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SEISMIC PERFORMANCE ANALYSIS OF OPEN GROUND STOREY STRUCTURES: INFLUENCE OF BUILDING HEIGHT AND LATERAL LOAD RESISTING SYSTEMS

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Keywords	*Abstract*
Open Ground Storey, Soft Storey, Lateral Load Resisting Systems, Shear Walls, Seismic Performance, Reinforced	Open Ground Storey (OGS) structures are inherently vulnerable to seismic failure due to their soft storey behavior, which significantly reduces lateral stiffness and increases the risk of collapse during earthquakes. To address this critical issue, the implementation of additional Lateral Load Resisting Systems (LLRS) is essential for enhancing the seismic resilience of these buildings. This study focuses on the behavior of three-dimensional (3-D) OGS infilled reinforced concrete (R.C.) frames subjected to seismic loads. Specifically, it investigates two types of LLRS: the provision of stiff columns at the

Concrete Frames, SAP 2000.	ground floor and the installation of shear walls in various locations and configurations. The performance of these enhanced OGS structures is compared with conventional OGS configurations and bare frames, both with and without considering the effects of infilled frames. A comprehensive literature survey revealed several gaps, including the limited analytical investigations on the feasibility of shear walls as LLRS for OGS structures under lateral (earthquake) loads, the predominance of two-dimensional (2D) single bay models in existing studies, and the absence of comparative analyses across different building heights and earthquake zones as specified in IS 1893-2002. To bridge these gaps, the present study employs analytical modeling and analysis using SAP 2000 to evaluate 3-D R.C. framed structures with varying heights (low, medium, and high), different heights of the open ground floor, and across all seismic zones outlined in IS 1893-2016. Additionally, the study assesses the relative performance of shear walls placed at corners, sides, cores, and combinations thereof. The primary objectives of this research are to understand the dynamic behavior of infilled and OGS frames during earthquakes, evaluate the effectiveness of different LLRS configurations in providing adequate lateral strength, stiffness, and ductility, and identify the optimal shear wall arrangements to mitigate the soft storey effect. By achieving these objectives, the study aims to inform structural design practices, ensuring the safety and minimal damage of high-rise OGS buildings in seismic regions.

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1.0 INTRODUCTION

Open Ground Storey (OGS) structures, commonly referred to as soft storey buildings, are a prevalent architectural feature in urban environments. These structures are characterized by an open ground floor, typically used for parking or commercial purposes, with the upper floors serving as residential or office spaces. This design prioritizes functional and aesthetic requirements over structural resilience, often leading to significant discontinuities in the stiffness and strength distribution along the height of the building. This imbalance results in a soft-storey effect, making OGS structures particularly vulnerable to seismic forces [1].

The popularity of OGS structures stems from the increasing demand for parking spaces in densely populated urban areas. However, the removal of infill walls and partitions at the ground level creates a critical weakness, as these elements provide lateral stiffness and resistance to horizontal forces, such as those induced by earthquakes. The upper floors, supported by the stiffer infilled walls, behave differently under seismic loading, causing an uneven distribution of forces that concentrates stress on the open ground floor [2][3].

Research on the seismic performance of OGS buildings highlights their susceptibility to collapse during earthquakes due to the soft-storey mechanism [4][5]. Earthquakes in regions such as India, Turkey, and Japan have demonstrated the dangers associated with OGS structures, with many buildings experiencing partial or total collapse during seismic events [6][7]. These failures underscore the need for more stringent design codes and retrofitting measures aimed at enhancing the performance of soft-storey buildings during earthquakes [8][9].

Numerous studies have been conducted to assess the seismic vulnerability of OGS structures. For instance, Kose [10] examined the behavior of soft-storey buildings under various seismic loading conditions and concluded that the lack of lateral stiffness at the ground level significantly increases the risk of collapse. Other research has focused on retrofitting methods to improve the seismic performance of these structures. Techniques such as adding shear walls, steel bracings, or moment-resisting frames have been shown to enhance the structural integrity of OGS buildings [11][12].

The performance of OGS structures is influenced by various factors, including the height of the building, the number of storeys, the distribution of mass and stiffness, and the quality of materials used in construction. Studies by Jain et al. [13] and Paulay and Priestley [14] have demonstrated that taller buildings with more storeys are particularly vulnerable to soft-storey failure due to the cumulative effect of lateral forces acting on the structure. Additionally, the use of poor-quality materials or inadequate construction practices can further exacerbate the vulnerability of these buildings during seismic events [15][16].

Despite the known risks associated with OGS structures, they continue to be widely used, particularly in developing countries where rapid urbanization and high land costs make them an attractive option for developers. In response to this challenge, researchers have called for the implementation of more rigorous building codes and standards that specifically address the unique vulnerabilities of OGS buildings [17][18]. The Indian Standard IS 1893, for example, has been updated to include provisions for the design of OGS structures, requiring the incorporation of additional seismic-resistant features [19].

In recent years, advanced modeling techniques and experimental studies have been employed to better understand the behavior of OGS structures under seismic loading. Finite element analysis (FEA) and shake table tests have provided valuable insights into the failure mechanisms of these buildings and have informed the development of more effective retrofitting strategies [20][21]. Studies by Chopra [22] and Asteris et al. [23] have shown that the addition of infill walls, diagonal bracing, or energy-dissipating devices can significantly improve the seismic resilience of OGS buildings. Additionally, base isolation systems have been explored as a means of reducing the seismic demand on soft-storey buildings. Research by Skinner et al. [24] and Naeim and Kelly [25] indicates that base isolation can effectively decouple the structure from ground motion, thereby reducing the forces transmitted to the open ground storey. However, the high cost of implementing such systems has limited their widespread adoption in practice [26][27].

To further enhance the understanding of OGS structure vulnerabilities, studies have explored the role of soil-structure interaction, which can exacerbate the soft-storey effect under seismic loads. Research by Rajeev and Tesfamariam [29] highlights the importance of accounting for ground conditions in seismic design, showing that poor soil conditions can increase the likelihood of structural failure. Additional research on the effect of soil properties on OGS performance confirms the need for detailed geotechnical assessments before construction [30].

Retrofitting has been identified as a critical solution to mitigate seismic risks in existing OGS structures. Numerous retrofitting techniques, including the use of advanced materials like Carbon Fiber Reinforced Polymer (CFRP) and steel braces, have been studied extensively [31][32]. According to Maheri and Akbari [33], CFRP retrofitting can significantly enhance the lateral load resistance of soft-storey buildings. Other studies have focused on dissipative braces and energy-absorbing devices, which have been shown to reduce the likelihood of collapse by enhancing the building's ability to absorb and dissipate seismic energy [34][35].

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Recent advancements in retrofitting methods also include the use of external steel frames, which provide additional lateral stiffness to the ground storey without significantly altering the building's architectural layout [36][37]. Moreover, Banerjee and Halder [30] explored the use of buckling-restrained braces as an effective retrofitting measure, concluding that these systems can significantly improve seismic resilience in OGS buildings. The lessons learned from past earthquakes, coupled with ongoing advancements in structural engineering, will play a crucial role in addressing the challenges posed by OGS structures [38][39].

2.0 SCOPE OF THE STUDY

The provision of infills (Masonry walls) as well as open ground storey are two important functional requirements of almost all the urban multi-storey buildings, and hence, cannot be eliminated.

Open ground storey (OGS) buildings are commonly constructed in populated countries like India since they provide much needed parking space in an urban environment. Failures observed in past earthquakes show that the collapse of such buildings is predominantly due to the formation of soft-storey mechanism in the ground storey columns.

Alternative measures need to be adopted for this specific situation.

Some of the possible schemes to achieve the above are

i) provision of stiffer columns in the first storey, and

ii) provision of shear walls in the building.

An extensive computational study has been conducted to find out the behavior of open ground floor buildings as well as their seismic vulnerability.

The Scope of study of the present investigation is discussed in detail for 96 numbers of 3-D Models (G+14 frame-72 Models, G+6 frame -12 Models and G+18 frame-12 Models).

To compare the results of analysis maximum displacement of open ground floor structure provided with LLRS (Masonry infill and Internal shear wall) to full in filled framed structure with respect to following criteria

a) Varying heights of ground floor relative to upper floor for medium raised structure (G+14, Zone III).

b) Varying height of the structure (low: G+6, medium: G+14 and high raised: G+18).

c) Changing Earthquake Zones (II, IV and V) for medium raised structure(G+14).

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3.0 BUILDING DESCRIPTION

3.1 Number of Storeys

The buildings considered for study have storeys of G+14(H=49m, 48m,47.36), G+18 (H=61.8m) and G+6(H=23.4m).

3.2 Number of bays

5 x 7 bays i.e. 5 bays along X direction of span 5 m each and 7 bays along Y direction of 5 m each considered.

4.0 TYPES OF MODELS CONSIDERED

1. Model-1: Bare Frame (Infill mass considered) without any LLRS (Without infill and shear wall)
2. Model-2: Frame with full infill (Infilled frame effect considered)
3. Model-3: Frame with Open Ground Storey (OGS) without any LLRS (Infill mass considered)

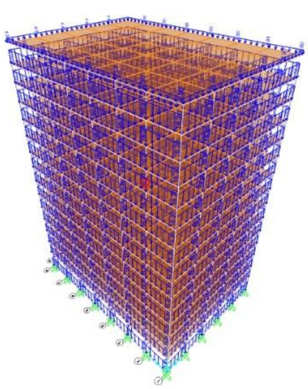
***Infilled frame effect at Rest floors considered for Model 4 to 12**

(Rest floors being all floors above the OGS)

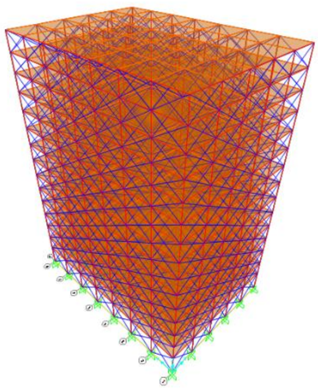
4. Model-4: OGS Frame
5. Model-5: OGS Frame with stiff columns provided at ground floor
   (Column size increased from 500mm to 700mm to increase stiffness at G.F.)
6. Model-6: OGS Frame with Shear walls at Corners spans (Total length of Shear wall= 5x8=40m)
7. Model-7: OGS Frame with Shear wall at Sides (Central peripheral 1 ½ span provided with shear wall along both X-direction and Y-direction. Total length of Shear wall=5x4+ 2.5x8=40m)
8. Model-8: OGS Frame with Shear wall at Sides (Central peripheral span provided with shear wall along both X-direction and Y-direction. Total length of Shear wall=5x4=20m)
9. Model-9: OGS Frame with Shear wall at Core (Central core provided with shear wall along both X-direction and Y-direction. Total length of Shear wall=5x4=20m)
10. Model-10: OGS Frame with Shear wall at Corner half span (Total length of Shear wall= 2.5x8=20m)
11. Model-11: OGS Frame with Shear wall at Corner and Core (Shear walls are provided at Corner as well as Core. Total length of Shear wall= 5x8+5x4=60m)
12. Model-12: OGS Frame with Shear wall at Corner and Side (Shear walls are provided at Corner as well as Sides spans. Total length of Shear wall= 5x8+5x4=60m)

SAP2000 is a stand-alone-finite-element-based structural program for analysis and design of civil structures. It has been developed by research engineers computers and structures based in USA. It offers an intuitive, yet powerful user interface with many tools to aid in the quick and accurate construction of models, along with the sophisticated analytical techniques needed to do the most complex projects.

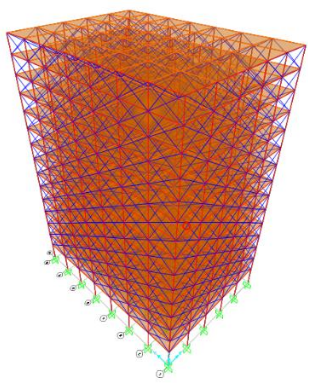
SAP2000 is object based, meaning that the models are created using members that represent the physical reality. A beam with multiple members framing into it is created as a single object, just as it exists in the real world, and the meshing needed to ensure that connectivity exists with the other member is handled internally by the program. Results for analysis and design are reported for the overall object and not for each sub-element that makes up the object, providing information that is both easier to interpret and more consistent with the physical structure.



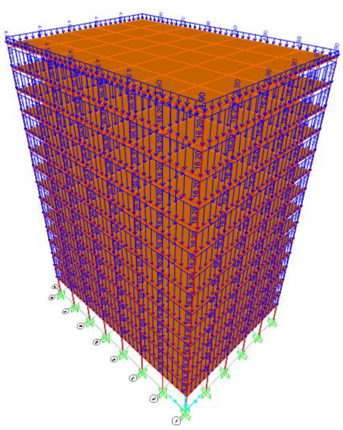
Model -1



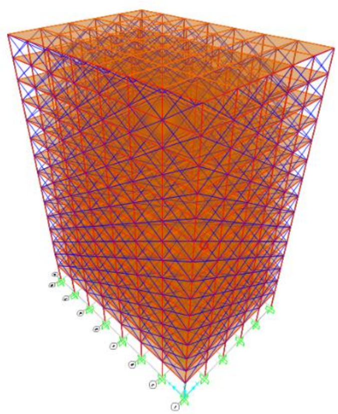
Model-2



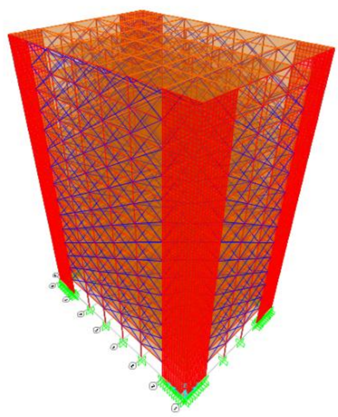
Model-3



Model-4



Model-5



Model-6

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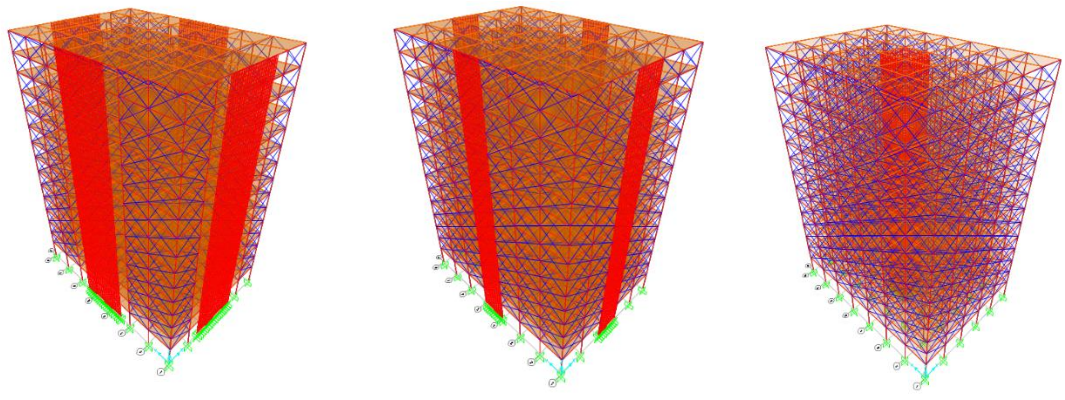
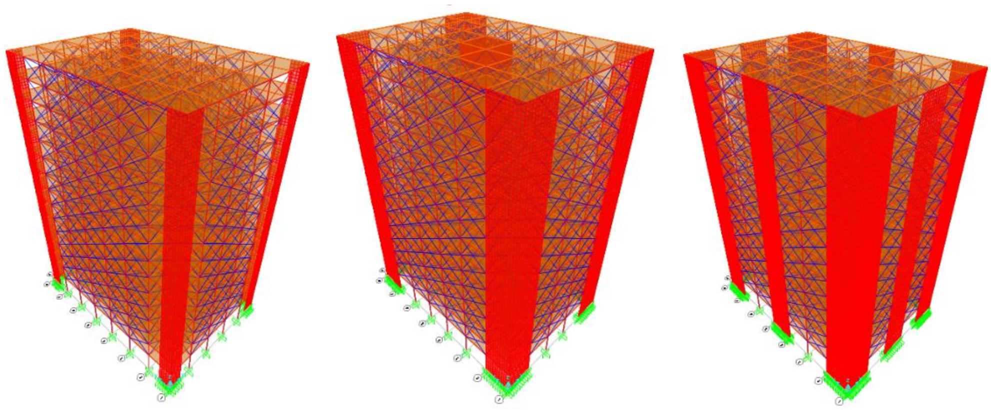


Model-7 **Model-8** **Model-9**



Model-10 **Model-11** **Model-12**

Fig. 1: SAP models for analysis

5.0 CROSS SECTIONAL PROPERTIES AND MATERIAL CONSTANTS

Material constants are considered as shown below:

Grade of Concrete : M25

Grade of Steel : Fe415

Characteristic strength of concrete, f_{ck} : 25Mpa

Density of Concrete : 25 kN/m^3

Modulus elasticity of concrete, E_{fe}: $5000\sqrt{f_{ck}} = 5000 \times \sqrt{25}$ =25000Mpa=25000x10^3 kN/m^2

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Poisson's ratio of concrete, μ	: 0.2
Density of brick masonry, ρ	:19.2 kN/m^3
Modulus of elasticity of brick masonry, E_{me}	:1.8x10^{6}kN/m^2
Poisson's ratio of brick masonry	: 0.20

**Modulus of elasticity of brick masonry (E_{me}) varies for different types of brick and from country to country. As per the literature survey, its value adopted for previous research works ranges from 1.3 x 10^6 KN/m^2 to 4.2 x 10^6 kN/m^2. K S Jagadish et.al (2008) [40] conducted experimental work for different types of bricks available in India and they arrived at E_{me} for brick masonry. For present study E_{me} of 1.8x10^{6}kN/m^2, for masonry consists of local bricks selected from K S Jagadish et.al (2008) [41] is adopted.

6.0 SIZE OF EQUIVALENT DIAGONAL STRUT

The behavior of Infilled Frame may be idealized with a diagonal compression strut of width *a*. The width of equivalent strut for the infill panel is calculated using the formula as follows:

$$a = 0.175(\lambda_1 h_{col})^{-0.4} r_{\inf}$$

Where

$$\lambda_1 = \left[\frac{E_{me} t_{\inf} \sin 2\theta}{4 E_{fe} I_{col} h_{\inf}}\right]^{1/4}$$

$$\theta = \tan^{-1}\left(\frac{h_{\inf}}{L_{\inf}}\right)$$

h_{col} = Column height between centrelines of beams, m.
h_{inf} = Height of infill panel, m.
E_{fe} = Expected modulus of elasticity of frame material, kN/m^2
E_{me}= Expected modulus of elasticity of infill material, kN/m^2
I_{col} = Moment of inertia of column, m^4.
L_{inf} =Length of infill panel, m.
r_{inf} =Diagonal length of infill panel, m.
t_{inf} =Thickness of infill panel and equivalent strut, m.
θ = Angle whose tangent is the infill height-to- length aspect ratio, radians.
λ_1 =Coefficient used to determine equivalent width of infill strut.
A=Cross sectional area of diagonal strut, m^2.

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Calculated value of diagonal strut as shown in Table 1:

Table 1 : Size of diagoanal strut

Column size	I_{col}	h_{col}	r_{inf}	θ	λ_1	a	$A=axt_{inf}$	Size of diagonal strut
500x500mm	0.005208	2.56	5.617	27.11^0	0.7082	0.775	0.178	775x230mm
500x500mm	0.005208	3.2	5.936	32.61^0	0.6895	0.757	0.174	757x230mm
500x500mm	0.005208	4.2	6.530	40^0	0.6569	0.761	0.175	761x230mm

7.0 RESULTS AND DISCUSSION

Seismic analysis of 3-D framed structure with various cases i.e. Bare frame (with infill mass effect), Solid Infilled frame, Open Ground Storey (OGS), OGS with Stiff column at ground floor, OGS with Shear wall at various locations are carried out using SAP2000*Ver.15 commercial software package.

The results of fully infilled frame are compared with that of bare frame to evaluate the effectiveness of infill. Also the results of OGS with infill effect at Storeys above are compared with OGS without infill effect. The effectiveness of provision of Stiff column at Ground Storey location and Shear wall at various locations is done by comparing with fully infilled structure and OGS with infill effect at Storey above.

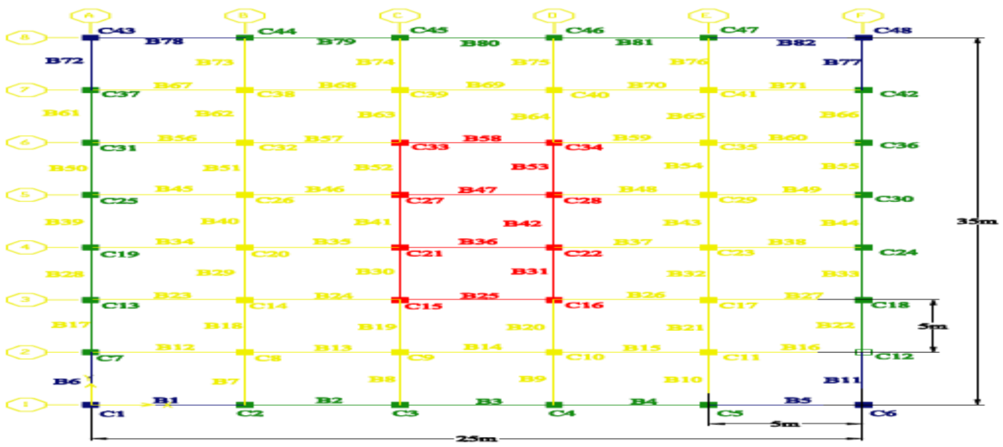

Fig. 2: The beam and column designation adopted

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To understand the behaviour, columns and beams at different locations, the columns & beams are classified as in Table 2 & designated as in fig.2.

Table 2: COLUMN AND BEAM CLASSIFICATION

CLASSIFICATION	COLUMN / BEAM DESIGNATION
CORNER COLUMNS	C1, C6, C43, C48- 4Nos.
PERIPHERAL COLUMNS	C2, C3, C4, C5, C7, C12, C13, C18, C19, C24, C25, C30, C31, C36, C37, C42, C44, C45, C46, C47- 20Nos.
INNER PERIPHERAL COLUMNS	C8, C9, C10, C11, C14, C17, C20, C23, C26, C29, C32, C35, C38, C39, C40, C41-16Nos.
CORE COLUMNS	C15, C16, C21, C22, C27, C28, C33, C34 - 8Nos.
CORNER BEAMS	B1, B5, B6, B11, B72, B77, B78, B82- 8Nos.
PERIPHERAL BEAMS	B2, B3, B4, B17, B22, B28, B33, B39, B44, B50, B55, B61, B66, B79, B80, B81- 16Nos.
INNER PERIPHERAL BEAMS	B13, B14, B15, B18, B21, B29, B32, B40, B43, B51, B54, B62, B65, B68, B69, B70, B7, B8, B9, B10, B73, B74, B75, B76, B12, B16, B23, B27, B34, B38, B45, B49, B56, B60, B67, B71 -36Nos.
CORE BEAMS	B24, B25, B26, B35, B36, B37, B46, B47, B48, B57, B58, B59, B19, B30, B41, B52, B63, B20, B31, B42, B53, B64-22Nos.

7.1 Maximum Displacement

Maximum displacement at all storeys for G+14 structure observed in Model 1 and 2 is presented in fig.3 and fig. 4 indicates displacement of Model 4(OGS) for G+14 structure of different G.F. /F.F. height ratio.

7.2 Infill effect

Displacement at roof level for Model 1 and Model 2 observed are 113.94mm and 39.24mm respectively, this shows that if infill is considered reduction in lateral displacement of about 65% is recorded when compared to bare frame(only mass of infill considered). Fig. 4 shows the height vs. displacement.

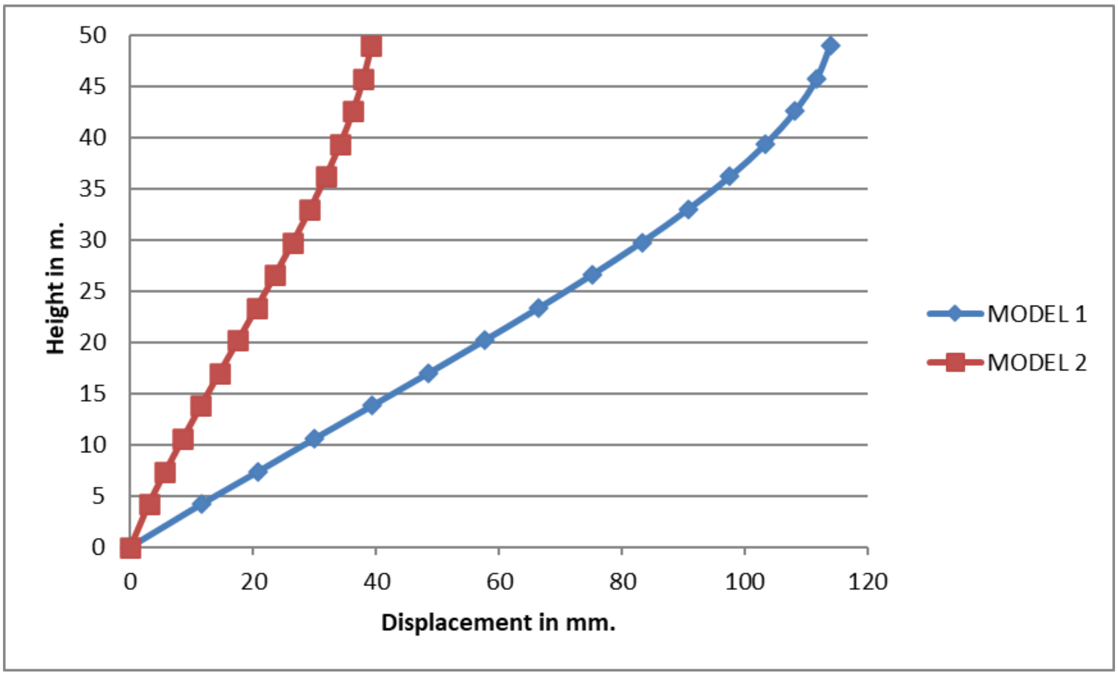

Fig. 3: Height Vs. Displacement (G+14-Bare frame and Infilled Frame)

7.3 Open Ground Storey effect

Displacement at G.F. level observed for model 2(full infill) is 2.99mm and is increased to 13.5mm in case of model 4 due to reduction of stiffness at G.F.

An increase in lateral displacement at top storey level is also observed due to OGS in comparison to infilled frames. The extent of increase is up to an 19% .

7.4 Systems adopted to offset Open Ground Storey effect

a) Considering G+14 structure

Displacement at roof level for fully infilled frame (Model 2) is 39.24mm. It is observed that displacement of Model 6 to 12 is less than 42mm. This is due to provision of shear wall in OGS.

Table 3: Percentage reduction in displacement by provision of shear walls

Model	Displacement in mm	% Reduction Compared to Model 2(fully infilled frame)
MODEL 2	39.24	-
MODEL 5	39.66	No reduction observed

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MODEL 6	25.68	34.55%
MODEL 7	25	36.28%
MODEL 8	32.14	18%
MODEL 9	32.33	17.6%
MODEL 10	33.74	14%
MODEL 11	22.96	41.14%
MODEL 12	18.91	49.51%

7.5 Varying height of the G.F. with respect to F.F.

It is observed from fig.4. that lateral displacement was reduced if G.F. height is reduced with respect to rest floor. For height ratio (G.F/F.F.) 0.80, 1.00 and 1.3 maximum roof displacement are 41.7mm, 45.1mm and 53.1mm respectively. Percentage increase in lateral displacement for 1m raise of G.F. height with respect to F.F. is about 15%

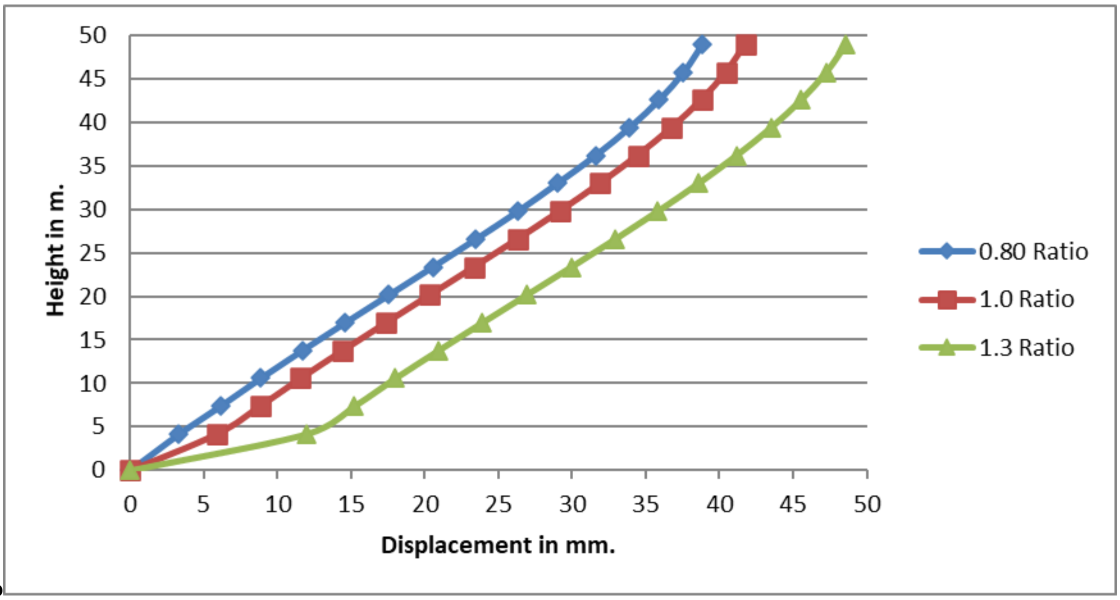

Fig. 4: Height vs. Displacement for G+14 structure (OGS –Model 4)

7.6 Different Earthquake Zones

Table 4 shows lateral displacement for G+14 structure in all earthquake Zones. It is observed from the Table 4 that displacement increases drastically as zone increases and performance of shear wall is very good in controlling displacement in all zones.

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Table 4: G+14 structure -Lateral displacement in all earthquake zones

MODELS	Displacement in mm			
	Zone II	Zone III	Zone IV	Zone V
MODEL 1	71.34	113.94	170.96	256.43
MODEL 2	24.52	39.24	58.86	88.29
MODEL 3	71.34	127.15	170.96	256.43
MODEL 4	30.36	48.57	72.86	109.3
MODEL 5	24.79	39.66	59.49	89.24
MODEL 6	16	25.68	38.53	57.79
MODEL 7	15.7	25	37.48	56.16
MODEL 8	20	32.14	48.22	72.33
MODEL 9	20.2	32.33	48.5	72.75
MODEL 10	21.3	33.74	51.13	76.7
MODEL 11	14.35	22.96	34.45	51.67
MODEL 12	12.16	18.91	29.18	43.77

a) Structures of different heights (G+6, G+14 & G+18)

Displacement of all structures considered is presented in Table 5. It is observed that as the height of the structure increases, lateral displacement also increases.

Table 5: Lateral displacement for structures of different heights

MODEL	Displacement in mm		
	G+6	G+14	G+18
MODEL 1	37.25	113.94	152.82
MODEL 2	10.75	39.24	58.21
MODEL 3	37.25	127.15	172.1
MODEL 4	17.52	48.57	69.8
MODEL 5	11.8	39.66	59.73
MODEL 6	6.2	25.68	37.48
MODEL 7	5.76	25	37.66
MODEL 8	8.55	32.14	47.33
MODEL 9	7.64	32.33	49.91
MODEL 10	9.8	33.74	48.33
MODEL 11	5.1	22.96	34
MODEL 12	5.02	18.91	26.91

Table 6 : Height of structure / Maximum Displacement $[(h/\Delta_{max})\times 10^{-3}]$

Structure	MODEL Nos.											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
G+6	1.59	0.46	1.59	0.75	0.50	0.26	0.25	0.37	0.33	0.42	0.22	0.21
G+14	2.33	0.80	2.59	0.99	0.81	0.52	0.51	0.66	0.66	0.69	0.47	0.39
G+18	2.47	0.94	2.78	1.13	0.93	0.61	0.61	0.77	0.81	0.78	0.55	0.44

Displacement at each floor level increases as the height of the building increases. From the Table 6, it is observed that increase in maximum sway is found to be 1.32 times from G+6 to G+14 and 1.50 times from G+6 to G+18 structure.

Table 7: Percentage reduction in displacement by provision of shear walls for all structures considered

Model	% Reduction Compared to Model 2(fully infilled frame)		
	G+6	G+14	G+18
MODEL 6	42%	34.55%	35.61%
MODEL 7	46.41%	36.28%	35.3%
MODEL 8	20.46%	18%	18.69%
MODEL 9	29%	17.6%	14.25%
MODEL 10	8.8%	14%	16.97%
MODEL 11	52%	41.14%	41.59%
MODEL 12	53.3%	49.51%	53.7%

From Table 7, it is observed that Model 6, 7 (40m length shear wall) reduces deflection of about 35%, Model 8,9 &10 (20m length shear wall) reduces deflection to an extent 10 to 30%, Model 11, 12(60m length shear wall) reduces deflection to an extent of 40 to 50%. From this it is clear that increasing length of shear wall is beneficial for all height of structures.

b) Structures of different heights (G+6, G+14 & G+18)

Displacement of all structures considered is presented in Table 8. It is observed that as the height of the structure increases, lateral displacement also increases.

Table 8: Lateral displacement for structures of different heights

MODEL	Displacement in mm		
	G+6	G+14	G+18
MODEL 1	37.25	113.94	152.82
MODEL 2	10.75	39.24	58.21

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MODEL 3	37.25	127.15	172.1
MODEL 4	17.52	48.57	69.8
MODEL 5	11.8	39.66	59.73
MODEL 6	6.2	25.68	37.48
MODEL 7	5.76	25	37.66
MODEL 8	8.55	32.14	47.33
MODEL 9	7.64	32.33	49.91
MODEL 10	9.8	33.74	48.33
MODEL 11	5.1	22.96	34
MODEL 12	5.02	18.91	26.91

Table 9: Height of structure / Maximum Displacement $[(h/\Delta_{max})\times 10^{-3}]$

Structure	MODEL Nos.											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
G+6	1.59	0.46	1.59	0.75	0.50	0.26	0.25	0.37	0.33	0.42	0.22	0.21
G+14	2.33	0.80	2.59	0.99	0.81	0.52	0.51	0.66	0.66	0.69	0.47	0.39
G+18	2.47	0.94	2.78	1.13	0.93	0.61	0.61	0.77	0.81	0.78	0.55	0.44

Displacement at each floor level increases as the height of the building increases. From the Table 9, it is observed that increase in maximum sway is found to be 1.32 times from G+6 to G+14 and 1.50 times from G+6 to G+18 structure.

Table 10: Percentage reduction in displacement by provision of shear walls for all structures considered

Model	% Reduction Compared to Model 2(fully infilled frame)		
	G+6	G+14	G+18
MODEL 6	42%	34.55%	35.61%
MODEL 7	46.41%	36.28%	35.3%
MODEL 8	20.46%	18%	18.69%
MODEL 9	29%	17.6%	14.25%
MODEL 10	8.8%	14%	16.97%
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MODEL 12	53.3%	49.51%	53.7%

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From Table 10, it is observed that Model 6, 7 (40m length shear wall) reduces deflection of about 35%, Model 8,9 &10 (20m length shear wall) reduces deflection to an extent 10 to 30%, Model 11, 12(60m length shear wall) reduces deflection to an extent of 40 to 50%. From this it is clear that increasing length of shear wall is beneficial for all height of structures.

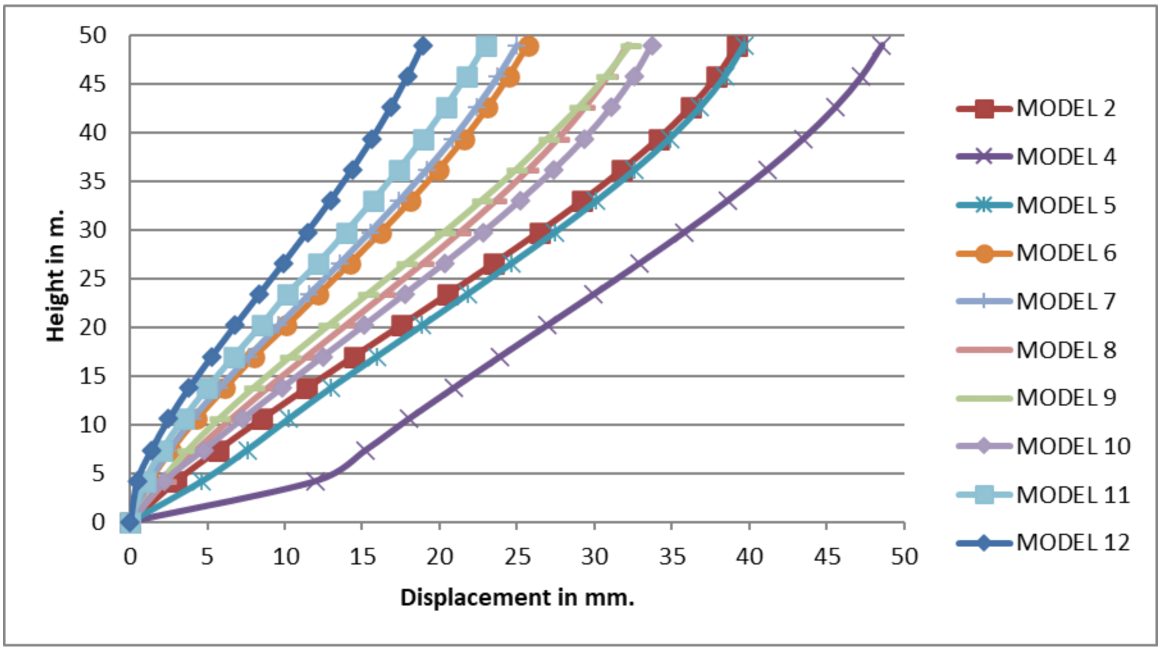

Fig. 5: Height vs. Displacement for G+14 structure

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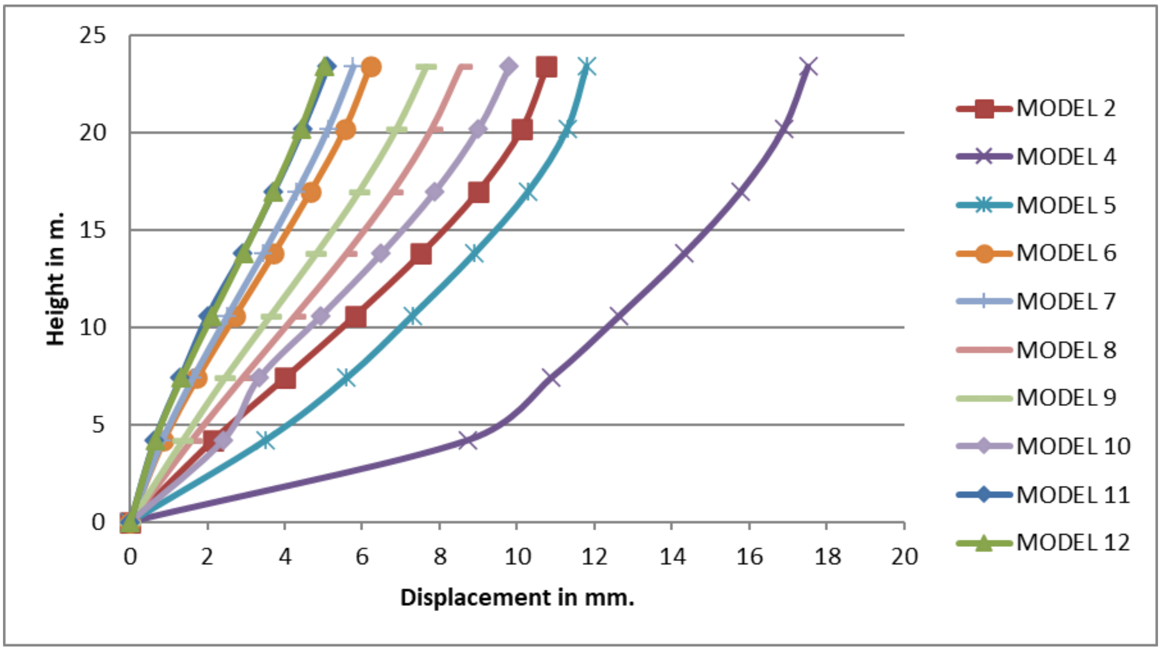

Fig.6: Height vs. Displacement for G+6 Structure

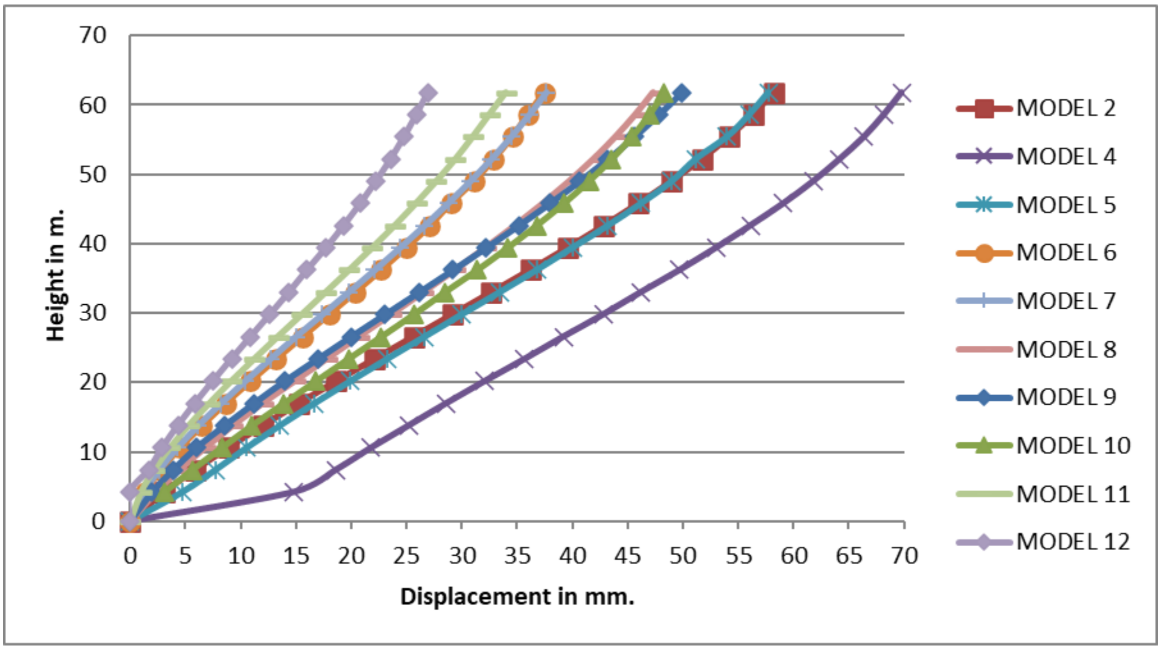

Fig. 7: Height vs. Displacement for G+18

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Fig. 5, 6 & 7 shows graphical representation of Height vs. Displacement for all structures considered. Sudden change in slope observed at G.F. for Model 4, which indicates Open Ground Storey effect.

CONCLUSIONS

In the present investigation an attempt has been made to evaluate the seismic effects due to Open Ground Storey 3-D infilled frames of Seven, Fifteen and Nineteen Storey provided with and without LLRS. The seismic analysis is carried out using the Equivalent Static Lateral Force Method (ESLM). Based on the limited study carried out the following conclusions are drawn.

1. In case of infilled frames lateral displacement at top storey level gets substantially reduced compared to bare frame due to infill effect. In case of G+6, G+14 & G+18 frames, reduction of 71%, 65% & 62% respectively are recorded.
2. In case of OGS structures the maximum displacement at G.F. level substantially increases due to loss of stiffness. Between fully infilled frame and OGS generally an increase of about 77% is recorded.
3. An increase in maximum lateral displacement at top storey level is also recorded due to OGS in comparison to fully infilled frames. The extent of increase on an average is 19%.
4. The displacement at each storey level increases as the height of the building increases. Maximum sway in case of OGS structures is found to be 1.32 times from G+6 to G+14 and 1.50 times from G+6 to G+ 18 structures.
5. Effectiveness in controlling lateral displacement increases as the length of shear wall increases for frame with OGS. For higher length of shear wall, displacement is found to be even less than that of fully infilled frames. Compared to fully infilled frames, Models 8,9 &10 (20m length shear wall) reduce lateral displacement to an extent of 10 to 30%, Models 6, 7 (40m length shear wall) to an extent of 35%, Models 11, 12(60m length shear wall) to an extent of 40 to 50% for structures with different heights considered.
6. Provision of shear walls of different length & different location is found to be highly effective in reducing the storey drift at G.F. as well as top storey sway generated due to OGS to an extent of even less than that of fully infilled frames.
7. In case of LLRS concerned to provision of Stiff columns in G.F., it is found to be effective to an extent that the resulting deflection almost equal to that of fully infilled frames. Hence, they are not as effective as that of shear walls.

AUTHOR(S) CONTRIBUTION

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CONFLICTS OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, And/or publication of this article.

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