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FAILURE CONTROL OF A SKYSCRAPER USING DIFFERENT METHODS OF RETROFITTING

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Abstract* — A skyscraper is a tall, continuously habitable building having multiple floors. The term was originally used to describe one of at least 35-50 floors, mostly designed for office, commercial and residential uses. A skyscraper can also be called a high-rise, but the term skyscraper is often used for buildings higher than 50 m (164 ft). One common feature of skyscrapers is having a steel framework that supports curtain walls. These curtain walls either bear on the framework below or are suspended from the framework above, rather than load-bearing walls of conventional construction. The load a skyscraper experiences is largely from the force of the building material itself. In most building designs, the weight of the structure is much larger than the weight of the material that it will support beyond its own weight. In technical terms, the dead load, the load of the structure, is larger than the live load. The basic principles of design for vertical and lateral loads (wind & seismic) are the same for low, medium or high rise building. But as building gets high, both vertical & lateral loads become controlling factors. The vertical loads increase in direct proportion to the floor area and number of floors. In contrast to this, the effect of lateral loads on a building is not linear and increase rapidly with increase in height. Due to these lateral loads, deflection & moments on steel components will be very high. By retrofitting the structure, these types of failures can be controlled. In the present analysis, a skyscraper with 40 floors has been analyzed. It is tested by different methods of retrofitting like shear walls, bracings and friction dampers at different locations. The building is considered on medium soil and analyzed in all the four zones (II, III, IV,V). Storey Shear, Moment, Torsion, Drift and Lateral Load have been compared for all the cases. A commercial package, ETABS has been used for analyzing the skyscraper of 120m height and for different zones. The results are presented using tables & graphs and the most optimized solution is found out.

INTRODUCTION

The term "skyscraper" was first applied to buildings of steel framed construction of at least 10 stories in the late 19th century, a result of public amazement at the tall buildings being built in major cities like Chicago, New York City, Tokyo, Beijing, etc. The structural definition of the word skyscraper was refined later by architectural historians, based on engineering developments of the 1880’s that had enabled construction of tall multi-Storey buildings. This definition was based on the steel skeleton as opposed to constructions of load-bearing masonry, which passed their practical limit in 1891 with Chicago's Monad Nock Building.

The design and construction of skyscrapers involves creating safe, habitable spaces in very tall buildings. The buildings must support their weight, resist wind and earthquakes, and protect occupants from fire. Yet they must also be conveniently accessible, even on the upper floors, and provide utilities and a comfortable climate for the occupants. The problems posed in skyscraper design are considered among the most complex encountered given the balances required between economics, engineering, and construction management.

RETROFITTING

Retrofitting refers to the addition of new technology or features to older systems in order to enhance the stability of the structure.

SEISMIC RETROFITTING

Seismic retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure due to earthquakes. With better understanding of seismic demand on structures and with our recent experiences with large earthquakes near urban centers, the need of seismic retrofitting is well acknowledged. Prior to the introduction of modern seismic codes in the late 1960s for developed countries (US, Japan etc.) and late

1970s for many other parts of the world (Turkey, China etc.), many structures were designed without adequate detailing and reinforcement for seismic protection. In view of the imminent problem, various research works have been carried out. State-of-the-art technical guidelines for seismic assessment, retrofit and rehabilitation have been published around the world – such as the ASCE-SEI 41and the New Zealand Society for Earthquake Engineering (NZSEE)'s guidelines.

The retrofit techniques outlined here are also applicable for other natural hazards such as tropical cyclones, tornadoes, and severe winds from thunderstorms. Whilst current practice of seismic retrofitting is predominantly concerned with structural improvements to reduce the seismic hazard of using the structures, it is similarly essential to reduce the hazards and losses from non-structural elements. It is also important to keep in mind that there is no such thing as an earthquake-proof structure, although seismic performance can be greatly enhanced through proper initial design or subsequent modifications.

INFILLS

EXTERNAL BRACINGS

Fig 1. showing structures retrofitted with Infills and External Bracings

OBJECTIVES OF THE STUDY

The primary objectives of the present study are:

- To analyse the skyscraper by retrofitting it with shear walls, steel bracings and with friction dampers. For this four models are developed
    - Model – 1(General Building)
    - Model – 2(Shear Walls)
    - Model – 3(Steel Bracings)
    - Model – 4(Friction Dampers)
- These models are analyzed for all the four earthquake zones by considering soil as medium type(II).

SCOPE OF THE INVESTIGATION

In the present study a typical 40 storied skyscrapper is analyzed using commercial ETABS v 9.7.4 using Dynamic Method of Analysis by retrofitting the structure with steel bracings, shear walls and friction dampers at different locations. The results are compared to the normal model and conclusions are made regarding the behaviour.

RETROFITTING

Retrofitting is making changes to an existing building to protect it from flooding or other hazards such as high winds and earthquakes. Retrofitting is advancement in the construction technology, including both methods and materials, to cope up with the increasing frequency and intensity of the natural hazards and their effects on buildings. Many houses existing today were built when little was known about where and how often floods and other hazardous events would occur or how buildings should be protected, and houses being built today may benefit from

improvements based on what we learn in the future. As a result, retrofitting has become a necessary and important tool in hazard mitigation
Retrofitting specifically for earthquake hazards is often referred to as “**rehabilitation**”.
In earthquake engineering terminology, Repair, Restoration and Retrofitting have acquired the following meanings:

- **Repair**: Actions taken for patching up of superficial defects and doing the finishes.
- **Restoration**: Action taken for restoring the lost strength of Structural elements.
- **Retrofitting**: Actions for upgrading the seismic restoring of an existing building. So that it becomes safer under the recurrence of likely future earthquakes.

NEED FOR SEISMIC RETROFITTING

- ❖ To ensure the safety and security of a building, employees, structure functionality, machinery and inventory
- ❖ Essential to reduce hazard and losses from non-structural elements.
- ❖ Predominantly concerned with structural improvement to reduce seismic hazard.
- ❖ Important buildings must be strengthened, whose services are assumed to be essential just after an earthquake like hospitals.

SEISMIC STRENGTHENING (RETROFITTING)

- ❖ It will involve actions for upgrading the seismic resistance of an existing building so that it becomes safer under the occurrence of probable future earthquakes.
- ❖ The seismic behavior of existing g buildings is affected by their original structural inadequacies, material degradation due to gain and alterations carried out during use over time. The complete replacement of such buildings in a given area is just not possible due to a number of social, cultural and financial problems. Therefore, seismic strengthening of existing undamaged or damaged buildings is a definite requirement. Seismic strengthening structural restoration and cosmetic repairs may sometimes cost up to 25 to 30 percent of the cost of rebuilding although usually it may not exceed 12 to 15 percent. Hence justification of strengthening work must be fully considered from cost point of view.

EARTHQUAKE RESISTANT RETROFITTING OF BUILDINGS

For achieving safety of buildings against collapse in a future severe earthquake, the following retrofitting actions are recommended. The amount and placing of the retrofitting element depends upon the seismic zone, the importance of the building and the stiffness of the base soil.

Seismic Retrofitting Techniques are required for concrete constructions which are vulnerable to damage and failures by seismic forces. In the past thirty years, moderate to severe earthquakes occurs around the world every year. Such events lead to damage to the concrete structures as well as failures.

Thus the aim is to focus on a few specific procedures which may improve the practice for the evaluation of seismic vulnerability of existing reinforced concrete buildings of more importance and for their seismic retrofitting by means of various innovative techniques such as base isolation and mass reduction.
So Seismic Retrofitting is a collection of mitigation technique for Earthquake engineering. It is of utmost importance for historic monuments, areas prone to severe earthquakes and tall or expensive structures.

BASIC CONCEPT OF RETROFITTING

This aims at:

- ✓ Up-gradation of lateral strength of the structure.
- ✓ Increase in the ductility of the structure.
- ✓ Increase in strength and ductility.

CLASSIFICATION OF RETROFITTING TECHNIQUES

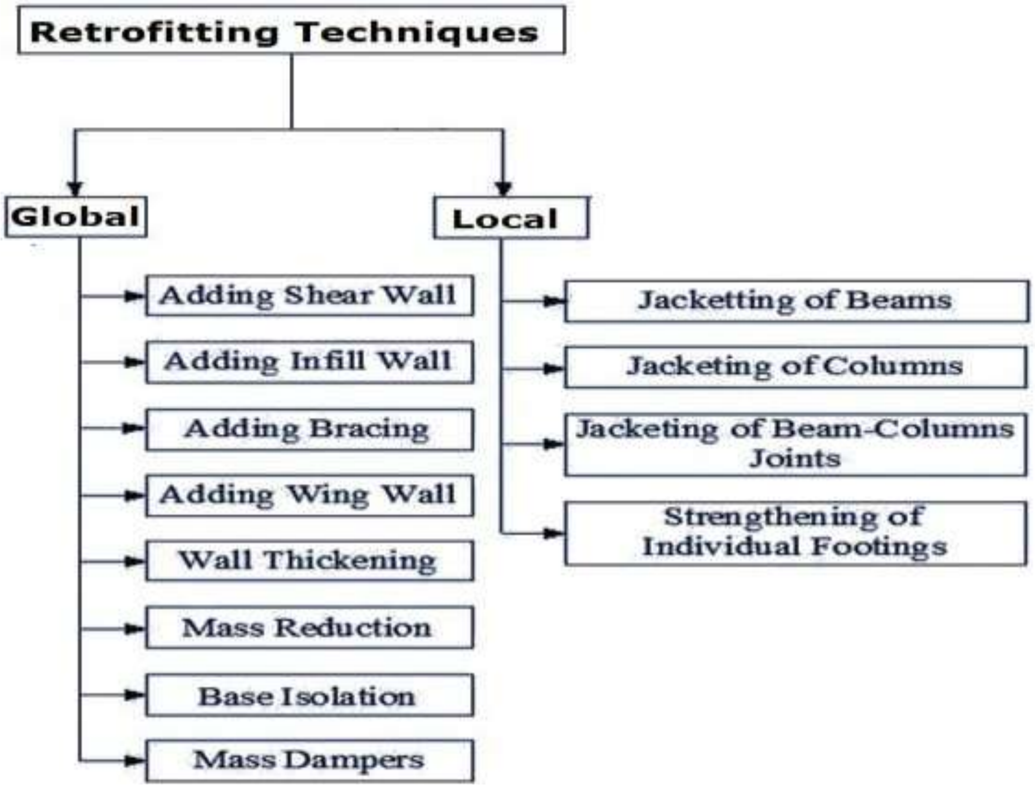


Fig 2. showing the classification of retrofitting techniques

MODELLING

GEOMETRICAL PROPERTIES

1. Height of typical Storey = 3 m
2. Height of ground Storey = 3 m
3. Length of the building = 21 m
4. Width of the building = 21 m
5. Span in both the direction = 21 m
6. Height of the building = 120 m
7. Number of stories = 40
8. Wall thickness = 230 mm
9. Slab Thickness = 150 mm
10. Grade of the concrete = M 30
11. Grade of the steel = Fe 500
12. Thickness of shear wall = 230 mm
13. Support = Fixed
14. Column sizes = 0.6m X 0.6m up to 40 Storey
15. Beam size = 0.4 m X 0.4 m
16. Live Load = 3kN/m^2
17. Floor finish = 1.5 kN/m^2
18. Shear Wall load = 17.25 kN/m on all floors expect terrace

Model 1: In this model building with 40 floors is considered as shown in figure. The dead loads of other elements are taken as member loads on the respective beams. This model is analyzed in all the four earthquake zones on medium soil.

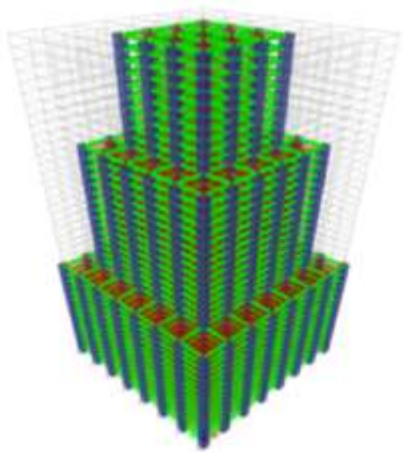


Fig 3. showing General Building

Model 2: In this model building with 40 floors is retrofitted with shear walls as shown in figure. The dead loads of other elements are taken as member loads on the respective beams. The shear wall load is considered as uniformly distributed load on beams. This model is analyzed in all the four earthquake zones on medium soil. The loads are taken same as in Model 1.

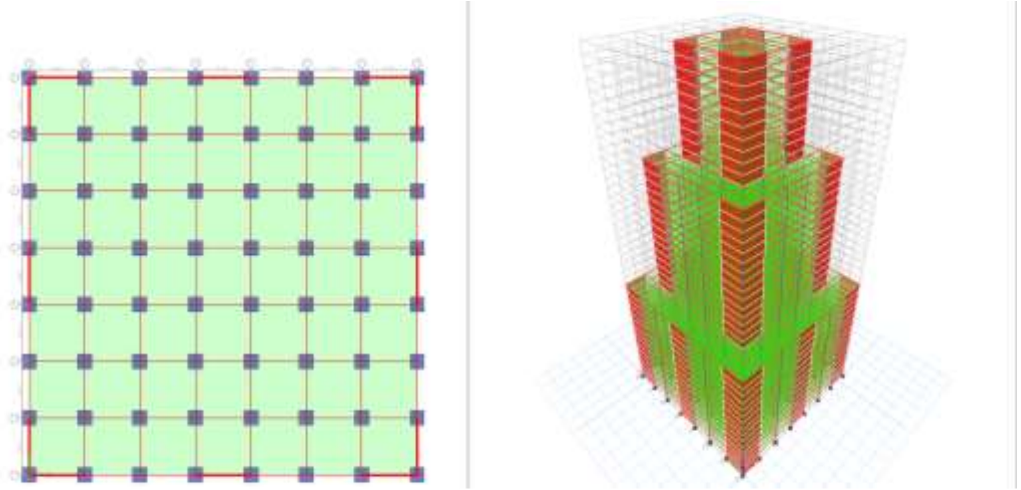


Fig 4. showing Model retrofitted with shear walls

Model 3: In this model building with 40 floors is retrofitted with steel bracings as shown in figure. The dead loads of other elements are taken as member loads on the respective beams. This model is analyzed in all the four earthquake zones on medium soil. The loads are taken as same in Model 1.

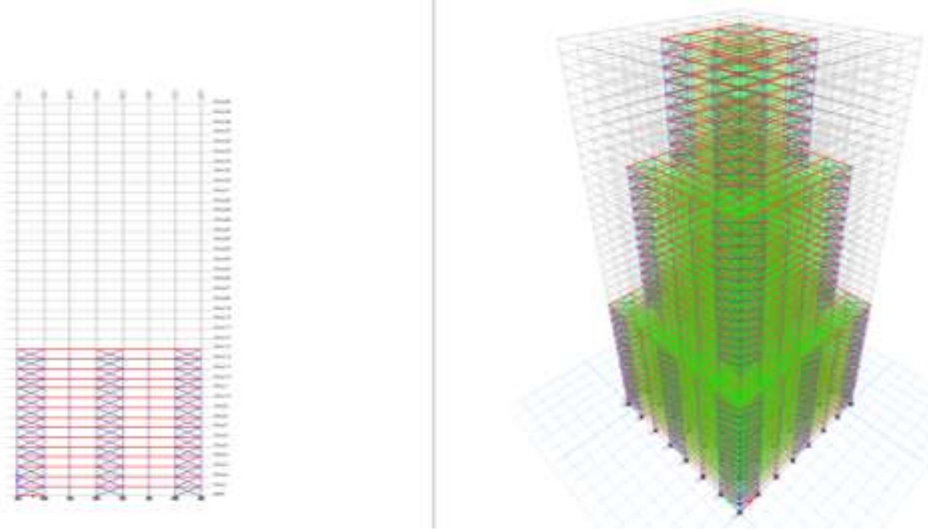


Fig 5. showing Model retrofitted with steel bracings

Model 4: In this model building with 40 floors is retrofitted with friction dampers as shown in figure. The dead loads of other elements are taken as member loads on the respective beams. This model is analyzed in all the four earthquake zones on medium soil. The loads are taken as same in Model 1.

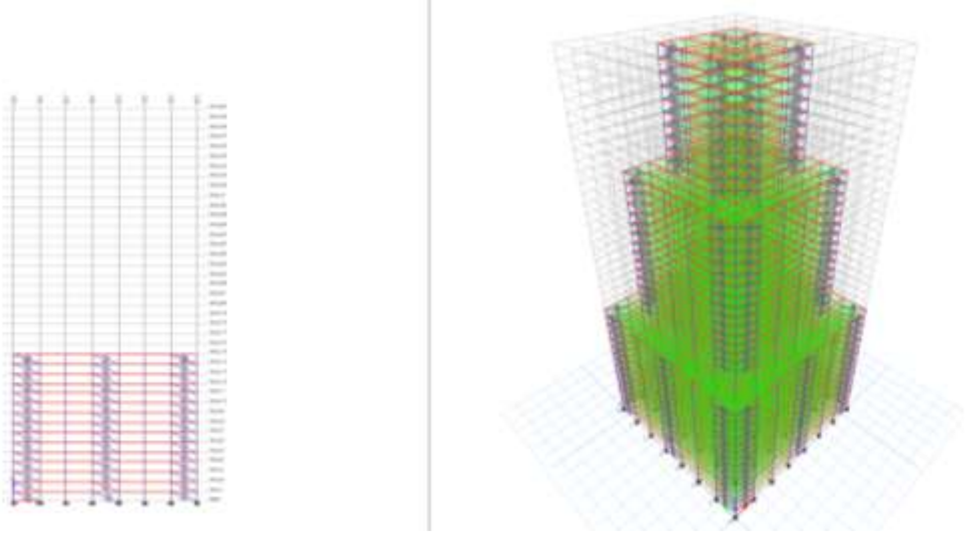


Fig 6. showing Model retrofitted with friction dampers

RESULTS AND DISCUSSIONS

The below nomenclature is used in the tables

1. GB – General Building
2. SW – Shear Wall
3. SB – Steel Bracings
4. FD – Friction Dampers
5. V_X – Shear in X- Direction
6. V_Y – Shear in Y- Direction
7. M_X – Moment in X- Direction
8. M_Y – Moment in Y- Direction
9. T – Torsion
10. P – Lateral Load(Y- Direction)
11. DL – Dead Load
12. LL – Live Load
13. EQX- Earthquake Load in X - Direction
14. kN – kilo Newton
15. m - metre

STORY SHEAR

Storey Shear in X-Direction

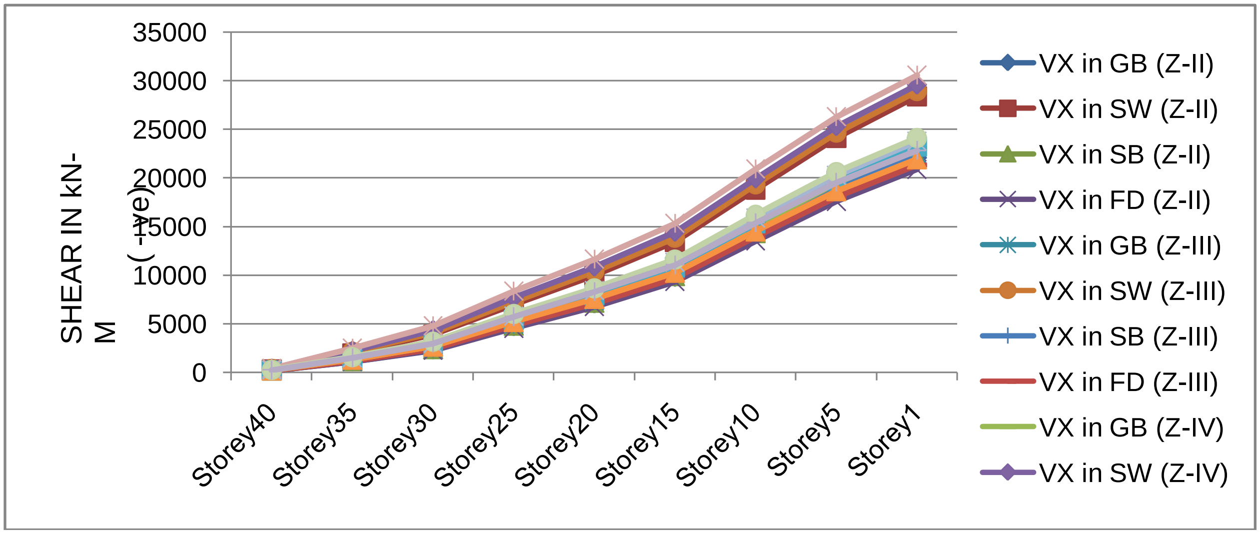
Storey shear in X – Direction for all the zones at storey levels 1, 5, 10, 15, 20, 25, 30, 35 and 40 is presented in table. From the results it is noticed that the shear value of the structure is high when it is retrofitted with shear walls followed by steel bracings and general building. Least shear values are noticed when the structure is retrofitted with friction dampers whose building shear values are less than even the general building. This is because of addition of extra weight in the form of retrofits to the structure. The shear values in all the cases decreased as the floors increased. A negative shear is observed. The maximum values are noticed at storey 1 and they are compared as follows. In zone – II, there is increment of 28.69% in the shear when the building is retrofitted with shear walls and 0.43% when the building is retrofitted with steel bracings. A decrement of 5.44% is observed when the structure is retrofitted with friction dampers. In zone – III there is an increment of 28.66% in the shear when the building is retrofitted with shear walls and 0.67% when the building is retrofitted with steel bracings. A decrement of 5.09% is observed when the structure is retrofitted with friction dampers. In zone – IV there is increment of 28.64% in the shear when the building is retrofitted with shear walls and 0.99% when the building is retrofitted with steel bracings. A decrement of 4.64% is observed when the structure is retrofitted with friction dampers. In zone – V there is increment of 28.60% in the shear when the building is retrofitted with shear walls and 1.44% when the building is retrofitted with steel bracings. An increment of 4.01% is observed when the structure is retrofitted with friction dampers.

Table 1. showing the storey shear values of all the models in the zones – II & III at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

Storey	V_X in GB (Z-II) in kN	V_X in SW (Z-II) in kN	V_X in SB (Z-II) in kN	V_X in FD (Z-II) in kN	Storey	V_X in GB (Z-III) in kN	V_X in SW (Z-III) in kN	V_X in SB (Z-III) in kN	V_X in FD (Z-III) in kN
Storey40	186.32	322.41	189.56	179.84	Storey40	199.11	339.09	204.29	194.57
Storey35	1128.95	1967.20	1153.83	1095.51	Storey35	1212.33	2086.97	1252.13	1193.81
Storey30	2343.66	3870.85	2386.46	2262.26	Storey30	2490.94	4079.09	2559.42	2435.22
Storey25	4739.93	6946.07	4802.95	4543.75	Storey25	4980.37	7266.03	5081.19	4821.99
Storey20	7084.16	9958.87	7160.62	6766.42	Storey20	7386.54	10353.10	7508.87	7114.67
Storey15	9816.12	13416.50	9901.34	9346.22	Storey15	10159.60	13859.60	10296.00	9740.86
Storey10	14226.90	18808.80	14319.20	13499.50	Storey10	14605.10	19292.30	14752.80	13933.10
Storey5	18600.10	24157.30	18694.90	17610.60	Storey5	18990.40	24655.00	19142.10	18057.80
Storey1	22084.90	28420.10	22180.00	20884.00	Storey1	22476.60	28919.40	22628.80	21332.80

Table 2. showing the storey shear values in X – direction of all the models in the zones – IV & V at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

Storey	V_X in GB (Z-IV) in kN	V_X in SW (Z-IV) in kN	V_X in SB (Z-IV) in kN	V_X in FD (Z-IV) in kN	Storey	V_X in GB (Z-V) in kN	V_X in SW (Z-V) in kN	V_X in SB (Z-V) in kN	V_X in FD (Z-V) in kN
Storey40	216.16	361.34	223.93	214.21	Storey40	241.75	394.71	253.40	243.68
Storey35	1323.49	2246.65	1383.19	1324.87	Storey35	1490.24	2486.17	1579.79	1521.47
Storey30	2687.31	4356.73	2790.03	2665.83	Storey30	2981.86	4773.19	3135.94	3011.74
Storey25	5300.96	7692.65	5452.19	5192.99	Storey25	5781.84	8332.57	6008.69	5749.49
Storey20	7789.71	10878.80	7973.20	7579.00	Storey20	8394.47	11667.30	8669.70	8275.50
Storey15	10617.60	14450.40	10822.20	10267.10	Storey15	11304.70	15336.70	11611.50	11056.30
Storey10	15109.30	19937.00	15330.90	14511.20	Storey10	15865.70	20904.00	16198.10	15378.40
Storey5	19510.80	25318.40	19738.30	18654.00	Storey5	20291.40	26313.60	20632.70	19548.40
Storey1	22998.90	29585.10	23227.10	21931.10	Storey1	23782.30	30583.60	24124.70	22828.70



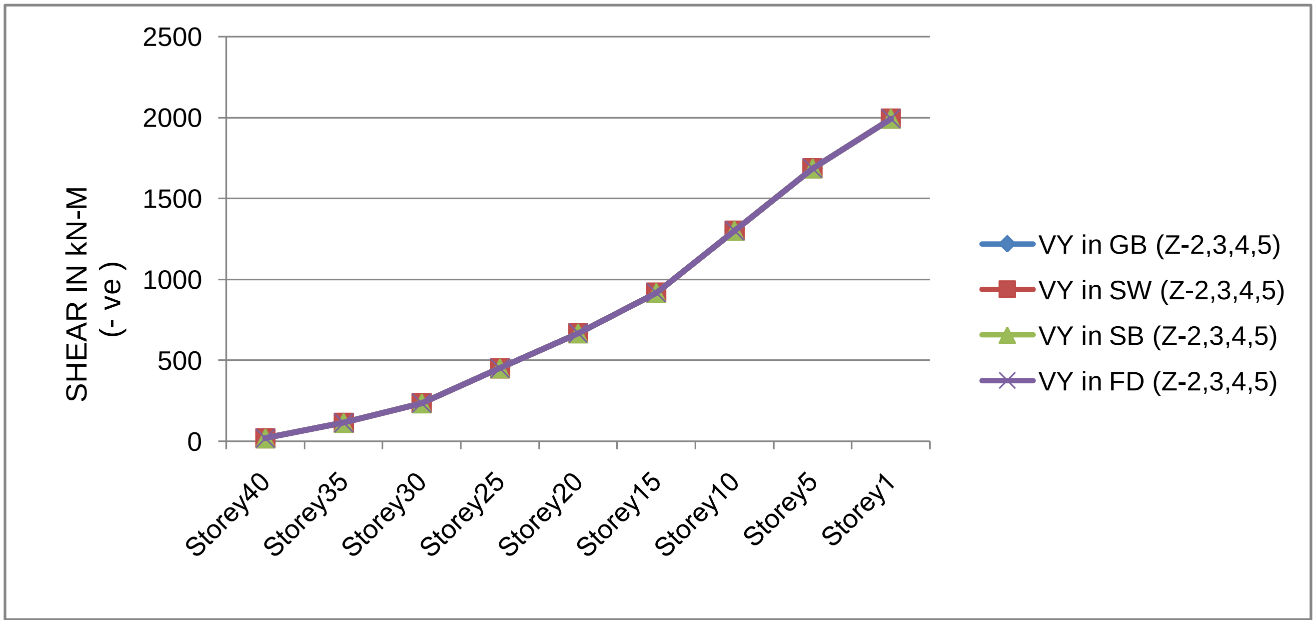
Graph 1. showing the results of the storey shear in X - direction of all the models in all the zones at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

Storey Shear in Y-Direction

Storey shear in Y- Direction in all the zones at storey levels 1, 5, 10, 15, 20, 25, 30, 35 and 40is presented in the table. From the result it is noticed that there is no change in shear in all the models as the load case that is considered 1.2(DL+LL+EQX), doesn't have a Y – variant. A negative shear is observed in all the cases. The above findings are depicted in the graph.

Table 3. showing the storey shear values in Y- direction of all the models in all the zones at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

STOREY	V_Y in GB (Z-2,3,4,5) in kN	V_Y in SW (Z-2,3,4,5) in kN	V_Y in SB (Z-2,3,4,5) in kN	V_Y in FD (Z-2,3,4,5) in kN
Storey40	19.2	19.2	19.2	19.2
Storey35	115.2	115.2	115.2	115.2
Storey30	235.2	235.2	235.2	235.2
Storey25	451.2	451.2	451.2	451.2
Storey20	667.2	667.2	667.2	667.2
Storey15	916.8	916.8	916.8	916.8
Storey10	1300.8	1300.8	1300.8	1300.8
Storey5	1684.8	1684.8	1684.8	1684.8
Storey1	1992.0	1992.0	1992.0	1992.0



Graph 2. showing the results of the storey shear in Y - direction of all the models in all the zones at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

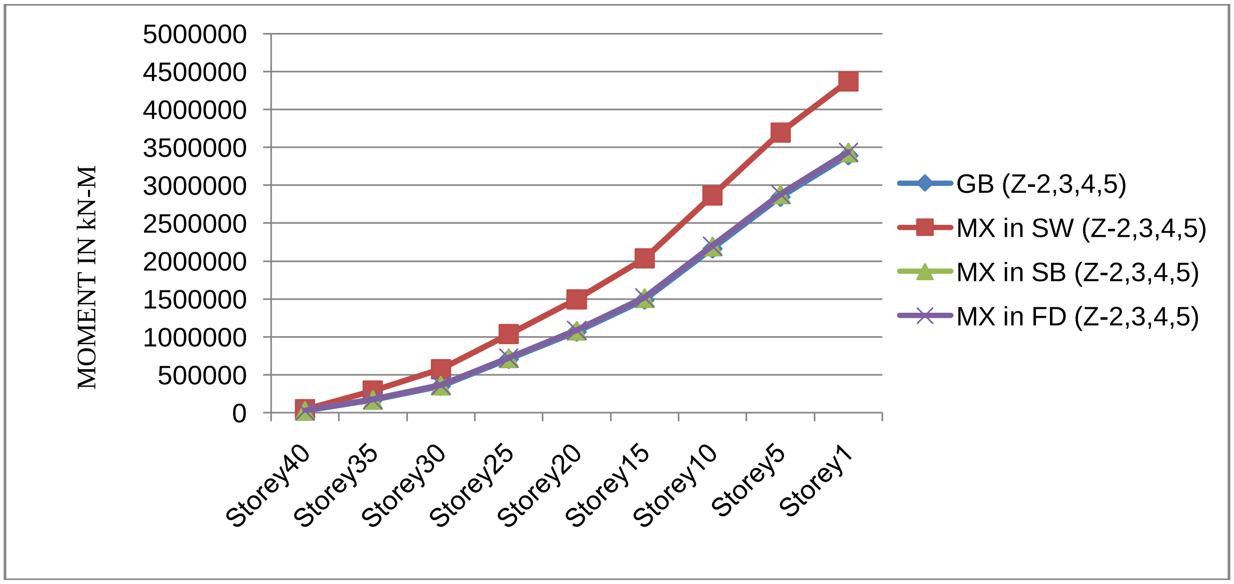
STOREY MOMENT

Storey Moment in X-Direction

Storey Moment in X-Direction in all the zones at level 1, 5, 10, 15, 20, 25, 30, 35 and 40 is presented in the table. From the results it is noticed that the moment value of the structure is high when it is retrofitted with shear walls followed by general building. Equal values are noticed when the structure is retrofitted with friction dampers and steel bracings whose storey moment values are very close to the general building. Same values are observed in the case of both steel bracings and friction dampers. Moments are higher for retrofitted models. This is because of addition of extra weight in the form of retrofits to the structure. For all the four zones same values are obtained owing to the load combination considered, a similar phenomenon to that of shear in Y- Direction. The moment values in all the cases decreased as the floors increased. The above findings are depicted in the graph. Maximum values obtained at the 1st floor in all the cases are compared and the same are depicted in the graph. An increment of 28.78% is observed in the case of shear walls and 1.28% is observed in the case of steel bracings and friction dampers when compared to general building in all the zones.

Table 4. showing the storey moment values in X – direction of all the models in all the zones at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

Storey	**M_X in GB (Z-2,3,4,5) in kN-m**	**M_X in SW (Z-2,3,4,5) in kN-m**	**M_X in SB (Z-2,3,4,5) in kN-m**	**M_X in FD (Z-2,3,4,5) in kN-m**
Storey40	27954.9	48520.4	28901.1	28901.1
Storey35	168594.0	291986.0	174271.0	174271.0
Storey30	352918.0	579138.0	363325.0	363325.0
Storey25	708744.0	1037791.0	723882.0	723882.0
Storey20	1067810.0	1499685.0	1087679.0	1087679.0
Storey15	1491595.0	2036580.0	1516668.0	1516668.0
Storey10	2166051.0	2865277.0	2198220.0	2198220.0
Storey5	2846267.0	3699734.0	2885532.0	2885532.0
Storey1	3394587.0	4371446.0	3438110.0	3438110.0



Graph 3. showing the results of the storey moment in X - direction of all the models in all the zones at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

Storey Moment in Y-Direction

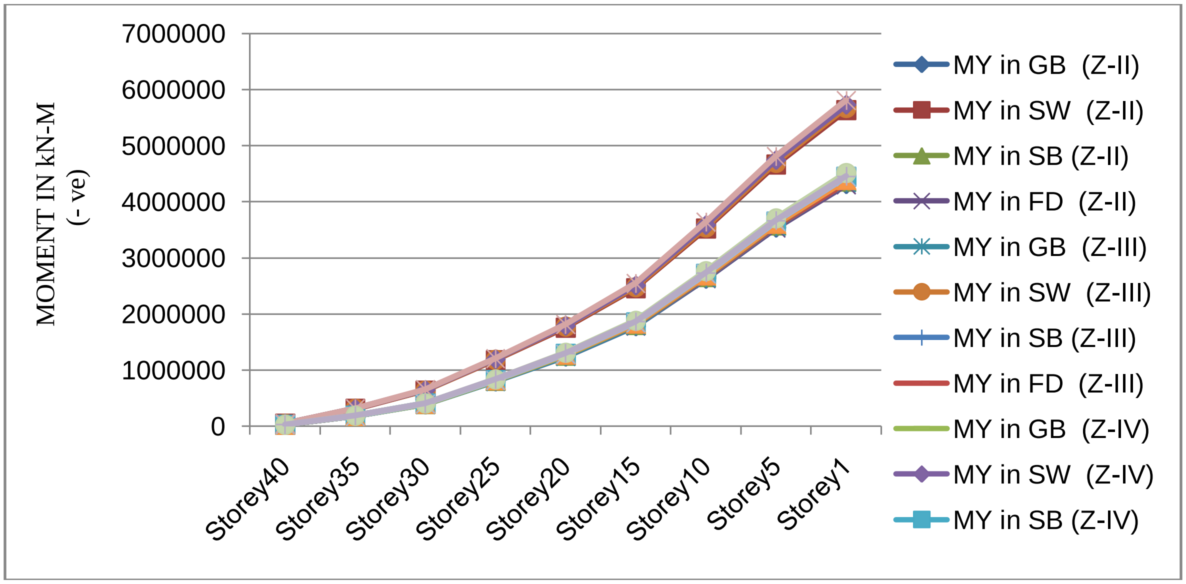
Storey Moment in Y-Direction in all the zones at level 1, 5, 10, 15, 20, 25, 30, 35 and 40 is presented in table. From the results it is noticed that the moment value of the structure is high when it is retrofitted with shear walls followed by steel bracings and general building. The moment values in the case of the friction dampers are the least. A negative moment is obtained. The moment values in all the cases decreased as the floors increased. The above findings are depicted in the graph. Maximum values are obtained at the 1st floor in all the cases. In zone – II there is increment of 30.75% in the shear when the building is retrofitted with shear walls and 1.19% when the building is retrofitted with steel bracings. A decrement of 0.1% is observed when the building is retrofitted with friction dampers. In zone – III there is increment of 30.75% in the shear when the building is retrofitted with shear walls and 1.92% when the building is retrofitted with steel bracings. A decrement of 0.03% is observed when the building is retrofitted with friction dampers. In zone – IV there is increment of 30.75% in the shear when the building is retrofitted with shear walls, 1.29% when the building is retrofitted with steel bracings. A decrement of 0.03% is observed when the building is retrofitted with friction dampers. In zone – V there is increment of 30.74% in the shear when the building is retrofitted with shear walls, 1.61% when the building is retrofitted with steel bracings. A decrement of 0.32% is observed when the building is retrofitted with friction dampers.

Table 5. showing the storey moment values in Y – direction of all the models in the zones – II & III at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

Storey	**M_Y in GB (Z-II) in kN-m**	**M_Y in SW (Z-II) in kN-m**	**M_Y in SB (Z-II) in kN-m**	**M_Y in FD (Z-II) in kN-m**	**Storey**	**M_Y in GB (Z-III) in kN-m**	**M_Y in SW (Z-III) in kN-m**	**M_Y in SB (Z-III) in kN-m**	**M_Y in FD (Z-III) in kN-m**
Storey40	28494.7	49274.0	29450.5	29421.4	Storey40	28533.1	49324.1.0	29494.7	29465.6
Storey35	179490.0	310503.0	185427.0	184814.0	Storey35	180378.0	311764.0	186471.0	185859.0
Storey30	387480.0	639135.0	398677.0	396701.0	Storey30	390147.0	642950.0	401819.0	399842.0
Storey25	795056.0	1177599.0	811817.0	806763.0	Storey25	800812.0	1185592.0	818547.0	813493.0
Storey20	1238095.0	1761613.0	1260661.0	1250503.0	Storey20	1248049.0	1775115.0	1272232.0	1262075.0
Storey15	1778645.0	2463473.0	1807642.0	1790279.0	Storey15	1793507.0	2483333.0	1824857.0	1807494.0
Storey10	2623657.0	3524117.0	2661099.0	2633028.0	Storey10	2644017.0	3551027.0	2684623.0	2656552.0
Storey5	3534468.0	4665223.0	3580418.0	3537669.0	Storey5	3560630.0	4699536.0	3610590.0	3567842.0
Storey1	4310224.0	5635728.0	4361572.0	4304224.0	Storey1	4341084.0	5676029.0	4397127.0	4339779.0

Table 6. showing the storey moment values in Y – direction of all the models in the zones – IV & V at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

Storey	**M_Y in GB (Z-IV) in kN-m**	**M_Y in SW (Z-IV) in kN-m**	**M_Y in SB (Z-IV) in kN-m**	**M_Y in FD (Z-IV) in kN-m**	**Storey**	**M_Y in GB (Z-V) in kN-m**	**M_Y in SW (Z-V) in kN-m**	**M_Y in SB (Z-V) in kN-m**	**M_Y in FD (Z-V) in kN-m**
Storey40	28584.2	49390.8	29553.7	29524.5	Storey40	28661.0	49490.9	29642.1	29612.9
Storey35	181563.0	313446.0	187864.0	187251.0	Storey35	183339.0	315969.0	189952.0	189340.0
Storey30	393703.0	648036.0	406007.0	404031.0	Storey30	399038.0	655666.0	412290.0	410314.0
Storey25	808487.0	1196250.0	827521.0	822466.0	Storey25	819999.0	1212237.0	840981.0	835926.0
Storey20	1261321.0	1793118.0	1287661.0	1277504.0	Storey20	1281228.0	1820121.0	1310805.0	1300648.0
Storey15	1813322.0	2509813.0	1847812.0	1830448.0	Storey15	1843045.0	2549534.0	1882243.0	1864880.0
Storey10	2671165.0	3586907.0	2715989.0	2687917.0	Storey10	2711885.0	3640727.0	2763037.0	2734965.0
Storey5	3595513.0	4745286.0	3650821.0	3608072.0	Storey5	3647837.0	4813912.0	3711166.0	3668417.0
Storey1	4382230.0	5729763.0	4444533.0	4387185.0	Storey1	4443950.0	5810364.0	4515643.0	4458295.0



Graph 4. showing the results of the storey moment in Y - direction of all the models in all the zones at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

TORSION

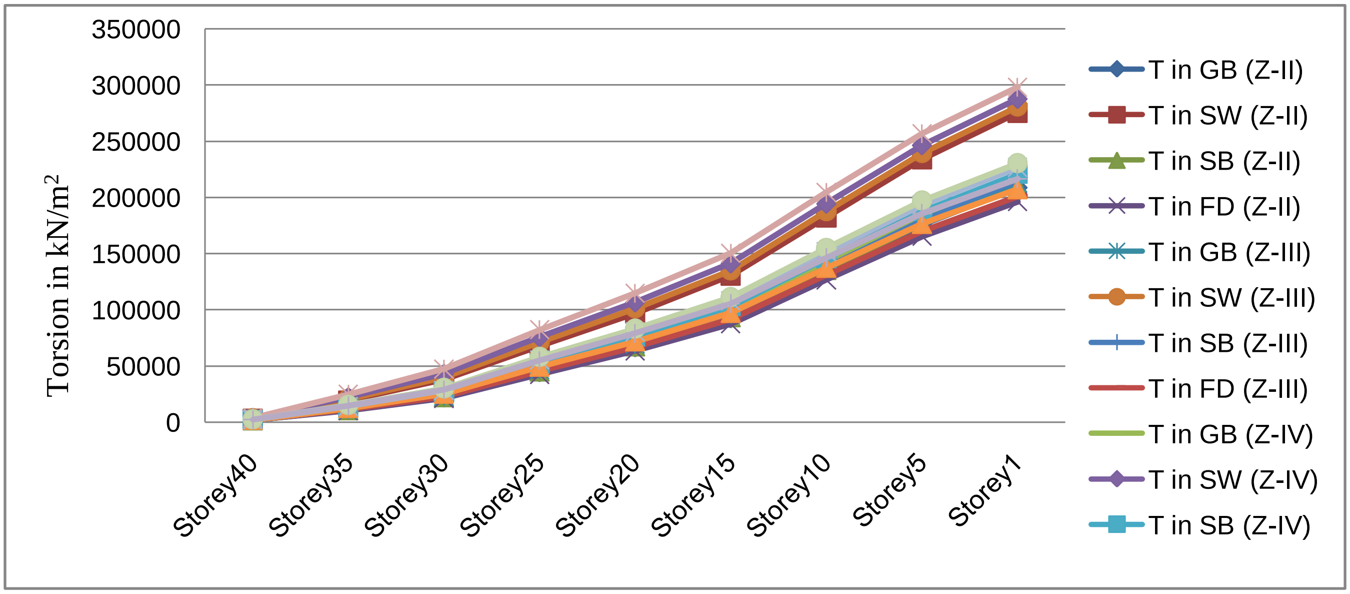
Building torsion values in all the zones are presented in the table at the storey level of 1, 5, 10, 15, 20, 25, 30, 35 and 40. From the results it is noticed that the torsion value of the structure is high when it is retrofitted with shear walls followed by shear walls, steel bracings and general building. Least torsion values are noticed when the structure is retrofitted with friction dampers. The torsion value in the case of shear walls is 155% of the general building. The torsion values in all the cases decreased as the floors increased. The above findings are depicted in the graph. Maximum values obtained at the 1st floor in all the cases are compared. In zone – II an increment of 31.83% is found when the structure is retrofitted with shear walls, 0.48% in the case of steel bracings. A decrement of 6.03% is seen in the case of friction dampers. In zone - III an increment of 31.74% is found when the structure is retrofitted with shear walls, 0.75% in the case of steel bracings. A decrement of 5.64% is seen in the case of friction dampers. In zone – IV an increment of 31.64% is found when the structure is retrofitted with shear walls, 1.09% in the case of steel bracings. A decrement of 5.13% is seen in the case of friction dampers. In zone – V An increment of 31.49% is found when the structure is retrofitted with shear walls, 1.6% in the case of steel bracings. A decrement of 4.41% is seen in the case of friction dampers.

Table 7. showing the torsion values of all the models in the zones – II & III at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

Storey	T in GB (Z-II) in kN/m^2	T in SW (Z-II)) in kN/m^2	T in SB (Z-II)) in kN/m^2	T in FD (Z-II)) in kN/m^2	T in GB (Z-III)) in kN/m^2	T in SW (Z-III)) in kN/m^2	T in SB (Z-III)) in kN/m^2	T in FD (Z-III)) in kN/m^2
Storey40	1735.54	3164.49	1769.53	1667.47	1869.85	3339.68	1924.23	1822.17
Storey35	10529.20	19330.80	10790.40	10178.10	11404.60	20588.40	11822.50	11210.20
Storey30	21903.60	37939.20	22353.10	21049.00	23450.00	40125.60	24169.10	22865.00
Storey25	44580.50	67744.90	45242.10	42520.50	47105.10	71104.50	48163.70	45442.10
Storey20	66710.90	96895.40	67513.70	63374.60	69885.90	101035.00	71170.30	67031.20
Storey15	92526.00	130330.00	93420.80	87592.10	96132.90	134983.00	97564.60	91735.80
Storey10	134423.00	182534.00	135393.00	126786.00	138394.00	187610.00	139945.00	131338.00
Storey5	175926.00	234277.00	176921.00	165536.00	180024.00	239502.00	181617.00	170231.00
Storey1	208983.00	275503.00	209982.00	196374.00	213096.00	280745.00	214694.00	201086.00

Table 8. showing the torsion values of all the models in the zones – IV & V at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

Storey	**T in GB (Z-IV)) in kN/m^2**	**T in SW (Z-IV)) in kN/m^2**	**T in SB (Z-IV)) in kN/m^2**	**T in FD (Z-IV)) in kN/m^2**	**T in GB (Z-V)) in kN/m^2**	**T in SW (Z-V)) in kN/m^2**	**T in SB (Z-V)) in kN/m^2**	**T in FD (Z-V)) in kN/m^2**
Storey40	2048.93	3573.28	2130.49	2028.43	2317.54	3923.66	2439.89	2337.83
Storey35	12571.90	22265.00	13198.70	12586.30	14322.70	24780.00	15263.00	14650.60
Storey30	25511.90	43040.90	26590.50	25286.40	28604.70	47413.70	30222.60	28918.50
Storey25	50471.30	75584.00	52059.20	49337.60	55520.50	82303.20	57902.40	55180.80
Storey20	74119.20	106554.00	76045.80	71906.70	80469.10	114833.00	83359.00	79219.90
Storey15	100942.00	141186.00	103090.00	97260.80	108156.00	150492.00	111377.00	105548.00
Storey10	143689.00	194379.00	146016.00	137409.00	151631.00	204533.00	155121.00	146514.00
Storey5	185488.00	246468.00	187877.00	176492.00	193684.00	256918.00	197268.00	185883.00
Storey1	218580.00	287735.00	220977.00	207369.00	226806.00	298220.00	230401.00	216793.00



Graph 5. showing the results of the torsion of all the models in all the zones at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

STOREY DRIFT

Storey Drift in X- Direction

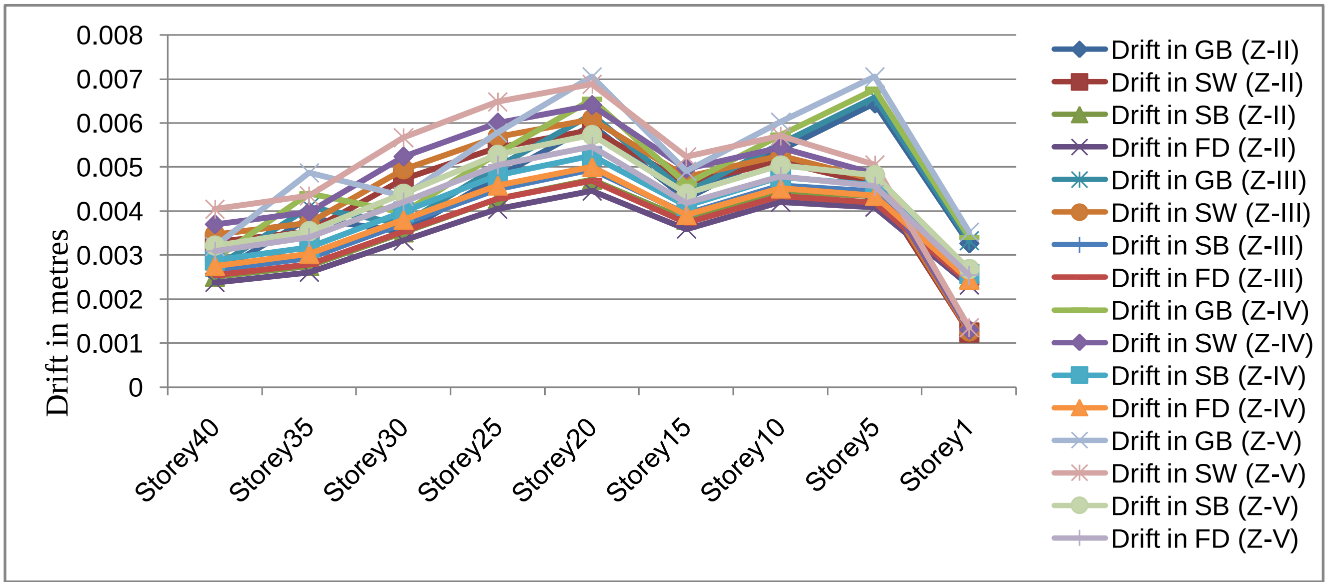
Storey drift in X – Direction in all the Zones is presented in the table. From the results it is noticed that the storey drift value of the structure decreased when the structure is retrofitted with steel bracings and friction dampers for all the floors. But in the case of shear walls is decreased from storey 1 – 11, 16 - 20, 31 – 36. For rest of the floors it increased. Optimum deflection control is observed in the case of friction dampers. The above findings are depicted in the graph. Maximum storey drift values are compared. In zone – II a successive decrement in the drift is observed when the structure is retrofitted with in the order of shear walls, bracings and friction dampers and decrement in the case of shear walls is 36.68% which is less when compared to bracings and dampers which are at 38.36% and 41.90%. In zone – III a successive decrement in the drift is observed when the structure is retrofitted with in the order of shear walls, bracings and friction dampers and decrement in the case of shear walls is 36.61% which is less when compared to bracings and dampers which are at 38.1% and 41.57%. In zone - IV a successive decrement in the drift is observed when the structure is retrofitted with in the order of shear walls, bracings and friction dampers and decrement in the case of shear walls is 36.51% which is less when compared to bracings and dampers which are at 387.78% and 41.16%. in zone – V a successive decrement in the drift is observed when the structure is retrofitted with in the order of shear walls, bracings and friction dampers and decrement in the case of shear walls is 36.54% which is less when compared to bracings and dampers which are at 37.78% and 40.72% .

Table 9. showing the storey drift values in X – direction of all the models in the zones – II & III at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

Storey	**Drift in GB (Z-II) in m**	**Drift in SW (Z-II) in m**	**Drift in SB (Z-II) in m**	**Drift in FD (Z-II) in m**	**Drift in GB (Z-III) in m**	**Drift in SW (Z-III) in m**	**Drift in SB (Z-III) in m**	**Drift in FD (Z-III) in m**
Storey40	0.00257	0.00330	0.00251	0.00237	0.00272	0.00347	0.00267	0.00254
Storey35	0.00385	0.00355	0.00275	0.00260	0.00408	0.00373	0.00293	0.00279
Storey30	0.00352	0.00473	0.00352	0.00333	0.00371	0.00495	0.00372	0.00353
Storey25	0.00478	0.00545	0.00427	0.00404	0.00501	0.00569	0.00450	0.00427
Storey20	0.00595	0.00585	0.00471	0.00446	0.00620	0.00609	0.00495	0.00469
Storey15	0.00428	0.00464	0.00380	0.00359	0.00442	0.00478	0.00394	0.00373
Storey10	0.00539	0.00513	0.00445	0.00420	0.00553	0.00526	0.00459	0.00433
Storey5	0.00645	0.00461	0.00434	0.00409	0.00658	0.00471	0.00445	0.00420
Storey1	0.00326	0.00125	0.00246	0.00232	0.00332	0.00127	0.00251	0.00237

Table 10. showing the storey drift in X – direction of all the models in the zones – IV & V at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

Storey	**Drift in GB (Z-IV) in m**	**Drift in SW (Z-IV) in m**	**Drift in SB (Z-IV) in m**	**Drift in FD (Z-IV) in m**	**Drift in GB (Z-V) in m**	**Drift in SW (Z-V) in m**	**Drift in SB (Z-V) in m**	**Drift in FD (Z-V) in m**
Storey40	0.00291	0.00370	0.00289	0.00276	0.00320	0.00404	0.00322	0.00309
Storey35	0.00440	0.00398	0.00318	0.00303	0.00487	0.00435	0.00354	0.00340
Storey30	0.00396	0.00524	0.00399	0.00380	0.00434	0.00567	0.00439	0.00421
Storey25	0.00531	0.00601	0.00481	0.00458	0.00578	0.00648	0.00528	0.00505
Storey20	0.00654	0.00640	0.00526	0.00500	0.00705	0.00688	0.00573	0.00547
Storey15	0.00461	0.00496	0.00412	0.00391	0.00491	0.00524	0.00440	0.00418
Storey10	0.00572	0.00544	0.00477	0.00452	0.00601	0.00571	0.00504	0.00479
Storey5	0.00677	0.00485	0.00459	0.00435	0.00704	0.00505	0.00482	0.00457
Storey 1	0.00340	0.00130	0.00258	0.00244	0.00352	0.00135	0.00268	0.00254



Graph 6. showing the results of the storey drift in X - direction of all the models in all the zones at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

Storey Drift in Y-Direction

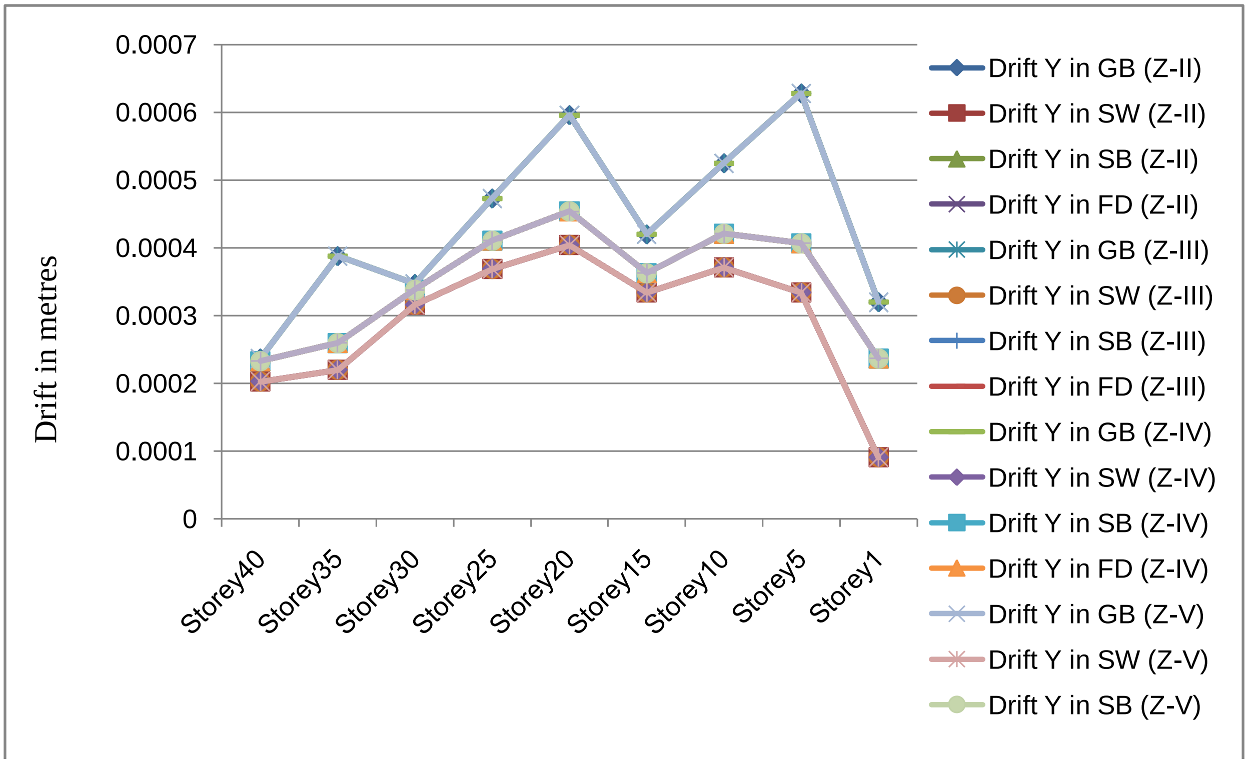
Storey drift in Y – Direction in all the zones is presented in the table. From the results it is noticed that the storey drift value of the structure decreased when the structure is retrofitted with steel bracings and friction dampers and shear walls for all the floors. Optimum deflection control is observed in the case of shear walls. Same values are noticed in the case of steel bracings and friction dampers and the values of all the cases are same in all the zones as that of moment in X - Direction. The above findings are depicted in the graph. Maximum storey drift values are compared. The values are same in all the zones. The decrement in the case of shear walls is 52.89% which is high when compared to bracings and dampers which are equal at 40.72% each and the drift in Y-direction is very much controlled in the case of shear walls but both bracings and dampers are yielding same results.

Table 11. showing the storey drift values in Y – direction of all the models in the zones – II & III at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

Storey	**Drift Y in GB (Z-II) in m**	**Drift Y in SW (Z-II) in m**	**Drift Y in SB (Z-II) in m**	**Drift Y in FD (Z-II) in m**	**Drift Y in GB (Z-III) in m**	**Drift Y in SW (Z-III) in m**	**Drift Y in SB (Z-III) in m**	**Drift Y in FD (Z-III) in m**
Storey40	0.00024	0.00020	0.00023	0.00023	0.00024	0.00020	0.00023	0.00023
Storey35	0.00039	0.00022	0.00026	0.00026	0.00039	0.00022	0.00026	0.00026
Storey30	0.00035	0.00032	0.00034	0.00034	0.00035	0.00032	0.00034	0.00034
Storey25	0.00047	0.00037	0.00041	0.00041	0.00047	0.00037	0.00041	0.00041
Storey20	0.00060	0.00040	0.00045	0.00045	0.00060	0.00040	0.00045	0.00045
Storey15	0.00042	0.00033	0.00036	0.00036	0.00042	0.00033	0.00036	0.00036
Storey10	0.00053	0.00037	0.00042	0.00042	0.00053	0.00037	0.00042	0.00042
Storey5	0.00063	0.00033	0.00041	0.00041	0.00063	0.00033	0.00041	0.00041
Storey1	0.00032	0.00009	0.00024	0.00024	0.00032	0.00009	0.00024	0.00024

Table 12. showing the storey drift values in Y – direction of all the models in the zones – IV & V at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

Storey	**Drift Y in GB (Z-IV) in m**	**Drift Y in SW (Z-IV) in m**	**Drift Y in SB (Z-IV) in m**	**Drift Y in FD (Z-IV) in m**	**Drift Y in GB (Z-V) in m**	**Drift Y in SW (Z-V) in m**	**Drift Y in SB (Z-V) in m**	**Drift Y in FD (Z-V) in m**
Storey40	0.00024	0.0002	0.00023	0.00023	0.00024	0.0002	0.00023	0.00023
Storey35	0.00039	0.00022	0.00026	0.00026	0.00039	0.00022	0.00026	0.00026
Storey30	0.00035	0.00032	0.00034	0.00034	0.00035	0.00032	0.00034	0.00034
Storey25	0.00047	0.00037	0.00041	0.00041	0.00047	0.00037	0.00041	0.00041
Storey20	0.00060	0.00040	0.00045	0.00045	0.00060	0.00040	0.00045	0.00045
Storey15	0.00042	0.00033	0.00036	0.00036	0.00042	0.00033	0.00036	0.00036
Storey10	0.00053	0.00037	0.00042	0.00042	0.00053	0.00037	0.00042	0.00042
Storey5	0.00063	0.00033	0.00041	0.00041	0.00063	0.00033	0.00041	0.00041
Storey1	0.00032	0.00009	0.00024	0.00024	0.00032	0.00009	0.00024	0.00024



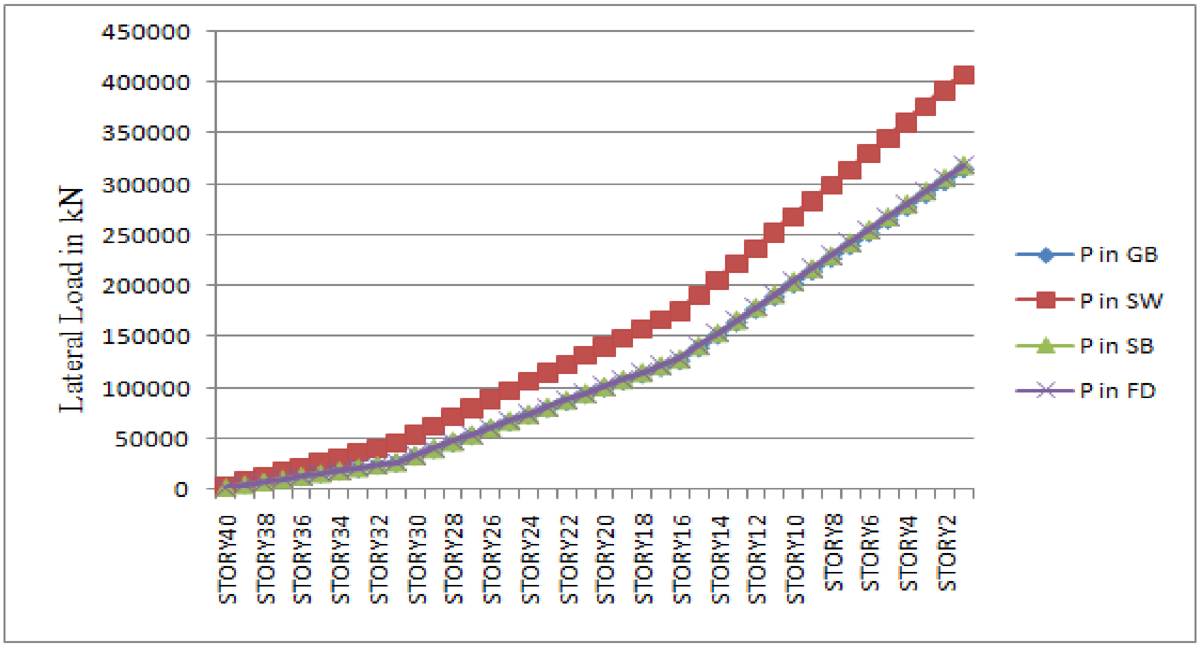
Graph 7. showing the results of the storey drift in Y - direction of all the models in all the zones at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

LATERAL LOAD

Load acting in the gravity direction is called lateral load. It increases with the increase in the floors. Lateral load values in all the zones at storey level 1, 5, 10, 15, 20, 25, 30, 35 and 40 are presented in the table and are same in all the zones. From the results it is noticed that the lateral load on the structure decreased with the height of the structure. It is maximum in the case of shear walls and minimum in the case of general building but same for steel bracings and friction dampers. Same values are noticed in all the zones as the loads acting on the structure didn't change throughout the work. The above findings are depicted in the graph. Maximum lateral load values are noticed in storey 1 in all the cases and are same in steel bracings and friction dampers. An increment of 29.57% is observed in the case of shear walls and 1.32% in the case of both steel bracings and fixed dampers when compared to the general building. This is because of addition of the weight of the retrofits to the structure.

Table 13. showing the storey shear values of all the models in all the zones at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

Storey	P in GB (Z-2,3,4,5) (kN)	P in SW (Z-2,3,4,5) (kN)	P in SB (Z-2,3,4,5) (kN)	P in FD (Z-2,3,4,5) (kN)
Storey40	2658.72	4617.33	2748.83	2748.83
Storey35	15952.30	27704.00	16493.00	16493.00
Storey30	33264.70	54809.50	34255.90	34255.90
Storey25	66652.30	97990.20	68094.10	68094.10
Storey20	100040.00	141171.00	101932.00	101932.00
Storey15	139276.00	191180.00	141664.00	141664.00
Storey10	201908.00	268501.00	204972.00	204972.00
Storey5	264540.00	345822.00	268279.00	268279.00
Storey1	314645.00	407679.00	318790.00	318790.00



Graph 8. showing the results of the lateral load of all the models in all the zones at storey level 1, 5, 10, 15, 20, 25, 30, 35, 40.

CONCLUSIONS

The present work is concentrated on the failure control of a 40 storied skyscraper by retrofitting it with shear walls, steel bracers and friction dampers. The models are analyzed on medium soil at zones II, III, IV & V. Storey shear, moment, torsion, storey drift and lateral load were studied. From the results obtained the conclusions have been made as follows

1. Amongst all the three retrofits used, friction dampers are yielding the best results and hence it can be concluded that friction dampers are the best retrofits.
2. Optimum control of drift in X-direction is observed when the structure is retrofitted with friction dampers followed by steel bracings and shear walls.
3. Regarding the drift in Y-direction, optimum control is achieved in the case of shear walls and both steel bracings and shear walls are yielding same results.
4. The decrements observed when the structure is retrofitted with shear walls and steel bracings are closely following each other when compared to friction dampers in the case of drift in X-direction.
5. Best control of drift is observed in the case of all models in Y-direction when the structure is retrofitted with friction dampers.
6. Except drift there is an increment in all parameters particularly in the case of shear walls because of the addition of loads of the retrofits to the structural members.
7. When the structure is retrofitted with friction dampers a decrement is observed in all parameters in almost every zone.
8. The storey drift in any storey due to the minimum specified design lateral force, with partial load factor of 1.0 shall not exceed 0.004 times the storey height. The maximum storey drift in the research is 0.0073 m found in storey 18 of the general building which is less than 0.012 (0.004*3) m which is within the permissible limits as per IS 1893(Part 1) : 2002.
9. In all the four zones, shear in y-direction is same in each of the zone for all the four models because the load case that is considered is 1.2(DL+LL+EQX). Hence the shear is same for all the models.
10. In all the four zones, moment in x-direction is same in all the zones but different for each of the model because the load case that is considered is 1.2(DL+LL+EQX). As the shear in Y- direction is same so the moment is same in the opposite direction but differs for each model.
11. Lateral load is the load acting in the gravity direction. In the present analysis we have analyzed the models in various zones but the loads considered on the models are same for all the models in all the zones. Hence the lateral load is same in all the four zones but differ from model to model as that of moment in X-direction because of variation in the weights of retrofits.
12. An approximate increase of 28.6% in the shear in X – Direction is observed when the structure is retrofitted with shear walls.

13. An approximate increase of 30.75% in moment in Y – Direction is observed in all the zones when the structure is retrofitted with shear walls.
14. The increment in torsion in all the zones is negligible when the steel bracers are used as retrofits.
15. A decrement in torsion is observed when the building is retrofitted with friction dampers in all the zones
16. Decrement in moment in Y- Direction when the building is retrofitted with friction dampers is negligible.

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