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A Comparative Study of Flat Slab System and Regular Beam-Slab System for Symmetric and Asymmetric Building Structure

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Abstract - *The application of a high-rise flat slab system is not studied in depth for symmetric and asymmetric building structures. This article focuses on a comparative study of flat slab systems for various cases of symmetric and asymmetric building structures. The base shear and story displacement for the considered cases are obtained using ETABS. Quantities of concrete and steel are calculated using ETABS & RCDC, followed by cost calculation. For investigating the effectiveness of a flat slab system, a comparative study between regular beam-slab structure and flat slab structure (with & without drops) is carried out. It is observed that the use of a flat slab system reduces the base shear and concrete weight of the building. Also, the cost of the building with a flat slab system is observed to be increasing compared to regular beam-slab buildings due to an increase in steel weight.*

Keywords - *Asymmetric, Base Shear, Drop, Flat Slab, Reinforced Concrete*

I. INTRODUCTION

Beam and slab construction has the advantage of providing intermediate supports to the slabs, thus reducing the effective span of the slabs. However, the beams require deeper depths, leading to more heights required of buildings or fewer clearances. A flat slab system consists of a two-way reinforced concrete slab supported directly by columns without beams and permits longer spans. Sometimes drop panels or capitals are also provided around the top of columns to enhance the punching shear capacity. Flat slab buildings are becoming popular for multi-story buildings due to their several advantages, e.g., ease of construction, larger clear height, simpler formwork, etc. Lateral resistance depends on the flexural stiffness of the components and their connections.

In the past, many researchers have investigated the performance of reinforced concrete flat slab structures. Gayed and Ghali[2] (2020) had found that long-term deflection controls the minimum thickness of RC flat plates, while shear resistance is controlled by shear reinforcement and flexural reinforcement above columns. Sen and Singh[7] (2020) proposed that flat slabs should be designed for gravity load alone, and shear walls can be designed to control inter-story drift due to the inadequacy of flat slab systems in high seismicity areas. Polak[5] (2005) had found that transverse reinforcement using shear bolts increases punching shear capacity and post-failure ductility of slab-column connections. Surumi et al.[9] (2014) had found that the provision of shear reinforcement in the joint core region can be a practical option for detailing exterior wall-flat slab connections in seismic risk regions. Yu and Wang[10] (2018) proposed that connection from steel tubular column to flat concrete slab can provide sufficient punching shear resistance in realistic flat slab construction. Qian and Li[6] (2013) had found that the vulnerability of RC flat slab structures to progressive collapse is very high, as the load re-distribution is not significant due to the absence of beams.

The application of a high-rise flat slab system is not studied in depth for symmetric and asymmetric building structures. In this article, the behavior of various RC flat slab building cases compared with regular beam-slab building is investigated under similar parameters. First, all the building structures are modeled and analyzed using ETABS; second, regular beam-slab buildings are designed using RCDC software, while flat slab buildings are designed using ETABS and RCDC.

The specific objectives of the study are summarized as: (i) To study the behavior of flat slab system for high rise symmetric and asymmetric building, (ii) To carry out the parametric study of flat slab system for various cases of building structures, (iii) To estimate quantities of concrete and steel to find out the overall cost of the building, (iv) To find the effectiveness of flat slab system for overall building height, (v) To ascertain strength and serviceability of building with flat slab system under significant shear.

II. STRUCTURAL MODEL

The system is idealized symmetric and asymmetric buildings consisting of rigid decks supported by structural elements. The following assumptions are made for the system under consideration:

- The floor of the superstructure is considered rigid.
- The force-deformation relationship of the structure is within the elastic range.

The following conditions are fulfilled by the flat slab system.

- The slab has minimum-three continuous spans in each direction.
- The aspect ratio in each panel is less than two.
- The ratio of successive span lengths is within 0.75 to 1.33.
- The design live load is less than three times the dead load.

Various cases considered for building structures and plan view of those cases are shown in Figure 1 and Figure 2, respectively.

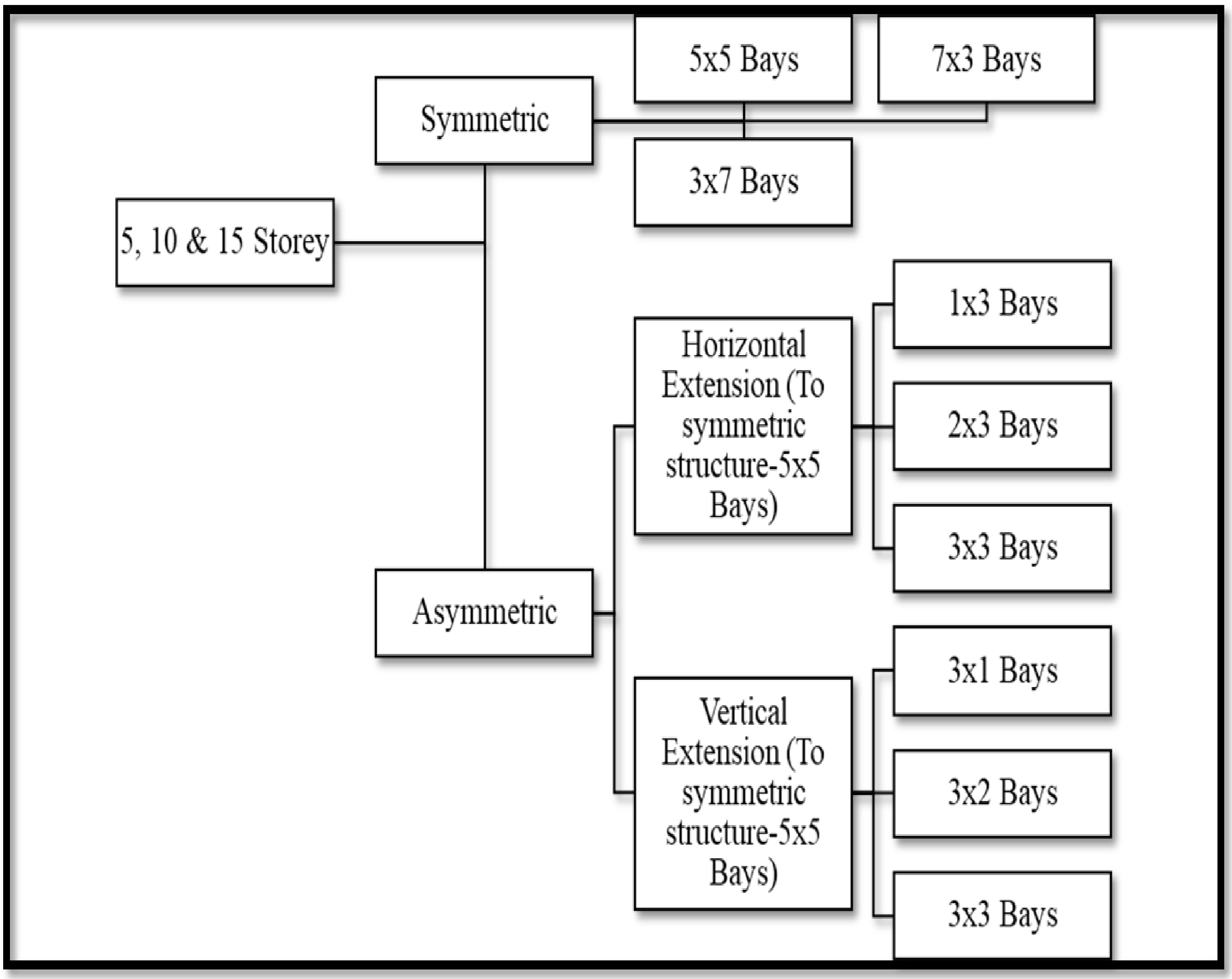


Figure 1. Various Cases of Building Structure

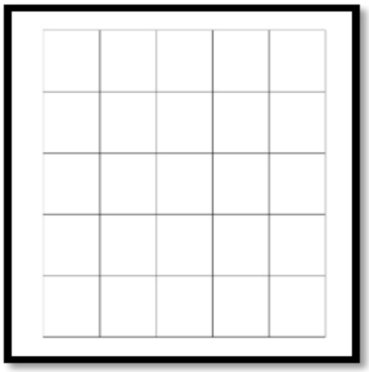


Figure 2 (a)

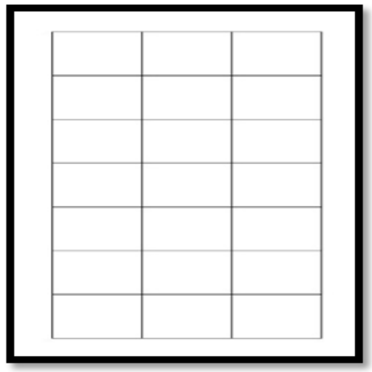
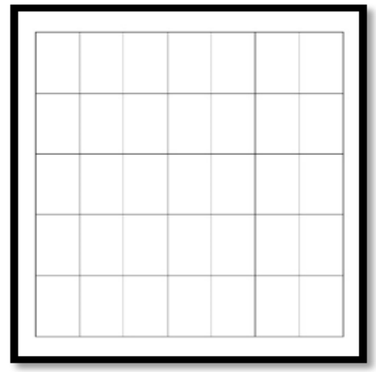


Figure 2 (b)



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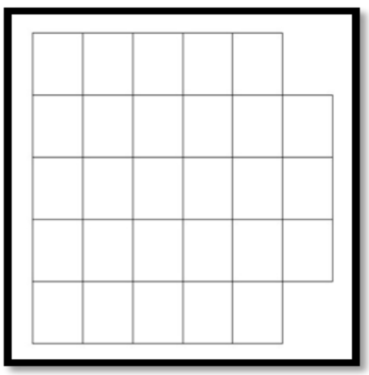

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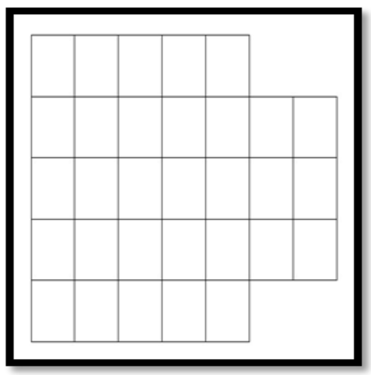

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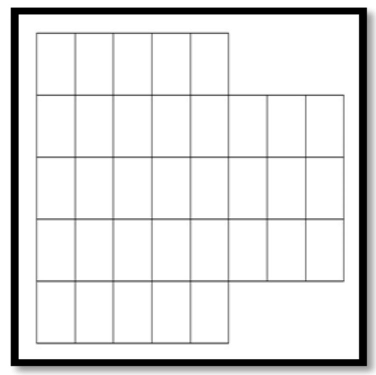

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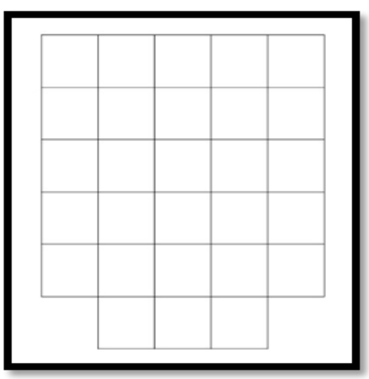

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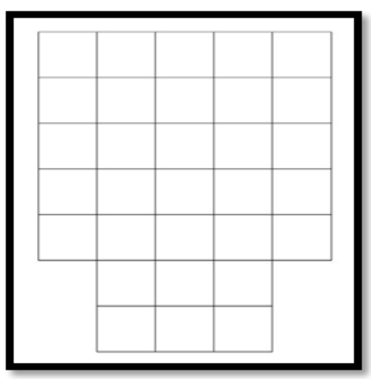

Figure 2 (h)

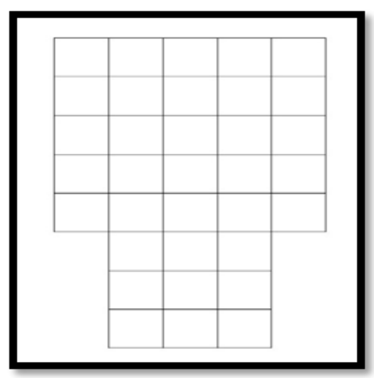

Figure 2 (i)

Figure 2. Plan View of Various Cases; (a) 5x5 bays, (b) 3x7 bays, (c) 7x3 bays, (d) H.E.-1x3 bays, (e) H.E.-2x3 bays, (f) H.E.-3x3 bays, (g) V.E.-3x1 bays, (h) V.E.-3x2 bays, (i) V.E.-3x3 bays

III. NUMERICAL STUDY

Analysis and design of 5, 10 & 15 storied, symmetric and asymmetric buildings are performed using ETABS and RCDC according to IS-456 & IS-13920. In each case, three models are created; (Model-1) regular beam-slab structure, (Model-2) flat slab structure with peripheral beams, (Model-3) flat slab structure with drops and peripheral beams. The response quantities of interest are base shear, maximum story displacement, concrete quantity, steel quantity, and cost. Parameters of the building are considered as per Table I, II, III & IV. Dimensions of structural elements are decided such that value of maximum story drift reaches critical near permissible value or punching shear ratio reaches critical according to IS code for following load combinations; (Comb1) DL+EQX, (Comb2) DL+EQY.

Table I. Parameters of the Building

Parameters		Values	Units
Typical Story Height		3.5	m
Bay Size		5 x 6	m
Drop Panel Size (Model-3 only)		1.7 x 2	m
Grade of Concrete	Model-1	M30	-
	Model-2	M35 (Beam, Slab) & M45 (Column)	-
	Model-3		
Garde of Steel		Fe500	-
Additional Dead Load		1.5	kN/m^2
Live Load		4	kN/m^2
Seismic Zone		3	-
Importance Factor		1.5	-
Response Reduction Factor		5	-
Soil Type		Medium	-

Table II. Model-1: Regular Beam-Slab Structure

			No. of Stories		Column Size (mm)	Beam Size (mm)	Slab Thickness (mm)
Symmetric		***5x5***	5		500 x 500	400 x 700 300 x 400 (Tie Beam)	245
			10	(5-10)	600 x 600		
				(0-5)	700 x 700		
			15	(10-15)	600 x 600		
				(5-10)	700 x 700		
				(0-5)	800 x 800		
		3x7	5		500 x 500	400 x 700 300 x 400 (Tie Beam)	225
			10	(5-10)	550 x 550		
				(0-5)	650 x 650		
			15	(10-15)	600 x 600		
				(5-10)	700 x 700		
				(0-5)	800 x 800		
		7x3	5		500 x 500	400 x 700 300 x 400 (Tie Beam)	200
			10	(5-10)	600 x 600	400 x 650 300 x 400 (Tie Beam)	
				(0-5)	700 x 700		
			15	(10-15)	600 x 600		225
				(5-10)	700 x 700		
				(0-5)	800 x 800		
Asymmetric	***Horizontal Extension***	***1x3***	5		500 x 500	400 x 600 300 x 400 (Tie Beam)	225
			10	(5-10)	600 x 600	400 x 700 300 x 400 (Tie Beam)	
				(0-5)	700 x 700		
			15	(10-15)	600 x 600	400 x 575 300 x 400 (Tie Beam)	200
				(5-10)	700 x 700		
				(0-5)	800 x 800		
		2x3	5		500 x 500	400 x 625 300 x 400 (Tie Beam)	225
			10	(5-10)	550 x 550	400 x 500 300 x 400 (Tie Beam)	200
				(0-5)	650 x 650		

			No. of Stories		Column Size (mm)	Beam Size (mm)	Slab Thickness (mm)
Asymmetric	*Horizontal Extension*	***2x3***	15	(10-15) (5-10) (0-5)	600 x 600 700 x 700 800 x 800	400 x 700 300 x 400 (Tie Beam)	200
		3x3	5		500 x 500	400 x 700 300 x 400 (Tie Beam)	200
			10	(5-10) (0-5)	600 x 600 700 x 700	425 x 700 300 x 400 (Tie Beam)	
			15	(10-15) (5-10) (0-5)	600 x 600 700 x 700 800 x 800		
	Vertical Extension	***3x1***	5		500 x 500	400 x 675 300 x 400 (Tie Beam)	225
			10	(5-10) (0-5)	600 x 600 700 x 700	400 x 700 300 x 400 (Tie Beam)	200
			15	(10-15) (5-10) (0-5)	600 x 600 700 x 700 800 x 800		
		3x2	5		500 x 500	400 x 700 300 x 400 (Tie Beam)	225
			10	(5-10) (0-5)	600 x 600 700 x 700		200
			15	(10-15) (5-10) (0-5)	600 x 600 700 x 700 800 x 800	425 x 700 300 x 400 (Tie Beam)	
		3x3	5		500 x 500	400 x 700 300 x 400 (Tie Beam)	200
			10	(5-10) (0-5)	600 x 600 750 x 750	400 x 570 300 x 400 (Tie Beam)	
			15	(10-15) (5-10) (0-5)	600 x 600 700 x 700 800 x 800	415 x 725 300 x 400 (Tie Beam)	

Table III. Model-2: Flat Slab Structure with Peripheral Beams Structure

		No. of Stories		Column Size (mm)	Beam Size (mm)	Slab Thickness (mm)
Symmetric	***5x5***	5		600 x 600	230 x 300 (Periphery) 300 x 400 (Tie Beam)	250
		10	(5-10) (0-5)	600 x 600 750 x 750	400 x 500 (Periphery) 300 x 400 (Tie Beam)	300
		15	(10-15) (5-10) (0-5)	650 x 650 750 x 750 800 x 800		270
	3x7	5		600 x 600	230 x 300 (Periphery) 300 x 400 (Tie Beam)	260
		10	(5-10) (0-5)	600 x 600 750 x 750	400 x 500 (Periphery) 300 x 400 (Tie Beam)	320
		15	(10-15) (5-10) (0-5)	650 x 650 750 x 750 800 x 800	400 x 525 (Periphery) 300 x 400 (Tie Beam)	270

			No. of Stories		Column Size (mm)	Beam Size (mm)	Slab Thickness (mm)
Symmetric		***7x3***	5		600 x 600	230 x 300 (Periphery) 300 x 400 (Tie Beam)	260
			10	(5-10) (0-5)	600 x 600 730 x 730	400 x 500 (Periphery) 300 x 400 (Tie Beam)	300
			15	(10-15) (5-10) (0-5)	650 x 650 750 x 750 800 x 800		250
Asymmetric	***Horizontal Extension***	***1x3***	5		600 x 600	230 x 300 (Periphery) 300 x 400 (Tie Beam)	260
			10	(5-10) (0-5)	625 x 625 750 x 750	400 x 500 (Periphery) 300 x 400 (Tie Beam)	300
			15	(10-15) (5-10) (0-5)	650 x 650 750 x 750 800 x 800	400 x 575 (Periphery) 300 x 400 (Tie Beam)	270
		2x3	5		600 x 600	230 x 300 (Periphery) 300 x 400 (Tie Beam)	260
			10	(5-10) (0-5)	625 x 625 750 x 750	400 x 500 (Periphery) 300 x 400 (Tie Beam)	325
			15	(10-15) (5-10) (0-5)	650 x 650 750 x 750 800 x 800	400 x 650 (Periphery) 300 x 400 (Tie Beam)	270
		3x3	5		600 x 600	230 x 300 (Periphery) 300 x 400 (Tie Beam)	260
			10	(5-10) (0-5)	625 x 625 750 x 750	400 x 500 (Periphery) 300 x 400 (Tie Beam)	325
			15	(10-15) (5-10) (0-5)	650 x 650 750 x 750 800 x 800	400 x 675 (Periphery) 300 x 400 (Tie Beam)	270
	Vertical Extension	***3x1***	5		600 x 600	230 x 300 (Periphery) 300 x 400 (Tie Beam)	260
			10	(5-10) (0-5)	625 x 625 750 x 750	400 x 500 (Periphery) 300 x 400 (Tie Beam)	325
			15	(10-15) (5-10) (0-5)	650 x 650 750 x 750 800 x 800	400 x 600 (Periphery) 300 x 400 (Tie Beam)	270
		3x2	5		600 x 600	230 x 300 (Periphery) 300 x 400 (Tie Beam)	260
			10	(5-10) (0-5)	625 x 625 750 x 750	400 x 500 (Periphery) 300 x 400 (Tie Beam)	325
			15	(10-15) (5-10) (0-5)	650 x 650 750 x 750 800 x 800	400 x 650 (Periphery) 300 x 400 (Tie Beam)	270
		3x3	5		600 x 600	230 x 300 (Periphery) 300 x 400 (Tie Beam)	260
			10	(5-10) (0-5)	625 x 625 750 x 750	400 x 500 (Periphery) 300 x 400 (Tie Beam)	325
			15	(10-15) (5-10) (0-5)	650 x 650 750 x 750 800 x 800	400 x 700 (Periphery) 300 x 400 (Tie Beam)	270

Table IV. Model-3: Flat Slab Structure with Drops and Peripheral Beams

			No. of Stories		Column Size (mm)	Beam Size (mm)	Slab Thk.(mm)	Drop Thk. (mm)
Symmetric		***5x5***	5		600 x 600	230 x 300 (Periphery) 300 x 400 (Tie Beam)	160	250
			10	(5-10) (0-5)	600 x 600 725 x 725	400 x 575 (Periphery) 300 x 400 (Tie Beam)	200	300
			15	(10-15) (5-10) (0-5)	625 x 625 725 x 725 800 x 800	400 x 600 (Periphery) 300 x 400 (Tie Beam)		
		3x7	5		600 x 600	230 x 300 (Periphery) 300 x 400 (Tie Beam)	170	250
			10	(5-10) (0-5)	600 x 600 725 x 725	425 x 650 (Periphery) 300 x 400 (Tie Beam)	200	300
			15	(10-15) (5-10) (0-5)	625 x 625 725 x 725 800 x 800	400 x 600 (Periphery) 300 x 400 (Tie Beam)		
		7x3	5		600 x 600	300 x 500 (Periphery) 300 x 400 (Tie Beam)	160	250
			10	(5-10) (0-5)	600 x 600 725 x 725	400 x 700 (Periphery) 300 x 400 (Tie Beam)	210	300
			15	(10-15) (5-10) (0-5)	625 x 625 725 x 725 800 x 800	450 x 700 (Periphery) 300 x 400 (Tie Beam)		
Asymmetric	*Horizontal Extension*	***1x3***	5		600 x 600	230 x 350 (Periphery) 300 x 400 (Tie Beam)	170	250
			10	(5-10) (0-5)	600 x 600 725 x 725	400 x 625 (Periphery) 300 x 400 (Tie Beam)	200	300
			15	(10-15) (5-10) (0-5)	625 x 625 725 x 725 800 x 800	400 x 650 (Periphery) 300 x 400 (Tie Beam)		
		2x3	5		600 x 600	230 x 350 (Periphery) 300 x 400 (Tie Beam)	175	250
			10	(5-10) (0-5)	600 x 600 725 x 725	400 x 675 (Periphery) 300 x 400 (Tie Beam)	200	300
			15	(10-15) (5-10) (0-5)	625 x 625 725 x 725 800 x 800	400 x 700 (Periphery) 300 x 400 (Tie Beam)	200	300
		3x3	5		600 x 600	230 x 350 (Periphery) 300 x 400 (Tie Beam)	180	250
			10	(5-10) (0-5)	600 x 600 725 x 725	400 x 675 (Periphery) 300 x 400 (Tie Beam)	225	300
			15	(10-15) (5-10) (0-5)	625 x 625 725 x 725 800 x 800	400 x 700 (Periphery) 300 x 400 (Tie Beam)		
	Vertical Extension	***3x1***	5		600 x 600	230 x 350 (Periphery) 300 x 400 (Tie Beam)	160	250
			10	(5-10) (0-5)	600 x 600 725 x 725	400 x 625 (Periphery) 300 x 400 (Tie Beam)	200	300
			15	(10-15) (5-10) (0-5)	625 x 625 725 x 725 800 x 800	400 x 650 (Periphery) 300 x 400 (Tie Beam)	200	300

			No. of Stories		Column Size (mm)	Beam Size (mm)	Slab Thk.(mm)	Drop Thk. (mm)
Asymmetric	*Vertical Extension*	*3x2*	5		600 x 600	230 x 350 (Periphery) 300 x 400 (Tie Beam)	160	250
			10	(5-10) (0-5)	600 x 600 725 x 725	400 x 625 (Periphery) 300 x 400 (Tie Beam)	200	300
			15	(10-15) (5-10) (0-5)	625 x 625 725 x 725 800 x 800	400 x 675 (Periphery) 300 x 400 (Tie Beam)		
		3x3	5		600 x 600	230 x 350 (Periphery) 300 x 400 (Tie Beam)	175	250
			10	(5-10) (0-5)	600 x 600 725 x 725	400 x 575 (Periphery) 300 x 400 (Tie Beam)	210	300
			15	(10-15) (5-10) (0-5)	625 x 625 725 x 725 800 x 800	400 x 700 (Periphery) 300 x 400 (Tie Beam)		

IV. RESULTS

The peak responses of base shear & story displacement, concrete quantity, and steel quantity are obtained for each case using ETABS and RCDC. The cost of the building for each case is calculated according to current market rates, which are shown in Table V. The variation in parameters listed above are plotted for each case of a building which is shown in Figures 3, 4, 5, 6 & 7, respectively.

Table V. Current Market Rates

Grade of concrete	Rate per CMT (Rs.)
M30	5250
M35	5780
M45	6625
Grade of steel	**Rate per kg (Rs.)**
Fe500	62

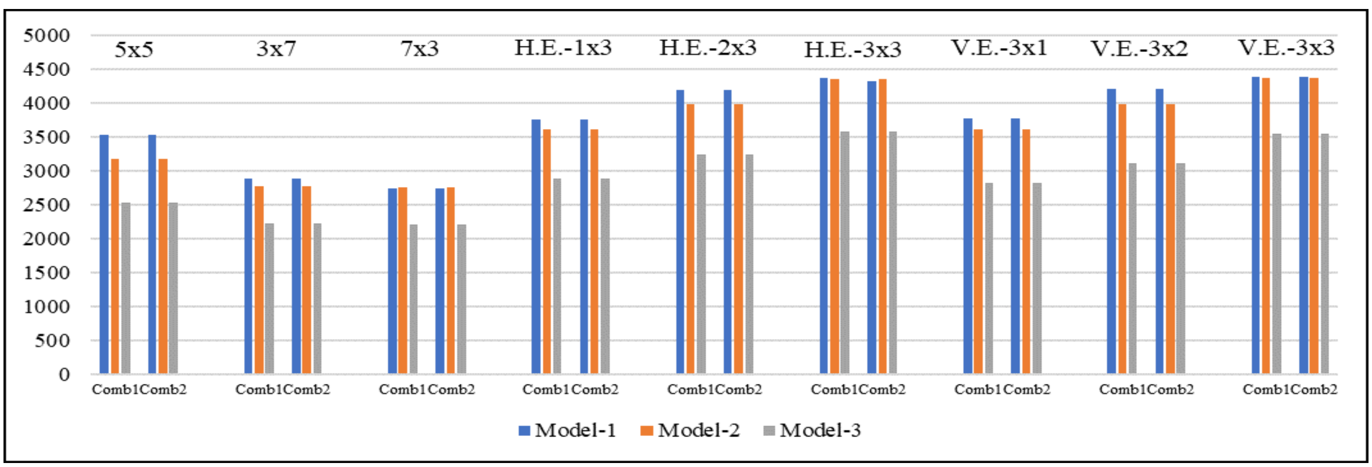

Figure 3 (a)

For 5-stories, the use of a flat slab system shows a reduction in base shear by an average of 13.15%.

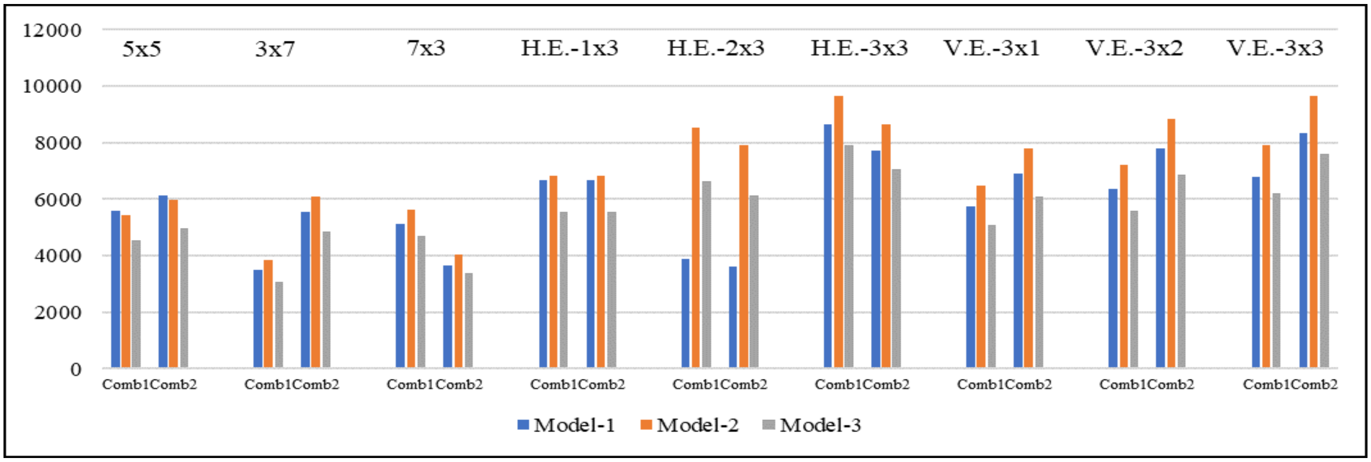

Figure 3 (b)

For 10-stories, the use of a flat slab system shows a reduction in base shear by an average of -9.11%.

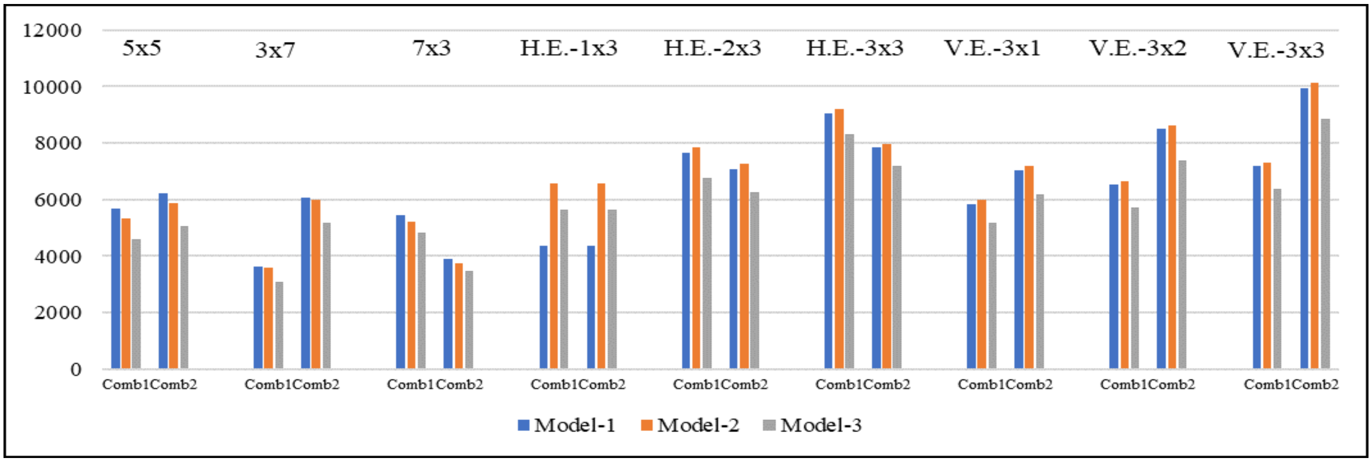

Figure 3 (c)

For 15-stories, the use of a flat slab system shows a reduction in base shear by an average of 1.10%.

Figure 3. Base Shear Values for Buildings with (a) 5-stories, (b) 10-stories, (c) 15-stories

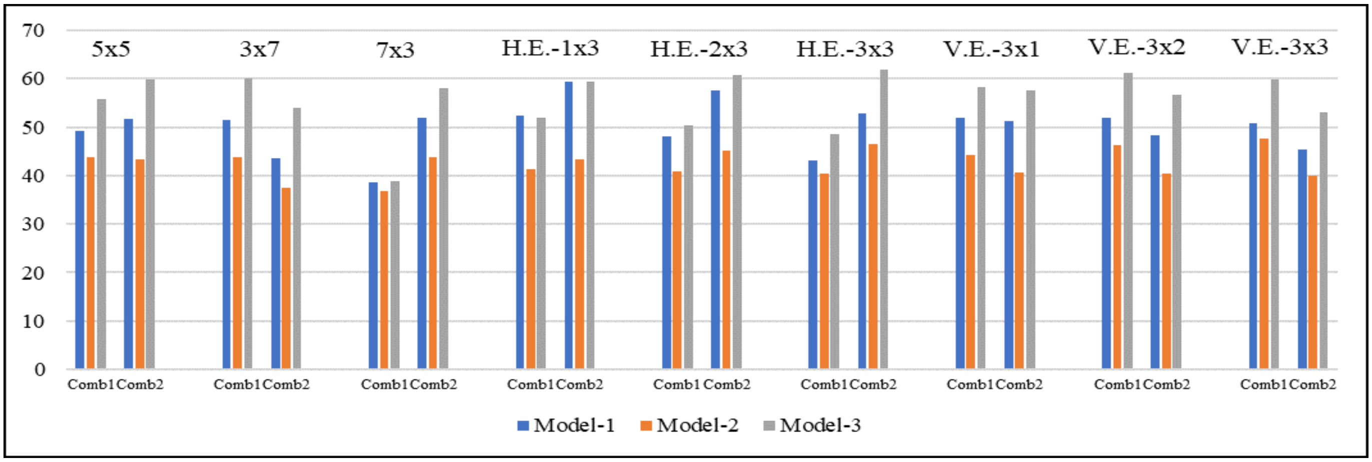

Figure 4 (a)

For 5-stories, model-3 shows an increase in story displacement by an average of 31.26% compared to model-2.

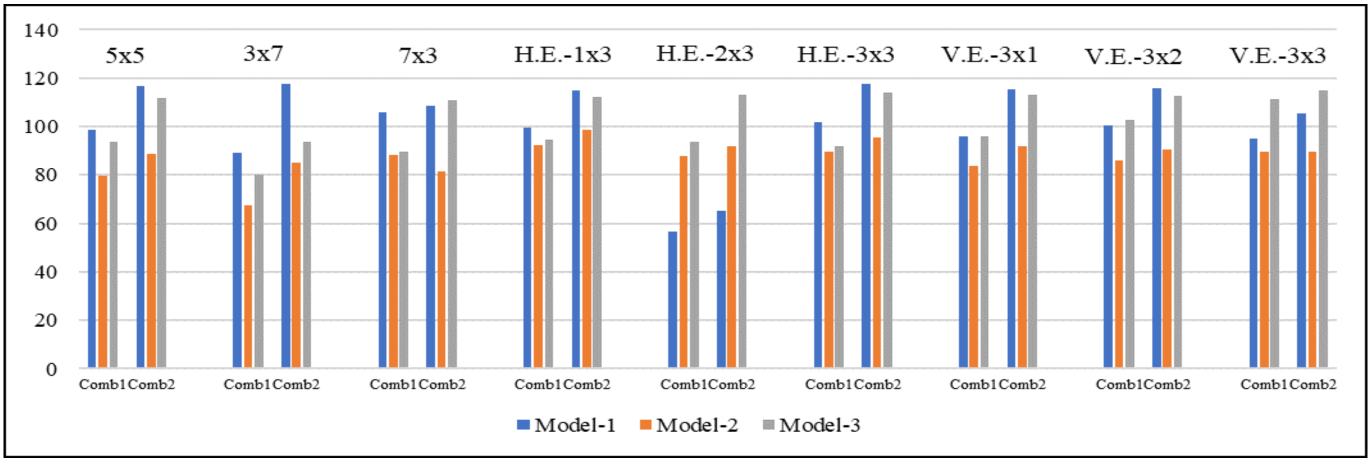

Figure 4 (b)

For 10-stories, model-3 shows an increase in story displacement by an average of 17.26% compared to model-2.

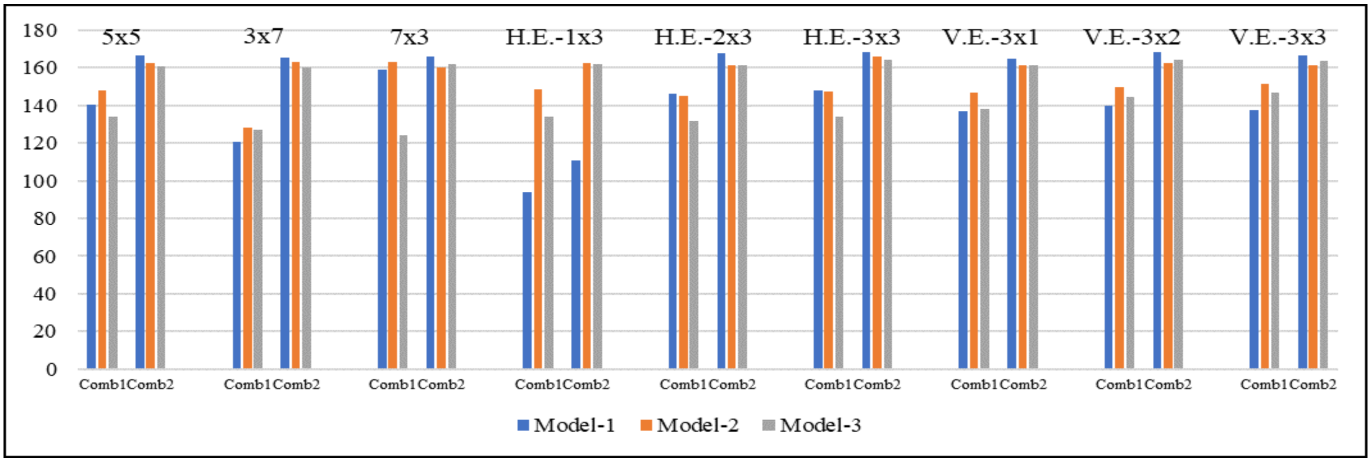

Figure 4 (c)

For 15-stories, model-3 shows an increase in story displacement by an average of -4.17% compared to model-2.

Figure 4. Maximum Story Displacement Values for Buildings with (a) 5-stories, (b) 10-stories, (c) 15-stories

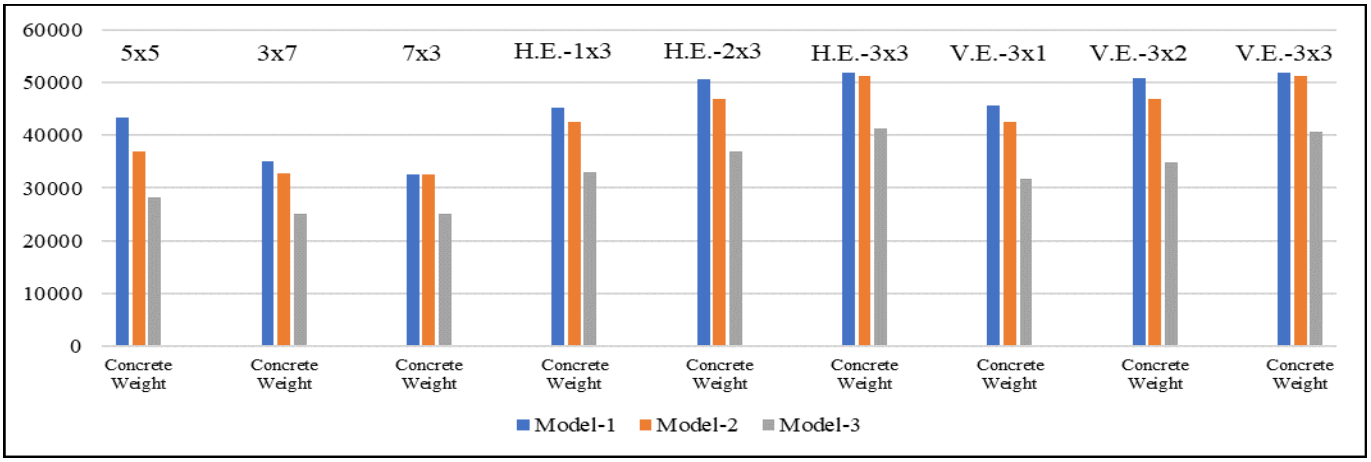

Figure 5 (a)

For 5 stories, the concrete weight of a flat slab system is reduced by an average of 16.45%.

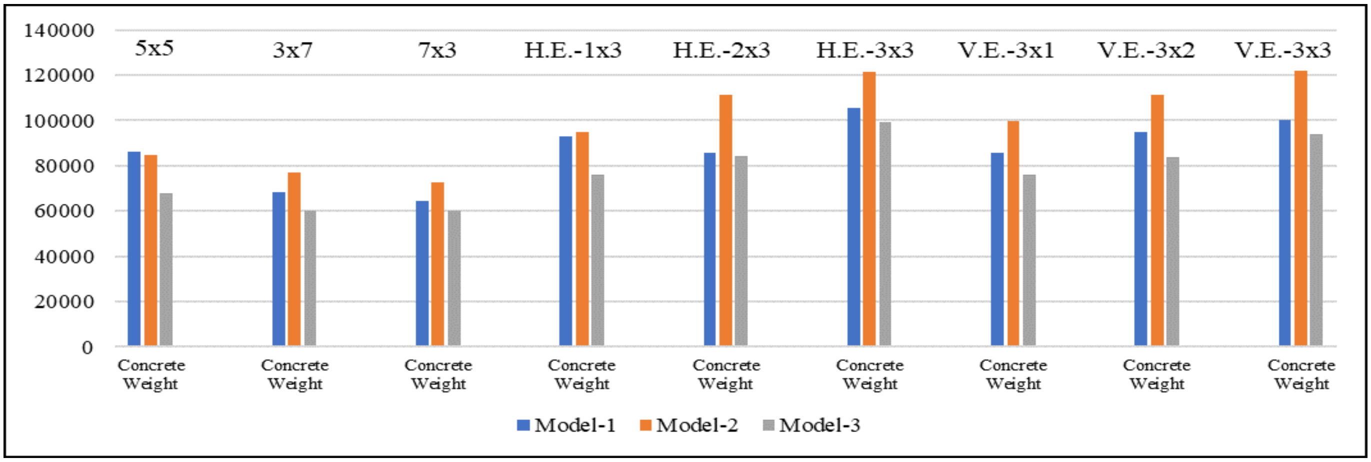

Figure 5 (b)

For 10 stories, the concrete weight of a flat slab system is reduced by an average of -1.73%.

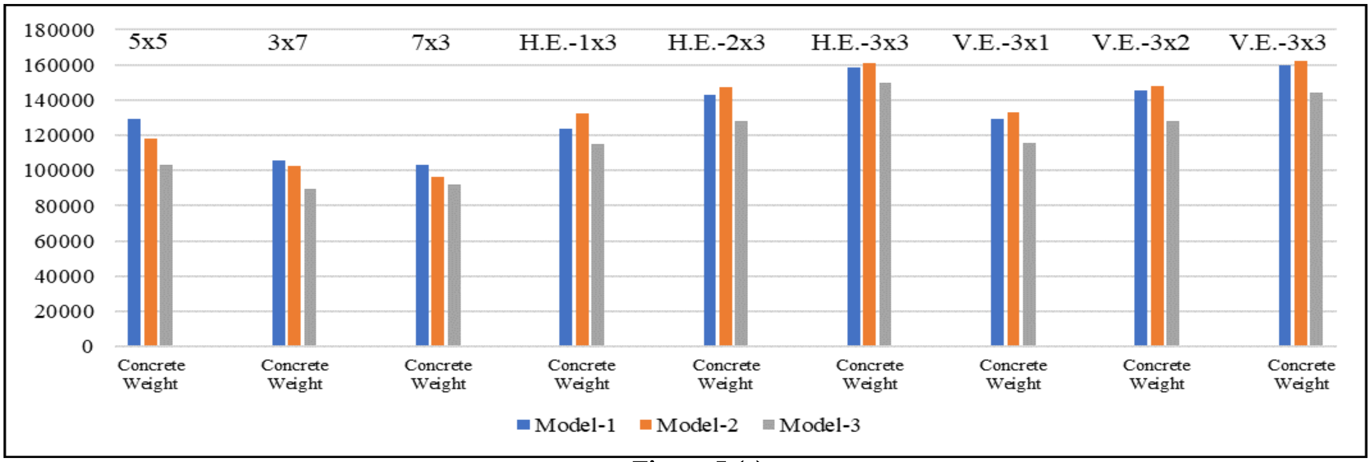

Figure 5 (c)

For 15 stories, the concrete weight of a flat slab system is reduced by an average of 5.65%.

Figure 5. Concrete Weight Values for Buildings with (a) 5-stories, (b) 10-stories, (c) 15-stories

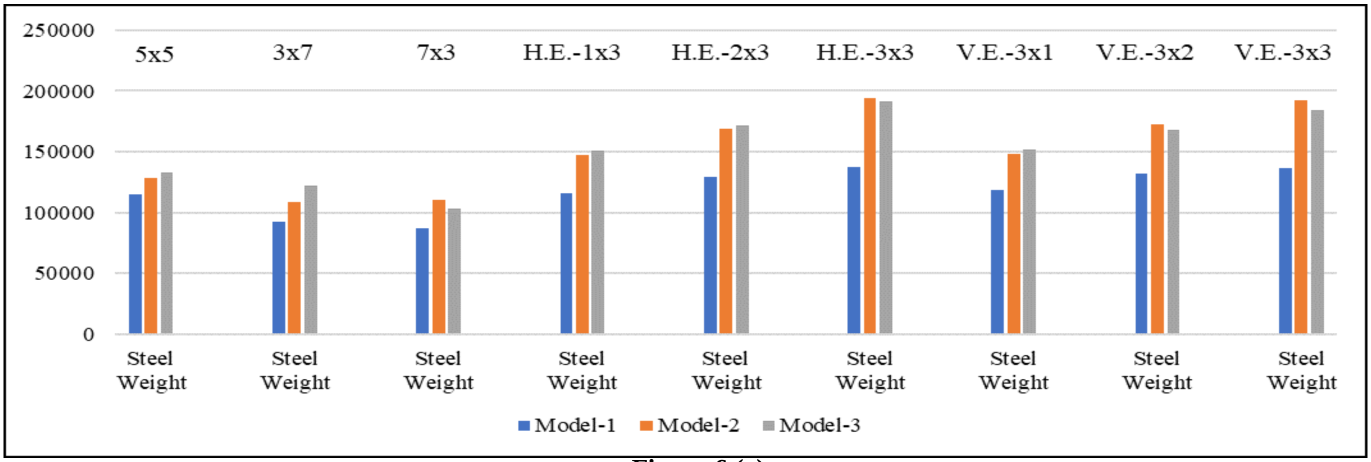

Figure 6 (a)

For 5-stories, the weight of steel for a flat slab system is increased by an average of 28.30%.

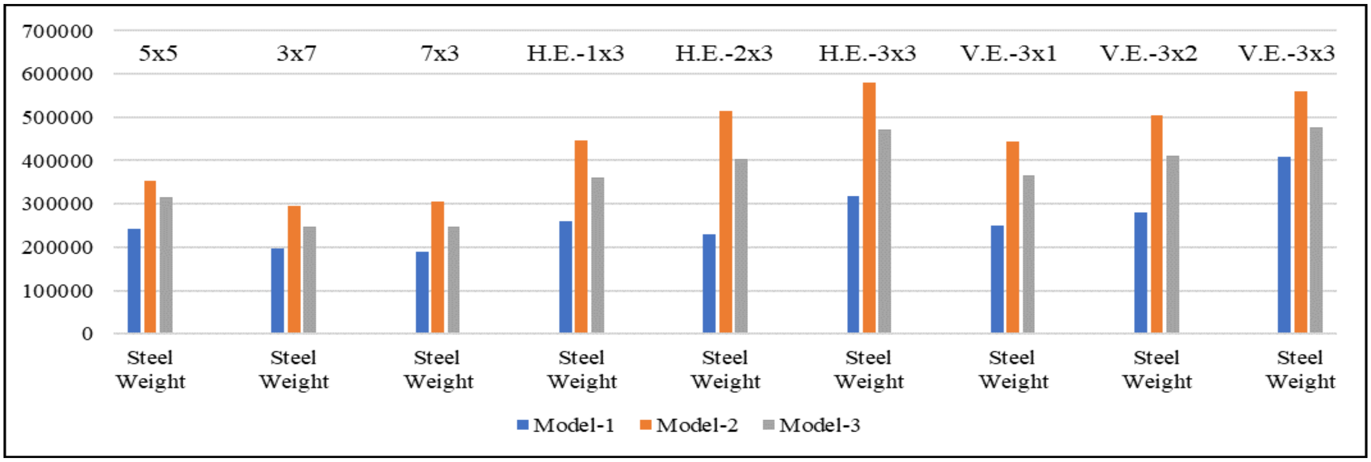

Figure 6 (b)

For 10-stories, the weight of steel for a flat slab system is increased by an average of 54.82%.

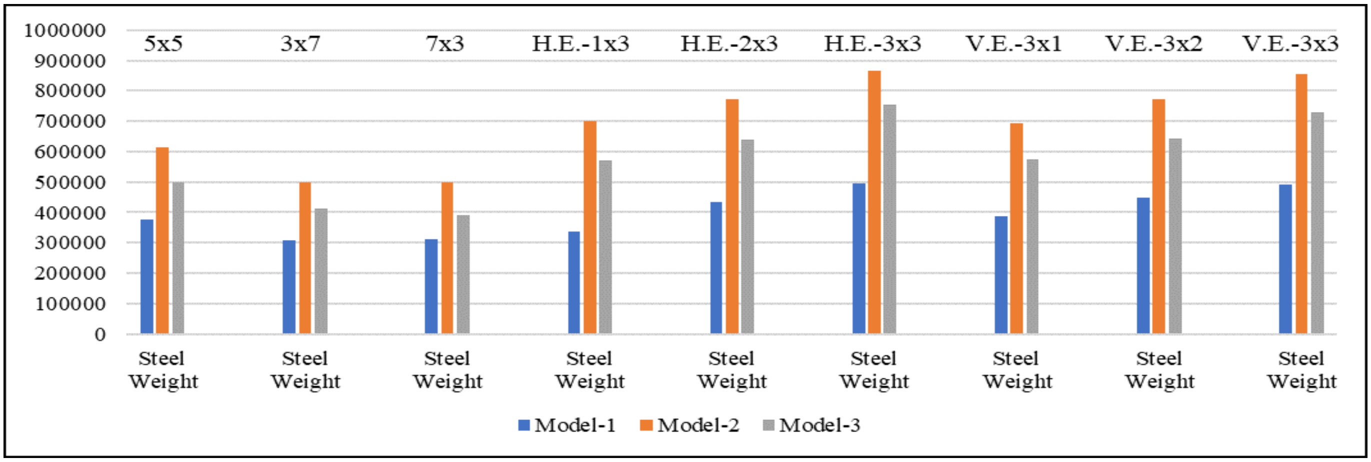

Figure 6 (c)

For 15-stories, the weight of steel for a flat slab system is increased by an average of 59.48%.

Figure 6. Steel Weight Values for Buildings with (a) 5-stories, (b) 10-stories, (c) 15-stories

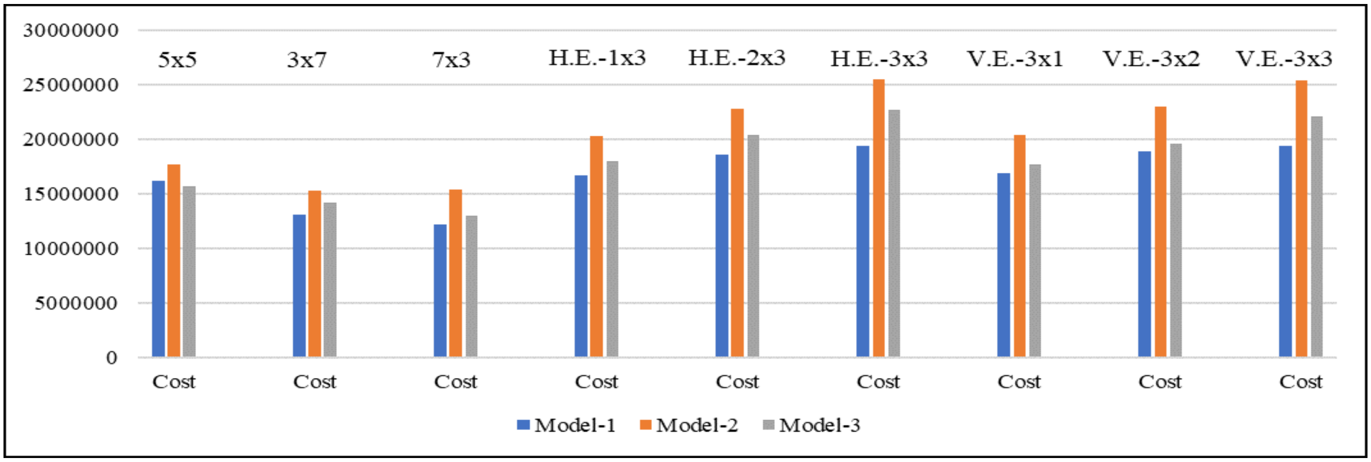

Figure 7 (a)

For 5-stories, a flat slab building is costlier than a regular beam-slab building by an average of 14.97%.

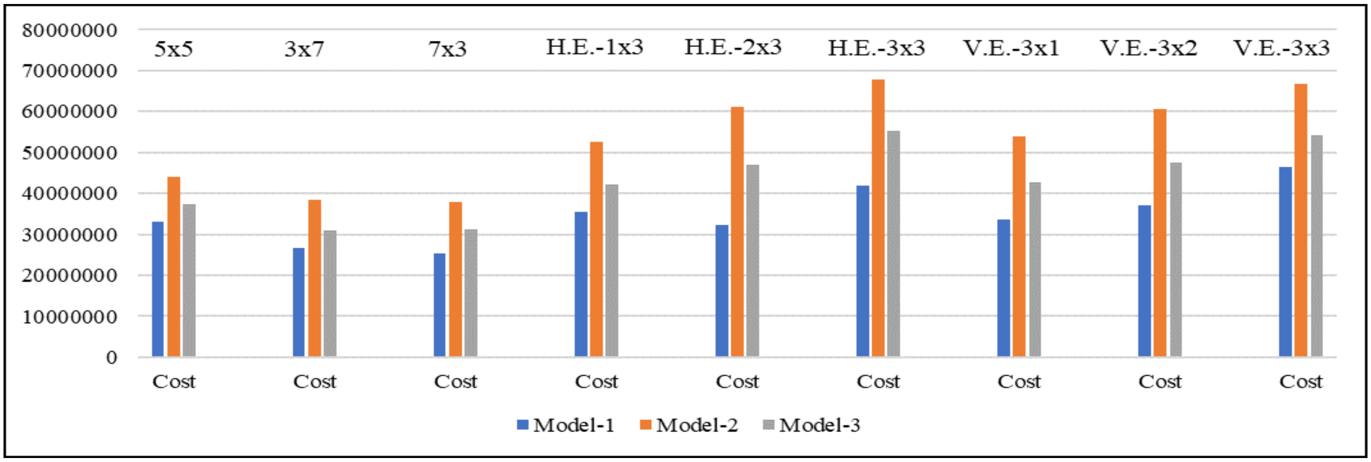

Figure 7 (b)

For 10-stories, a flat slab building is costlier than a regular beam-slab building by an average of 39.64%.

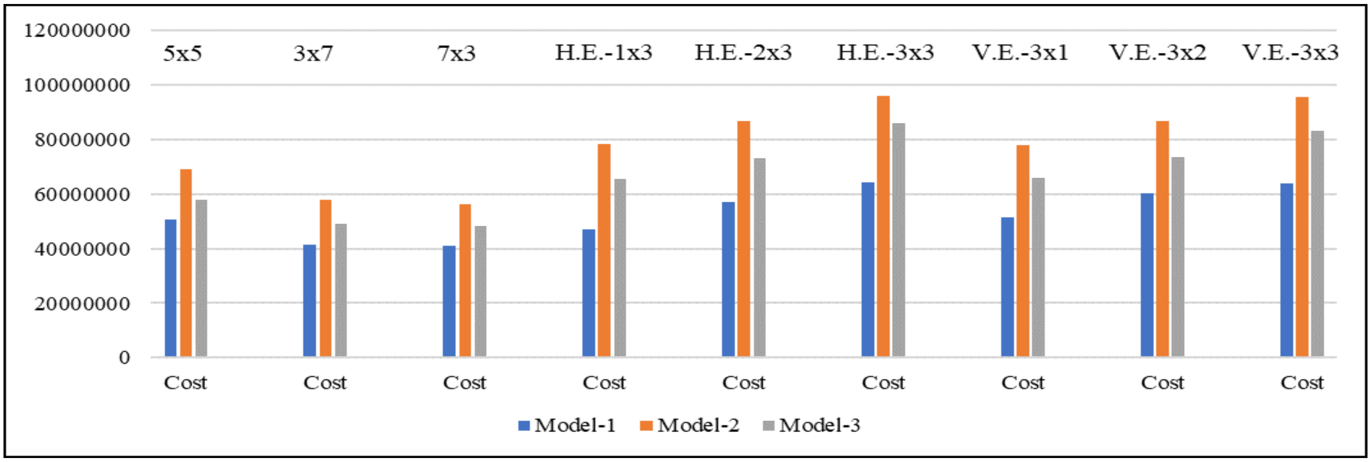

Figure 7 (c)

For 15-stories, a flat slab building is costlier than a regular beam-slab building by an average of 36.73%.

Figure 7. Cost of Buildings with (a) 5-stories, (b) 10-stories, (c) 15-stories

V. CONCLUSION

In this article, 5, 10 & 15 storied, symmetric and asymmetric buildings are investigated using ETABS and RCDC according to IS-456 and IS-13920. The results shown above are evaluated to study the effectiveness of a flat slab system. From the trend of the results of the present numerical study, the following conclusions can be drawn,

- It is observed that the base shear is reduced up to 2% by providing a flat slab system.
- The buildings with drop panels show an increase in maximum story displacement compared to buildings without drop panels due to reduced floor stiffness.
- The concrete weight of flat slab buildings is reduced up to 7% compared to regular beam-slab buildings.
- Building with flat slabs shows an increase in steel weight up to 48% compared to regular beam-slab buildings.
- It is observed that flat slab buildings are up to 31% costlier than regular beam-slab buildings.
- The increase in the cost of building with a flat slab structure as compared to the regular beam-slab structure is more significant for high-rise buildings as compared to a low-rise building.

VI. FUTURE SCOPE

The present study considers similar flat slab buildings. More studies can be done at the various loading stages with different building parameters or a combination of them, which will give deeper insight into the efficiency of a flat slab system. Dynamic analysis can be done, and the capacity of the system can be studied under time-history analysis or response spectrum analysis. Also, Different design parameters can be applied with a view to understanding the behavior of flat slab structures under vertical ground motion. Certainly, more sophisticated flat slab structures can be created to quantify the results.

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