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Seismic Analysis of Masonry Infilled Structure with Open Ground Storey and Refuge Storey

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Abstract- The study examines the seismic performance of reinforced concrete (RC) frame structures with masonry infill, focusing on the presence of Open Ground Storey (OGS) and Refuge Storey. Utilizing ETABS software, two distinct building plans L-shaped and Box-shaped are modeled to assess their seismic performance across different seismic zones as per IS 1893:2016. These features create a soft-storey condition, making them vulnerable to collapse during earthquakes. The study compares structures with and without infill walls across different seismic zones of India. Results show higher vulnerability in structures with OGS and refuge floors, requiring enhanced load-resisting systems and ductile detailing. The analysis is performed on dynamic analysis by Response spectrum method using computer software E-TAB. The study recommends design recommendations and mitigations startegies to improve seismic resilience.

Keywords: Response Spectrum Analysis, Masonry Infills, Open Ground Storey, Refuge storey, E-TAB, Different Seismic Zones, L-Shape & Box Shape

1) Introduction

India's urbanization and high population density have led to the construction of multi-storey reinforced concrete (RC) frame buildings with masonry infill walls. These infill walls, although non-structural, significantly influence lateral stiffness, strength, and seismic behavior. The absence of infill walls in urban constructions, such as Open Ground Storeys (OGS) and Refuge Storeys, creates structural weaknesses under seismic loading, especially in medium to high seismic zones. Past earthquakes like the 2001 Bhuj earthquake and Nepal 2015 earthquake have highlighted the importance of understanding the dynamic response of masonry infilled buildings with OGS and refuge floors. This study evaluates the seismic performance of these structures across different seismic zones using analytical techniques like Response Spectrum Analysis.

In this study, the seismic performance of a G+10 reinforced concrete (RC) building is evaluated using ETABS software, focusing on the effects of masonry infill walls, open ground storeys (OGS), and refuge floors. The analysis adheres to the guidelines specified in IS 1893:2016, employing the Equivalent Diagonal Strut Method to model the infill walls.

The building is analyzed in both bare frame and infilled frame configurations across India's seismic Zones II, III, IV, and V, considering medium soil conditions. Two distinct plan configurations are examined L-shaped and box-shaped layouts. This comparative study aims to assess the impact of plan irregularities and infill presence on seismic response parameters such as base shear, storey drift, lateral displacement & lateral loads. The aim is to provide insights into how architectural features affect seismic behavior and suggest structural modifications or design guidelines to enhance earthquake resistance, especially in seismically sensitive regions.

2) Literature Reviews

1. **Parth Shah, Roshni John (Jan-2024)** – ***"Study of Seismic Effect on Different Types of Infill Walls"*** The paper discusses to evaluate the response of infill walls subjected to seismic loads for regular plans located in zone 3. The response includes Story displacement, Story drift, Base shear. They analyses to study the behaved pattern of seismic. waves of buildings with various types of infill walls in this case G+20 RCC framed building is used. The paper concludes that Base shear for x direction came the most for precast concrete infill walls and the least was of bare frame.

2. **Shuenn-Yih Chang , Guo-Chen Hsu,and Chiu-Li Huang (Aug 2023) –** ***"Experimental Study of RC Frame Infilled with Opening Brick Wall"***

This study tested three reinforced concrete bare frames filled with brick walls in different shapes i.e full brick walls, opening brick walls, and top opening brick walls. The failure modes of each specimen were observed through cyclically loading tests. The study suggests that diagonal force transfer mechanisms can be simulated using compressive bracing.

3. **Ankur Thakur and K. Senthil (Aug 2023) –** ***"Seismic performance of confined masonry walls with different infill materials: a comparative study"***

This study compares four materials, AAC blocks, LWC panels, fly ash bricks, and clay bricks, for suitability as infill materials in confined masonry construction. The results show that AAC blocks perform better than other materials, attracting the least earthquake force. The study also found that LWC concrete panels and fly ash bricks perform well, but may require minor modifications in column size for specific scenarios. The choice of infill material largly influences the seismic behavior of CM structures.

4. **Ahmet Gullua and Genco Karames (Aug 2021) –** ***"Effect of building importance factor on seismic performance of RC frame type shopping malls subjected to pulse-like records "***

This study examines two malls with the lower factor using new seismic standards, finding that while there may be issues with story drifts, the average results meet the life safety level. It suggests keeping the importance factor at 1.0 for malls near faults to control costs.

5. **Wongsa Wararuksajja, Suchart Limkatanyu , Jarun Srechai, Sutat Leelataviwat , Trirat Sungkamongkol (July 2021) –** ***"Seismic design method for preventing column shear failure in reinforced concrete frames with infill walls "***

This study assessed a design method to prevent local failures in RC columns due to this interactions.Simplified equations and finite element analysis were used to assess frame demands.An RC frame with a masonry wall was tested, showing that local failures could be avoided and resulting in ductile behavior with minimal cracking.

6. **Majid Mohammadi , Moein Mirzaei, Mohammad Reza Pashaie (Aug 2021) –** ***"Seismic performance and fragility analysis of infilled steel frame structures using a new multi-strut model "***

This paper assesses the seismic response of infilled moment-resisting steel frames using a multi-strut model.Two structures were analyzed with differen configurations.,Results indicate that URM infills provide benefits at lower limit states but worsen performance at higher limit states, particularly in the Collapse Prevention state.

7. **Malihe Hejazi , Ali Jalaeefar (June 2021) –** ***"Effect of infills on seismic resilience of special steel moment resisting frames "***

This study examines how infills affect the seismic resilience of special steel moment resisting frames. Three design modes are compared: without infills, with infills, and with infills having openings. The findings indicate that infills can greatly reduce structural damage and improve resilience, especially in low rise frames.

8. **Hendrik Wijaya, Pathmanathan Rajeev, Emad Gad and Anita Amirsardari (June 2020) –** ***"Effect of Infill-Wall Material Types and Modeling Techniques on the Seismic Response of Reinforced Concrete Buildings"***

This study explored how different infill materials and modeling methods affect the seismic performance of RC buildings. Three building heights with various masonry types were analyzed using nonlinear dynamic analysis and probabilistic seismic demand models.

9. **Fabio Di Trapani,Luca Giordano, and Giuseppe Mancini (Feb 2019) –** ***"Progressive Collapse Response of Reinforced Concrete Frame Structures with Masonry Infills"***

The paper studies how masonry infills affect the collapse response of reinforced concrete frame structures. Results indicate that infilled frames are significantly stronger and stiffer than bare frames, also changing damage patterns and safety margins.

10. **Syed Humayun Basha, Sachin Surendran and Hemant B. Kaushik, M.ASCE (June 2020) –** ***"Empirical Models for Lateral Stiffness and Strength of Masonry-Infilled RC Frames Considering the Influence of Openings"***

The study explored how reinforced concrete frames filled with fly-ash brick masonry and different sizes of central openings respond to lateral loads. Results showed that frames with openings behaved differently than those without. The drift limits improved with openings when adhering to earthquake standards.

11. **Shuang Li, Aff.M.ASCE, Mehmet Metin Kose, Sidi Shan and Halil Sezen, F.ASCE (June 2019)-** ***"Modeling Methods for Collapse Analysis of Reinforced Concrete Frames with Infill Walls"***

The study examines the progressive collapse behavior of RC infilled frames through experiments and numerical simulations. A new three-strut model is developed to better simulate damage in infill walls.

12. **Ali Jalaeefara, Azam Zargar (June 2021) –** ***"Effect of infill walls on behavior of reinforced concrete special moment frames under seismic sequences "***

This study examined how infill walls affect reinforced-concrete frames during earthquakes. It used 4, 8, and 12-storey frames with different configurations analyzed using Open Sees software . Results show infill walls increase strength but reduce ductility.

13. **Varun Singh Chandel, I. Yamini Sreevalli (Sept 2018) –** ***"Numerical study on influence of masonry infill in an RC frame."***

This study aims to understand the behavior of fully infilled RC masonry frames compared to open ground storey (OGS) frames. Study examines the interaction of masonry infill with RC frame structures, focusing on factors like strength, mortar, concrete, and infill distribution. Results show failure occurs at the ground storey, despite infilled or open ground storey structures.

14. Koce TODOROV, Ljupco LAZAROV (June 2018) – "Incremental Dyanamic analysis of Infilled frames with open ground storey"

A study analyzed reinforced concrete frames with masonry infill, revealing irregular distribution can lead to unfavorable seismic performance. The study found that low-rise buildings experience soft storey mechanisms, while mid-rise buildings reduce seismic demand. High-rise buildings' damage distribution depends on infill characteristics and ground motion frequency.

15. **Siamak Sattar and Abbie B. Liel –** ***"Seismic Performance of Reinforced Concrete Frame structures with an without Masonry infill walls"***

This study assesses the seismic performance of these buildings, utilizing dynamic analysis of nonlinear simulation models to obtain probabilistic predictions of the risk of structural collapse. The evaluation is based on structures with design and detailing characteristics representative of pre-1975 California construction. This research quantifies the effect of the presence and configuration of masonry infill walls on seismic collapse risk. Seismic performance assessments indicate that, of the configurations considered (bare, partially-infilled and fully-infilled frames), the fully-infilled frame has the lowest collapse risk and the bare frame is found to be the most vulnerable to earthquake-induced collapse.

3) Research Methodology

3.1 Aim

"Seismic Analysis of Masonry Infilled structures with Open Ground Storey & Refuge Storey"

3.2 Objectives

1. To analyze infill and without infill multi-storey RC building model with Open Ground Storey (OGS) and Refuge Storey configurations using ETABS software.
2. To analyze both 'L' shaped and 'Box' shaped geometries to assess the impact of plan irregularities on seismic performance.
3. To perform seismic analysis of modelled structures across different seismic zones.
4. To compare all analytical model with help of graph.

3.3 Methodology

- By using Dynamic Analysis methods to design infilled frames under seismic loading conditions.
- Study involves G+10 building analyzed for different seismic zones (II, III, IV, V).
- Analysis performed using E-TAB software.
- Parameters compared across models are Lateral displacement, Lateral loads, Drift storey & Base shear.
- Material Used

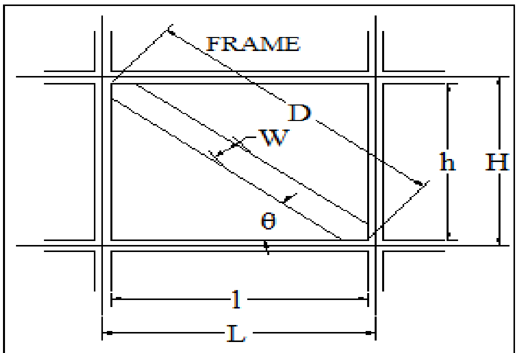
  Concrete - Characteristic compressive strength (f_{ck}) = 30 MPa

  Steel - Yield Stress (f_y) = 500 MPa
- **Loads Calculation approach**

The analysis has been carried out for dead load (DL), live load (LL), and earthquake load in both direction i.e. sway to left (-EL) and sway to right (+EL) by standard computer package ETAB. The combinations of the above loads have been made according to CL 6.3 of IS1893-2016 and they are given below

1.5 (DL+LL) 1.2 (DL+LL+ EL) 1.2(DL+LL-EL)
1.5 (DL+EL) 1.5 (DL-EL) 0.9DL+1.5EL
0.9DL-1.5EL

3.4 Equivalent Diagonal Strut Methods



(a)

The simplest equivalent strut model includes a single pin-jointed strut. Paulay and Priestley suggested the width of equivalent strut as,

$$w = 0.25d$$

Where,

d = Diagonal length of infill panel

W = Depth of diagonal strut

Another model for masonry infill panels was proposed by Mainstone in 1971 where the cross-sectional area of strut was calculated by considering the sectional properties of the adjoining columns.

$$W = 0.175\,(\lambda H)^{-0.4}\,D$$

3.5 Design Seismic Base Shear

The total design lateral force or seismic base where shear along any principle direction shall determined by the following expression:

$$V_b = A_h W$$

Where

W –Seismic weight of the building

A_h= Design horizontal acceleration spectrum value

$$Ah = \frac{Z}{2} \times \frac{I}{R} \times \frac{Sa}{g}$$

Where,

Z= Zone factor

Seismic Zone	II	III	IV	V
Seismic Intensity	Low	Moderate	Severe	Very Severe
Z	0.10	0.16	0.24	0.36

Sl No.	Structure	Importance Factor
(1)	(2)	(3)
i)	Important service and community buildings, such as hospitals; schools, monumental structures; emergency buildings like telephone exchange, television stations, radio stations, railway stations, fire station buildings; large community halls like cinemas, assembly halls and subway stations, power stations	1.5
ii)	All other buildings	1.0

Importance Factor I

NO.	TYPE OF RESISTIG FRAME	R-Factor
1	Ordinary RC moment resisting frame (OMRF)	3
2	Special RC moment resisting frame (SMRF)	5

Response Reduction Factor R

Type of Structure	R(G+10)
Zone	II, III. IV, V
Foundation Level to Ground Level	3 M
Floor to Floor Height	3 M
Live Load	3 KN/M^2
Material	M30 AND Fe500

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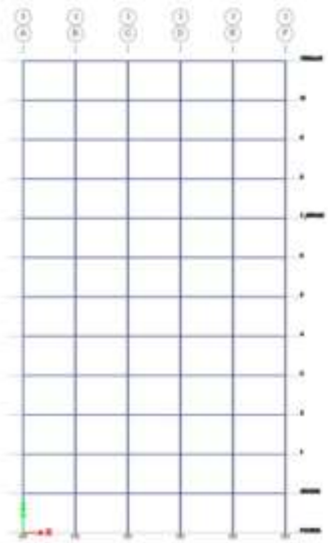
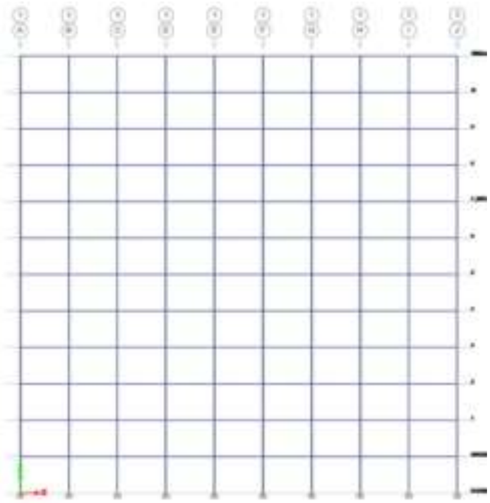
Seismic Analysis	Equivalent Diagonal Strut Method
Size of Column	C= 300 x 500
SIZE OF BEAM	B=230 x 600
Size of Diagonal Strut	230 x 530
Depth of Slab	150 MM
Design Philosophy	Limit State Method (IS 456-2000)

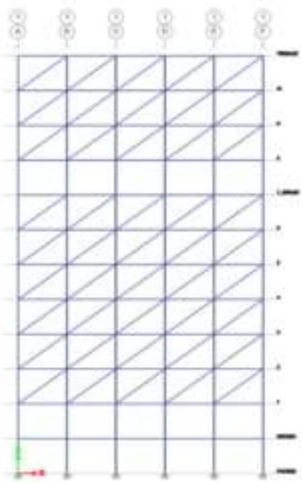
4) Performance Analysis



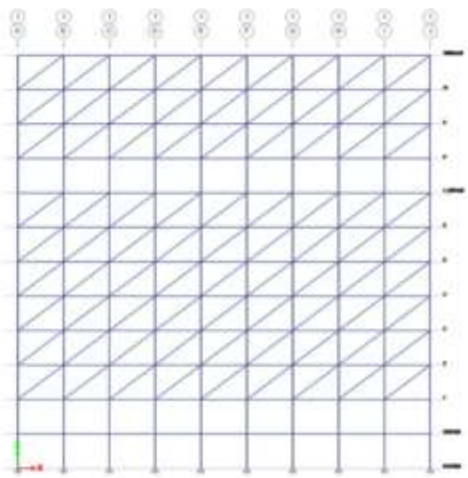
Without infill Box shape Elevation



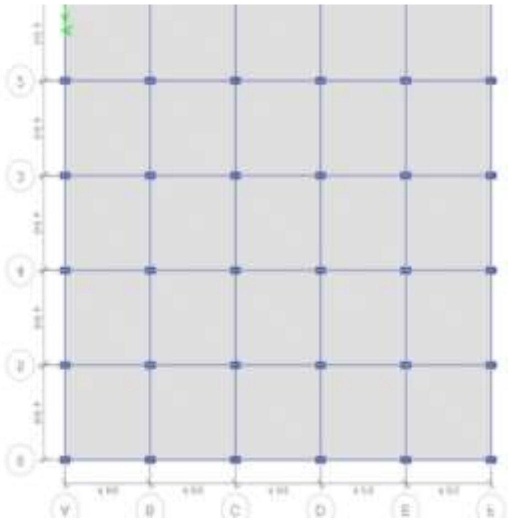
Without infill L shape Elevation



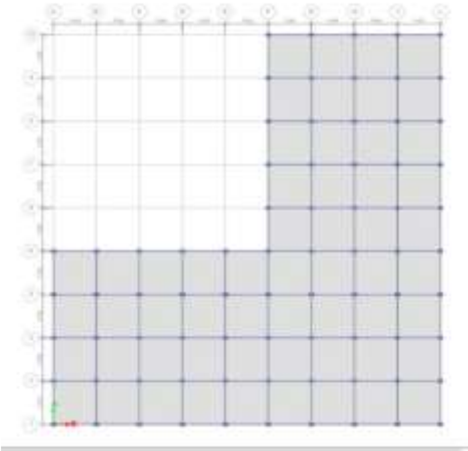
Infill Box shape Elevation



Infill L shape Elevation



Box shape Plan

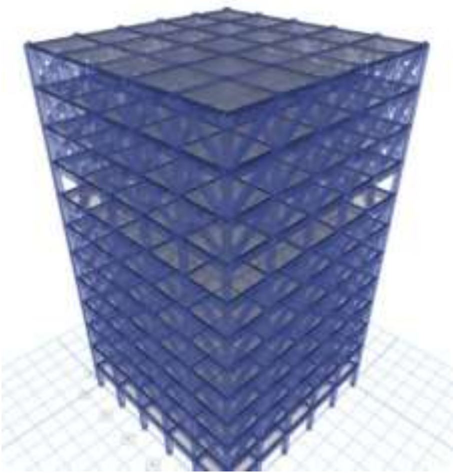


L shape Plan

4.2 Models for Different Seismic Zones

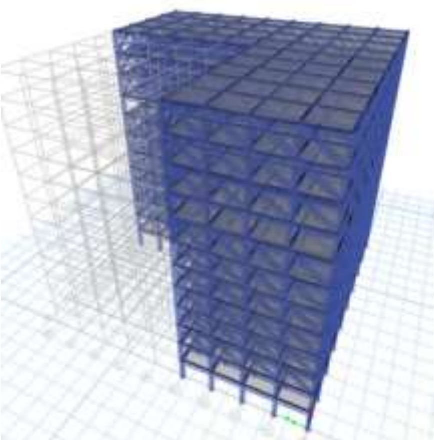
In this case study, the Sixteen models are prepared for (G+10) Storey.

Model I: RC frame with infill Masonry, Box shape, Seismic zone – II, III, IV, V



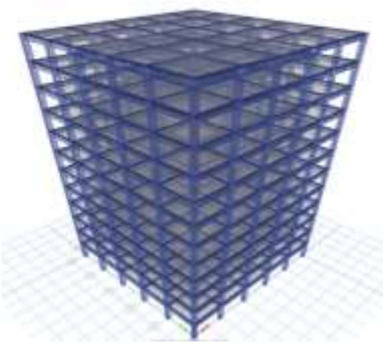
Infill Box Shape Model

Model II: RC frame with infill Masonry, L shape, Seismic zone – II, III, IV, V



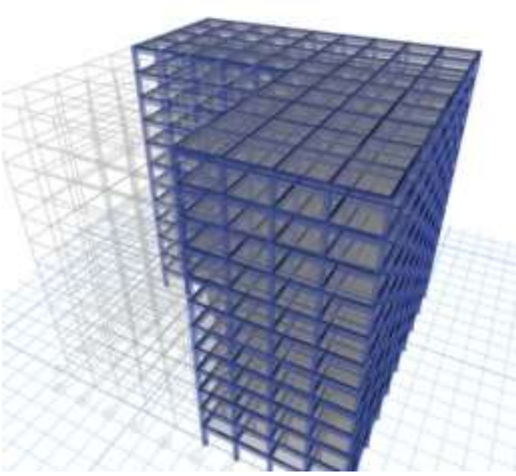
Infill L Shape Model

Model III: RC frame without infill Masonry, Box shape, Seismic zone – II, III, IV, V



Without Infill Box Shape Model

Model IV: RC frame without infill Masonry, L shape, Seismic zone – II, III, IV, V



Without Infill L Shape Model

4.3 Load Cases & Load Pattern

Load Cases

Load Pattern

4.4 Results

The results shown in the form of

- Lateral Displacement
- Lateral Load
- Storey Drift
- Base Shear

Example: L Shape Result

Seismic zone: III

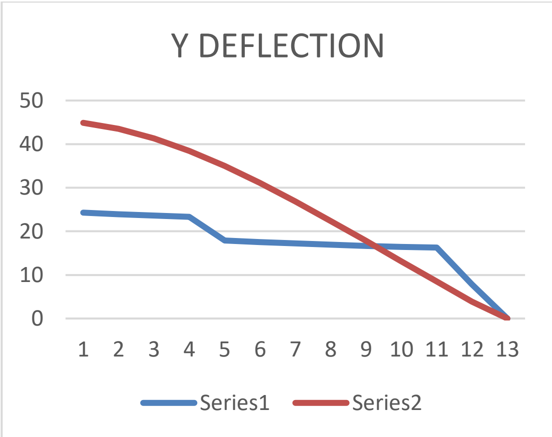
DEFLECTION (MM)					
STOREY	**HEIGHT**	**EQX (FILL)**	**EQX (NO FILL)**	**EQY (FILL)**	**EQY (NO FILL)**
TERRACE	36	17.235	35.24	24.287	44.888
10	33	16.908	33.954	23.943	43.523
9	30	16.605	32.077	23.613	41.329
8	27	16.297	29.677	23.289	38.434
7_REFUGE	24	12.708	26.858	17.863	34.976
6	21	12.404	23.718	17.532	31.079
5	18	12.119	20.343	17.222	26.856
4	15	11.846	16.814	16.93	22.406
3	12	11.588	13.2	16.658	17.815
2	9	11.346	9.562	16.407	13.155
1	6	11.161	5.956	16.27	8.487
GROUND	3	5.169	2.485	7.818	3.897
FOOTING	0	0	0	0	0

LATERAL LOAD (KN)					
STOREY	**HEIGHT**	**EQX (FILL)**	**EQX (NO FILL)**	**EQY (FILL)**	**EQY (NO FILL)**
TERRACE	36	795.8837	415.214	555.5243	310.0763
10	33	841.1687	362.8468	587.133	270.9692
9	30	695.1807	299.8734	485.2339	223.9415
8	27	461.525	242.8974	322.143	181.3926
7_REFUGE	24	364.6618	191.919	254.5327	143.3225
6	21	340.6386	146.938	237.7646	109.7313
5	18	250.2651	107.9544	174.6842	80.6189
4	15	173.7952	74.9683	121.3085	55.9854
3	12	111.2289	47.9797	77.6374	35.8306
2	9	62.5663	26.9886	43.6711	20.1547
1	6	22.7914	11.9949	15.9083	8.9577
GROUND	3	4.4439	2.9987	3.1018	2.2394
FOOTING	0	0	0	0	0

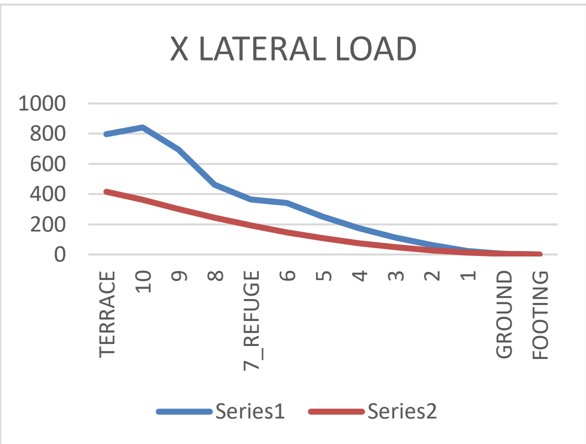
BASE SHEAR (KN)			
EQX (FILL)	**EQX (NO FILL)**	**EQY (FILL)**	**EQY (NO FILL)**
4124.14	1932.57	2878.64	1443.22

STOREY DRIFT					
STOREY	**HEIGHT**	**EQX (FILL)**	**EQX (NO FILL)**	**EQY (FILL)**	**EQY (NO FILL)**
TERRACE	36	4.90E-05	0.00019	5.10E-05	0.000205
10	33	4.50E-05	0.000278	4.90E-05	0.000329
9	30	4.60E-05	0.000356	4.80E-05	0.000434
8	27	0.000532	0.000418	0.000806	0.000518
7_REFUGE	24	4.50E-05	0.000465	4.90E-05	0.000584
6	21	4.20E-05	0.0005	4.60E-05	0.000633
5	18	4.00E-05	0.000523	4.30E-05	0.000667
4	15	3.80E-05	0.000535	4.00E-05	0.000688
3	12	3.60E-05	0.000539	3.70E-05	0.000698
2	9	3.50E-05	0.000534	3.50E-05	0.000699
1	6	0.000888	0.000514	0.001252	0.000691
GROUND	3	0.000766	0.000368	0.001158	0.000584
FOOTING	0	0	0	0	0

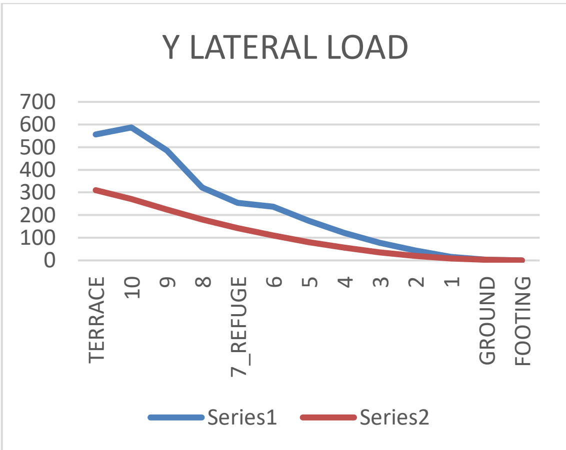
DeflectionVariation in X Dir



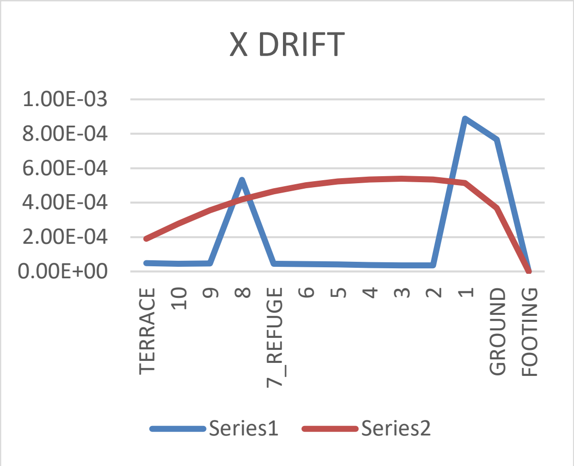
Deflection Variation in Y Dir



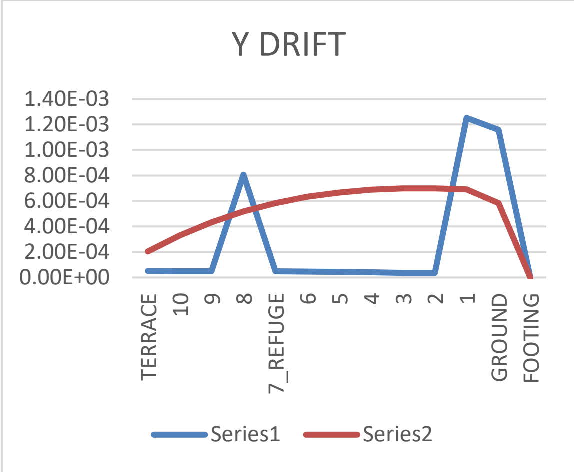
Lateral Load Variation in X Dir



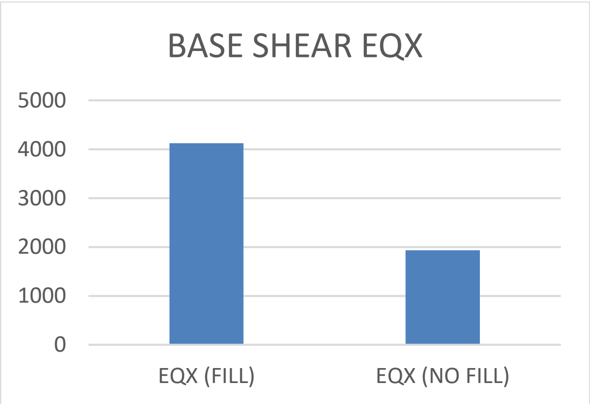
Lateral Load Variation in Y Dir

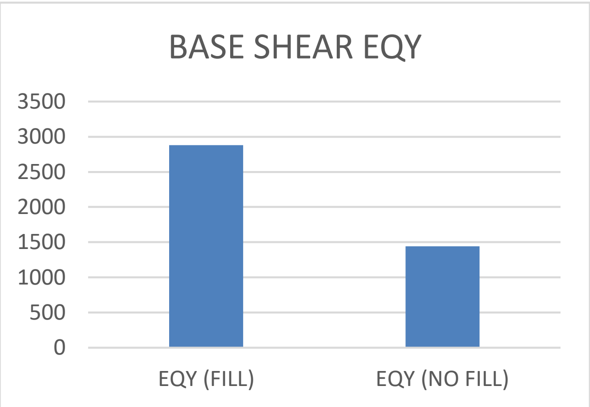


Storey Drift Variation in X Dir



Storey Drift Variation in Y Dir





Base Shear Variation in X Dir

Base Shear Variation in Y Dir

4.5 Conclusion

➢ Masonry infill walls significantly increases the lateral stiffness and strength of RC frames, leading to reduced natural periods and improved seismic performance.

➢ Structures with open ground storeys are prone to soft-storey mechanisms, leading to increased inter-storey drifts and potential collapse during seismic events.

➢ L-shaped buildings exhibit torsional irregularities, resulting in uneven distribution of seismic forces and increased vulnerability.

➢ Box shaped (regular plan) buildings demonstrate more uniform seismic response with reduced torsional effects, leading to better overall performance under seismic loading.

➢ Structures located in higher seismic zones (e.g., Zone V) experience greater seismic demands, necessitating robust design strategies, including the use of masonry infill and appropriate structural configurations, to ensure safety and performance.

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