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Assessment of Seismic Behavior of Flat Slabs in G+20 Building Structure

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Abstract*— *Flat-slab building structures possesses major advantages over traditional slab-beam-column structures because of the free design of space, shorter construction time, architectural –functional and economical aspects. Flat-slab structural system is significantly more flexible for lateral loads then traditional RC frame system due to absence of deep beams and that makes the system more vulnerable under seismic events

With few modifications by addition of beams and RC walls, flat slab system can be considered with acceptable seismic risk. Perimeter beams and RC walls improve strength and stiffness, improving seismic behaviour of flat slab construction system. Flat slab building structures are significantly more flexible than traditional concrete frame/wall or frame structures, thus becoming more vulnerable to second order P-∆ effects under seismic excitations. The characteristics of the seismic behaviour of flat slab buildings suggest that additional measures for guiding the conception and design of these structures in seismic regions are needed, as for instance the possible combination with other seismic resistant structural systems.

This paper aims to evaluate the Seismic behaviour of flat slab buildings in comparison to conventional reinforced concrete beam slab system used in combination with columns and shear walls, using ETABS analysis and design software. The study focuses on analysing and comparing key parameters such as displacement, inter-storey drift, base shear and modal mass participation by application of both wind and seismic loadings for the dynamic analysis.

I. INTRODUCTION

History

The first known systematic attempt to gain information on the stiffness of flat plates was undertaken by M.N. Patel in a doctoral program, completed in 1957, whose purpose was "to study the interaction between a column and a flat slab due to an unbalanced moment at the joint caused by any external or internal load".

In 1965, J. Carpenter presented in a doctoral thesis the results of an analytical and experimental study of the elastic behaviour (stiffness properties, distribution of moments and deflections) of flat plate structures subjected to lateral loads.

In the history of the development of flat slab design for uniform vertical loading, four major milestones are worth mention which helped in shaping the research on flat slabs.

1) The derivation by Nichols in 1914 of an expression for the total static moment in an interior-panel;
2) The determination by Westergaard and Slater in 1921 of the distribution of moments within-panel;
3) The devising of an equivalent frame design method by Dewell and Hammill in the early 1930’s;
4) The extensive programme of experimental and analytical work commenced at the University of Illinois in 1956, leading to the improved and rationalised design methods incorporated in the 1971 A.C.I. Code.

A. Lateral Loads

Lateral loads due to wind and earthquake governs the design rather than the vertical loads. The lateral loads are the premier ones because in contrast to vertical load that may be assumed to increase linearly with height; lateral loads are quite variable and increase rapidly with height. Under a uniform wind and earthquake loads the overturning moment at the base is very large and varies in proportion to the square of the height of the building. The lateral loads are considerably higher in the top storey rather than the bottom storey due to which building tends to act as cantilever. These lateral forces tend to sway the frame. In many of the seismic prone areas there are several instances of failure of buildings which have not been designed for earthquake loads. All these reasons make the study of the effect of lateral loads very important.

Flat slab punching shear is critical design consideration in structural engineering, this is in particular for flat slab-column systems in reinforced concrete structures. Punching failure forms a conical or pyramidal shape of cracked concrete around the perimeter of the column, leading to sudden collapse.

Buildings with flat slabs frequently experience unbalanced moments, which are caused by unequal spans or stress on either side of the column. When such situations occur, the punching phenomenon becomes asymmetrical, and the slab's punching strength decreases.

As a result, the column pierces the slab's outermost layer. Diagonal tension fractures that develop around the loaded area give rise to a conical failure surface, which causes punching shear failure.

Indian and international Codes provide guidelines for calculating the punching shear stress and accordingly design slab thickness to provide punching shear resistance and based on economy and practical limitations of acceptable slab thickness the codes provide formulae for calculation the reinforcement required to resist the punching shear. e.g. IS 456, IS 13920, ACI 318 and Eurocode 2.

IS 1893 (Part1):2016 highlights the following four main desirable attributes of an earthquake resistant building:

- Robust structural configuration
- At least a minimum elastic lateral stiffness,
- At least a minimum lateral strength, and
- Adequate Ductility.

Different types of structural irregularities are as follows:

B. Vertical Irregularity

Stiffness Irregularity: A soft storey has lateral stiffness that is less than 70% of that of the storey above or less than 80% of the average lateral stiffness of the three storeys above. An extreme soft storey has lateral stiffness that is less than 60% of that of the storey above or less than 70% of the average stiffness of the three storeys above. This includes structures like buildings that are raised on stilts.

Mass Irregularity: Mass irregularities exist when the effective mass of any storey exceeds 150 % of the effective mass of an adjacent storey.

Vertical Geometric Irregularity: Geometric irregularity exists when the horizontal

dimension of the lateral force resisting system in any storey is more than 150% of that in an

adjacent storey Brahme et al [12].

Discontinuity in capacity - Weak Storey: A weak storey is one whose storey lateral strength is less than 80% that of the storey above. The strength of all seismic force-resisting elements that share the storey's shear in the considered direction makes up the storey's lateral strength.

In-Plane Discontinuity in Vertical Elements Resisting Lateral Force: An in-plane offset of the lateral force resisting parts greater than their length.

Plan Irregularity

Torsion Irregularity: When the maximum storey drift, calculated with design eccentricity, at one end of the structure transverse to an axis is greater than 1.2 times the average of the storey drifts at the two ends of the structure, torsional irregularity is considered to exist.

Re-Entrant Corners: Re-entrant corners are present in the plan configurations of a structure and its lateral force resisting system when both of the structure's projections beyond the corner exceed 15% of the plan dimension in the given direction. Re-entrant, lack of continuity, or "inside" corners, which are frequent features of overall building layouts that, in a plan, assume the shape of an L, T, H, +, or combination of these shapes, come from the absence of tensile capacity and force concentration.

Diaphragm Discontinuity: Diaphragms with abrupt discontinuities or fluctuations in stiffness, such as those with cut-out or open portions larger than 50% of the total enclosed area or changes in effective diaphragm stiffness of more than 50% from one level to the next.

Out-of-Plane Offsets: Inconsistencies in a lateral force resistance path, such as offsets of vertical elements that aren't in the plane.

Non-parallel Systems: An in-plane offset of the lateral force resisting parts greater than their length Brahme et al [12].

Seismic Behavior of Flat Slab Building Structures

Seismic behavior of Flat Slabs is dependent on several structural and design factors which are examined in this section of the report, these are as follows:

C. Seismic Hazard

Seismic vulnerability is a critical parameter in conjunction with seismic hazard and exposure in defining seismic risk to building structures. The Characteristics i.e. the intensity, duration and frequency of seismic ground vibrations is dependent on the magnitude of earthquake, its focal depth, distance to epicentre, characteristics of the path through which seismic waves travel and the soil strata on which the structure is founded. The predominant direction of ground vibration is usually horizontal, however the Code (IS 1893-Part-1) recommends special attention to be given to the effects of vertical ground motion on prestressed members, cantilevered beams, girders and slabs. Actual forces that are developed in the structures during earthquakes are much greater than the design forces specified in the standard.

Figure 1 of IS 1893-Part-1 divides the country into seismic zones based on the severity of seismic hazard and provides response spectrum plot of design acceleration Sa/g Vs natural time period T, corresponding to 5 percent damping.

a. Seismic Vulnerability

Seismic vulnerability of building structures refers to its susceptibility to damage or collapse during an earthquake.

Factors influencing Seismic Vulnerability are as follows:

- Design and age of structure- Irregular or asymmetric buildings are more vulnerable to torsional effects during earthquakes. Older structures which are not designed to specifications my not comply with prevailing seismic design codes and standards.
- Geotechnical Conditions- Geotechnical parameters that vary based on the site locations influence the seismic behavior and buildings on weak or liquefaction prone soils may encounter higher risks.
- Material Properties and usage- Grade of concrete and steel reinforcement and detailing practices such as ductile detailing have greater influence on the response (extent of damage) and usability of buildings after seismic event.

b. Structural Systems

Using flat slab systems in seismic regions requires careful consideration due to their limited stiffness, ductility, and lateral load resistance. To ensure safety and compliance with seismic design requirements, flat slab systems are often combined with other structural systems that provide lateral load resistance and mitigate vulnerabilities.

Building structures with Flat slabs in seismic regions encounter the following challenges:

1. Lack of Lateral Stiffness:

Flat slabs rely solely on slab-column connections for lateral load resistance, which is insufficient in high-seismic zones.

2. Punching Shear at Column-Slab Connections:

Earthquake forces induce unbalanced moments and increased shear stresses, which can lead to brittle punching shear failure.

3. Drift and Deformation:

Flat slab systems may experience excessive lateral drift, making them unsuitable as standalone systems in seismic regions.

4. Low Ductility:

The absence of beams limits the redistribution of forces and reduces the structure's ability to absorb seismic energy.

To overcome these challenges Flat slab systems are combined with following complementary structural systems designed to resist lateral loads.

A. Flat slabs with Shear Walls

Shear walls are vertical structural elements designed to resist lateral loads and control drift.

Flat slabs primarily carry vertical loads, while shear walls handle seismic forces.

B. Flat Slabs with Core Walls

Core walls, often around staircases or elevators, act as a centralized lateral load-resisting system.

Flat slabs are designed to transfer loads to the core walls.

c. Aspects of Seismic Design

1. Punching Shear at Slab-Column Connections:

Earthquake-induced lateral drifts cause unbalanced moments and high shear stresses.

Failure at slab-column connections can lead to progressive collapse.

2. Story Drift:

Storey drift in any storey shall not exceed 0.004 times the storey height, under the action of design base shear as per Clause 7.11.1 of IS 1893-Part-1.

Storey drift can be controlled by increasing the lateral stiffness of structure, limits on drift ensure the structure remains operational and prevents progressive collapse during and after an earthquake.

3. Force Transfer between slab and shear walls:

Flat slabs act as diaphragms to distribute lateral forces across the structure and transfer them to shear walls. Types of diaphragms are Rigid, Semi-rigid and flexible, for the purpose of this analysis Semi-Rigid diaphragms are considered.

Shear forces are transferred from the flat slab to the shear walls through shear friction or dowel action. Proper reinforcement to be provided to ensure slab wall interface can resist these shear forces.

Earthquake induced moments in the slab can result in forces being transferred to the shear walls, the slab-wall connection must accommodate rotational demands to avoid local failure.

4. Torsional Effects:

Placement of the shear walls is critical and improper placement can result in torsional behaviour, increasing seismic demands

II. OUTCOME OF LITERATURE REVIEW

An overview of the literature reviewed specifies the below mentioned points associated with seismic behavior of flat slabs:

1. Lowest mode of vibration in flat slab buildings is the torsional mode, torsion in the first mode is characteristic with purely flat slab systems. To address this design must focus on balancing stiffness and mass distribution, enhancing diaphragm action and strategically integration lateral force resisting elements.
2. Uniform cracking in slabs and shear walls does not alter the mode shapes much and the building behaves as a system where the slab-column frame carries the gravity load and the resistance to lateral load was provided by shear walls.
3. Flat slab structures exhibit higher flexibility compared to traditional frame structures. In order to limit deformation demands under the seismic excitations, combination with other stiffer structural systems as shear walls is advisable.
4. Lateral Deformation for the Flat slab building is more as compared to both the wide beam and conventional beam system. Flat slab system has least lateral stiffness and hence undergoes more lateral deformation.

III. CODES AND STANDARD GUIDELINES

A. List of Codes

IS 456-2000 – Code of Practice for Plain & Reinforced Concrete Structure.

IS: 875 (Part 1) – 1987 – Code of Practice for Unit weights of buildings materials.

IS: 875 (Part 2) – 1987– Code of Practice) for building and structures-imposed loads.

IS: 875 (Part 3) – 2015 – Code of Practice for buildings and structures – wind load.

IS: 875 (Part 5) – 1987 – Code of Practice for Design Loads. (other than earthquake).

IS 1893 (Part 1):2016 – Criteria for Earthquake Resistant Design of Structure.

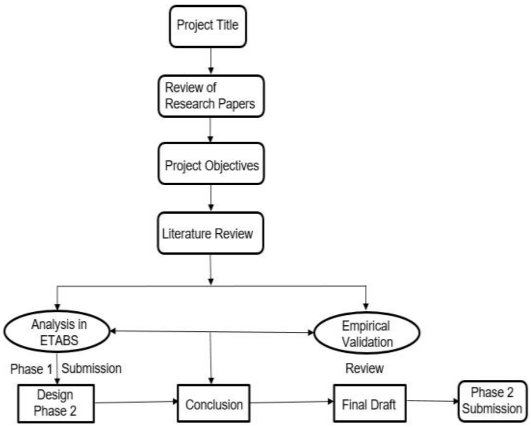
IS 13920:2016 – Ductile design and detailing of reinforced concrete structures.

IS 800:1984 & 2007 – Code of practice for general construction in steel.

IS 16700:2017 – Criteria for Structural Safety of Tall Concrete Buildings.

FEMA 310 – Handbook for Seismic Evaluation of Buildings-1998.

B. Work Flowchart



C. Material Modelling

The primary material defined and assigned to objects in the analysis is concrete and steel. All the horizontal floor elements are modelled to the required thicknesses and assigned section properties.

The geometry of the slab and wall elements is assigned meshing either by floor auto-mesh or wall auto-mesh as appropriate. The floor elements are assigned semi-rigid diaphragms based on their realistic behavior as recommended from several experimental studies.

The base of the structure is assigned fixed supports however, spring supports can be assigned with stiffness to idealize the pile foundations.

D. Material Properties

The concrete elements have been assigned with grade of concretes based on their function as follows:

Slabs- M30

Beams- M30

Walls/Columns- M40

Grade of Reinforcement Shall be FE500D suitable for ductile detailing

Table I: Seismic Load is applied as per IS 1893-Part-1-2016 for zone 3.

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

Table 2 of the Indian Standard IS 1893: (Part 1) 2016 classifies the seismic intensity of Zone III as moderate and the corresponding seismic acceleration is 0.16 as shown below.

The foundation is considered as Pile Foundation & Piles are anchored in hard rock. So, the soil type is considered as Hard Soil.

The Hard Soil is classified as Soil Type I as per IS 1893 Part 1 – 2016.

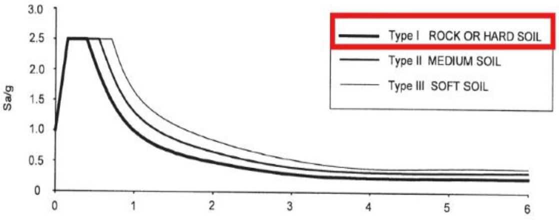
Seismic loads on the building are calculated based on IS 1893 Part 1 – 2016. Since the building lateral force resisting system is ductile shear walls, the formula used for calculating the seismic periods for the purpose of design is

$$T_a = (0.075*h^{0.75}) \ / \ (A_w)^{0.5} >= 0.09 \times H/\sqrt{D}$$

Where,

A_w = total effective area of walls in 1st storey of the building.

As outlined in page 24 of IS 1893 – Part I. Response spectrum method is used for building design. The response spectrum function used in the analysis is the function corresponding to type II soil (rock) as shown in the figure below:



2B SPECTRA FOR RESPONSE SPECTRUM METHOD

FIG. 2 DESIGN ACCELERATION COEFFICIENT (S_a/g) (CORRESPONDING TO 5 PERCENT DAMPING)

The design base shear Vb for each direction is scaled to match the base shear calculated using the fundamental period Ta defined in equation 4.1 above. A damping ratio of 5% of critical (typical concrete buildings) is used for the building analysis.

Basic input parameters for the seismic load are shown on the table below:

Table II:

No	Description	Value	Reference
1.	Seismic zone factor Z	0.16 (III)	IS 1893 Clause 6.4.2, Page 10, Table 3
2.	Structure importance	1.2	IS 1893 Clause 7.2.3, Page 19,

	coefficient – I		Table 8
3.	Site Classification	I	As per Geotechnical Report
4.	Response reduction factor R Ductile Shear Walls	4	IS 1893 Clause 7.2.6, Page 20, Table 9
5.	% of Live load considered in seismic	25% for loads ≤ 3 KN.m2 50% for loads > 3 KN.m2	IS 1893 Clause 7.3.1 Page 20, Table 10

Table III: Time Period Calculations

Time Period Calculations	**1 BHK**		**2 BHK**		**3 BHK**	
	X Direction	Y Direction	X Direction	Y Direction	X Direction	Y Direction
$\frac{0.09h}{\sqrt{d}}$	1.206Sec	1.367Sec	1.119Sec	1.25Sec	0.9249Sec	1.598Sec
0.0675H0.75	1.545Sec	1.545Sec	1.545Sec	1.545Sec	1.545Sec	1.545Sec

IV. PRIMARY LOADS AND LOAD COMBINATIONS

Table IV: ETABS – 21.0 -software is used for analysis.

Primary Loads		
	Dead Load	DL
	Live Load	LL
	Super dead	SDL
	Earthquake in X direction	SPEC 1
	Earthquake in Y direction	SPEC 2
	Earthquake in Z direction	SPEC 3
	Wind in X direction	WLX
	Wind in Y direction	WLY
	Across wind in X direction	AWYX
	Across wind in Y direction	AWXY

Table V: Stiffness/Property Modifiers Used for Design.

STIFFNESS /PROPERTY MODIFIERS		
Line Elements	**SLS**	**ULS**
a. Frame Beams		
MI About 2 Axis	0.7	0.35
MI About 3axis	0.7	0.35
Torsional Constant	1.0	0.01
b. Secondary Beams		
MI About 2 Axis	0.7	0.35
MI About 3axis	0.7	0.35
Torsional Constant	1.0	0.01
c. Columns		
MI About 2 Axis	0.9	0.7
MI About 3axis	0.9	0.7
Torsional Constant	1.0	1.0
Shell Elements	**SLS**	**ULS**
a. Slabs		
Bending M11 Direction	0.35	0.25
Bending M12 Direction	0.35	0.25
Bending M22 Direction	0.35	0.25
Membrane F11 Direction	0.35	0.1
Membrane F12 Direction	0.35	0.1
Membrane F22 Direction	0.35	0.1
b. Shear Walls		
Bending M11 Direction	0.9	0.7
Bending M12 Direction	0.9	0.7
Bending M22 Direction	0.9	0.7
Membrane F11 Direction	0.9	0.7
Membrane F12 Direction	0.9	0.7
Membrane F22 Direction	0.9	0.7

V. RESULTS AND DISCUSSION

A. Displacement

Conventional RCC Slab Beam Structure system with Shear walls Table VI

Table VI: Diaphragm Center of Mass Displacements

Story	**Diaphragm**	**Output Case**	**Case Type**	**UX**	**UY**	
				mm	mm	**Permissible Limit**
TERRACE	D1_SEMIRIGID	WX	LinStatic	18.568	0.011	H/500 =130
TERRACE	D1_SEMIRIGID	WY	LinStatic	-0.057	26.337	H/500 =130
TERRACE	D1_SEMIRIGID	GWX	LinStatic	19.851	-0.02	H/250=260
TERRACE	D1_SEMIRIGID	GWY	LinStatic	-0.018	27.288	H/250=260
TERRACE	D1_SEMIRIGID	SPEC1	LinRespSpec	18.917	0.047	H/250=260
TERRACE	D1_SEMIRIGID	SPEC2	LinRespSpec	0.252	24.432	H/250=260

RCC Flat slab structural system with Shear walls Table VII

Table VII: Diaphragm Center of Mass Displacements

Story	**Diaphragm**	**Output Case**	**Case Type**	**UX**	**UY**	
				mm	mm	**Permissible Limit**
TERRACE	D1_SEMIRIGID	WX	LinStatic	27.105	-0.002	H/500 =130
TERRACE	D1_SEMIRIGID	WY	LinStatic	-0.178	34.997	H/500 =130
TERRACE	D1_SEMIRIGID	GWX	LinStatic	29.351	-0.176	H/250=260
TERRACE	D1_SEMIRIGID	GWY	LinStatic	-0.202	36.22	H/250=260
TERRACE	D1_SEMIRIGID	SPEC1	LinRespSpec	19.847	0.304	H/250=260
TERRACE	D1_SEMIRIGID	SPEC2	LinRespSpec	0.589	27.329	H/250=260

From the comparison of displacements, it is evident that Flat slab structural system with Shear walls experiences higher displacements compared to conventional RCC Slab Beam System

B. Story Drift

Conventional RCC Slab Beam Structure system with Shear walls Table VIII

Table VIII: Story Drifts

Story	**Output Case**	**Case Type**	**Direction**	**Drift**	**Permissible Limit**
13TH FLOOR	WX	LinStatic	X	0.00019	0.002
13TH FLOOR	WY	LinStatic	Y	0.000247	0.002
13TH FLOOR	SPEC1	LinRespSpec	X	0.000351	0.004
13TH FLOOR	SPEC2	LinRespSpec	Y	0.000395	0.004
12TH FLOOR	WX	LinStatic	X	0.000197	0.002
12TH FLOOR	WY	LinStatic	Y	0.00026	0.002
12TH FLOOR	SPEC1	LinRespSpec	X	0.000353	0.004
12TH FLOOR	SPEC2	LinRespSpec	Y	0.0004	0.004
8TH (REFUGE)	WX	LinStatic	X	0.000214	0.002
8TH (REFUGE)	WY	LinStatic	Y	0.000297	0.002
8TH (REFUGE)	SPEC1	LinRespSpec	X	0.00035	0.004
8TH (REFUGE)	SPEC2	LinRespSpec	Y	0.000406	0.004
7TH FLOOR	WX	LinStatic	X	0.000214	0.002

Story	Output Case	Case Type	Direction	Drift	Permissible Limit
7TH FLOOR	WY	LinStatic	Y	0.000301	0.002
7TH FLOOR	SPEC1	LinRespSpec	X	0.000347	0.004
7TH FLOOR	SPEC2	LinRespSpec	Y	0.000404	0.004

RCC Flat slab structural system with Shear walls Table IX

Table IX: Story Drifts

Story	Output Case	Case Type	Direction	Drift	Permissible Limit
13TH FLOOR	WX	LinStatic	X	0.000502	0.002
13TH FLOOR	WY	LinStatic	Y	0.000606	0.002
13TH FLOOR	SPEC1	LinRespSpec	X	0.000561	0.004
13TH FLOOR	SPEC2	LinRespSpec	X	0.000582	0.004
12TH FLOOR	WX	LinStatic	X	0.000526	0.002
12TH FLOOR	WY	LinStatic	Y	0.000648	0.002
12TH FLOOR	SPEC1	LinRespSpec	X	0.000569	0.004
12TH FLOOR	SPEC2	LinRespSpec	X	0.0006	0.004
8TH (REFUGE)	WX	LinStatic	X	0.000583	0.002
8TH (REFUGE)	WY	LinStatic	Y	0.000777	0.002
8TH (REFUGE)	SPEC1	LinRespSpec	X	0.000582	0.004
8TH (REFUGE)	SPEC2	LinRespSpec	X	0.000641	0.004
7TH FLOOR	WX	LinStatic	X	0.00058	0.002

Drift measured at the Middle storey is the highest for both the Structural systems, however the Flat slab structural system experiences a higher drift compared to conventional beam slab system.

C. Base Shear

Conventional RCC Slab Beam Structure system with Shear walls Table X

Table X: Base Reactions

Output Case	Case Type	FX	FY
		kN	kN
DEAD	LinStatic	0	0
LIVE	LinStatic	0	0
SDL	LinStatic	0	0
EQX	LinStatic	2856.2087	0
EQY	LinStatic	0	-2856.2087
WX	LinStatic	-2071.603	0
WY	LinStatic	0	-2609.1919
GWX	LinStatic	2105.6534	0
GWY	LinStatic	0	-2579.9255
SPEC1	LinRespSpec	3322.7804	160.674
SPEC2	LinRespSpec	118.3153	3454.2617
LIVE1	LinStatic	0	0
SPEC3	LinRespSpec	387.1219	369.1947
AWYX	LinStatic	-720.3684	0

Output Case	Case Type	FX	FY
		kN	kN
AWXY	LinStatic	0	-796.8766

RCC Flat slab structural system with Shear walls Table XI

Table XI: Base Reactions

Output Case	Case Type	FX	FY
		kN	kN
DEAD	LinStatic	5.793E-07	0
LIVE	LinStatic	0	0
SDL	LinStatic	0	-8.331E-07
EQX	LinStatic	-2560.2957	0
EQY	LinStatic	0	-2560.2957
WX	LinStatic	-2071.603	0
WY	LinStatic	3.245E-06	-2609.1919
GWX	LinStatic	-2105.6534	0
GWY	LinStatic	0	-2579.9254
SPEC1	LinRespSpec	2158.168	399.5664
SPEC2	LinRespSpec	533.202	2133.623
LIVE1	LinStatic	0	0
SPEC3	LinRespSpec	379.2684	1120.0263
AWYX	LinStatic	-720.3684	0
AWXY	LinStatic	0	-796.8766
LIVE2	LinStatic	0	0

Base Reactions due to seismic load case are higher for Conventional beam-slab system and lower for RCC Flat Slab system.

D. Modal Participating Mass Ratios

Conventional RCC Slab Beam Structure system with Shear walls Table XII

Table XII: Modal Participating Mass Ratios

Case	Mode	Period	UX	UY	SumUX	SumUY	RZ
		sec					
Modal	1	2.158	9.645E-07	0.7291	9.645E-07	0.7291	0.000005127
Modal	2	2.035	0.646	0.000002469	0.646	0.7291	0.0684
Modal	3	1.793	0.0646	0.000002972	0.7106	0.7291	0.6462
Modal	4	0.633	0	0.1383	0.7106	0.8674	0
Modal	5	0.576	0.1327	0	0.8434	0.8674	0.0082
Modal	6	0.407	0.0307	0	0.874	0.8674	0.0757
Modal	7	0.32	0.000007936	0.0478	0.874	0.9152	0.00001368
Modal	8	0.207	0.0833	0.0001	0.9573	0.9153	0.0068
Modal	9	0.188	0.0002	0.000002818	0.9575	0.9153	0.0001
Modal	10	0.164	0.00003709	0.0172	0.9575	0.9325	0.0017
Modal	11	0.163	0.0003	0.0362	0.9578	0.9687	0.0003
Modal	12	0.074	0.00002967	0	0.9579	0.9687	0.0056

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RCC Flat slab structural system with Shear walls Table XIII

Table XII: Modal Participating Mass Ratios

Case	Mode	Period	UX	UY	SumUX	SumUY	RZ
		sec					
Modal	1	2.509	0.5104	0.0003	0.5104	0.0003	0.197
Modal	2	2.456	0.0003	0.7314	0.5107	0.7318	0.00003367
Modal	3	2.09	0.1917	0.00001496	0.7025	0.7318	0.507
Modal	4	0.714	0.000008969	0.1245	0.7025	0.8563	0.000003378
Modal	5	0.678	0.1039	0.00001472	0.8064	0.8563	0.0307
Modal	6	0.523	0.0442	0	0.8507	0.8563	0.0965
Modal	7	0.354	0.00001988	0.049	0.8507	0.9053	0.00001161
Modal	8	0.256	0.0792	0.001	0.9299	0.9062	0.0057
Modal	9	0.2	0.0117	0.028	0.9416	0.9343	0.0002
Modal	10	0.168	0.000007395	0.0036	0.9416	0.9378	0.00001397
Modal	11	0.139	0.0053	0.026	0.9469	0.9639	0.0013
Modal	12	0.097	0.0044	0.0044	0.9513	0.9683	0.0039

For the Modal Case Torsion is developed in the first mode for Flat slab structure system, The mass participating in translation for first mode is more than 70% for Conventional beam slab system and only 50% for Flat slab system. As more than 50 % mass is mobilized in the first mode torsional effects can be ignored, however reconfiguration of shear walls may result in better performance by eliminating torsion in first mode.

For conventional Beam Slab system with shear walls Story Response - Maximum Story Displacement

This is story response output for a specified range of stories and a selected load case or load combination.

Name	**StoryResp1**		
Display Type	Max story displ	Story Range	All Stories
Load Case	SPEC1	Top Story	OHWT TOP
Output Type	Not Applicable	Bottom Story	BASE

Plots for Displacement, Story Drift, Base Shear and Modal Mass Participation Ratios

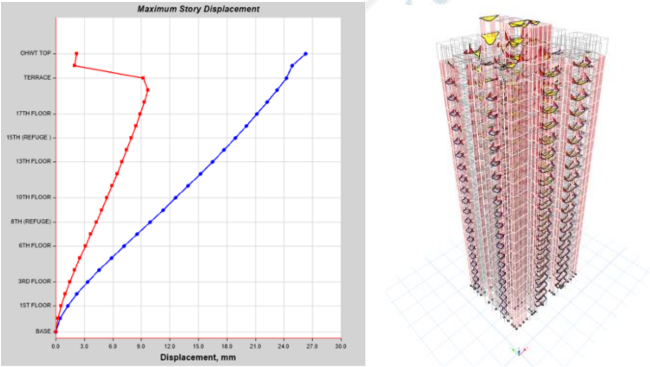

Fig.1. BMD

RCC Flat slab structural system with Shear walls Story Response - Maximum Story Displacement

This is story response output for a specified range of stories and a selected load case or load combination.

Name	**StoryResp1**		
Display Type	Max story displ	Story Range	All Stories
Load Case	SPEC1	Top Story	OHWT TOP
Output Type	Not Applicable	Bottom Story	BASE

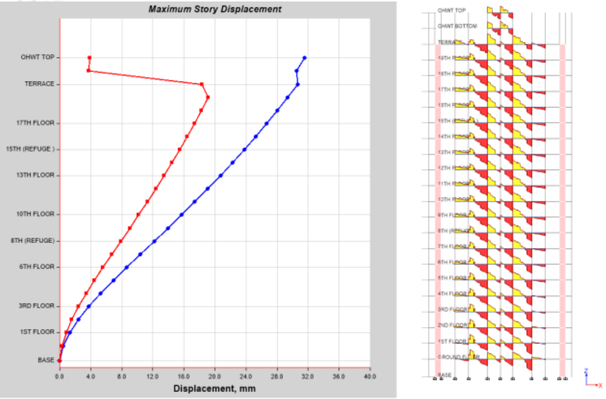

Fig. 2. SFD

The maximum storey displacement for Flat Slab system is observed to be higher compared to the storey displacement for beam slab system.

For conventional Beam Slab system with shear walls Story Response - Maximum Story Drifts

This is story response output for a specified range of stories and a selected load case or load combination.

Name	**StoryResp3**		
Display Type	Max story drifts	Story Range	User Specified
Load Case	SPEC1	Top Story	TERRACE
Output Type	Not Applicable	Bottom Story	BASE

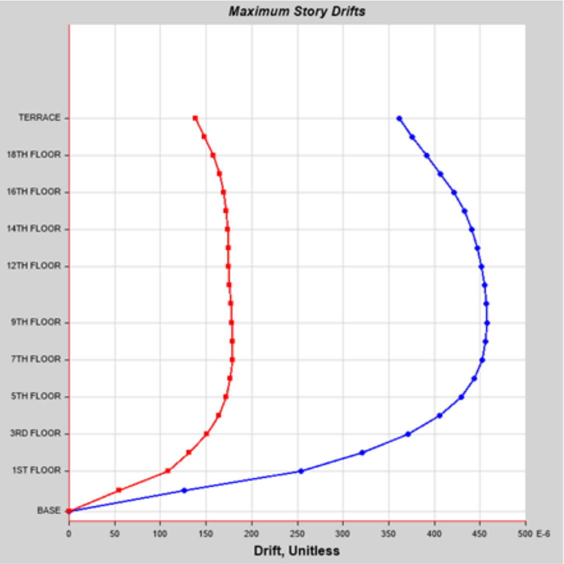

Fig. 3

RCC Flat slab structural system with Shear walls Story Response - Maximum Story Drifts

This is story response output for a specified range of stories and a selected load case or load combination.

Name	**StoryResp2**		
Display Type	Max story drifts	Story Range	User Specified
Load Case	SPEC1	Top Story	TERRACE
Output Type	Not Applicable	Bottom Story	BASE

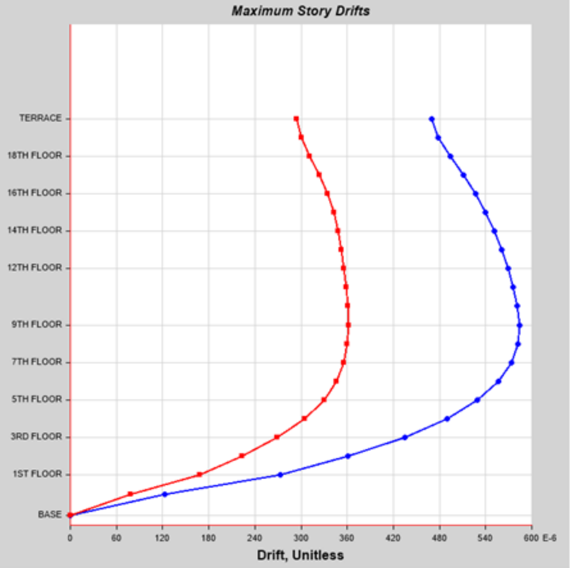

Fig. 4

The storey drift for Flat slab structural system is much higher compared to conventional beam slab system.

VI. CONCLUSION AND SCOPE FOR UPCOMING RESEARCH WORK

1. From the results of analysis it is established that due to the reduced stiffness of Flat slab structure the displacement and story drift are observed to be higher compared to conventional RCC Beam-slab structure.
2. The value of seismic base shear is observed to be higher for conventional RCC Beam-slab system compared to the Flat slab structure.
3. When the Modal participating mass ratios are compared it is evident that Torsion is developed in the first mode for Flat slab building structure, this identifies and matches the observations of other research available in the field of seismic analysis and design of flat slabs.
4. The upcoming research will include design of flat slab-shear wall/column connection and utilization of shear reinforcement to control the drift of Flat slab building structure. Also as a part of the current research it is intended to develop a checklist which will provide guidance on the best practices and their implementation for designing robust structures using Flat Slabs with shear walls.

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