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Performance Based Seismic Design of Braced Composite Multi Storied Building

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Abstract: Steel-concrete composite construction system is an efficient, economical and innovative method for seismic resistance of multi storied buildings. This paper represents a study on economic aspects of G+4 multi storied building designed by using braced frame composite construction. Since ductility, stiffness, inter storied drift and lateral displacements are the critical issues in seismic design of buildings, different types of braced frame models are developed in this study and evaluated its structural performance. Equivalent static method of seismic analysis used in the analysis of geometric models and the results are compared with STRAP software. This study makes an attempt, to develop efficient geometric models for new constructions, and to provide necessary structural configuration against retrofitting of the existing structures, constructed in earthquake prone regions.

Keywords- Composite construction, seismic zone, ductility, lateral displacement, braced model, Strap software.

I. INTRODUCTION

Composite structures are reliable and show good performance against stiffness, strength, ductility, and which are the key parameters for design of seismic resistance high raised buildings. Braced frame models are efficient means to transfer lateral forces caused by wind and earthquake. Braced frames are less weight than shear walls, so that it will attract less seismic forces. Braced frames models are proven effective means to enhance ductility of the structure and efficient means to control inter storey drift and lateral displacement of the structure.

D.R Panchal et al. [1] , concluded that Steel–concrete composite system perform excellent seismic performance than conventional RCC and Steel Buildings. From Literature review it shows that Braced frame models can also perform excellent seismic resistance in earth quake prone regions. Seyed Hamid Hashemi [2], explained that eccentrically braced frames have high stiffness against the lateral loads such as earthquake and perfect ability to absorb energy. Egor P. Popov et al. [3], provided an overview of seismic resistance eccentrically braced frames with particular emphasis on the behavior and design of shear links. Rafeel Sabelli et al. [4] gave the guide lines on seismic design of steel special concentrically braced frame systems. Due to the truss action generated by the braced frames, the lateral forces are effectively transferred to the foundation with well-defined energy dissipation system .Braced frame action improves seismic characteristics like ductility, stiffness, energy dissipation, and decrease inter-storey drift of the structure. In this context, this paper explains how to develop efficient building models in seismic region. For the purpose of design study, G+4 commercial building selected in seismic zone III in India with wind speed 50m/sec. The plan dimension of the building is 30.5X18.5m with total height 18.75m (each storey height 3.75m) as shown in Table 1& fig 1. Due to constrained architectural requirements, large span column free areas are proposed (10m & 6m span) in both longitudinal and lateral directions of the building. Due to enhanced commercial operations in the structure and to maintain geometric symmetry, separate provisions are made for lift, stair ways, and other accessories and the design scope excluded from the present study.

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II. OBJECTIVE OF STUDY

The objective of this study is to develop efficient building models by using combination of CBF & EBF braced frames. Five types of multi storied braced frame models are developed in seismic zone III, and evaluated its structural performance with respect to member strength, ductility and inter storey drift. Equivalent static method used for seismic analysis and the results are verified by STRAP software. The results of all five models are analyzed (Ref Table 2-5) and selected an efficient structural model for design of five storied commercial building.

Table 1: Data for analysis of G+4 building

Type of structure	Braced frame composite construction		**Grade of concrete**	M 30
Number of storey's	G+4		**Grade of Reinforced steel**	Fe 415
Plan dimensions	30X18m		**Seismic loads**	As per IS 1893
Each floor height	3.75m		**Thickness of composite slab**	130mm
Foundation system	Raft foundation		**Size of composite columns**	500x500mm
Soil conditions	Medium stiff gravel soil		**Size of steel beams**	UB 610X229mm
Wind speed	50m/sec		**Size of steel column**	UC 305X305mm
Seismic zone	Zone III		**Size of steel bracings**	178x76x4mm channel section [ ]
Zone factor	0.16		**Live loads on slab**	$4kn/m^2$
Importance factor	1.0		**Floor finish**	$1kn/m^2$
Structural steel	S275 (Fy: 275 N/MM^2)		**Damping ratio**	5 %

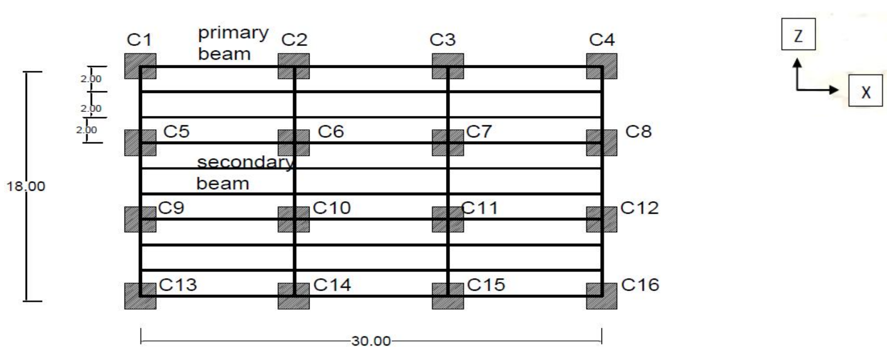

Fig 1 Typical floor Plan of G+4 commercial building

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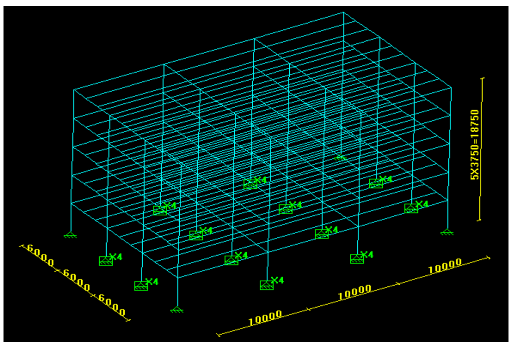
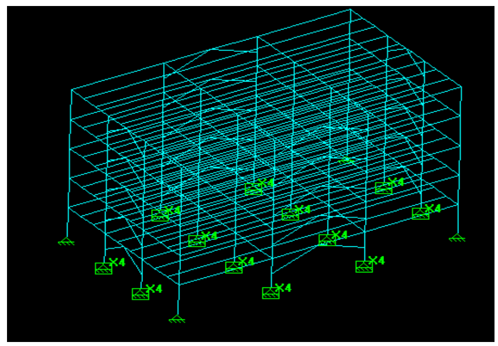
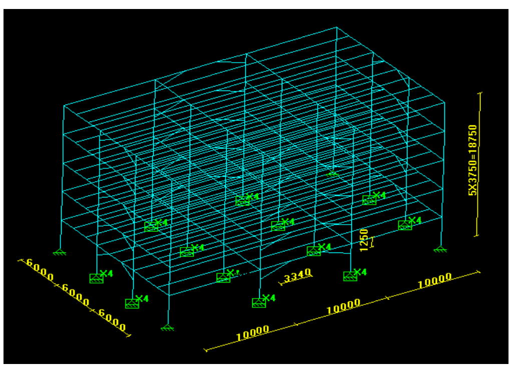
Fig 1: Shows typical floor plan and position of 16 columns represented by C1 to C16 and beams. All the column sections are made with encased steel concrete composite construction. The spacing between the columns are 6m in lateral direction [x direction] and 10m in longitudinal direction [y direction].Beams are divided in to two categories as primary and secondary beams. Primary beams are directly rest on columns with restrained end conditions. Secondary beams are those which are connected to the primary beams by semi rigid connections. Secondary beams are provided with stud type shear connectors to facilitate composite action by floor slab.



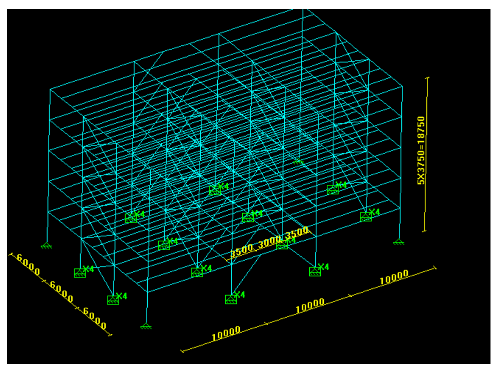
(a): Bare frame composite structure-(without bracing)



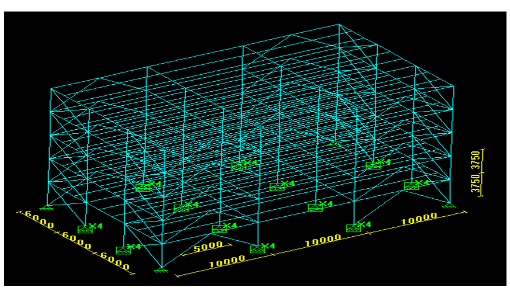
(b): Knee -type concentric mid span bracing



(c): Haunch type eccentric mid span bracing



(e): Chevron & X type eccentric and concentric bracing



(d) K & X type concentric end span bracing

Fig 2: (a), (b), (c), (d), (e) Five different types of Braced Composite models

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III.ANALYSIS

Fig 2: Constitute five different types of braced frame models (a, b, c, d, and e) considered in the analysis. Model (a) is a bare frame five storied structure without bracings. Model (b) is a knee type concentric bracing arranged in the mid span of external frame in both X & Z directions. Model (c) is a haunch type eccentric bracing pattern arranged in the mid span of external frame in both X & Z directions. Model (d) is a K & X type concentric bracing pattern respectively, arranged in the end span of external frame in both X & Z directions. Model (e) is a chevron & X type eccentric and concentric bracing pattern arranged in the end span of external frame in both X & Z directions respectively. The explained five types of building models analyzed by using Equivalent static method and the results are verified by STRAP software. Design parameters such as support reactions, bending moment, shear force, overall deflection, and story drift are verified as per the values presented in Table 3, 4, 5 & 6.

IV. RESULTS

Table 2 Maximum moments and forces in External Beams of five different models

ANALYSIS OF FORCES IN EXTERNAL BEAMS				
TYPE OF BRACED MODEL	**BEAM LOCATION**	**DIRECTION**	**MAX SHEAR FORCE**	**MAX BENDING MOMENT**
			KN	**KN-M**
MODEL -I (unbraced)	END SPAN	**X**	95.9	246
		Z	7.88	326
	MID SPAN	**X**	55.4	145
		Z	7.88	326
MODEL -II (knee braced)	END SPAN	**X**	91.9	245
		Z	11.9	390
	MID SPAN	**X**	46.1	69
		Z	133	120
MODEL -III (haunch braced)	END SPAN	**X**	64.9	171
		Z	11.9	390
	MID SPAN	**X**	320	520
		Z	451	492
MODEL -IV (K & X type concentric bracing)	END SPAN	**X**	58.8	38.4
		Z	11.9	328
	MID SPAN	**X**	91.9	245
		Z	11.9	328
MODEL –V(chevron & X type eccentric and concentric bracing)	END SPAN	**X**	95.9	246
		Z	7.88	326
	MID SPAN	**X**	178	225
		Z	7.88	326

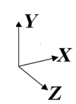

Table 2, Represents the Analysis of forces in external beams for five different braced composite models, the forces which are maximum shear forces and maximum bending moments of end span and mid span of External Beams.

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ANALYSIS OF FORCES IN INTERNAL BEAMS				
TYPE OF BRACED MODEL	BEAM LOCATION	DIRECTION	MAX SHEAR FORCE	MAX BENDING MOMENT
			KN	KN-M
MODEL -I (unbraced)	END SPAN	X	144	374
		Z	7.88	678
	MID SPAN	X	63.4	171
		Z	7.88	678
MODEL -II (knee braced)	END SPAN	X	167	448
		Z	16	740
	MID SPAN	X	167	448
		Z	16	740
MODEL -III (haunch braced)	END SPAN	X	113	300
		Z	17.8	715
	MID SPAN	X	113	300
		Z	10.2	733
MODEL -IV (K & X type concentric bracing)	END SPAN	X	136	371
		Z	16	618
	MID SPAN	X	136	371
		Z	16	618
MODEL -V (chevron & X type eccentric and concentric bracing)	END SPAN	X	144	374
		Z	7.88	613
	MID SPAN	X	217	265
		Z	7.88	613

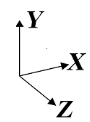

Table 3 Maximum moments and forces in internal beams of five different models

	COLUMNS	FX	FY	FZ	MX
		KN	KN	KN	KN-M
MODEL -I (unbraced)	C6	219	4656	96.2	1010
	C7	219	4656	95.8	1010
	C10	219	4656	96.2	1010
	C11	219	4656	95.8	1010
MODEL -II (knee braced)	C6	6.9	4622	57.6	249
	C7	6.9	4622	57.6	249
	C10	6.9	4622	57.6	249
	C11	6.9	4622	57.6	249
MODEL -III (haunch braced)	C6	27.2	5677	82.4	388
	C7	27.2	5677	82.1	386
	C10	27.2	5677	80.1	386
	C11	27.2	5677	79.8	385
MODEL -IV (K & X type concentric bracing)	C6	1.7	4622	29.6	88.1
	C7	1.7	4622	29.6	88.1
	C10	1.7	4622	29.6	88.1
	C11	1.7	4622	29.6	88.1
MODEL -V (chevron & X type eccentric and concentric bracing)	C6	255	4661	242	76.6
	C7	255	4661	242	76.6
	C10	255	4662	242	76.6
	C11	255	4659	242	76.6

Table 4 Maximum Support Reactions for internal columns C6, C7, C10, and C11 of five different models

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Table 3, Represents the Analysis of forces in internal beams for five different braced composite models, in which maximum shear forces and maximum bending moments of end span and mid span Internal Beams. In model -V (chevron & X type eccentric and concentric bracing) which shows the lesser values than any other models and all sections are safe under Lateral loads and Gravity Loads. Table 4 Represents the Internal Column support reactions, Forces along X, Y, Z directions, which shows FX, FY, FZ and Moments along X-direction, which shows MX are presented.

Table 5 Maximum Support Reactions for External Columns C1, C2, C3, C9, C13, and C14and C15 of five different models

EXTERNAL COLUMN SUPPORT REACTIONS						
MODELS	**COLUMNS**	**FX**	**FY**	**FZ**	**MX**	**MZ**
		KN	**KN**	**KN**	**KN-M**	**KN-M**
MODEL -I (unbraced)	C1	937	1363	115	1023	3509
	C2	220	2659	134	1035	
	C3	220	2562	134	1035	
	C9	219	2448	96.5	1010	
	C13	935	1363	115	1023	3598
	C14	218	2562	134	1035	
	C15	218	2521	134	1035	
MODEL -II (knee braced)	C1	194	1363	77.2	261	603
	C2	226	2759	96.9	274	
	C3	226	2759	96.9	274	
	C9	16.8	3237	455	602	
	C13	194	1363	77.2	261	603
	C14	226	2759	96.9	274	
	C15	226	2759	96.9	274	
MODEL -III (haunch braced)	C1	413	1696	99	397	1231
	C2	161	3243	113	402	
	C3	161	3243	108	496	
	C9	80.5	3802	375	710	
	C13	413	1696	104	404	1231
	C14	161	3243	132	426	
	C15	161	3243	132	425	
MODEL -IV (K & X type concentric bracing)	C1	312	2032	256	100	117
	C2	274	2533	66.8	113	
	C3	274	2533	66.9	113	
	C9	16.2	2576	242	87.9	
	C13	312	2123	311	100	117
	C14	274	2533	66.8	113	
	C15	274	2533	66.9	113	
MODEL -V (chevron & X type eccentric and concentric bracing)	C1	79.4	1363	49.6	78.8	178
	C2	208	2577	69.2	91.1	
	C3	208	2578	69.2	91.1	
	C9	21.2	2471	216	76.6	
	C13	79.5	1363	49.6	78.8	178
	C14	209	2577	69.2	91.1	
	C15	209	2578	69.2	91.1	

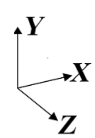

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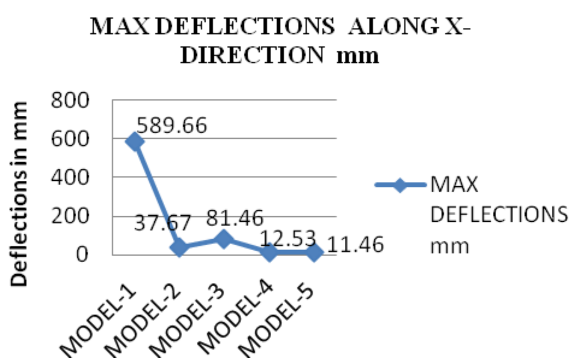
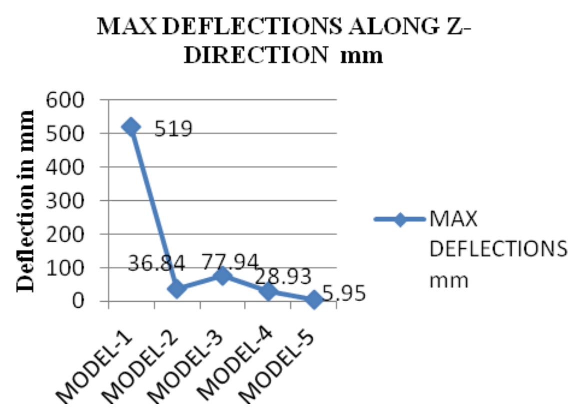
Table 5 Represents the External Column support reactions, Forces along X, Y, Z directions, which shows FX, FY, FZ and Moments along X, Z-direction, which shows MX and MZ are presented. During Analysis all external Column sections are failed except in model 5, because of combination of Eccentric and Concentric bracings are used in modeling of structure in model-5.



(a)



(b)

Fig 3: (a) represents the maximum overall deflection of a building along x-direction, (b) represents the maximum overall deflection of a building along z- direction. From the above figures we can observe that maximum deflection of model-5 (chevron & X type eccentric and concentric bracing) is Less than other models. Hence Model -5 is proposed for design of composite multi storied building.

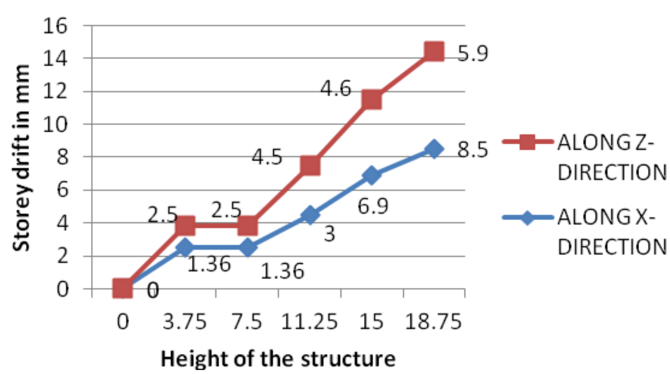


Fig 4: Storey Drift for Model-5 along X & Z direction

The above figure represents the Storey Drift for model 5 along x & z direction, the storey drift is taken by considering the lateral loads along x & z direction. From the figure we can observe that the top storey at height of 18.75 m has maximum drift.

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V. RESULTS AND DISCUSSIONS

1. Considering overall deflection of the structure, (X & Z directions), bending moments, shear forces in beams and column, model IV is selected from the five trail models.
2. In model – 4, The Lateral Load Resistance System provided by arrangement of Eccentric braced frames (as shown in figure) in both external and internal mid spans (X direction) and Concentric X type braced frames in mid span in both external and internal mid spans (Z direction.)
3. Due to the truss action formed in the braced frame model, the design may concentrate distribution of seismic lateral loads by bracings and both external, internal walls are exempted to transfer shear loads by other structural members. This consideration helps to avoid soft storey failure in seismic multi storied buildings.
4. Maximum lateral deflections of G+4 multi storied building is limited to X direction 8.5 mm (long span of building) and Z direction 5.95mm(Short span direction of the building)
5. The Maximum inter storey drift between the floors are limited to 1.8mm (X direction) and 1.5mm(Direction), which are less than allowable tolerance limits in buildings.

VI. CONCLUSIONS

1. Braced frame models are efficient means to show ductile performance of the structure, and they provide effective means of lateral load resistance system.
2. The overall displacement and inter storey drift of the structure can effectively controlled by adopting braced frame models.
3. The designer has versatility to adopt different patterns of braced frames for lateral load resisting system.
4. Braced frames are light weight structure with good strength and stiffness .Due to this reason; these models are less susceptible against seismic forces acting on the structure.
5. Braced composite construction is an effective measure for construction of earth quake resistant multi storied buildings due to the fact that both structural and material performance shows efficient considerations to control seismic forces.
6. Soft storey effect can effectively controlled by braced frame action .This concept is very useful for retrofitting of, and seismic up gradation of the existing multi storied buildings.

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