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# Cost Modelling and Seismic Evaluation of Lateral load resisting systems for High rise RCC structures

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***Abstract:*** Even though the structures are designed for seismic resistance, the structures may or may not perform to the extent that they are designed for. Increasing height and slenderness has changed the view from static vertical loads to lateral dynamic loads generated by earthquakes and wind. Hence the impact of earthquake or wind loads acting on the structures become an important part of the design. The study has been done for different zones and different soils as specified in IS 1893 on case studies. Shear wall and steel bracing systems are most effective means to adopt to add more stiffness in frames. Different kinds of lateral load resisting structures available like moment resisting structures, bracing systems and shear walls have been studied. Usage of these systems in the structure are different for given site conditions and location since the parameters are changed based on parameters. In multi-storied structures the lateral load consists of both the seismic loads as well as wind loads. At varying multiple heights the factors like story displacement, story drifts and base shear are changed based on conditions. Implications of the cost is studied using a dual configuration of the structural systems such as shear wall and bracing provided for seismic resistance.

***Index Terms* - Bracing, Shear wall, Storey drift, Base shear, Seismic analysis, lateral load systems**

## 1. INTRODUCTION

Increasing height and slenderness has changed the structural engineers view from static vertical loads to lateral dynamic loads generated by earthquakes and wind (C Bhuta & Pareekh, 2016). Hence the impact of earthquake or wind loads acting on the structures become an important part of the design. The study has to be done for different zones and different soils as specified in IS 1893 on case studies (Baikerikar & Kanagali, 2014). Shear wall and steel bracing systems are most effective means to adopt to add more stiffness in frames. Though bracings have less stiffness in comparison to shear wall, self-weight of bracings are less in consideration to concrete shear walls. (Smitha & L, 2017)

Different kinds of lateral load resisting structures are available such as moment resisting frames (MRF), shear walls, outrigger system, bracings, Frame tube system and diagrid system (Shaligram & Parikh, 2018). Usage of these systems in a structure are different for given site conditions and location since the parameters are changed based on parameters. In multi-storeyed structures the lateral load consists of both the seismic loads as well as wind loads. At varying multiple heights the factors like storey displacement, storey drifts and base shear are changed based on conditions (Arum & Akin kunmi, 2011).

The impact of horizontal loads on the structure depends upon the weight of a building. As the self-weight of the structure increases, the seismic forces acting on the building also increases. Hence to reduce that seismic weight of the structure bracing system can be used in high-rise buildings. Implications of the cost is observed in using a shear walls and a dual configuration of the shear walls also steel bracing provided for seismic resistance (Kumawat, et al., 2018).

### 1.1 Ordinary Moment resisting frame

Ordinary moment resisting frames are used where the shear wall provision is limited such as circumstances where architectural limitations are imposed. The solutions of (S.M. Auta, 2012) work revealed that OMRF is proved to be cost-effective up to 20 floors while (Smith & Coull, 2015) discussed that it could be cost-effective for structures up to 25 floors, The solutions of (S.M. Auta, 2012) work revealed that OMRF is economic up to 20 floors while (Smith & Coull, 2015) discussed that it could be cost-effective for structures up to 25 floors, over which their response is expensive to control.

### 1.2 Shear Walls

Shear wall is a structural component used to withstand horizontal forces, that is to say parallel to the partition line. For slender walls with strong deformation, shear walls withstand the horizontal and vertical loads because of cantilever Action (C Bhuta & Pareekh, 2016). Preliminary design is important in cost modelling because it quickly estimates a primary elements for the cost of a structure. The detailed and final design can provide a more accurate approach to the shear wall core's end-construction costs but it requires more time for design and analysis. Therefore, (Chrysanidis & Panoskaltsis, 2016) argue that practically the measurement of the concrete component is more costly than the primary reinforcement bars.

### 1.3 Bracing system

Bracing systems consists of steel, wood and concrete elements that disperse loads equally and improve the stability of the structure. They resist lateral forces, usually with bracing components supported in compression or stress. The bracing mechanism is thus highly effective in the resistance of horizontal loads. However also the key reason for the bracing method to be effective is that bracing renders the framework horizontally rigid. On the basis of the types of braces studied, bracing systems are mainly categorized on the basis of whether the bracing systems are attached to a column beam joint or to a column beam joint. (Khan, et al., 2015).

### 1.4 Aim

The aim of the paper is to study the structural behavior of lateral load resisting systems and its impact on cost for high-rise RCC structures.

### 1.5 Objectives

1. To study the structural behaviour of lateral load resisting systems of high rise RCC structures.
2. To evaluate the seismic performance of selective lateral load resisting systems for given input design parameters.
3. To derive the cost parameters for the selective lateral load resisting systems and compare the cost with seismic parameters.

### 1.6 Scope of Work

a. Plan irregularities are not considered in this studies.

b. To design and analyze the mid high-rise structures located in seismic zone IV.

### 1.7 Methodology

In the current study, seismic analysis of 30 storied structure is done for seismic zone IV for earthquake and wind forces using ETABS. A total of 5 cases derived using OMRF, shear wall, bracing are studied.

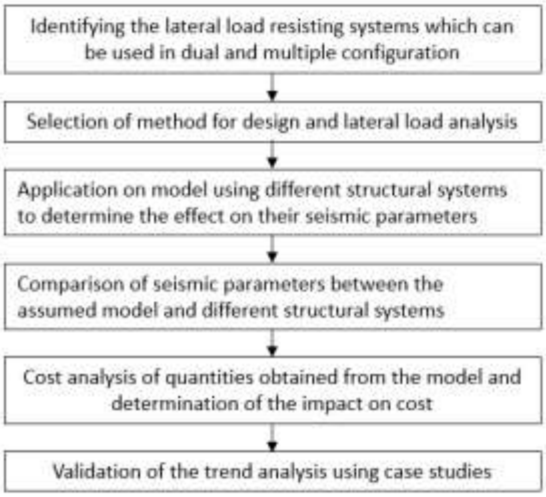



Figure 1 Methodology

## 2. LITERATURE STUDY

(Goyani, et al., 2016) presents within the study, it is addressed that after the earthquake, there are many shortcomings in these systems, including the inability to follow earthquake design standards and the lack of seismic resistance features. The use of passive dampers is now becoming a cost-effective option to increase seismic perforation. As per (Ras A, et. al. 2014) when it comes to removing unnecessary energy such as turbulence, earthquake and wind energy dissipation systems in civil engineering structures. It was concluded from their analysis that the efficiency of the building structure in seismic loading was greatly improved following the implementation of the damped system as opposed to the bare frame and the braced framework. Passive energy dissipaters are typically fairly inexpensive.

As per (Khan, et al., 2015) Incorporation of ductile detailing maximizes base shear capacity. The existence of the RC wall openings decreases the base shear carrying maximum from the wall. With reduction in the aspect ratio of the structure reduces the shear capacity of the base building.

In the research, (Chrysanidis & Panoskaltsis, 2016) found that there was an over-estimation of 35% between the preliminary design and the final design. The quantities were calculated and the parametric estimating was done to obtain the final costs. The costs form preliminary design can be estimated easily without any computer simulation and analysis. As per the study of (M N & S K, 2014) incorporation of ductile detailing maximizes base shear capacity. The existence of the RC wall openings decreases the base shear carrying maximum from the wall. With reduction in the aspect ratio of the structure reduces the shear capacity of the base building.

## 3. METHOD OF ANALYSIS

The seismic analysis has to be carried out for the structures as they have lack of resistance to earthquake and wind forces. Hence a selection method for analysis has been devised based on IS 1893.

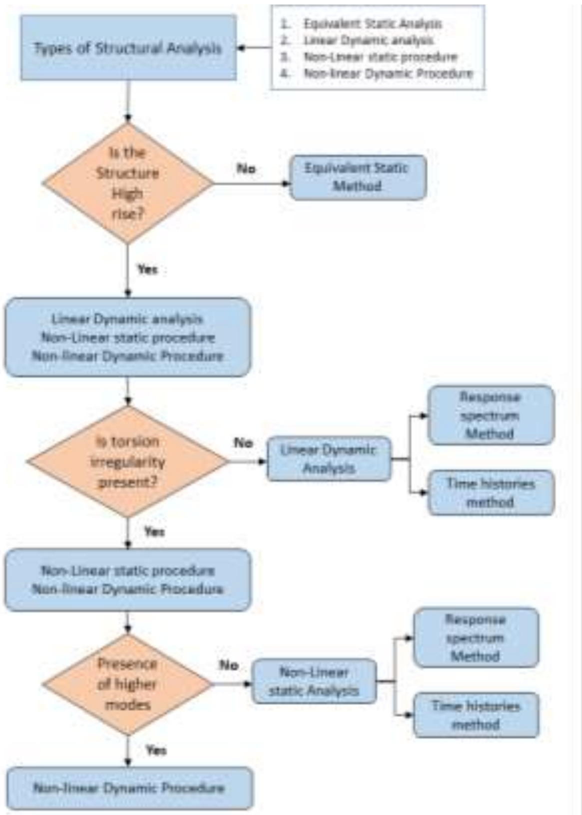



Figure 2 Method of Analysis

Based on the above flow chart, a building of G+30 storied on Zone IV with a regular structure, linear dynamic analysis using response spectrum analysis can be used.

## 4. PARAMETRIC ANALYSIS

### 4.1 General description

The parametric model is considered in Zone IV with the following given parameters.

| SESISMIC PARAMETERS | |
|---|---|
| Type of building | Multi Storied Building |
| Seismic Zone considered | Zone IV |
| Type of soil | Medium |
| Plan of the Building | 20m x 20m |
| Each Bay Size considered | 5m x 5m |
| Height of Building | 90 m |
| Floor to floor height | 3 m |
| Beams | B1 - 0.3m x 0.6m |
| Columns | 0.8m x 0.8m |
| Slab thickness | 0.125m |
| Shear Wall thickness | 0.3m |
| Bracing considered | ISMB 500 |
| Live load | 3.5 kN/m2 |
| Dead load of wall | UDL 12kN/m |
| Concrete | M35 |
| Steel | Fe 415 |
| Damping | 5% |

Based on the combinations of three selected lateral load resisting structures, 5 cases are developed.

### 4.1 Cases of study

Model 1: OMRF structure
Model 2: Shear Walls in centre
Model 3: Shear Wall at perimeter
Model 4: Bracings in in centre (X Bracing)
Model 5: Bracings at perimeter (X Bracing)

**4.2 Plan of the building**

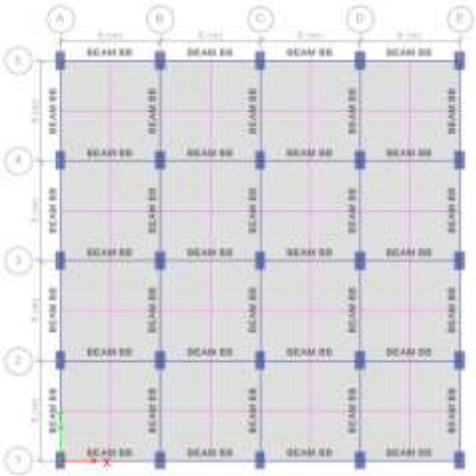


Figure 3 Structural Plan

**4.3 3D model of the structure**

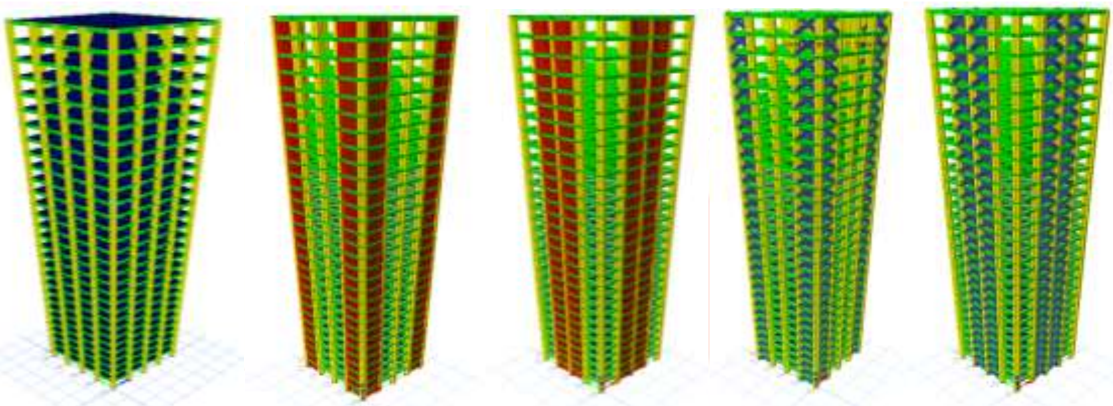
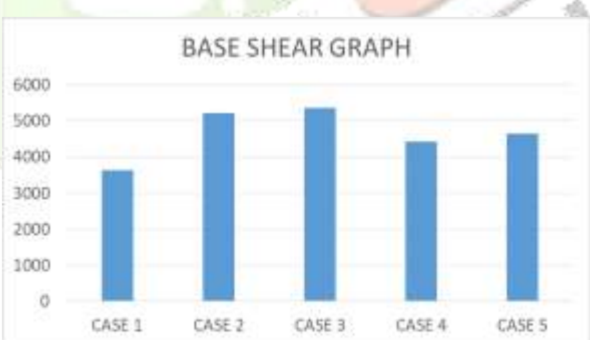


Figure 4 Cases 1 to 5 (From Left to right)

**4.4 Analysis and Results**
**Results for Soft soil (Zone IV)**
**a. Base shear**



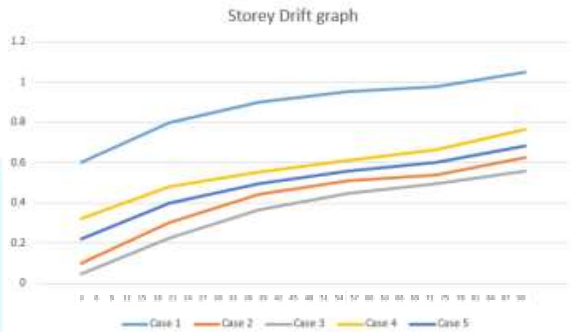

- It is observed from the analysis that, the base shear increases as the soil type changes from hard to soft.
- Shear wall produces high base shear because of its seismic weight.
- Base shear of OMRF is less compared to other structural systems.
- It has been observed that Base Shear is decreased as the time period increases.
- Percentage difference between case 3 (Shear wall in middle) and case 1 (OMRF) is 32.38%.

**b. Lateral displacement graph**

- OMRF structure gives higher lateral displacement compared to other systems.
- Case 3 performs better in terms of lateral displacement.
- The pattern of displacement is observed in the sequence of shear wall, bracing and then ORMF structure.
- Top story displacement variation between shear wall and bracing is 13.02%.

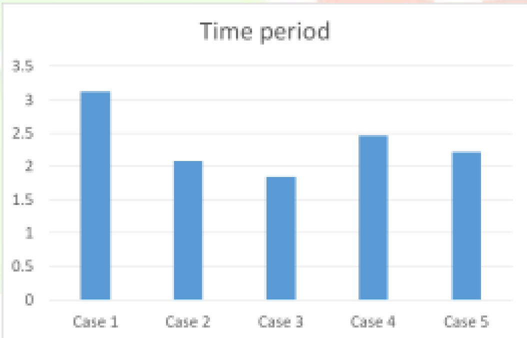

**c. Storey dirft**

- Storey drift is observed to be same in X-dir and Y-dir in case of regular structure.
- In case of OMRF structure it is observed that the storey drift increases gradually up to 10 storeys and then is constant.
- Provision of shear wall in the soft soil has shown better seismic performance compared to medium and hard soil.




**d. Time Period**

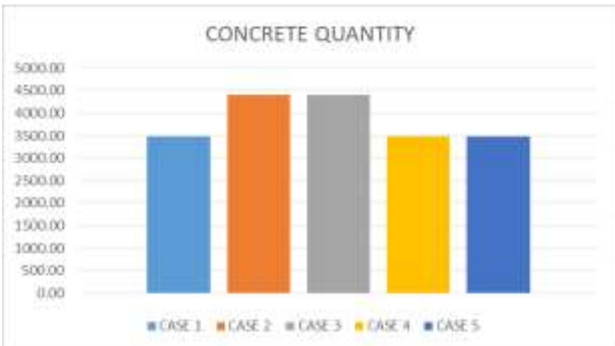
- It has been observed that as the seismic weight increases, time period decreases.
- Structures in soft soil produce greater time period compared to medium soil and hard soil.
- OMRF structure gives higher time period compared to other systems.
- Shear wall when placed in the middle, time period decreases.




**4.5 Cost Comparison**

Cost comparison is done based on the quantity calculation of concrete and steel.

**a. Quantity Estimation**




- Quantity of Concrete is higher in cases 2 and 3, because of the provision of shear walls. Hence the seismic weight of the structure is also higher.
- Concrete quantity in OMRF is lesser due to the absence of lateral load resisting system.
- There is a difference of 21% in concrete quantity between OMRF system and shear wall system.
- 24.6% of steel higher is used in Bracing system compared to conventional OMRF frame.

**b. Cost estimation**

The cost components are calculcated based on the quantities obtained.


**4.6 Inferences from the parametric analysis**

- From the analysis it is observed that the base shear decrease as the soil type changes from soft to hard.
- Shear wall produces high base shear because of its seismic weight.
- Base shear of OMRF is less compared to other lateral resisting systems.
- It has been observed that Base Shear decreases when the time period is increased.
- With the increase in height of the building, storey displacement and drift increases.
- OMRF frame produces higher storey displacements and drifts.
- Using of shear wall and bracing in OMRF structures, storey displacements and drifts are significantly reduced.
- Soft soil should be taken care of as the base shear, storey displacement and drift are very less.
- As the height of the building increases time period also increases because of the mass of the overall building.

**5. CASE STUDY ANALYSIS -VALIDATION**

Case studies have been discussed to study the seismic parameters such as lateral displacement, drift of the storey, displacement of the storey and time period, can be found from the analysis of the parametric model. These parameters are then compared to the variable of a single element to determine the optimum lateral load resistance system for the given study conditions.

### 5.1 General Description

DLF Square is an office building of G+24. The following seismic parameters are analyzed.

| SESISMIC PARAMETERS | |
|---|---|
| Type of building | Multi Storied Building |
| Seismic Zone considered | Zone IV |
| Type of soil | Medium |
| Plan of the Building | 41.6 x 41.6 |
| Each Bay Size considered | 6m x 4m |
| Height of Building | 98 m |
| Floor to floor height | 3.2 m |
| Beams | B1 - 0.3m x 0.6m |
| Columns | 0.8m x 0.8m |
| Slab thickness | 0.125m |
| Shear Wall thickness | 0.3m |
| Bracing considered | ISMB 500 |
| Live load | 3.5 kN/m2 |
| Dead load of wall | UDL 12kN/m |
| Concrete | M35 |
| Steel | Fe500 |
| Damping | 5% |

### 5.2 Structural framing plan

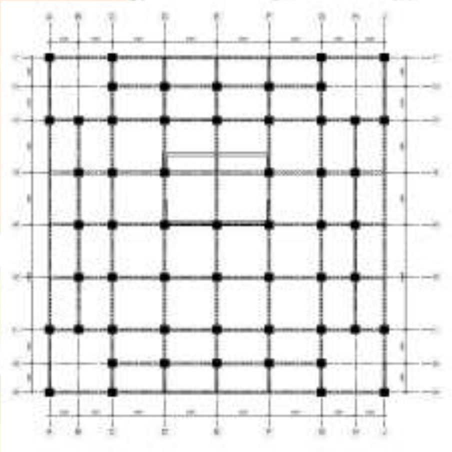


Figure 5 Structural Plan

### 5.3 3D model of the structure

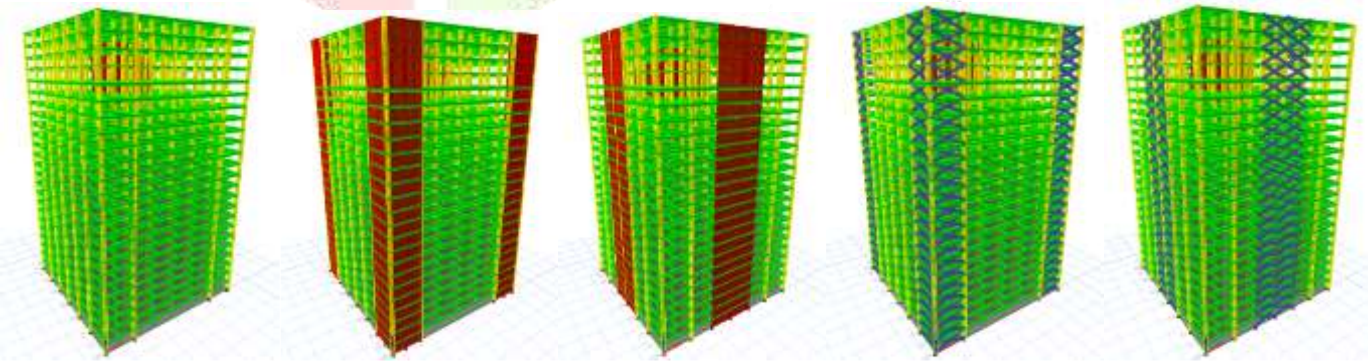
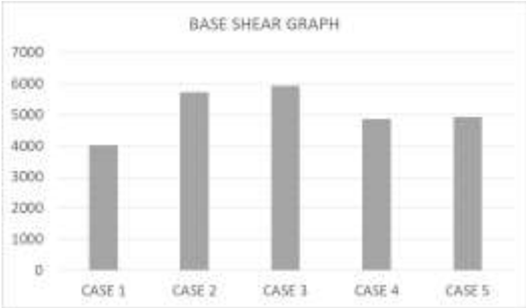


Figure 6 Cases 1 to 5 (From left to right)

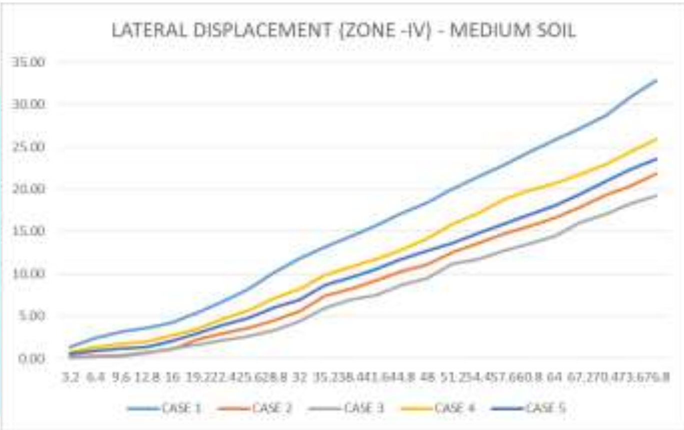
**5.4 Analysis and Results**

1. **Results for medium soil (Zone IV)**
   a. **Base shear**




Shear wall produces high base shear because of its seismic weight. Base shear of OMRF is less compared to other structural systems. It has been observed that Base Shear is decreased as the time period increases. Percentage difference between shear wall and OMRF is 29.8%. The difference between Bracing and OMRF is 17.2%.

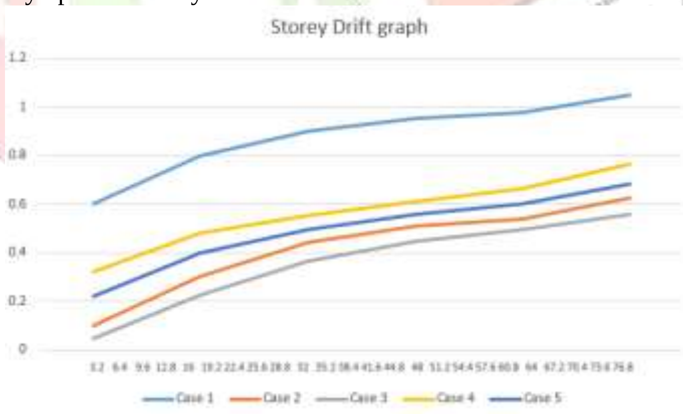
2. **Lateral Displacement**




Lateral displacement is same in both X-Dir and Y-Dir since it's a regular structure. OMRF structure gives high lateral displacement compared to other systems (33.8mm). Case 3 performs better in terms of displacement with displacement of 19.1mm. The pattern of displacement is observed in the sequence of shear wall, bracing and then ORMF structure.

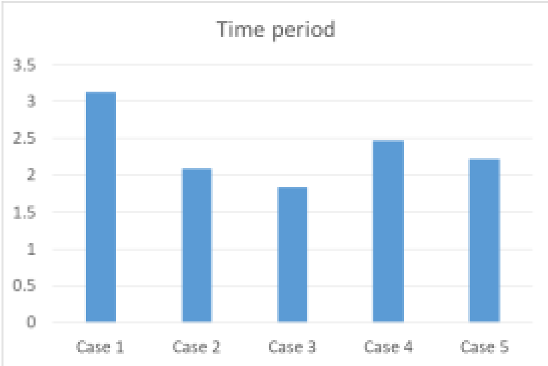
3. **Storey Drift**

Storey drift is observed to be same in X-dir and Y-dir in case of regular structure. In case of bracing and shear walls structure it is observed that the storey drift increases gradually up to 10 storeys and then is constant.



**4. Time Period**

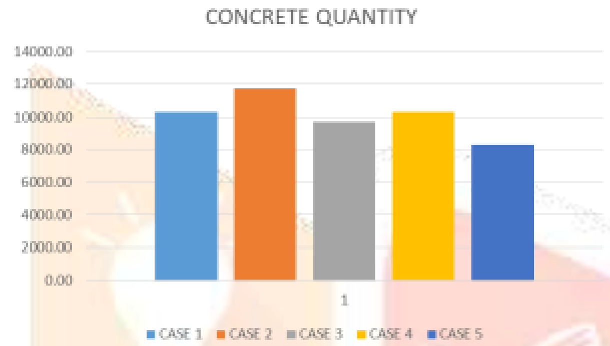
It has been observed that as the seismic weight increases, time period decreases. Structures in soft soil produce greater time period compared to medium soil and hard soil. OMRF structure gives higher time period compared to other systems. Shear wall when placed in the middle, time period decreases. Difference of time period between case 3 and OMRF is almost 1.51 seconds. Difference between case 5 and case 1 is 1.2 seconds.




**5.5 Cost Comparison**

Cost comparison is done based on the quantity calculation of concrete and steel.

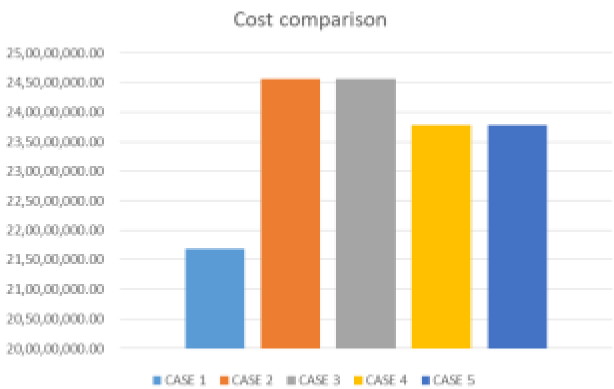
**a. Quantity Estimation**





- Quantity of Concrete is higher in cases 2 and 3, because of the provision of shear walls. Hence the seismic weight of the structure is also higher.
- Concrete quantity in OMRF is lesser due to the absence of lateral load resisting system and lesser seismic performance.
- There is a difference of 11% in concrete quantity between OMRF system and shear wall system.
- 13.6% of steel higher is used in Bracing system compared to conventional OMRF frame.

**b. Cost comparison**




It has been observed that the cost difference is 3.4 % in between Shear wall and bracing systems, 11.7 % difference in between shear wall and OMRF frame and 8.8 % difference in between bracing and OMRF frame.

## 6. RESULTS AND DISCUSSION

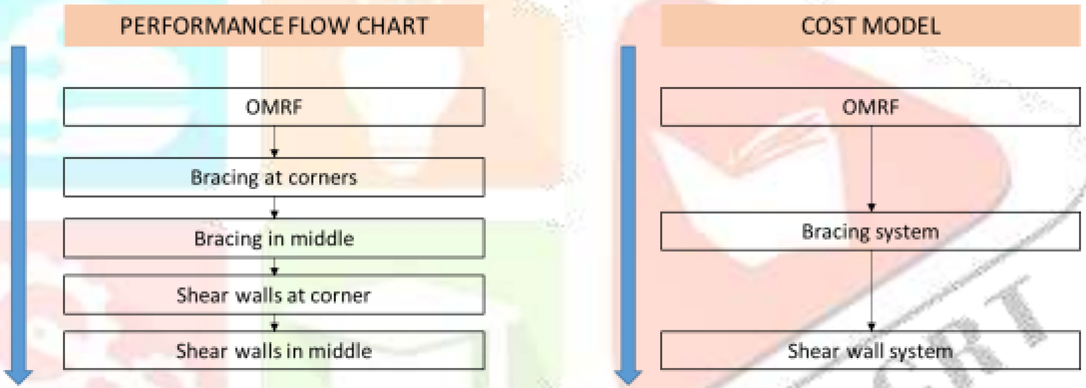
It can be clearly observed that the values from the case studies and the parametric study do not match. This is because of the change in parameters, dimensions of the structures, irregularities present in the structure. Hence the trend of the cases has to be studied instead of the quantitative data.

- From the analysis it is observed that the base shear decrease as the soil type changes from soft to hard.
- Shear wall produces high base shear because of its seismic weight.
- Base shear of OMRF is less compared to other lateral resisting systems.
- It has been observed that Base Shear decreases when the time period is increased.
- Percentage difference in cost between case 3 (Shear wall in middle) and case 1 (OMRF) is 32.38%.
- With the increase in height of the building, storey displacement and drift increases.
- Using of shear wall and bracing in OMRF structures, storey displacements and drifts are significantly reduced.
- Soft soil should be taken care of as the base shear, storey displacement and drift are very less.
- As the height of the building increases time period also increases because of the mass of the overall building.

## 7. CONCLUSION

From this study we can derive the following primary conclusions.

1. With the increase in height of the building, storey displacement and drift increases. OMRF frame produces higher storey displacements and drifts. Using of shear wall and bracing in OMRF structures, storey displacements and drifts are significantly reduced.
2. From the analysis it has been observed that OMRF frame produces higher deflections compared to other systems. In the higher seismic zones, higher displacement sand drifts are observed. The base shear also increase with increase in self-weight. Hence the base shear was also high in case where shear walls are used.
3. The storey shear is high for moments in ZONE 4 and Zone 5. Higher value of shear is observed in zone 5 comparison to zone 4. Also from the analysis it has been observed that for every addition of 15 floors, time period of the structure has been increased by 50%.
4. Base shear of the structure increases with the increase in the self-weight of the structure. Hence the total seismic weight of the structure is proportional to the base shear.
5. Using of the shear wall increases the stiffness and the stability of the structure. But the costs associated with this is very high.




Economically bracing system is better used in 30 storeyed buildings given the conditions and cost. If the project requires better performance then, shear wall case can be used. Shear wall used in the centre can be beneficial than using in the corners. Hence the suitability of the structure is entirely dependent upon the stake holders whether to select the optimised cost or the optimised performance.

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