Retrofitting Of Reinforced Concrete Frames Using Different X Bracing Configurations

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Abstract - Recent earthquakes have caused catastrophic impact on many multi storied RCC buildings. Their seismic inadequacy was attributed to reasons such as insufficient design loads, flawed design, flawed construction or any changes in the building occupancy. Retrofitting techniques are adopted for eliminating these structural deficiencies. Retrofitting is defined as the judicious modification of the structural properties of an existing building in order to improve its performance in future earthquakes. Among the various retrofitting methods available, steel braces are considered as one of the most efficient solution for upgrading seismic performance of RC framed structures. The use of X type steel bracing system for improving an existing industrial building is examined, in the viewpoint of increasing its resistance to potential earthquake or any other damage that is likely to affect it in the future. For this purpose, various X bracing configurations formed by bracing the middle, corner as well as alternate frames of the building are considered. A comparative study is conducted to identify the ideal X type bracing configuration for retrofitting the building by studying various parameters such as lateral displacement, storey drift, axial forces, bending moment, shear force and story stiffness.

Key Words: Alternate, Braces, Configurations, Displacement, Drift, Frames, Retrofitting, Shear, Storey

1.INTRODUCTION

In light of the present situation of rapidly increasing population with the land area remaining constant, multistoried buildings has become inevitable. As these buildings become more and more slender with increasing height, the effect of earthquake ground motion and lateral winds increases. This will produce lateral displacements which may exceed the permissible limits or can even lead to failure, depending on its present condition. Retrofitting is the modification of existing structure with additional or new components to increase the efficiency of the structure. Retrofitting is predominantly concerned with structural improvement thereby reducing the seismic hazards. Different retrofitting techniques include addition of shear wall, bracing, jacketing of beams and columns, base isolation, wall thickening etc.

In medium and high rise structures, loads acting on the structure mainly consist of gravity loads and lateral loads. The lateral loads are due to wind, blast and earthquake etc. So the structure should have sufficient stiffness and strength laterally to perform satisfactorily to these occasional loads. In recent years, steel bracing is commonly used to increase the seismic strength of RC framed structure, either for rehabilitation of structure damaged by earthquake or for strengthening of an undamaged structure, made necessary by the revisions in structural design or loading by standard codes of practice. Considering the ease of construction and the relatively low cost, steel bracings appears to be attractive compared to other conventional upgrading techniques. A large number of existing reinforced concrete frame structures are in need of seismic retrofitting because of inadequate lateral resistance. A multistoried industrial building is selected in seismic zone III and its performance under seismic loads is studied using ETABS 2016 software. Any inadequacy in earthquake resistance of the building is fulfilled by finding out the most suitable steel bracing configuration as its retrofitting solution.

2.BUILDING SPECIFICATIONS

The building that has been selected for the analysis is a B+G+4 storey rectangular industrial building with an industrial area on each floor. It is a framed structure having base dimensions 4166cm x 2920cm.The building is located in Angamaly, Ernakulum, Kerala in seismic zone III and founded on medium soil, which is the reference ground condition. The building selected is modeled on ETABS 2016 as per its existing condition and also with various bracing configurations which will modify its performance. The information used for modeling the building is given in Table 1. The superstructure was modeled using ETABS 2016 as a space frame with a grid of columns in the vertical direction, interconnected with beam members in the orthogonal direction in each floor level. It was modeled with shear walls in place of lift wells. The nodes, that are the meeting points of beams with beams and beams with columns, were treated as rigid joints due to monolithic construction. The end of columns at the bottom of the model was elongated to a depth of 1.5m with fixed support at the end, to represent the pile foundation of the building. All walls and slabs were modeled as thin shell elements. The plan, 3D view and elevation in both X and Y directions are shown using figure 1 and 2.

Table -1: Building Specifications

Building type	Industrial
Foundation	1.9m below GL
Typical floor height	4.2m
Wall thickness	20cm
Slab thickness	11cm
Column size	C1-300mm x 500mm C2-250mm x 500mm C3-400mm x 700mm C4-200mm x 500mm
Beam size	B1-200mm x 500mm
Staircase details	Rise-15cm Tread 30cm
Superstructure	Brick masonry
Grade of concrete	M25
Grade of steel	HYSD415
Density of brick masonry	20kN/m^3
Density of concrete	25kN/m^3
Modulus of elasticity of concrete	25000N/m^2
From IS 1893(part 1):2016	
Seismic zone	III
Zone factor	0.16
Response reduction factor	3
Importance factor	1.5
From IS 875(part 3):2015	
Wind speed	39m/s
Terrain category	2
Risk coefficient	1.06
Topography factor	1

3.EQUIVALENT STATIC ANALYSIS OF THE BUILDING

The building was analyzed for all load combinations as specified in IS 456:2000 and IS 1893:2016 using equivalent static analysis, with frames without braces as well as braced frames. From previous studies [3], [4], it is evident that X bracing is comparatively more efficient than other types of bracings and hence it is selected for retrofitting the industrial building under consideration. The braces were provided using the ideal steel section ISHB225, which was automatically selected in ETABS 2016 by the auto select option. Apart from the original building without braces, four different trial configurations using X bracing are considered. The various analysis models thus formed are alternate system type 1, alternate system type 2, corner braces and middle braces whose elevations are shown in figures 3, 4, 5 and 6 respectively.

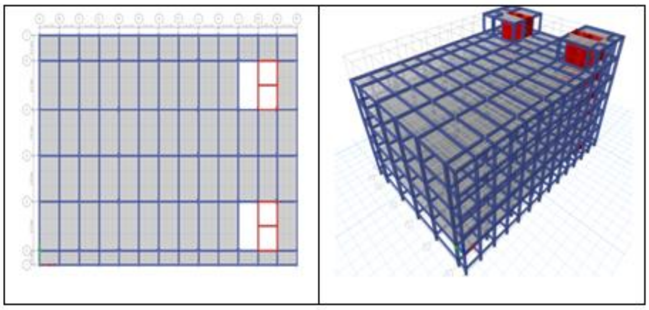

Fig-1. Typical plan view and three dimensional view of the building modeled in ETABS 2016

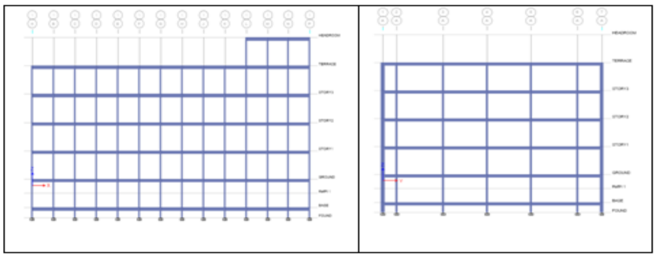

Fig-2. Typical elevation view of the building in X direction and Y direction respectively

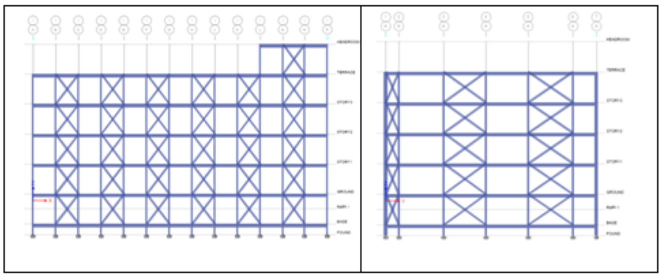

Fig-3. Alternate system of bracings Type 1.

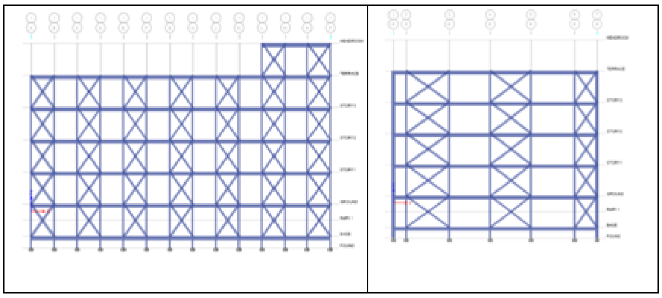

Fig- 4. Alternate system of bracings Type 2.

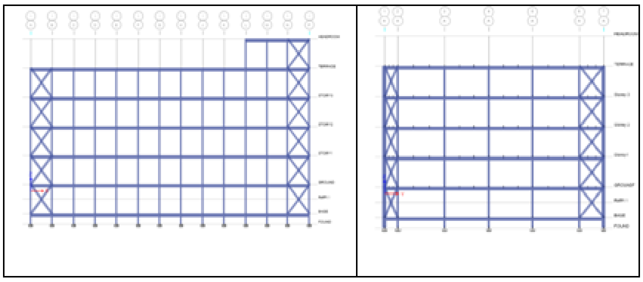

Fig-5. Corner bracing system

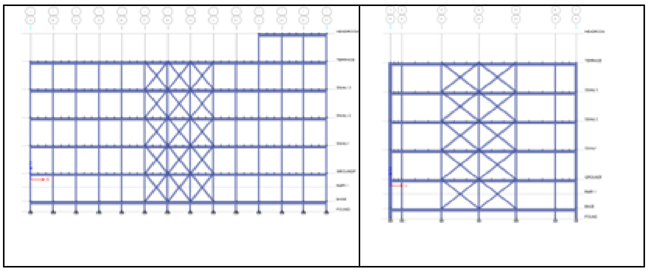

Fig-6. Middle bracing system

4 OBSERVATIONS AND RESULTS

After conducting the equivalent static analysis the parameters such as storey displacement, storey drift, bending moment, shear force, axial force and story stiffness in the columns, are compared for the model without any bracing and for the models with bracing at different positions.

4.1 Lateral Displacement

Variation of lateral displacement in X and Y direction are shown in chart 1 and 2 respectively. It is observed that lateral displacement is reduced to large extent for middle braces in X, Y direction.

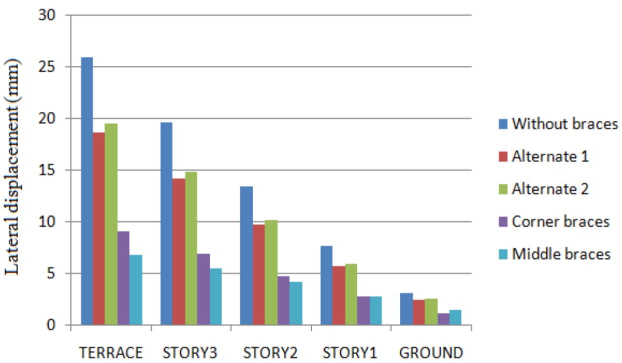

Chart -1. Variation of lateral displacement in the X direction

The reduction in lateral displacement in X direction is 74% while it is almost 77% in Y direction, due to the application of bracings in the middle bays of the building.

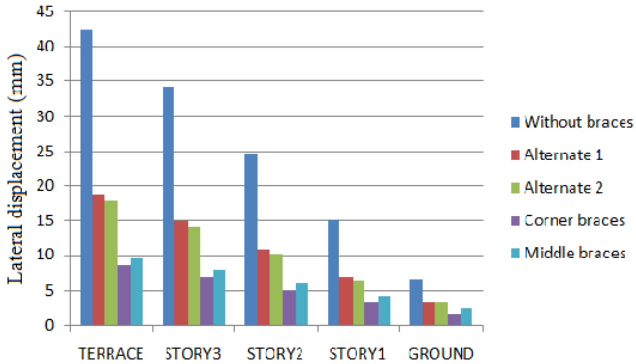

Chart -2. Variation of lateral displacement in the Y direction

4.2 Storey Drift

Inter-storey drift is an important indicator of structural behavior in performance based seismic analysis. It is one of the particularly useful engineering response quantity and indicator of the structural performance, especially for high rise buildings. The inter-storey drift of building structures is defined as relative translational displacement between two consecutive floors. It is the displacement of one level relative to the other level above or below. Variation of storey drifts in X and Y direction are shown in chart 3 and 4 respectively.

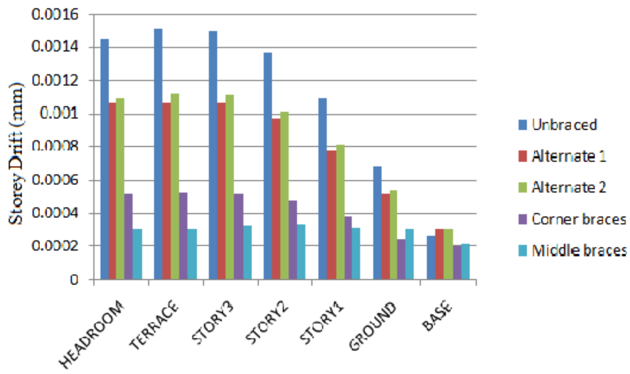

Chart -3. Variation of storey drift in the X direction

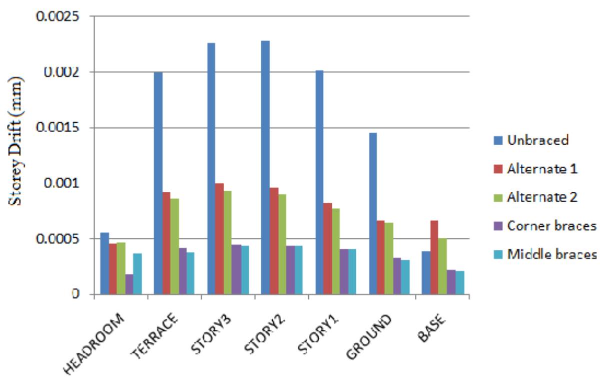

Chart -4. Variation of storey drift in the Y direction

It can be observed from the graph that the storey drifts are reduced to largest extent for the building with middle braces while these are maximum for the system without bracing, both in X and Y directions.

4.3 Bending Moment

A comparison is made between the maximum values of bending moment in columns (in kNm) in the various stories, in figure 7. It can be observed that the bending moment values decrease for the braced models under seismic load and the lowest value is observed for the model with middle braces. This is because the bracings provided create an alternative path for the transmission of the loads into the ground.

Floor level	DL+LL	Seismic load				
		Without bracing	Alternate bracing 1	Alternate bracing 2	Corner bracing	Middle bracing
Headroom	21.7963	69.573	38.8085	39.8566	42.5973	40.3177
Terrace	61.8998	121.87	85.1253	84.7287	88.1619	84.4458
Storey3	71.1318	141.8842	98.5215	98.4236	101.9792	98.2416
Storey2	64.4775	136.5057	92.0096	92.0906	95.3311	91.7569
Storey1	73.0181	144.4023	100.1212	100.3368	104.1338	100.4335
Ground floor	54.2456	78.1893	63.8305	63.6854	63.3859	63.5947
Base	6.7632	69.1759	27.4583	13.624	26.7497	26.1761

Fig-7. Bending Moment in kNm

4.4 Shear Force

The maximum shear force in columns (in kN) values in different stories are compared to find that it decreases on the application of bracings similar to that of bending moment. This is also due to the formation of alternative load paths involving bracings.

Floor level	DL+LL	Seismic load				
		Without bracing	Alternate bracing 1	Alternate bracing 2	Corner bracing	Middle bracing
Headroom	10.092	40.5698	19.0252	19.9065	21.2004	19.6545
Terrace	24.8025	52.7509	35.1046	34.7772	36.4559	34.6046
Storey3	34.8115	68.3051	47.944	47.8415	49.4902	47.9224
Storey2	30.751	61.3486	42.8272	42.7198	44.1463	42.7873
Storey1	33.2487	60.0806	44.243	44.136	45.5411	44.4009
Ground floor	17.2086	34.1296	24.797	24.8304	25.0045	24.9095
Base	5.595	22.0872	29.2793	30.7578	23.1286	24.5668

Fig-8. Shear force in kN

4.4 Axial force

The maximum axial force in columns (in kN) is compared for different stories. Even though there is a decrease in the axial force value in the topmost storey, for all the below stories the value slightly increases.

Floor level	DL+LL	Seismic load				
		Without bracing	Alternate bracing 1	Alternate bracing 2	Corner bracing	Middle bracing
Headroom	46.5582	75.1499	54.0607	60.626	54.3367	47.5514
Terrace	343.4991	377.8472	381.7617	380.2722	379.0306	380.8354
Storey3	797.7248	945.2746	948.2336	947.8804	947.3129	948.0476
Storey2	1276.1061	1514.0405	1517.9654	1517.4497	1516.631	1517.7043
Storey1	1756.0099	2085.6338	2089.7519	2089.1011	2088.091	2089.4248
Ground floor	2238.5353	2661.8499	2665.0125	2664.2739	2663.1542	2664.6318
Base	2291.1307	2724.4222	2724.6885	2723.9369	2722.7986	2724.2977

Fig-9. Axial force in kN

4.5 Storey Stiffness

Storey Stiffness (in kN/m) in X and Y direction are shown in figure 10 and 11 respectively. The increased stiffness for the braced models is the reason for the improvement of the properties of the building in terms of lateral displacement, storey drift, bending moment etc.

Floor level	Storey Stiffness X				
	Without bracing	Alternate bracing 1	Alternate bracing 2	Corner bracing	Middle bracing
Headroom	59528.737	93291.513	98167.41	72874.603	92465.142
Terrace	337403.036	528053.167	541815.099	403398.773	530144.658
Storey3	574337.923	897846.169	906985.71	682929.465	890617.928
Storey2	758940.323	1178169.913	1186039.19	899390.067	1155881.374
Storey1	1032138.384	1575676.42	1576155.432	1218047.755	1527983.272
Ground floor	1545377.269	2535653.628	2597921.885	1969930.02	2507386.533
Base	14929242.072	8817376.532	9001275.829	9653155.255	8261254.337

Fig-10. Storey Stiffness in X direction

Floor level	Storey Stiffness Y				
	Without bracing	Alternate bracing 1	Alternate bracing 2	Corner bracing	Middle bracing
Headroom	167716.441	194620.715	200926.681	176278.365	201005.108
Terrace	484796.411	788918.704	836400.525	591711.917	895336.407
Storey3	712379.334	1228767.33	1308116.453	914125.96	1361031.669
Storey2	828584.595	1505996.411	1604651.635	1105699.448	1640341.672
Storey1	975040.945	1883634.028	2013292.511	1339762.923	2003864.66
Ground floor	1348383.224	2529868.754	2648742.944	1942684.11	2591483.029
Base	14388229.903	5099505.781	5071795.526	6076752.885	4695765.248

Fig-11. Storey Stiffness in Y direction

5 CONCLUSION

Based on the studies conducted, steel bracings can be considered as an effective strategy for retrofitting of RC structures. The lateral stiffness of the building have significantly improved in X and Y directions by 55% and 20% respectively due to the application of middle braces. Thus from all four arrangements of X bracing system, the arrangement with middle braces gives better performance for the building under consideration Steel bracings with middle braces have drastically reduced the flexure demand of building by 31% and shear demand by 27% when compared to un-braced building. After the analysis of structure with different types of X bracing configurations, it is concluded that the overall displacement of the structure decreases. However the maximum reduction in the lateral displacement is due to the application of middle braces. The steel braces given in the middle frames of the building reduce the lateral displacement by almost 74% along X direction and 77% along Y direction. In terms of reduction in storey drift, middle braces are found to be the most efficient compared to other configurations, even though there is increase in both column axial force.

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