A Study on Effect of Shear Wall in Seismic Analysis of Building

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Abstract

With the proliferation of population and increasing demands for the space in urban areas, the need for tall structures has been grown up significantly. Tall structures are susceptible under dynamic loading which mainly threatens in form of time dependent lateral loading caused from mainly earthquake and wind. Response spectrum analysis is widely used in such cases to evaluate the seismic capacity of a structure. The present literature focuses on two different models with and without using shear walls at different positions. The article showcases the parametric study in terms of storey drift, displacement and base shear comparison for different location of shear wall in the building. The results are unique and fruitful for future attention.

Keywords: Shear wall, Base Shear, Storey Drift, Displacement, Response spectrum.

1. Introduction

Earthquake is a natural phenomenon that occurs due to the relative displacement of the tectonic plates along and across plate boundaries. Plate boundaries can be classified as convergent, divergent and transform. Convergent plate boundaries and transform plate boundaries cause larger damage whereas divergent boundaries cause lesser damage. An earthquake of a given magnitude causes different levels of intensities of shaking in the neighboring locations of its focal point and therefore the structural damage induced in the buildings differs from location to location. In earthquake resistant design, due to the random motion of ground the building will reacts differently which can be classified into three different cases as (i) minor shaking with no structural damage, (ii) moderate shaking with minor structural damage and (iii) severe earthquake with both structural and non-structural damage (Figure 1). Ground motion induces inertia force in the building in terms of a displacement-type loading. Among the structural elements columns and walls are the most important in transferring the loads, so for tradition construction designing of the floor slab and beam should receive more important. Poorly designed reinforced concrete columns can be disastrous. It was observed that during the BHUJ earthquake in 2001 (India), many buildings collapsed due to the failure of the ground storey column. Therefore engineers have come out with many techniques to resist the lateral forces by increasing the stiffness by providing shear walls, bracing system, and moment-resisting system. Nowadays, structures are normally design based on the performance of the building or structure.
1.1 Shear Wall

A shear wall is a structurally designed wall that is incorporated in building frames to increase the lateral stiffness against the ground motion and other kinds of lateral forces. A shear wall positioned in the building wall is designed to resist lateral forces. Shear wall is reinforced concrete cantilever wall which is placed vertically from the base or foundation. The design and detailing of the shear wall should be ductile to resist the lateral force and to dissipate energy through flexural yielding at one or more plastic hinges. Providing shear wall will not only resist earthquake force but also the wind force (lateral force) and increases the strength of the structure. By providing shear wall in the RC building, the stiffness of the structure increases and also the lateral displacement is minimized as compared to building without shear wall.

According to studies, it is observed that the position of the shear wall in the building plays an important role in earthquake resisting buildings design. From many studies it is found that most appropriate place for position for placement of shear wall at the point is by coinciding center of gravity and center of rigidity of mass. Mostly building with a shear wall placed in the outer corner and periphery of the building gives more effective results in reducing the lateral displacement of the building. And also to reduce the ill effect of twisting in building the shear wall should be placed in symmetrical manner.

Sharath Irappa K et. al. (2015) made a non-linear static analysis (pushover method) of G+9 storey asymmetric building with shear wall and without shear wall using SAP 2000 for Zone factor III by considering medium soil type. It is observed that a structure having re entrant corners performs well in case of regular plan than the irregular one. The performance of the building changes with the variation in the irregularities. The building is analyzed using the pushover analysis method and the results obtained are compared, performance of the building with and without shear wall is observed and all other required parameters are obtained and compared. An increase in base shear and decrease in displacement is observed in the presence of shear wall after pushover analysis. The performance level observed to be in LS-CP level in both the direction without shear wall under CP-C and LS-CP level with shear wall. However, a lesser base shear is observed in the presence of shear wall as it resist the seismic excitation to some extent. Guruputrayya et. al. (2017) after anticipating few methods to increase the lateral stiffness by varying the position of shear walls, observed that base shear vs. displacement results shows more roof displacement for building in sloping ground and so is more susceptible under dynamic force compared to the building on plain grounds. Suchita H et. al. (2016) studied RC frames of different irregularity in plan (conforming to IS 1893-2002) and compared with regular plan (rectangular) with models of different storied and pushover analysis is performed on all the models using software SAP 2000.

As per the pushover nonlinear static analysis, the hinges are more formed in beam and a very few in the columns. Using nonlinear static analysis, analytical investigation of both regular and irregular shaped buildings are carried out. As the irregularities of building goes on increasing compared to regular building base shear decreases to 10-13% in G+5, 15-18% in G+10 and 15-20% in G+15 but displacement remains constant. Romy M et. al. (2011) discussed on two multistory buildings, seven and eleven storey height model using software package SAP 2000.
for zone v (i.e. most prominent to earthquake force) region in India. For studying the effectiveness in resisting lateral force, six different type of shear wall with variation of their position is considered. Both the buildings are analyzed (i.e. response spectrum analysis, time history analysis and equivalent static analysis) and compared. For the dynamic time history analysis method, time history data of EL-Centro earthquake have been taken for the time history analysis. In this paper, finding the displacement and checking the storey drift of the building i.e. as per IS code 1893(2002) it should be within the limit of 0.004 times the height of the building for different types of analysis. According the studies it is observed that as compare to response spectrum and time history analysis, equivalent static method show least lateral displacement. The storey drift of the building is within the limit as per IS 1893 part 1. The percentage variation of storey drift for U-shape shear wall in seven storey height between response spectrum and equivalent static method is given by 2.69%, similarly for eleven Storey is 24.47%. The percentage variation of storey drift for seven and eleven storey is 30.21% and 61.39%. Even though our present study has not considered time history analysis, still it will give a better understanding about the objectives of the project.

Syed Khasim M et. al. (2014) Study presents 3D analytical model of thirty storied building with different positioning of shear wall for symmetrical buildings model and analyzed using ETABs. The displacement of the storey is compared with regard to different method of analysis such as equivalent static method, response spectrum method and pushover analysis. Capacity, demand and performance level are compared and cited. For non linear static procedure FEMA (273/356) and ATC-40 (applied technology council, 1996) are used.

It is very prominent from the above study that shear wall provides not only an exaggerated lateral stiffness and high energy indulgence capacity to the buildings but also the appropriate positioning of the shear wall is also important to achieve the maximum performance. Therefore the objective of study gives us insight about the effect of shear wall when provide in different location in RC rigid frame building to resist the seismic force and to check their seismic performance.

2. Seismic Analysis

The purpose of seismic analysis is to assess the behavior of a structure when subjected to dynamic load and excitation at its base. These loads can be of any types like weight of people, wind, furniture, snow etc. or due to shaking of ground (i.e. earthquake), blasting activity near by the structure also causes ground motion etc. The static loads are very slow or static on the time rate graph. Besides, when the applied force has a high rate of change with respect to time, then it is categorized under dynamic analysis. The outcome of a dynamic analysis is expressed mainly with the displacement and acceleration because unlike static analysis here the force is instantaneous with respect to time.

When an earthquake waves strikes the base or foundation of any structure, the structure automatically reacts with respect to the ground motion. It has been observed that the response of the structure is usually greater with respect to ground motion. This increased structural response as compared to the ground due to earthquake wave is referred as the dynamic amplification. The dynamic amplification depends on the engineering properties of the structure such as the natural period of vibration, damping, and type of foundation and detailing of the structure. This dynamic response can be analyzed by mathematical modeling using time history method or another simple method involves a ready- made response spectrum developed by Housner and as per IS 1893-2002.

Dynamic analysis shows the actual behavior of structure as compared with static analysis method. Equivalent static analysis method works well for a simple regular building, low-to-medium-rise building. Hence, this type of method is sufficient.

2.1 Types of Seismic Analysis

Based on linearity and non linearity, different methods are adopted for seismic analysis of buildings and following are methods given below:
- Equivalent static analysis (linear static)
- Response spectrum analysis (linear dynamic)
- Pushover analysis (non linear static)
• Time history analysis (non linear dynamic)

2.2 Equivalent static analysis

In the era of increasing tall structures around the globe, dynamic analyses have become a must for the structures specifically for taller structures. Seismic analyses have become mandatory before design specifically in the earthquake prone areas. It is observed that for seismic analysis of equivalent static method is widely used and proved as sufficient unless any special cases as per the different codes of practices. Equivalent static analysis takes account of not only the soil condition and time period of the structure but it also takes care about the zone factor and importance factor overall. However, different codes have exercised different provisions by incorporating different parameters as per requirement.

In equivalent lateral force method the seismic force (base shear) is distributed in terms of storey shear to every floor along its height. The storey shear is proportional to its seismic weight.

2.3 Response spectrum analysis

The response spectrum is the linear-dynamic response analysis of building or structure which is subjected to lateral/seismic force. Response spectrum is a single degree of freedom system based analysis. Response spectrum curve of building subjected to lateral/earthquake force can be plotted considering time period (horizontal axis) vs. acceleration, velocity, displacement (vertical axis) to find the peak response of structure with respect to past earthquake force applied on it.

It is an elastic dynamic approach which assumes that the dynamic response of a structure can be found by considering the response of the building to different modes of vibration independently and then recombining them suitably to study their combined effects. The plot of the peak responses (viz. Displacement, acceleration etc.) of an elastic structure having single degree of freedom can be obtained after applying ground acceleration with a specified damping in the structure. The dynamic response spectrum analysis (IS code 1893-2002) gives us following engineering properties below;

• The natural period of vibration of the structures response to the dynamic motion.
• Building provided with different types of foundation
• The damping properties of the structure
• Importance factor of the building
• The structural ductility can be represented by response reduction factor.

![Fig. 2 Response spectra for 5% damping (IS 1893-2002)](image-url)
The response spectrum for acceleration is expressed in terms of gravity and is called the average response acceleration coefficient (\(Sa/g\)). The design acceleration spectrum specified in IS 1893-2002, for 5% damping factor.

2.4 Pushover analysis

To determine the inelastic strength and displacement capacity of a structure, pushover analysis is proved to be a valuable method to assess the design weaknesses. Pushover Analysis provides the option to perform the analysis as per FEMA - 356 and ATC-40. It is a static non-linear analysis under fixed gravity loads and progressively increasing lateral loads. If a the structure is subjected to different gravity and lateral loads finite element modal of the frame can be obtained through SAP 2000 software. The magnitude of the lateral load is gradually increased and various failure of structural elements as crack, plastic hinge formation and yielding is recorded and accordingly their performance is determined. The weak links inside the structure can be determined by this method robustly.

Static Nonlinear Analysis technique also called as pushover analysis has gain more importance for past few years. Based on the plastic hinge formed in the structural member, the hinge properties gives the idea related to the performance of the structure during pushover analysis method. Most of the plastic hinges are formed in beams members and a very few in columns. Redistribution of internal forces occurs with progressive plastic hinge formation, some hinge location, local collapse may occur due to plastic deformation exceed its limit. The structure is pushed until the global collapse is achieved, the adequate number of plastic hinges form develops a collapse mechanism or the system cannot withstand the load pattern to sustain force equilibrium.

The pushover analyses is performance based analysis which grant us the information regarding performance of the structure by applying lateral forces or pushing the structure till collapse limit, with respect to this plastic hinge present in structure defines the performance of the structure. Pushover analysis shows the results about base vs. roof displacement (i.e. for a target displacement). From the hinges properties of the structure, the performance point (from capacity spectrum curve) and performance level of the structure is determined, according to performance of the structure it is designed. The hinges are formed more in the beam and less in column but with a limited damage. Also it is undesirable for a building consisting large amount of plastic hinge in column which will cause damage of structural.

![Fig. 3 capacity spectrum curve (ATC 40, 1996)](image)

2.4.1 Building performance level and ranges

Performance level defines the behaviour of the building condition. It shows a well defined point for measuring the scale of damages that is caused to the building due to earthquake wave. Performance is based on the damage of
structural and non structural system. It is a performance based analysis with respect to the hinge formation in the structural elements according the behaviour of the building as well as the particular element in known. Structural designation are from S-1 to S-2 and non structural designation are from N-A to N-D, this are defined in FEMA 356. Fig.4. Shown below is comprehensive force-displacement characteristic of a frame element (or hinge properties) and performance of the elements as per its hinge formation in the structure component is given. The ATC-40 document has developed modelling procedures, acceptance criteria and analysis measures for pushover analysis. The displacement behaviour of the hinges is defined through the points A, B, C, D, and E and three points marked as IO, LS and CP are used to denote the acceptance criteria for the hinge.

![Fig. 4 Force vs. deformation curve](image)

### 2.4.2 Performance level and damage range of the structure

- **Immediate occupancy (IO-S-1):**
  It means the damages after earthquake where minimum structural damage has taken place but the force (vertical and lateral) resisting arrangements of the building remains same with the pre earthquake strength and stiffness. A very limited structural damage may occur and minor repair can be done. Low risk of life safety is less in immediate occupancy level.

- **Damage control performance range (S-2):**
  In this level a minor risk of life injury and structural damage as compare to life safety level (L-S) level but damage of structure and life injury is more than that of immediate occupancy level (IO). Damage control performance design may be required to abate the rehabilitation time and operation breakdown. This range may be obtained by interpolating the value of S-1 and S-3.

- **Life safety (L-S):**
  In this case, due occurrence of earthquake it is seen that major structural damage takes place which is a life threatening to public and it will be desirable to repair some of the damage structure considering the economic reasons. Injuries can occur more than IO and L-S level.

- **Limit safety performance range (S-4):**
  It means limit of damage stage range between L-S and CP level. Design parameter of this range may be achieved by interpretation the value of (S-3 and S-5).

- **Collapse prevention (CP):**
  It denotes the building is the verge of failure or total collapse. Major structural failure may occur which will cause saviour life threatening damage to public due to the falling of structural debris. Repair work of the building is not recommended since the building is the verge of its failure, the strength is also decreased and large amount lateral
displacement is observed.

2.4.3 Non structural performance level

- **Operational performance level (N-A):**
  It means that in this level non-structural components are able to support the earthquake force. A very negligible amount of non structural damage may occur.

- **Immediate occupancy level (N-B):**
  This means minor amount of non-structural component damage can be seen and the building is safe for occupant.

- **Life safety level (N-C):**
  Damage stage indicates that significant important non-structural components damage has taken place in the building and the structure still has some capacity to resist the deformation until it reaches the final collapsed.

- **Hazard reduced level (N-D):**
  This means the damage stage where severe damage or near collapse of non structural component takes place. It is uneconomic to repair such structure. A significant amount of life injury takes place and causing severe damage due to earthquake.

2.5 Time history analysis

Time history analysis can be either linear method or non-linear method. Time history analysis is of two types’ i.e. modal analysis (fast linear or nonlinear method) and direct integration method. Time history analysis is dynamic response of structure with respect to time, when the base of the structure is subjected to specific ground motion time history data from the past earthquakes. Compared to the other types of analysis, time history analysis gives the actual non-linear response or behaviour of the structure under past earthquake data’s and gives better results. It is also a performance based design method, where hinges provided in the beams and columns shows the real and more accurate behaviour of the structure as compare to pushover analysis method. PEER ground motion database is a site where all past earthquake data of entire world is given. For every high rise building, time history method should be used to analyzed and designed.

3. Modeling and analysis

3.1 General description of the structure

The main objective of this study is to analysis the RC frame structure (residential building) using SAP 2000 software, with different positioning of shear wall in the building and checking the suitable placement of shear wall which is very effective in resisting earthquake force and the storey drift and also real behaviour of the building under earthquake force. Total eight models are generated, out of which two are without shear wall and remaining six with different positioning of shear wall for residential building. It is a simple structure design with column size is same throughout the height; similarly beam size is same in both the direction. Both the model-1 and model-2 has same material properties but different size.

First, model G+4 and second G+6 RC frame structure with varying position of the shear wall in each model using SAP 2000. In SAP 2000, the foundation of shear wall should be fixed. The building foundation is fixed and the capacity ratio should also be checked (i.e. as per IS code 456 the capacity ratio of column beam should be more then 1.2). All the following material properties, loading, load combinations, dimension of the structure are given below.
Table 1: Material properties used in RC frame structure

| Property                                  | Value                  |
|-------------------------------------------|------------------------|
| Grade of concrete                         | M20                    |
| Grade of reinforcing steel                | Fe 415                 |
| Modulus of Elasticity of steel ($E_s$)    | 210000 N/mm$^2$        |
| Modulus of Elasticity of concrete ($E_c$) | 22360.68 N/mm$^2$      |
| Characteristic strength of concrete ($f_{ck}$) | 20 N/mm$^2$           |
| Yield stress for steel ($f_y$)            | 415 N/mm$^2$           |
| Minimum tensile stress ($f_u$)            | 518.75 N/mm$^2$        |

3.2 Model 1 (G+4) RC Frame

Table 2: Dimensional size of members for model 1

| Member                      | Size          |
|-----------------------------|---------------|
| Beam                        | 300x500mm     |
| Column                      | 430x430mm     |
| Slab thickness              | 150mm         |
| Outer wall thickness        | 230mm         |
| Inner wall thickness        | 150mm         |
| Shear wall thickness        | 230mm         |
| Total height of the building| 17.5m         |
| Height of parapet wall      | 1.2m          |

Fig. 5(a) Plan and 3D view without shear wall (model-A)
Fig. 5 (b) Plan and 3D view with shear wall placed in the core (model-B)

Fig. 5 (c) Plan and 3D view with shear wall placed in corner (model-C)

Fig. 5 (d) Plan and 3D view with shear wall placed in periphery (model-D)
3.3 Model 2 (G+6) RC Frame

Table 3 Dimensional size of members for model 2

| Member          | Dimensions       |
|-----------------|------------------|
| Beam            | 230X450mm        |
| Column          | 430x430mm        |
| Slab thickness  | 150mm            |
| Outer wall thickness | 230mm          |
| Inner wall thickness | 150mm         |
| Shear wall thickness | 250mm         |
| Total height of the building | 17.5m           |
| Height of Parapet wall | 1.2m            |

![Fig. 6 (a) Plan and 3D view without shear wall (model A)](image)

![Fig. 6 (b) Plan and 3D view with shear wall placed in the core (model B)](image)
Response spectrum is a linear dynamic analysis which plots the peak or steady-state response (displacement, velocity or acceleration) of a series of oscillators of varying natural frequency that is caused due to ground motion. In IS: 1893 (Part 1): 2002, the design spectrum analysis response spectrum records the eight strong Indian ground motion due to earthquakes. The response spectrum for acceleration is expressed in terms of gravity and is called the average response acceleration coefficient (Sa/g). The design acceleration spectrum specified in IS 1893-2002, for 5% damping factor. In response spectrum method the peak response of the structure is calculated from model combination, following are the two methods given below:

- Complete Quadratic Combination method and
- Square Root of Sum of Square method
4. Results and discussion

The structure is analyzed for both G+4 and G+6 with shear and without shear walls at different positions, various parameters like displacement, storey drifts are compared. The details are shown as below.

![Fig. 7 (a)](image1) height vs. displacement curve without shear wall along x-direction

![Fig. 7 (b)](image2) height vs. displacement curve without shear wall along y-direction

![Fig. 7 (c)](image3) storey no vs. storey drift curve without shear wall along x-direction

![Fig. 7 (d)](image4) storey no vs. storey drift curve without shear wall along y-direction

![Fig. 7 G+4 model for bare frame (A)](image5)

![Fig. 8 (a)](image6) height vs. displacement curve for RCC frame with shear wall placed at the centre of the structure along x-direction

![Fig. 8 (b)](image7) height vs. displacement curve for RCC frame with shear wall placed at the centre of the structure along y-direction
Fig. 8 (c) storey no. vs. storey drift curve for RCC frame with shear wall placed at the centre of the structure along x-direction

Fig. 8 (d) storey no. vs. storey drift curve for RCC frame with shear wall placed at the centre of the structure along y-direction

Fig. 8 G+4 model when shear wall placed at the centre (B)

Fig. 9 (a) height vs. displacement curve for RCC frame with shear wall placed at the corner of the structure along x-direction

Fig. 9 (b) height vs. displacement curve for RCC frame with shear wall placed at the corner of the structure along y-direction

Fig. 9 (c) storey no. vs. storey drift curve for RCC frame with shear wall placed at the corner of the structure along x-direction

Fig. 9 (d) storey no. vs. storey drift curve for RCC frame with shear wall placed at the corner of the structure along y-direction

Fig. 9 G+4 model of shear wall placed at the corners (C)
Fig. 10 (a) height vs. displacement curve for RCC frame with shear wall placed at the periphery of the structure along x-direction

Fig. 10 (b) height vs. displacement curve for RCC frame with shear wall placed at the periphery of the structure along y-direction

Fig. 10 (c) storey no. vs. storey drift curve for RCC frame with shear wall placed at the periphery of the structure along x-direction

Fig. 10 (d) storey no. vs. storey drift curve for RCC frame with shear wall placed at the periphery of the structure along y-direction

Fig. 10 G+4 model when shear wall placed at the periphery of the structure (D)

Fig. 11 (a) Base shear along x-direction

Fig. 11 (b) Base shear along y-direction

Fig. 11 Comparison in base shear in both X and Y direction (model-1)
Fig. 12 (a) height vs. displacement curve for RCC frame in x direction

Fig. 12 (b) height vs. displacement curve for RCC frame in y direction

Fig. 12 (c) storey no. vs. storey drift curve for RCC frame in x direction

Fig. 12 (d) storey no. vs. storey drift curve for RCC frame in y direction

Fig. 12 G+6 model for RCC frame (A)

Fig. 13 (a) height vs. displacement curve with shear wall placed in core of the structure along x-direction

Fig. 13 (b) height vs. displacement curve with shear wall placed in core of the structure along y-direction
Fig. 13 (c) storey no. vs. storey drift curve with shear wall is placed in core of the structure along x-direction.

Fig. 13 (d) storey no. vs. storey drift curve with shear wall is placed in core of the structure along y-direction.

Fig. 13 G+6 model when shear wall is located in core of the structure (B)

Fig. 14 (a) height vs. displacement curve with shear wall placed at the centre as well as at corner of the structure along x-direction.

Fig. 14 (b) height vs. displacement curve with shear wall placed at the centre as well as at corner of the structure along y-direction.

Fig. 14 (c) storey no. vs. storey drift curve with shear wall placed at the centre as well at corner of the structure along x-direction.

Fig. 14 (d) storey no. vs. storey drift curve with shear wall placed at the centre as well as at corner of the structure along y-direction.

Fig. 14 Results for G+6 model for shear wall placed in the core and corner (C)
Results for G+6 model for shear wall placed in the periphery of the structure (D)

Fig. 15 Results for G+6 model for shear wall placed in the periphery of the structure (D)

Fig. 15 (a) height vs. displacement curve with shear wall placed at the periphery of the structure along x-direction

Fig. 15 (b) height vs. displacement curve with shear wall placed at the periphery of the structure along y-direction

Fig. 15 (c) storey no. vs. storey drift curve with shear wall placed at the periphery of the structure along x-direction

Fig. 15 (d) storey no. vs. storey drift curve with shear wall placed at the periphery of the structure along y-direction

Fig. 16 (a) Base shear in x direction

Fig. 16 (b) Base shear in y direction

Fig. 16 Comparison of base shear in both X and Y direction (model-2)
5. Conclusion

The findings of the study have been showcased in the previous section. It is observed that the position of shear wall in core as well as the corners shows minimum storey drift as compare to other type of shear wall placement. However, an increased amount of base shear is observed in such case for both x and y direction. In case of bare frames a usual trend of displacement is observed. The storey drift as per IS code 1893:2002 shall not go beyond 0.004 times of the storey height. So according to the studies storey drift does not exceed its limit. As a scope of future work further pushover analysis and time history analysis can be proposed to observe a more convergent result.
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