

# Cost Effective Stiffening of Building Structure at Optimized Level – A Case Study

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**ABSTRACT:** Major seismic events such as those that have occurred in Peru (August 13, 1868), Chile (May 22, 1960), Japan (1995), Bhuj, Central Western India (2001) and Western Coast of northern Sumatra (December 24, 2004) have continued to demonstrate the destructive power of earthquakes leading to the collapse of uncountable buildings, bridges as well as giving rise to great economic losses. In order to overcome its deadly effects in medium to high rise building, shear wall and bracing system is used to provide adequate stiffness, strength and energy dissipation to resist the lateral loads caused by earthquake. This paper focuses on a new concept of arresting the lateral deflection of a residential building by stiffening the top or intermediate storey at an optimized level. Here an attempt has been made to find out the appropriate level at which stiffening will prevent the lateral sway of the building to the greatest extent. This paper portrays the efficiency of the concept of stiffening with the help of response spectrum analysis of a five storey residential building in STAAD PRO which has been provided with shear wall and bracings at different levels. Altogether seven different cases have been considered and analyzed to determine the effectiveness of shear wall and bracing and to determine the optimum level of stiffening to arrest maximum deflection. Within the limited scope of this paper a comparative study of the seismic response of the building has been done to obtain an optimum combination of stiffness and strength keeping economy in mind.

**KEYWORDS:** Response Spectrum, bracing, shear wall, stiffening, optimized level

## I. INTRODUCTION

In seismically active zones, structures are often subjected to severe earthquake jolts causing tremendous damages to all engineering structures. Despite the improved technology, the location, the time of occurrence and intensity of earthquake is very difficult to predict. A structure which has a symmetrical plan will deflect without twisting on influence of horizontal load which will be constrained to some extent by the rigid floor slabs. Generally, structures are mainly designed for dead load, live load and wind load which is not sufficient for taking earthquake load. Hence, it is of utmost importance for all civil and construction engineers to adopt all necessary measures to counter the seismic effects. In order to dissipate the energy of earthquake different countries have different codal provisions for seismic design.

Shear wall and bracing system are the most efficient and practical method of increasing the seismic resistance by reducing lateral displacements and dissipating energy during strong motions. Shear walls are vertical elements of the horizontal force resisting system which resist forces directed along the length of the wall. They provide the necessary lateral strength to resist horizontal earthquake forces by transferring these horizontal forces to the next element in the load path below them. These other components in the load path may be other shear walls, foundation walls, floors, footings or foundations. Shear walls also provide lateral stiffness to prevent the roof or floor of a building from excessive side-sway thereby resisting structural damage. On the other hand bracings are steel or concrete structures which increases a structure's stability against lateral loads such as wind loading and seismic pressure by reducing lateral displacement, as well as the bending moment in columns.

The various aspects such as size and shape of building, location of shear wall and bracing in building, distribution of mass play a significant role in the seismic behavior of a structure. On addition of the bracing system, load could be transferred out of the frame and into the braces by the weak columns. The stiffness added by the bracing system is

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maintained almost up to the peak strength and is particularly important at serviceability state, where deformations are limited to prevent damage.

In this study, an attempt is made to assess the seismic behavior of buildings subjected to bracings at different levels to provide optimum stiffening effect with the help of the Staad Pro analysis. It aims at coming up with the most effective stiffening measure both in terms of economy and efficacy. The example discussed in this paper is a five storey residential building subjected to response spectrum analysis. The displacement results obtained for all the stories of the corner columns of the building have been compared to find out the optimum level where stiffening shows its maximum effect.

## II. LITERATURE SURVEY

A series of integrated analytical and experimental studies has been conducted to investigate the efficiency of shear wall and different types of bracings in enhancing lateral stiffness of structural members to withstand the earthquake jolts.

Nabin Raj .C et. al. (2012)[1] concluded that the bracing in bare frame increases the overall stiffness of the structure by preventing the excessive damage in non structural elements. Maximum inter story drift for frame without bracings occurs in storey just above the ground floor. For frame with bracings maximum inter story drift is found at height nearly to one third height of the building .Deflection pattern obtained is of flexure shape at lower heights and follows the shear configuration in upper heights.

M.D. Kevadkar et. al. (2013) [2]: In this paper the following conclusions were drawn (1) The concept of using steel bracing is one of the advantageous concepts which can be used to enhance structural strength and stiffness 2) Steel bracings reduce shear demands and flexure on beams and columns and transfer the lateral load through mechanism of axial load. 3) The lateral displacement and storey drift of the building is reduced by use of shear wall and steel bracing system to a considerable extent. 4) Shear wall has more storey shear as compared to steel bracing 5) Since the demand curve intersect near the elastic domain shear wall and steel bracing increases the level of safety. 6) Steel bracing has greater margin of safety against collapse as compared to shear wall.

Varsha R. Harne(2014) [3]: The models of the buildings were prepared in the commercial software STAAD PRO V8i by using different cross sections of RC shear wall i.e. Boxed type, L-type and Cross type shear wall and these are located at different locations such as along periphery, at corner and at middle position. Amongst all the load combinations, 1.5DL +1.5EQX is found to be the most critical load combination for all the models. It was also concluded that building with shear wall along periphery is more efficient than all other types of shear wall.

Umesh R. Biradar(2014) [4] : In this paper, the authors have analyzed seven models of different bracing systems for linear statics(ESA), linear dynamics, non linear static (Pushover analysis) and non linear dynamic analysis (time history analysis) in ETABS software. According to this paper, IS Code method does not provide suitable results for time period as the natural time period for bare frame and braced frame is same. So they have obtained the satisfactory results of time periods in ETABS by using ESA and RSA method. From careful observations of the analysis results it was concluded that X bracing is most efficient in resisting lateral loads.

Mohd. Atif (2015) [5]: In this paper, analysis and comparison of G +15 building with shear wall and three different patterns of bracings with three different positioning of it is done, considering all the four zones for earthquake. Parameters like displacement, axial force, bending moments of columns and shear moment, torsion of beams are calculated and graphical and tabular representation of data has been discussed in this paper. Linear Static Analysis method has been adopted for the analysis. It has been concluded that shear wall elements are very efficient in reducing lateral displacement of frame than that induced in braced frame and plane frame.

Prof. Bhosale Ashwini Tanaji(2015) [6]: Within the limited scope of the paper the authors used the various types of concrete bracings i.e. K-type, Diagonal, V-type and X-type of bracings and calculated the storey drift and displacement of building. The storey displacement of building reduces significantly by the use of concrete bracings where X-type of bracing reduces maximum displacement. The storey drift of concrete braced system is less as compared to the bare framed building thereby reducing the overall response of the structure. It was concluded that X-type of concrete bracing is found to be most efficient in terms of storey overturning.

MD. Samdhani Azad(2016) [7]: Their study focus on the building behavior against seismic forces by provision of either shear wall or steel bracing. The analysis of both shear wall or steel bracing systems was done using ETABS

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Software to determine the behavior and performance of each of the model. According to the results, a critical comparative study of the maximum displacement and storey drift of models was done and it was concluded that shear wall at mid portion of the building provides maximum safety against earthquake damage .

From the above literature it is evident that an ample research work has been carried out to find the most effective location for the construction of shear wall and the most effective type of bracing to be used to resist lateral loading. But there is no work on the optimum height at which buildings should be braced in order to have maximum resistance to deflection and also to maintain economy at the same time. So the main objective of this paper is to find out that optimum level at which bracings should be provided in the building to obtain the best combination of strength and stiffness both in terms of efficiency and cost effectiveness.

### III. STRUCTURAL MODELLING AND ANALYSIS

In order to assess the seismic behaviour, a symmetrical six storey residential building with four bays in the longitudinal direction and four bays in the transverse direction have been modelled in Staad Pro V8i. The plan area of the building is 12.0m by 12.0m as shown in Fig 1 with typical storey height of 3.0m and depth of foundation being 4.15m.

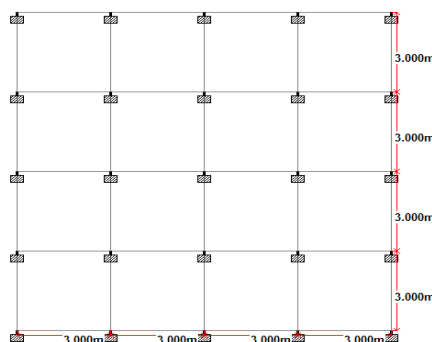


Fig 1: Plan of the building

The building having ordinary RC moment resisting frame is located at Kolkata which comes under seismic zone IV and has zone factor=0.24, Importance Factor=1.0, Response reduction factor R=3.0, Damping Ratio=5% and Rock and Soil Type Factor=2(medium soil). The other parameters of the building have been provided in Table 1.

Grade of concrete	M25
Modulus of elasticity	$2.5 \times 10^7 \text{ kN/mm}^2$
Shear Modulus	$1.04 \times 10^7 \text{ kN/m}^2$
Column size	600 mm x 600 mm
Beam size	400 mm x 400 mm
Slab thickness	150mm
Floor finish	1kN/m
Height Parapet Wall	1.5m
Live load	3kN/m
Thickness of external brick wall	250mm
Thickness of internal partition wall	125m
Unit weight of bricks	$20 \text{ kN/m}^3$
Unit weight of concrete	$25 \text{ kN/m}^3$
Weight of the brick wall	15kN/m
Weight of parapet wall	7.5kN/m
Thickness of the shear wall	300mm
Size of bracings	100mmx 100mm x 10 mm

Table 1: Different parameters of the building considered

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The required material properties like weight density, mass, shear modulus, modulus of elasticity, and design values of the material used can be modified as per the requirements or default values can be accepted. Beams and columns have been defined as 'frame elements' with the appropriate dimensions and the support condition considered is fixed. The Shear wall has been designed using STAAD's surface entity and single angle steel cross bracings are provided using angle sections. Then response spectrum analysis is done on the following seven cases to critically compare the seismic behaviour of the building.

1. Only Frame
2. Frame with shear wall
3. Frame with shear wall and bracing at 5<sup>th</sup> floor
4. Frame with shear wall and bracing at 4<sup>th</sup> floor
5. Frame with shear wall and bracing at 3<sup>rd</sup> floor
6. Frame with shear wall and bracing at 5<sup>th</sup> and 4<sup>rd</sup> floor
7. Frame with shear wall and bracing at 5<sup>th</sup>, 4<sup>th</sup> and 3<sup>rd</sup> floor.

## IV. RESULTS AND DISCUSSIONS

The lateral sway of the corner columns of the building have been considered for comparison of the seismic behavior. The numbering of the columns are shown in table in Fig 2.

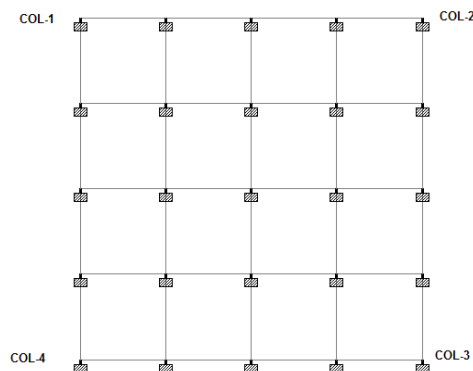


Fig 2: Column positions considered for comparison of results

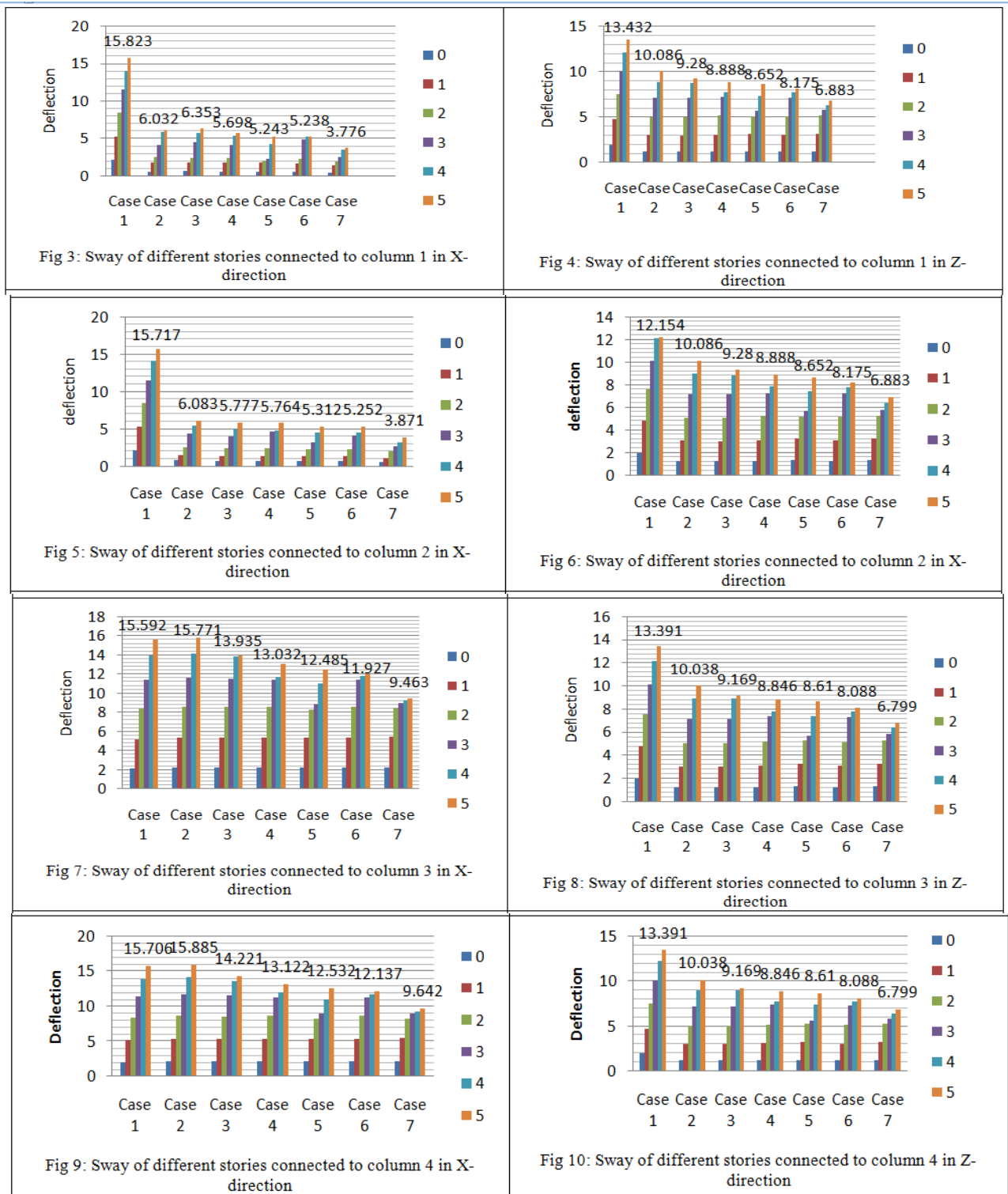
A comparison of the results of the lateral sway of columns 1,2,3 and 4 of all the seven cases has been shown in Fig-3,4,5,6,7,8 and 9 in the form of bar chart. In each of these graphical representations the Y axis denotes the lateral displacement while the X axis shows the different cases. The lateral drift of each of the stories have been plotted where 0,1,2,3,4 and 5 represents the ground floor, first floor, second floor, third floor, fourth floor and fifth floor respectively. Sway of the columns in both X and Z directions have been taken into consideration.

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It has been found that in Case 1 where only frame is present, the amount of sway of the top storey is maximum. This sway is significantly reduced in Case 2 where shear wall is present. The provision of bracing in the subsequent cases has also shown considerable decrement in the lateral deflection of the frame. On close examination of the results, it is very evident that the amount of sway greatly depends on the storey level at which it is braced. Sway is maximum if the structure is braced at top storey and it gradually decreases as the storey levels are closer to the base. The analysis also shows that more the number of stiffened stories more will be the sway resistance as in cases 6 and 7. Due to the high price of steel and concrete it is often difficult to use both shear wall and bracing at the same time. So in seismically active regions where the construction work has a limited budget bracing can be attached in one of the stories or a few stories depending on their elevation from the ground. More the bracings will be closer to the base of the building better will be the stiffening effect.

## V. CONCLUSION

The main objective of the paper is to provide the most efficient stiffening technique within a limited budget. The increment in lateral stiffness of the structure occurs due to large horizontal interaction forces that are induced between the walls and the frames at the levels just above and below the stiffened storey. The forces at the two levels are mutually opposite and form a force and a couple that restrain the lateral sway of the shear walls and hence the structure. The magnitudes of this restraining force and couple and their stiffening effect on the structure is maximum if the stiffened storey is located at the level where the racking component of the inclination of the frame is maximum. In order to find out the optimum height at which the stiffening effect is maximum a response spectrum analysis of a six storey residential building has been done in Staad Pro and the displacement results of its corner columns have been compared. From the graphical representations of the analysis output the following conclusions can be done:

1. The lateral stiffness of a wall-frame structure can be increased considerably by increasing the shear rigidity of a storey of the frames by providing cross bracings.
2. The lateral sway can be reduced by 50% or more with the addition of shear wall and bracing at proper position and at proper level.
3. More the number of stiffened storey greater is the stiffness of the structure.
4. The more stiffening is provided close to the base of the structure, the more rigid the structure becomes.
5. In places where the seismic activity is not much prominent stiffening just one storey of the building can reduce the lateral sway of by 30%

Though enough research work has already been carried out in this field but still there are lot of scope to come up with more efficient techniques to prevent seismic damages. This work can be further progressed by experimenting with different types of bracings provided at different storeys and by changing the position of the shear wall so that the energy dissipation is more causing least discomfort to the occupants and also to mitigate the deadly effects of seismic pounding.

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