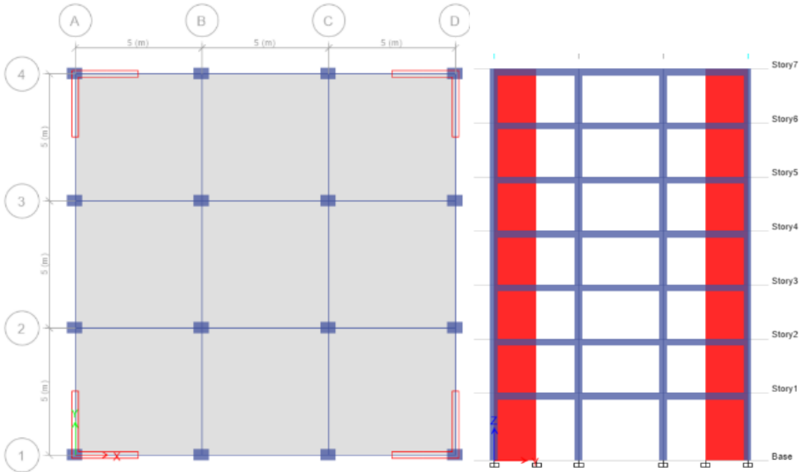



Fig 3. Plan of elevation view of model with corner shear wall

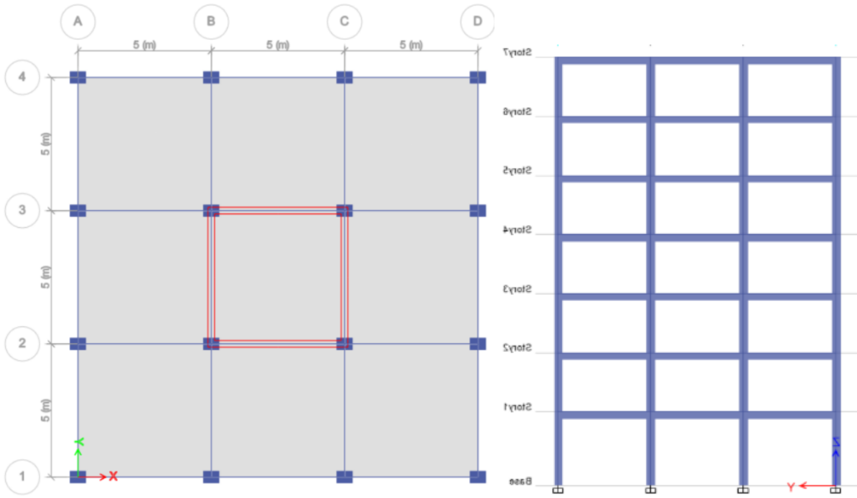



Fig 4. Plan and elevation of model with core shear wall

**Statement of project**

- Utility of building: Residential building
- No of storeys: G+7
- No. of staircases: 6
- Shape of the building: rectangular
- Type of construction: R.C.C framed structure
- Type of walls: brick wall

**Geometrics of building**

- Ground floor :4.0M
- Floor height :3.2M
- Height of plinth :1.5M from below foundation

- Depth of foundation :500MM
- Number of Stories :G+7

**Material used**

- Concrete Grade : M25, M30
- All steel grade : Fe415 Grade
- Type of steel bars : HYSD
- Bearing capacity of Soil : >180 N/m^2

**Different loads of the structure**

- Dead loads
- Imposed loads
- Seismic loads

Table 1
Description of models

| Sl. No | Description of the Models | |
|---|---|---|
| 1 | No. of Storey | G+7 |
| 2 | Typical Floor height | 3.2 m |
| 3 | Ground Floor height | 4 m |
| 4 | Plan dimension | 15 m x 15 m |
| 5 | Beam size | 250 mm x 400 mm |
| 6 | Column size | 450 mm x 600 mm |
| 7 | Thickness of slab | 150 mm |
| 8 | Concrete grade | M 25 |
| 9 | Rebar Grade | Fe 415 |
| 10 | Thickness of Shear wall | 150 mm |
| 11 | Dead load on slab | 1 $kN/m^2$ |
| 12 | Live load on slab | 3 $kN/m^2$ |
| 13 | Seismic load | As per IS 1893:2016 |
| 14 | Load Combinations | As per IS 1893:2016 |
| 15 | Importance Factor (I) | 1 |
| 16 | Response Reduction Factor (R) | 5 |

**3D Rendered view**

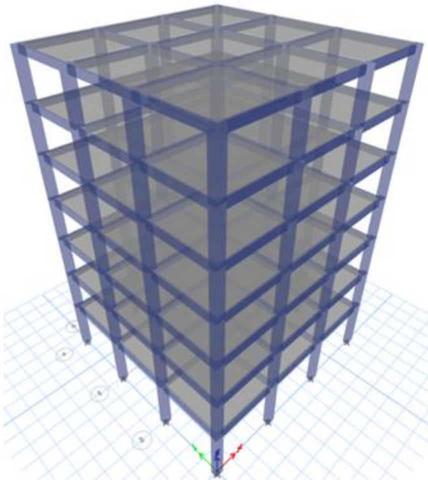


Fig. 5- 3D rendered view of bare frame model

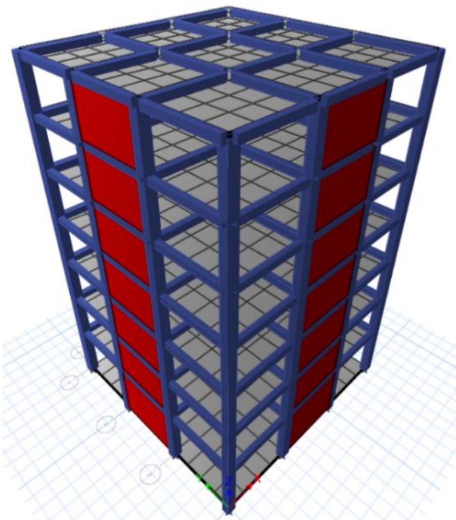


Fig. 6- 3D rendered view of model with shear wall at external centre

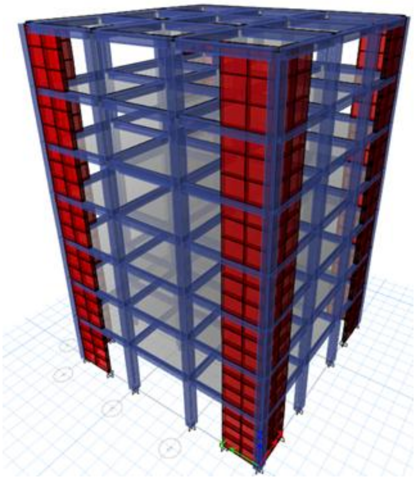


Fig. 7- 3D rendered view of model with corner shear wall

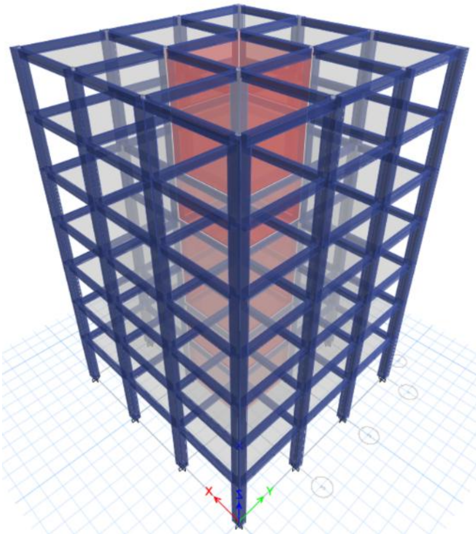
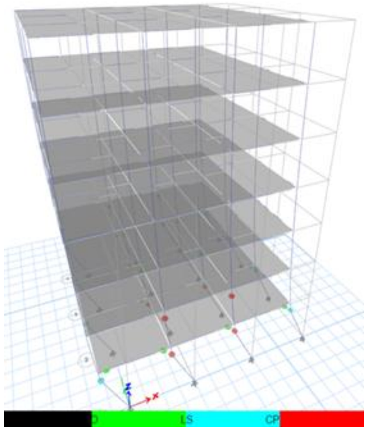


Fig. 8- 3D rendered view of model with core shear wall

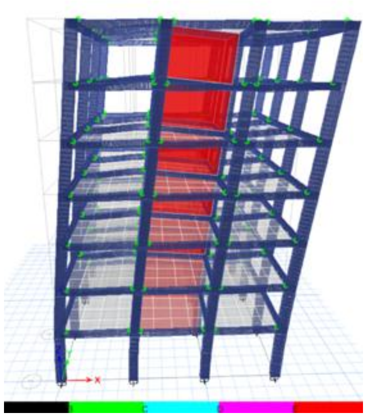
**Results**

The models are analysed statically and designed in ETABS 2019. The pushover analysis is carried out on all the models and performance point of the structure are determined.

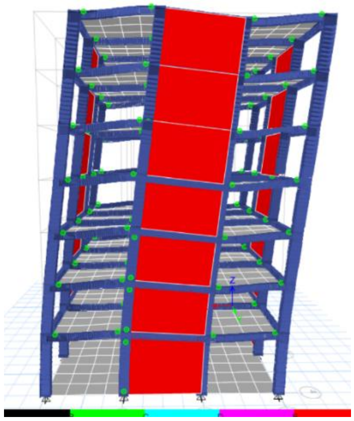
**Formation of hinges**



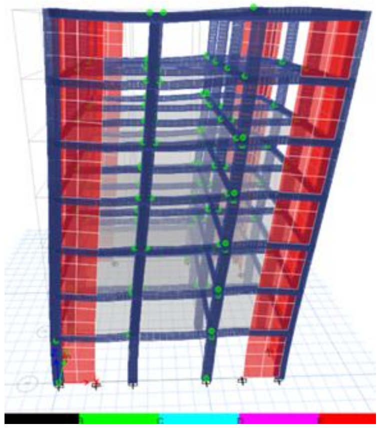
bare frame model



model with core shear wall



model with shear wall at external centre



model with corner shear wall
Fig 9. Formation of hinges

**Performance point**

Fig. 10,11,12 &13, and Table 2, and Table 3 shows curve capacity, the relationship between base shear and displacement occurred in each model gradually when there was a static nonlinear pushover. Performance point model 1 the greatest deflection than other models. It shows that building without a shear wall is more susceptible to failure. As per ATC 40, the buildings are pushed to a controlled displacement of 4% of the height of the structure. The performance point for all the RC models is determined and the performance point diagram are shown in table 3 and 4, and the figures below.

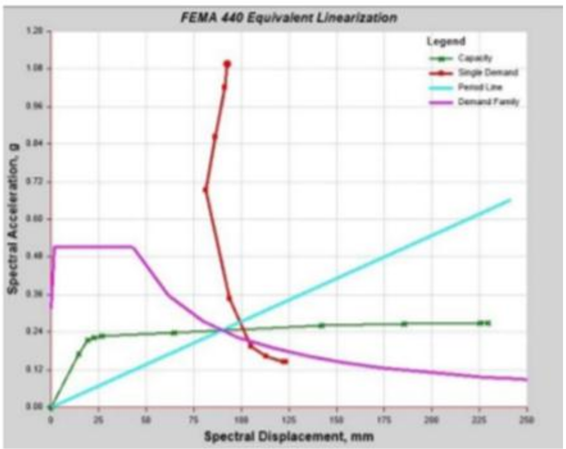



Fig 10. Capacity-Demand spectrum for bare frame

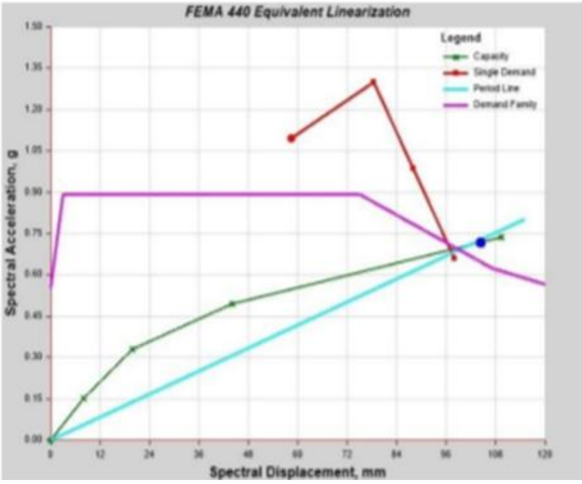



Fig 11. Capacity-Demand spectrum for frame with shear wall at exterior mid

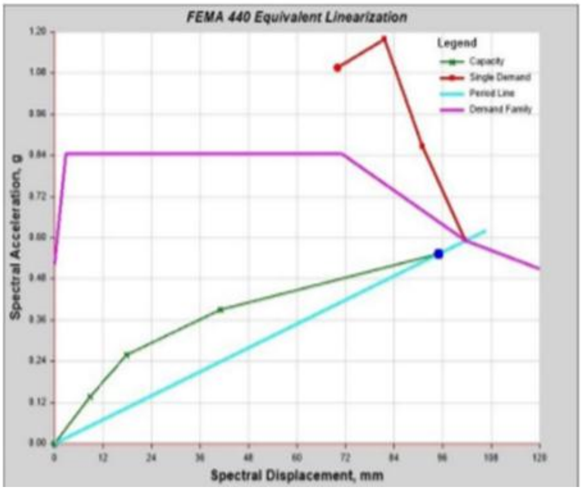



Fig 12. Capacity-Demand spectrum for frame with shear wall at corners

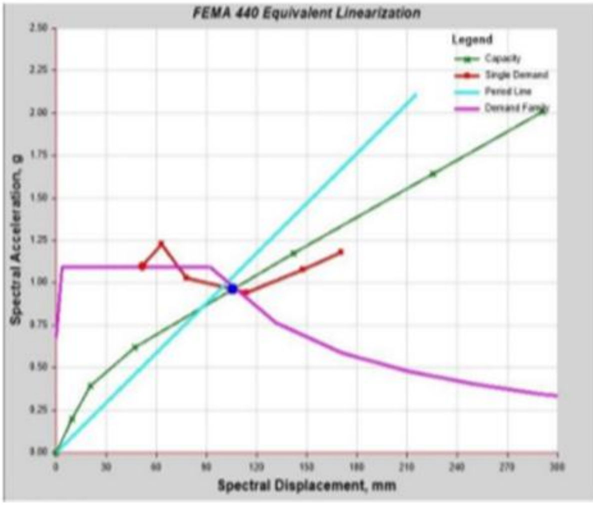



Fig 13. Capacity-Demand spectrum for frame with shear wall at core

Table 2
Base Shear and Displacement for Performance Point

| Model | Maximum Total Drift | Maximum Inelastic Drift | Performance Level |
|---|---|---|---|
| 1 | 0.0073 | 0.0068 | IO |
| 2 | 0.0035 | 0.0032 | IO |
| 3 | 0.0025 | 0.0023 | IO |
| 4 | 0.0022 | 0.002 | IO |

Table 3
Performance Level

| Model | Base Shear | Displacement(Mm) |
|---|---|---|
| 1 | 1987.5572 | 290 |
| 2 | 6183.506 | 140 |
| 3 | 8093.183 | 100 |
| 4 | 9800.714 | 90 |

**Base shear and displacement**

The comparison of base shear of each model is shown in Fig. 14 and Table 4.

Table 4
The Comparison of Base Shear

| Model | Base Shear | |
|---|---|---|
| | VRSX | VRSY |
| Model 1 | 701.5036 | 701.5036 |

| | | |
|---|---|---|
| Model 2 | 2367.484 | 2367.484 |
| Model 3 | 2424.912 | 2424.912 |
| Model 4 | 2838.9326 | 2838.9326 |

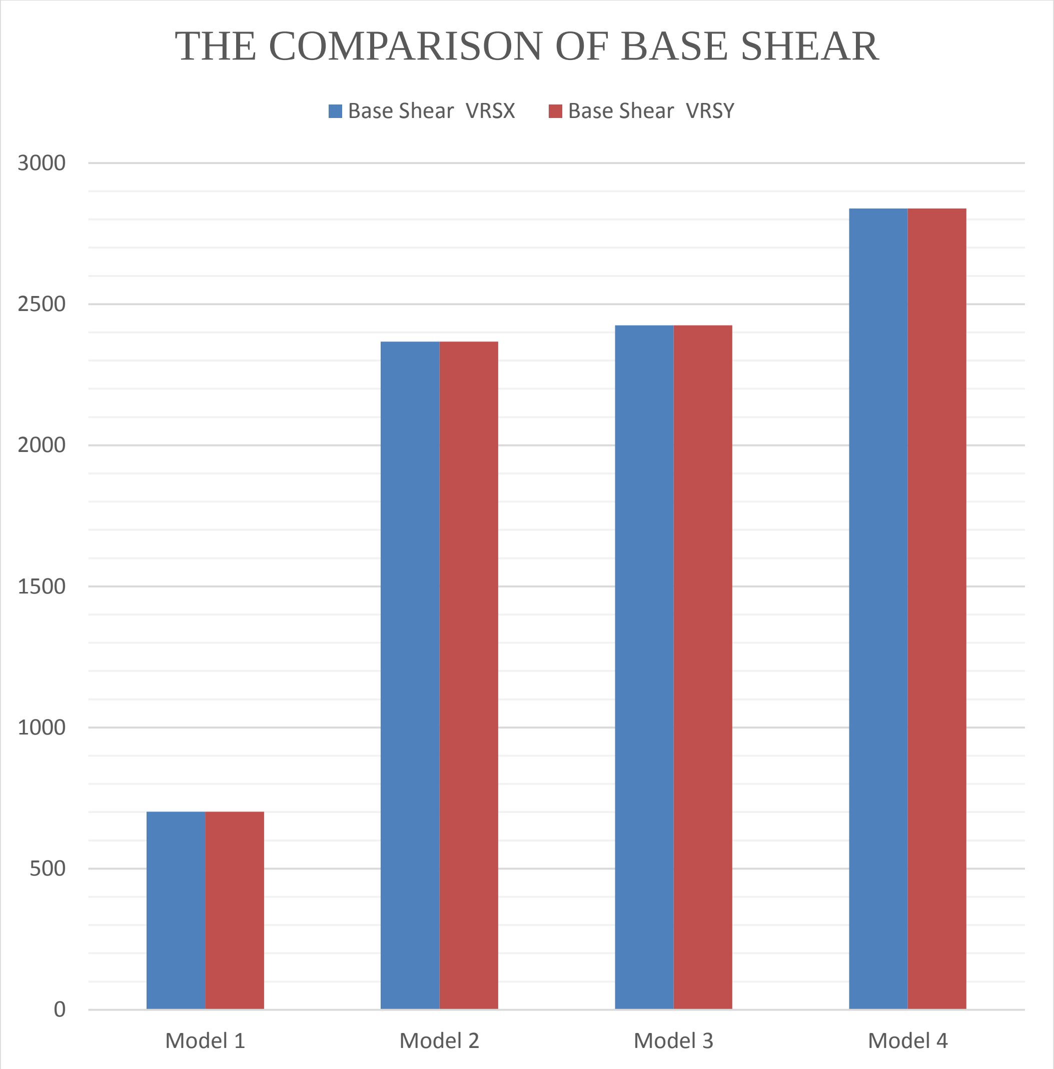


Fig 14. The Comparison of Base Shear

**Lateral displacement**

Lateral displacement of the floor (storey level) in x and y direction in each model have the same value because the building has symmetrical dimension. The comparison of maximum floor lateral displacement in each model can be seen in Fig. 15 and Table 5.

Table 5
The Comparison of Lateral Displacement

| Floor | Δ Max (Mm) | | | |
|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 4 |
| 7 | 24.507 | 15.213 | 9.344 | 7.069 |
| 6 | 21.622 | 12.164 | 7.479 | 5.641 |
| 5 | 18.181 | 9.211 | 5.681 | 4.269 |
| 4 | 14.271 | 6.452 | 4.008 | 2.996 |
| 3 | 10.027 | 4.009 | 2.527 | 1.874 |
| 2 | 5.712 | 2.015 | 1.311 | 0.958 |
| 1 | 1.904 | 0.619 | 0.435 | 0.308 |

Model 4 is the most effective model to reduce floor lateral displacement. That is, 61.432% compared to model 1. On the other hand, model 2 and 3 each reduced floor lateral displacement 17.647% and 50.618% compared to Model 1.

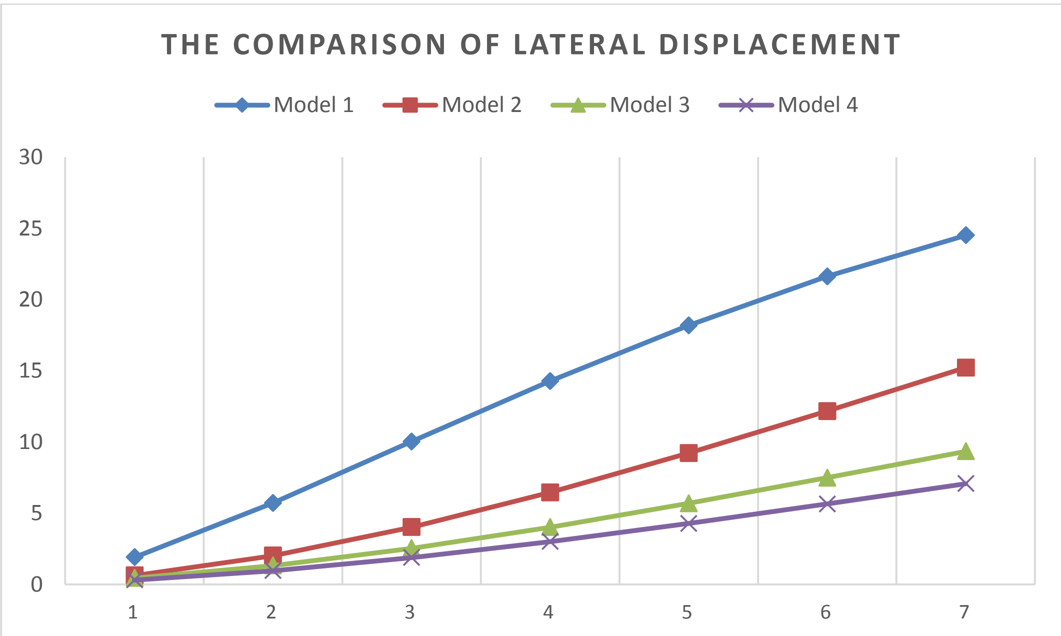



Fig 15. The Comparison of Lateral Displacement

**Drift ratio**

Fig. 16 and Table 6 shows drift ratio in each model with shear wall and without a shear wall. Model 1 is building without shear wall has most maximum drift ratio. Meanwhile, another three models used shear wall has lower drift ratio compared to model 1. The maximum point of drift ratio in the model which used shear wall is on floor 7. It indicated that shear wall caused drift ratio is on the higher floor. Therefore, the collapse of the base floor can be avoided. Model 2 has maximum drift ratio 35.48% more effective than model 1. Model 3 has maximum drift ratio 60.35% more effective than model 1. Model 4 is most effective with drift ratio 69.50% compared to model 1.

Table 6
Drift Ratio

| Floor | Drift Ratio | | | |
|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 4 |
| 7 | 0.00397 | 0.00382 | 0.00233 | 0.00178 |
| 6 | 0.00473 | 0.00369 | 0.00225 | 0.00172 |
| 5 | 0.00538 | 0.00345 | 0.00209 | 0.00159 |
| 4 | 0.00584 | 0.00305 | 0.00185 | 0.0014 |
| 3 | 0.00593 | 0.00249 | 0.00152 | 0.00115 |
| 2 | 0.00523 | 0.00174 | 0.00109 | 0.00081 |
| 1 | 0.00262 | 0.00077 | 0.00054 | 0.00038 |

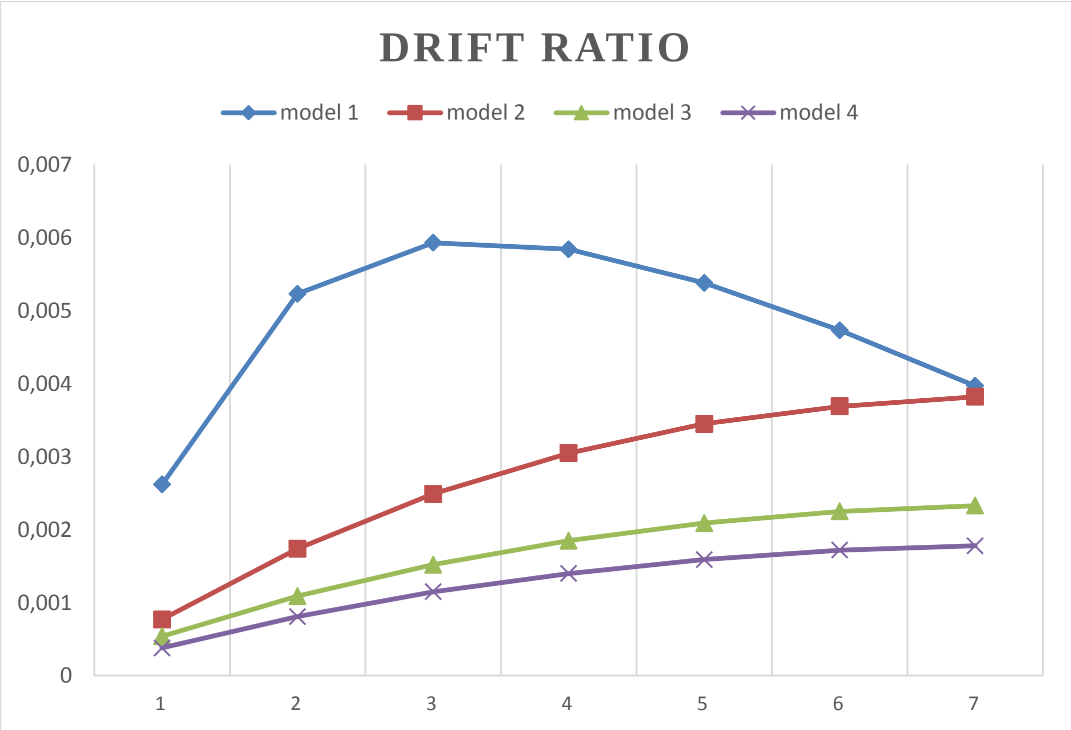


Fig 16. Drift Ratio

**Conclusion**

The conclusions obtained in the study of structure response caused by the earthquake and pushover analysis on four models are as follows: The maximum drift ratio occurred on model 1 namely model without a shear wall. Each model has different performance point, minimum performance point occurred on level 1, while maximum performance point occurred on level 4. Performance level of all model are immediate occupancy. In the last step of pushover analysis, the collapse of model 1 occurred on the floor 3 and 4, the collapse of model 2 and 3 occurred on the floor 7 , the collapse of model 4 occurred on the floor 6 . The collapse of model 3 was the same as model 2, but the base shear model 3 was greater than model 2. Based on the plastic hinge distribution, model 3 was most effective to reduce the seismic effect. Plastic hinges occurred on model 3 was less than other models. In the last step, the performance level of all model was on immediate occupancy.

The seismic performance evaluation of the building is studied based on pushover analysis. The building models with and without shear walls at different locations are modelled and pushover analysis is carried out using ETABS 2019 software. The analysis reports are taken in terms of Performance Point of the building, which gives the actual displacement and base shear of the building. The following conclusions are derived from the analysis process.

- Provision of shear wall has proved to be a good lateral load resisting system from the observation of performance point in the models with and without shear wall.
- Model 4, the model with shear wall at core shows higher performance point, which will obviously behave better compared to other models.
- The base shear value at performance point for model 4 is greater than all other models in X direction.
- The displacement at performance point is minimum for model 4 comparing other models.
- It is very clear that, model 4 shows better seismic performance than all other models.
- On comparison of models with and without shear wall, the RC frames with shear wall seems to perform better. The placement of shear wall also plays a major role in seismic performance of the frame. In our case, model 4 seems to be a judicious placement.

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