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Improving Behaviour of Reinforced Concrete Frame to Resist Lateral Stresses Using Dissipative Exoskeleton

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***Abstract*— The use of exoskeletal frames is an innovative approach to enhancing the seismic response of multi-story buildings. This approach involves adding a secondary structure around the existing building to provide additional lateral support and increase the building's resistance to seismic forces. The exoskeleton is typically made of steel or reinforced concrete and is designed to absorb and distribute the lateral forces generated by an earthquake, reducing the stress on the existing structure.**

The experiment aims to evaluate the effectiveness of this approach by comparing the performance of buildings with and without an exoskeletal frame. The study considers three different plan irregularity models with three different heights for each plan, totalling nine different models. The analysis of these models is done using CSI ETABS software, which allows for the evaluation of various parameters such as Base Shear, Storey Shear, Storey Displacement, Storey Drift, Overturning Moments, and Storey Stiffness.

The results of the experiment will provide valuable insights into the performance of exoskeletal frames in enhancing the seismic response of multi-story buildings. This information will be useful for architects, engineers, and construction professionals who are involved in the design and construction of buildings in seismic zones. The experiment is expected to contribute to the development of more effective and efficient methods for enhancing the seismic response of multi-story buildings, ultimately leading to safer and more resilient structures. One of the common characteristics for the amenity in contemporary multi-story building construction in metropolitan India is the soft storey. The construction of new columns and shear walls for the lateral loads is no longer an option for existing structures, whose capacity has been lowered and which are liable to collapse due to earthquakes since they have soft level floors. The complexity of the analysis and design of the structure can be greatly reduced with the use of contemporary technology and the use of software analysis in civil engineering. In this research, an analysis of the seismic response of the structure to static and dynamic earthquake loading has been conducted.

Keywords: Exoskeletal, Multi-Storey, RC Frame, Exoskeletal, Static and Dynamic Analysis, Seismic Loading, Multi-Storey, RC Frame, Exoskeletal

I. INTRODUCTION

In civil (structural) engineering, building structures with robust stability and durability using sustainable materials is challenging, to meet this requirement many of the researchers has introduced human civilization with different types of materials for sustainable development. During this process there were some materials which were available in abundant but not satisfying expected structural needs and some were good with the structural property but not economical. After so many experiments it was found that it is safe as well as economical to use composite material to build a structure. As we know the basic elements of RC framed buildings are Slabs, Beams, Columns or shear walls and foundations. These elements are primarily responsible to transfer load by interacting with each other. These elements are very efficient in transferring vertical loads and lateral loads. The main challenge is faced when this structure is faced with higher lateral forces such as wind force, blast force and mainly earthquake force. Recently earthquake have shown that existing old RC buildings which do not meet modern design terminologies are very vulnerable towards these lateral forces. The same failure is experienced in modern multi- story construction, with soft story floor these soft story floors are inherently vulnerable to collapse due to earthquake, functional and social needs such as parking space and offices spaces. To strengthening and adding members with more stiffness one can use an exoskeletal structure with steel frame.

Exoskeleton structures are a type of building design that has gained popularity in recent years due to their ability to provide additional support and enhance the structural integrity of buildings. This design involves adding a secondary structure, made of steel or reinforced concrete, to the exterior of a building to provide extra support against lateral forces. This approach is particularly useful in areas that are prone to earthquakes or high winds, as the exoskeleton is designed to absorb and distribute the forces generated by these natural events.

The use of exoskeleton structures has numerous benefits. For one, it can help reduce the complexity of the design process for buildings, as the exoskeleton provides additional support without requiring the construction of new columns or shear walls. This simplifies the design and construction process, resulting in cost savings and faster construction times. Exoskeleton structures also provide greater flexibility in architectural design, as the external structure can be designed in a variety of shapes and sizes to complement the building's aesthetics. This can result in more visually striking buildings that are also functional and resilient.

Overall, the use of exoskeleton structures represents a promising approach to enhancing the seismic response of buildings. By providing additional support against lateral forces, these structures can help reduce the risk of collapse during earthquakes and other natural disasters. As such, they are increasingly being used in modern building designs and are expected to continue to grow in popularity in the years to come.

II. PROBLEM STATEMENT

The problem that exoskeletal structures aim to address is the vulnerability of multi-story buildings to lateral forces, such as those generated by earthquakes or high winds. Traditional building designs often rely on new columns and shear walls to provide lateral support, but this approach can be expensive and may not be feasible for existing structures.

In contrast, exoskeletal structures offer a more flexible and cost-effective solution to this problem. By adding a secondary structure to the exterior of a building, these designs can enhance the building's resistance to lateral forces without requiring significant modifications to the existing structure. This approach is particularly useful in seismic zones where the risk of earthquakes is high and building codes require buildings to meet specific safety standards.

However, there are still questions about the effectiveness of exoskeletal structures in enhancing the seismic response of buildings. Factors such as the design of the exoskeleton, the materials used, and the size and shape of the building can all affect the effectiveness of this approach. As such, further research is needed to evaluate the performance of exoskeletal structures in different settings and to identify best practices for their design and construction.

Overall, the problem statement for exoskeletal structures is how to enhance the seismic response of multi-story buildings in a cost-effective and flexible way, while also meeting safety standards and ensuring structural integrity. Exoskeletal structures represent a promising solution to this problem, but more research is needed to fully understand their potential and limitations.

The studies done so far for exoskeletal frame also widely known as bracing are majority on small RCC structures or on industrial steel structures. The results are compared based on the values for the Base Shear, Storey Shear, Storey Displacement, Storey Drift, Overturning Moments, and Storey Stiffness. In the present work, the analysis is carried on the multi storey frames such as (G+20), (G+25) and (G+30) with three plan irregularities. The analysis was carried using CAD with the help of CSI ETABS. For all the models Response Spectrum analysis is performed and effectiveness of the exoskeletal frame is compared with without exoskeletal frame.

III. AIMS AND OBJECTIVES

The aim and objective of this project was to improve the behavior of the lateral resistance of the structure when the exoskeletal frame is retrofitted and to check the effectiveness of the same when used with plan irregularity of same plan area.

To achieve above objective, following sub objectives are to be achieved.

- To create and analyses a (G+20), (G+25), (G+30) story framed structure for dead load, live load and for the lateral loads. In CSI ETABS.
- To carry response spectrum analysis on the software model of bare frame structure under load combinations as given by I.S. Codes.
- To check how the model performs with different plan irregularities.
- To introduce exoskeleton for the same structures and perform the analysis under the load combinations as given by I.S. Codes.
- To check how the exoskeletal frame model performs with plan irregularities.
- To compare each model under the given parameters such as: Base Shear, Storey Shear, Storey Displacement, Storey Drift, Overturning Moments, and Storey Stiffness were compared.

To check the effectiveness of the exoskeletal frames with the bare frame models.

III. PROBLEM STATEMENT

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IV. METHODOLOGY

Model of (G+20), (G+25) and (G+30) storey frame structure frame is modeled with three plan irregularities of the same area. The plan irregularities were of Square shaped, rectangular shaped and L-Shaped model. With the help of exoskeletal frame, behavior of the model under lateral forces are checked. The parameters for the check of the model were as follows: Base Shear, Storey Shear, Storey Displacement, Storey Drift, Overturning Moments, and Storey Stiffness.

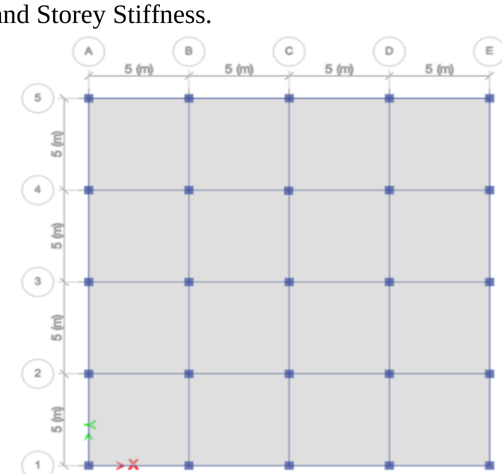

Fig-1 Plan of Square Shaped model

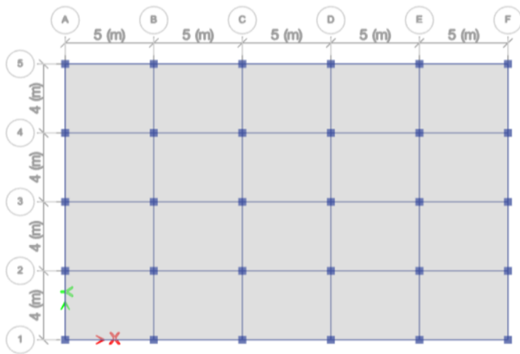

Fig-2 Plan of Square Shaped model

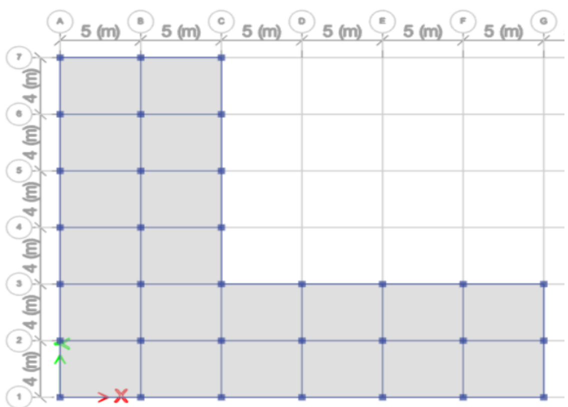

Fig-3 Plan of L-Shaped model

A. *Model Dimension and properties*

- Type of the Structure - Multi-storey RC frame structure.
- Number of Stories - G+20, G+25, G+30
- Floor to Floor Height - 3000m.
- Overall Height - 60m, 75m, 90m.
- Design Loads: -
  a) Weight of RCC 25 kN/ m^3.
  b) Structural Steel 78.5 kN/ m^3.
  c) Dead Load (DL) = 1.5kN/ m^2
  d) Live Load (LL)= 2kN/ m^2

B. Analysis Procedure in Software.

a) Step-1 Define the Code (i.e. IS 1893:2016) and geometry of structure.

- The grids of the structure are created
- Numbers of Stories are formed.
- Beams, columns and Slabs are made.

b) Step-2 Define Materials of Members

- Steel
- Concrete
- Rebar

c) Step-3 Define section of Members

- Beams and Columns
- Exoskeletal frames
- Slabs

d) Defining Loads

- Dead load and Live load
- Earthquake load
- Wind load

e) Load Combination

f) Assigning supports

- Hinge
- Fixed

g) Run Analysis

The software is used throughout the course of research for the analysis of the building models. The building structure is directly modeled in the software itself. Then the buildings are subjected to dead and live load as per Indian Standards and then the analysis of the structure is done.

Results are obtained in terms of storey displacement, storey drifts, storey shear, storey stiffness and base shear. Finally, comparison of the results is done.

IV. RESULTS AND DISCUSSION

CSI ETABS was used to carry out Modal analysis to find out the modal frequencies of the structure. For this, a modal load case was defined, and Eigen vector modes were used. The load type was set as Acceleration and load name was set as UX since vibrations along the X direction (along the longer span) were to be tested.

The maximum number of modes was set to 12 because along the X direction, the structure will have 3 translational mode shapes which usually appear within first 12 modes of the structure.

In response of the structure we see following points of the structure such as:

a) Base Shear
b) Storey Shear
c) Storey Displacement
d) Storey Drift
e) Overturning Moments
f) Storey Stiffness.

Data of the above points are given in tabulated form for all the plans with different storey heights:

A. *Data of Structure without Exoskeletal Frame*

1) Structure with maximum of 20 floors:

30 Storey Structure	Squared Shaped plan	Rectang-ular shaped plan	L-Shaped plan
Base Shear (EQX)	1218	1802	1890.4
(EQY)	1218	1442.1	1682.4
Storey Shear (EQX)	0	0	0
(EQY)	0	0	0
Storey displacement (EQX)	115.8	154.95	194.9
(EQY)	112.6	142.22	199.79
Storey Drift (EQX)	0.001904	0.002182	0.002526
(EQY)	0.001861	0.001923	0.002531
Overturning moment (EQX)	113.56	1.906	138.32
(EQY)	83092	106108	128288

Table no-1: Response of 20 storey Structure

2) Structure with maximum of 25 floors:

25 Storey Structure	Squared Shaped plan	Rectan-gular shaped plan	L-Shaped plan
Base Shear (EQX)	1446	1823.7	1881.84
(EQY)	1446	1458.97	1684.44
Storey Shear (EQX)	0	0	0
(EQY)	0	0	0
Storey displacement (EQX)	127.56	130.7	147.84
(EQY)	124	120	146.21
Storey Drift (EQX)	0.002171	0.002134	0.00222
(EQY)	0.002122	0.00188	0.0022
Overturning moment (EQX)	93.46	2.05	57.71
(EQY)	94865	92621	106186

Table no-2: Response of 25 storey Structure.

3) Structure with maximum of 30 floors.

20 Storey Structure	Squared Shaped plan	Rectan-gular shaped plan	L-Shaped plan
Base Shear (EQX)	1401.4	1450	1878.22
(EQY)	1401.4	1812.8	1680.17
Storey Shear (EQX)	0	0	0
(EQY)	0	0	0
Storey displacement (EQX)	85.68	78.98	108.93
(EQY)	83.5	107.7	103
Storey Drift (EQX)	0.001825	0.001629	0.002158
(EQY)	0.001772	0.002143	0.001964
Overturning moment (EQX)	50.97	0.884	20.68
(EQY)	69478.4	91450.83	84612.96

Table no-3: Response of 30 storey Structure.

B. *Data of Structure with Exoskeletal Frame.*

1) Structure with maximum of 20 floors

20 Storey Structure	Squared Shaped plan	Rectang-ular shaped plan	L-Shaped plan
Base Shear (EQX)	1721.11	1681.57	1929
(EQY)	1721.11	2101.96	1736.68
Storey Shear (EQX)	0	0	0
(EQY)	0	0	0
Storey displacement (EQX)	12.48	9.07	38.44
(EQY)	12.44	21.34	46.11
Storey Drift (EQX)	0.000332	0.000235	0.000766
(EQY)	0.00031	0.000415	0.000925
Overturning moment (EQX)	21.9	1.1	11.855
(EQY)	83203	1.1167	84710

Table no-4: Response of 20 storey Structure.

2) Structure with maximum of 25 floors.

25 Storey Structure	Squared Shaped plan	Rectan-gular shaped plan	L-Shaped plan
Base Shear (EQX)	1702	1866.113	1933
(EQY)	1702	1492.8	1730
Storey Shear (EQX)	0	0	0
(EQY)	0	0	0
Storey displacement (EQX)	20.74	27.47	53.17
(EQY)	20.70	39.47	63.65
Storey Drift (EQX)	0.000427	0.00046	0.000843
(EQY)	0.000426	0.000606	0.001013
Overturning moment (EQX)	39.35	3.64	57.1
(EQY)	102142	90563	104708

Table no-5: Response of 25 storey Structure.

3) Structure with maximum of 30 floors.

30 Storey Structure	Squared Shaped plan	Rectan-gular shaped plan	L-Shaped plan
Base Shear QX)	1436	2161.32	1941
(EQY)	1436	1729	1736.24
Storey Shear QX)	0	0	0
(EQY)	0	0	0
Storey splacement QX)	21	28.832	71.187
(EQY)	21	47.74	85.65
Storey Drift QX)	0.000363	0.000463	0.000934
(EQY)	0.000362	0.000655	0.000934
Overturning oment (EQX)	46.34	9.02	183.819
(EQY)	87151.73	123460	125822

Table no-6: Response of 30 storey Structure.

C. *Discussion.*

As comparing the results, it can be said that exoskeletal frame also widely known as bracing is helpful in overall behavior of the structure. We can see that using exoskeletal frame decreases the time period of the structure which indirectly helps in increasing the base shears. It is also noted that using the exoskeletal frame we can see some changes in mode shapes which helps to understand behavior of the structure.

Response of the structure is seen to be improved when compared with the exoskeletal frame it is seen that there is increase in base shear, displacement, drift, overturning and stiffness of the structure. When compared with and without exoskeletal frame.

Here are graphical comparison for base shear and Storey displacement.

CSI ETABS was used to carry out Modal analysis to find out the modal frequencies of the structure. For this, a modal load case was defined, and Eigen vector modes were used. The load type was set as Acceleration and load name was set as UX since vibrations along the X direction (along the longer span) were to be tested.

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Here are graphical comparison for base shear and Storey displacement.

Where,

W.E. denotes structure with exoskeletal frame and

W.O.E. denotes structure without exoskeletal frame.

1) Base Shears:

a) Storey with maximum of 20 floors:

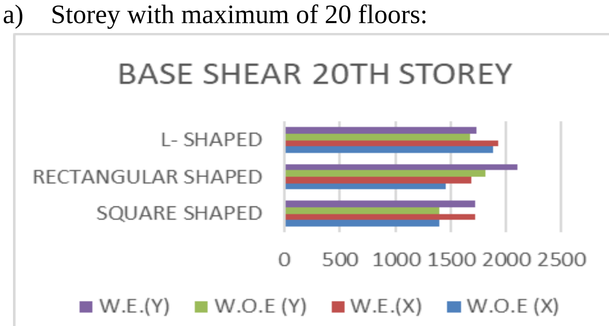

Fig-4 Base Shear of 20 Storey Structure.

b) Storey with maximum of 25 floors:

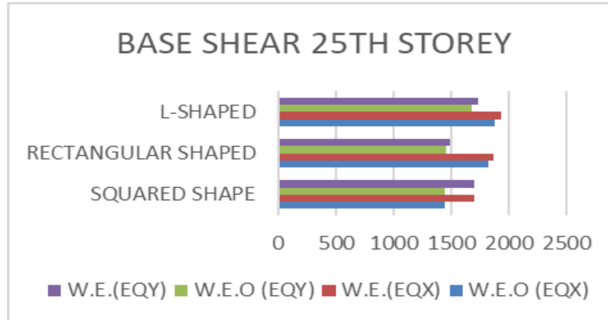

Fig-5 Base Shear of 25 Storey Structure.

c) Storey with maximum of 30 floors:

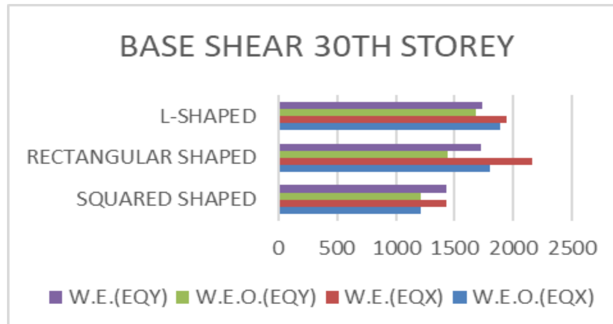

Fig-6 Base Shear of 30 Storey Structure.

2) Storey Displacement:

a) Storey with maximum of 20 floors:

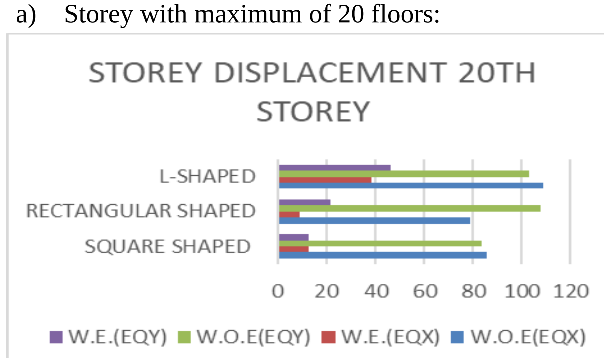

Fig-7 Storey Displacement of 20 Storey Structure.

b) Storey with maximum of 25 floors:

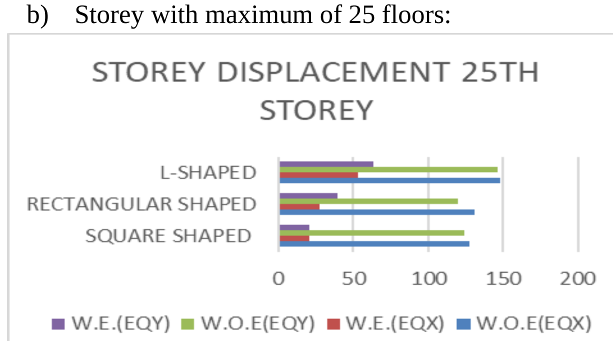

Fig-8 Storey Displacement of 25 Storey Structure.

c) Storey with maximum of 30 floors:

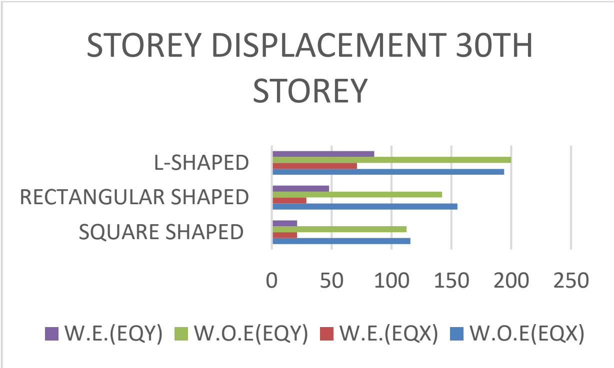

Fig-9 Storey Displacement of 30 Storey Structure.

As we can see the base shear, deflection, drift and stiffness of the building is increased we can say that exoskeletal frame can be used for retrofitting of the structure without harming the structure and it can be done very economically. As we know now India is in zone 2 in future if the earthquake force increases we can use the same approach to sustain the existing structure. Exoskeleton frame can also be used for optimizing the over all sizes of the building as well, as per graphical presentation the displacement can be reduced with exoskeletal approach.

V. CONCLUSION.

Exoskeleton structures have become an increasingly popular solution for improving the seismic performance of buildings in regions prone to earthquakes. The use of an exoskeleton frame can enhance the response of the structure and reduce the complexity of the analysis and design process. By accurately modeling the behavior of the structure and exoskeleton under static and dynamic earthquake loading, engineers can optimize the design of the exoskeleton to improve the overall performance of the building. As such, exoskeleton structures and their analysis through software analysis are likely to continue to play an important role in the design and construction of buildings in earthquake-prone regions.

It can be stated that using exoskeleton we can conclude the following points:

- It can be stated that Storey displacement is can be reduced using exoskeletal bracing.
- Base Shear is enhanced when compared with bare frame structure.
- Storey drift can be controlled using the exoskeletal frames.
- Overturning moments of the structure can be increased using exoskeletal frames.
- The lateral displacement of the structure is reduced by 55% to 80%

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