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QUANTITY AND COST MODELLING OF REINFORCED CONCRETE BUILDINGS OF 12 TO 20 STOREY DESIGNED FOR SEISMIC EFFECTS

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Abstract

Structural systems for reinforced concrete multi-storeyed buildings constitutes one of the major cost component of the total building cost. The structural system costs are influenced by the structural configurations meeting the architectural requirements, structural requirements for providing gravity load and lateral loads resistance for wind and earthquake forces, durability requirements and other factors. Cost predictions for providing required level of seismic resistance in structural components is relatively less understood aspect as very few studies are reported on this matter. There is a need to focus on the issue of cost implications to incorporate seismic safety in buildings. With this objective, the study presents a parametric cost study of the structural systems of medium rise reinforced framed buildings designed and detailed to withstand various levels of code specified seismic forces in different seismic zones of Indian subcontinent.

In this study, twelve to twenty storeyed reinforced concrete buildings with moment resisting frames in combination with shear walls with column grids commonly adopted for office occupancy are considered. All these buildings are designed for the design peak ground accelerations of 0.05g to 0.18g applicable for low to high seismic zones as per the Indian seismic code. The proposed quantity model provides for the component wise quantities of structural concrete, steel reinforcement and shuttering materials and the corresponding structural costs per square meter of the built up area of the buildings and thus providing the cost modelling of the structural systems designed for varying levels of seismic effects.

The study also presents a compilation of data on the constructed buildings in different seismic zones of India with the quantities of structural concrete and steel reinforcement used per square meter of the built up area of the buildings which broadly compares with the present study.

The results of the study, besides bringing out the information on the cost premium to be incurred for seismic safety, provides a simple parametric quantity and cost model for the structural systems of reinforced concrete multi-storeyed buildings designed for different levels of seismic resistance. The study provides an understanding of the economic implications of providing seismic safety in buildings and is useful for the cost management in practice.

Keywords: reinforced concrete buildings; seismic resistance; quantity model; cost model

1. Introduction

Structural systems with cast-in-situ reinforced concrete frames with masonry filler walls for enclosures and partitions are commonly adopted for medium rise buildings in many parts of the world. While systems with moment resisting frames coupled with solid floor diaphragm slabs are used up to 10 to 15 storeys, reinforced concrete shear walls in combination with moment resisting frames are adopted for increased heights to improve the lateral load resistance against wind and earthquake forces and to limit the sway deflections arising out of these forces.

The structural system constitutes the major cost component of the building and usually in the range of 40 to 50% of building civil works depending upon the overall building component specifications. When the building structure is designed to resist seismic effects the cost premium for providing seismic resistance increases depending up on the site seismicity, structural layout, height, occupancy type and other cost influencing parameters.

The basic cost of structural system and cost premium for incorporating seismic resistance with the considerations of structural configurations and seismic parameters are relatively less understood aspect of building cost economics. Inadequate information and awareness on the cost issues leads to incorrect presumptions that provision for seismic resistance would add to substantial cost increase. Towards this objective, the study reported herein presents the aspects of quantity and cost modelling of superstructure systems of reinforced concrete frame-shear wall buildings in the range of 12 to 20 storeys with structural layout suitable for office occupancy. Earlier studies on this aspect were carried out for low to medium rise buildings in the range of 2 to 10 storeys [1]. Separate studies are being done on the cost modelling aspects of foundation systems with differing soil conditions.

The component quantities of structural system and structural costs based on detailed seismic analysis and design are determined and expressed in terms of quantities and costs per square meter of the built up area of the building, an easily understood cost estimation parameter.

2. Building structural systems studied

The column grid spacing considered is 6mX6.5m which is commonly adopted for office building category. The trend is also to adopt increased grid spacing like 7.5mX7.5m to accommodate the car parking in the ground floor.

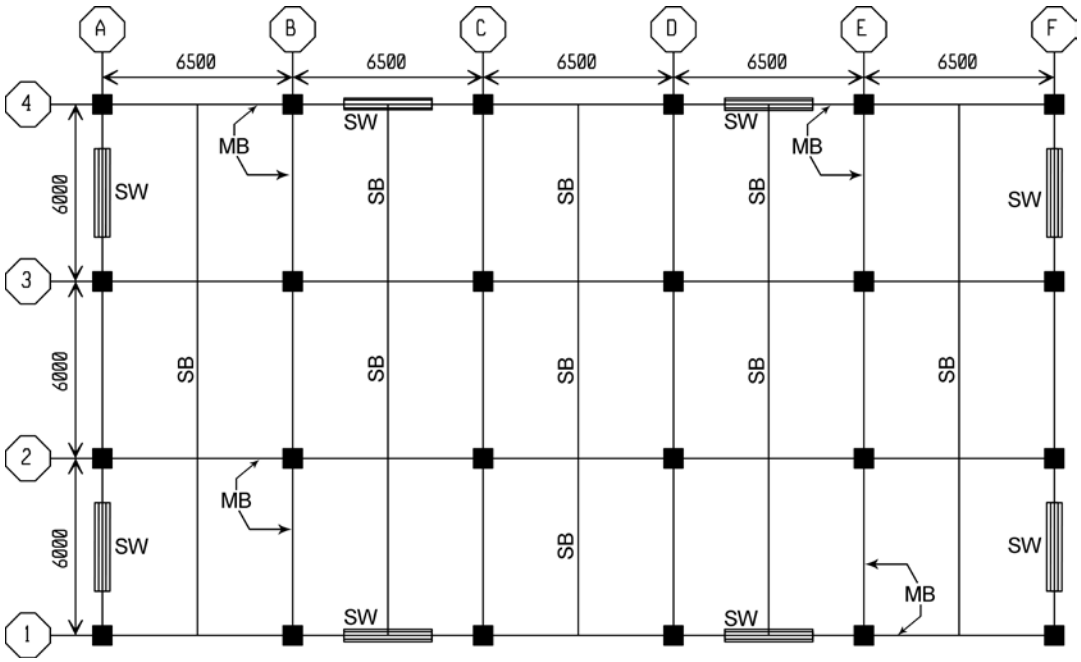

Fig. 1 – Structural framing plan

Five building heights are studied (12, 14, 16, 18 and 20 storeyed) providing structural system with frame shear wall combination. The shear walls are located symmetrically to obtain regular structural configuration for good seismic performance. Solid floor slab system is provided with secondary beams to reduce the floor slab thickness. The structural arrangement for typical floor is shown in Fig. 1. The column sizes adopted vary from 800mmX800mm to 500mmX500mm depending upon the building heights and the shear wall length is 3m and thickness vary from 350mm to 250mm. The main and secondary beam sizes adopted are 350 mmX650 mm and 450 mmX250 mm respectively. The floor slab thickness is 120mm. The concrete grade adopted are M35, M30 and M25 and steel reinforcement grade is Fe 500 as per the Indian codes.

3. Seismic hazards considered

Indian subcontinent is divided in to four seismic zones with increase in order of seismicity as low (Zone II), moderate (Zone III), severe (Zone IV) and very severe (Zone V). The zone factor (Z) representing the peak ground acceleration in these zones are 0.12g, 0.18g, 0.24g and 0.36g respectively and are shown in Table 1 along with the seismic intensity scale.

Table 1 – Seismic parameters of Indian seismic zones

Seismic Zone	Zone Factor (Z)	Design peak ground accelerations	Seismic intensity (MSK 64) scale
II Low seismic zone	0.10	0.05g	VI or less
III Moderate seismic zone	0.16	0.08g	VII
IV Severe seismic zone	0.24	0.12g	VIII
V Very severe seismic zone	0.36	0.18g	IX

As per Indian seismic code [2] the design base shear is calculated as;

$$V_b = \frac{Z}{2} * \frac{I}{R} * \frac{Sa}{g} \quad (1)$$

Wherein Z, I, R are the seismic zone factor, importance factor and response reduction factor respectively and the ground acceleration coefficient Sa/g is determined based on the response spectra specified in the code. To study the effect of increasing levels of earthquake forces based on the seismicity levels, the five buildings studied are considered located in four seismic zones mentioned above.

4. Structural modelling and seismic analysis

Three dimensional modelling of the structural systems are done with floor slabs treated as rigid diaphragms. The columns and beams are modelled as line elements and shear walls as in-plane wall elements. The seismic analysis and design is done by response spectrum method using the ETABS software.

The individual member design and detailing for the ductility requirements are done in accordance with Indian seismic codes [3,4]. Based on the seismic design and detailing for the five buildings in each of the four seismic zones, the quantities of structural concrete, steel reinforcement and shuttering are prepared floor wise for all the 20 cases following the standard quantity surveying practice.

5. Concept of quantity and cost modelling

5.1 The concept of quantity and cost modelling of structural system is based on the method of elemental cost analysis of buildings. In this method the total building system is divided in to major group elemental such as; architectural, structural and building services. The detailed quantity and cost analysis is carried out for each of the group elements constituting the major group elements. Structural system is taken as one of the major group element which is further divided in to superstructure and foundation as group elements. The superstructure is further divided as slab, beam, column and shear wall elements and their individual quantity and cost contributions to the structural system cost is determined. The proposed quantity and cost model for the structural system of the super structure of the building is expressed as the quantity and cost of the structural concrete, steel reinforcement and shuttering material per square meter of the built up area as under and illustrated in Fig. 2 for the 12 storeyed building.

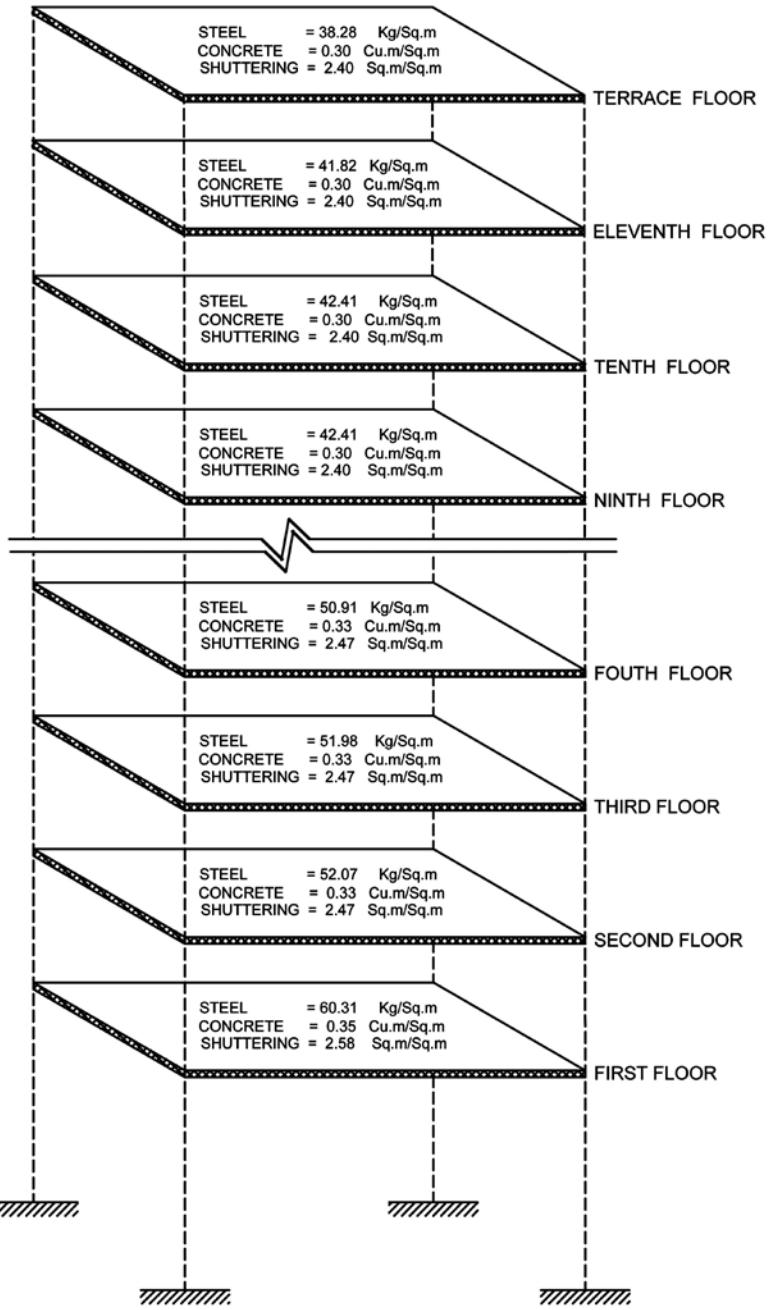

Fig. 2 – Quantity modelling of a 12 storey building in Zone V

5.2 The quantities of structural concrete, reinforcement steel and shuttering materials for slabs, beams, columns and shear walls for a particular floor are expressed as volume of concrete, weight of steel reinforcement and area of shuttering material per square meter of the built up area of the floor is termed as quantity modelling. This quantity model could be expressed for the individual floors and also as the average value for the entire building.

5.3 With the known quantities of structural materials and their prevailing unit rates of construction, the structural cost per square meter of the built up area of the individual floor as well as the average structural cost per square meter of the built up area of the entire building is determined. This structural cost per unit built up area, usually called as square meter costs, is termed as cost modelling of the structural system.

6. Determination of quantity and cost model

From the detailed designs and detailing of the structural members of the individual buildings, the quantities of structural concrete, steel reinforcement and shuttering areas required for the structural members at different floor levels are worked out by the standard quantity surveying methods. Structural quantities required for other elements like lintels and façade elements are also accounted. The floor wise structural quantities are divided by built up area of the floor to obtain these quantities per unit built up area of the floor. Also by considering the entire building, the average quantities of each of the three structural materials per square meter of the built up area are calculated for the five different heights of the buildings in four seismic zones and there by arriving the quantity modelling of the structural systems as shown in Table 2. From these calculations the consumption of steel reinforcement per cubic meter of concrete are also determined to bring out the variations due to building heights and seismic zones. This information is useful for the cost estimators in working out the bill of quantities.

Table 2. Quantity modelling of structural components in different seismic zones

Build	Zone	Steel reinforcement (kg/sqm)						Concrete (cum/sqm)						Shuttering (sqm/sqm)					
		COL	MB	SW	SB	SLAB	TOTAL	COL	MB	SW	SB	SLAB	TOTAL	COL	MB	SW	SB	SLAB	TOTAL
20 Storey	II	12.66	15.21	2.14	2.44	13.03	45.48	0.07	0.09	0.04	0.02	0.12	0.34	0.40	0.65	0.30	0.13	1.02	2.50
	III	12.66	16.85	2.20	2.44	13.03	47.17	0.07	0.09	0.04	0.02	0.12	0.34	0.40	0.65	0.30	0.13	1.02	2.50
	IV	12.86	19.13	2.44	2.44	13.03	49.90	0.07	0.09	0.04	0.02	0.12	0.34	0.40	0.65	0.30	0.13	1.02	2.50
	V	14.32	21.82	3.26	2.44	13.03	54.87	0.07	0.09	0.04	0.02	0.12	0.34	0.40	0.65	0.30	0.13	1.02	2.50
18 Storey	II	11.36	13.34	2.11	2.45	13.05	42.32	0.07	0.09	0.04	0.02	0.12	0.33	0.39	0.65	0.31	0.13	1.02	2.49
	III	11.36	15.12	2.18	2.45	13.05	44.17	0.07	0.09	0.04	0.02	0.12	0.33	0.39	0.65	0.31	0.13	1.02	2.49
	IV	11.86	17.63	2.33	2.45	13.05	47.32	0.07	0.09	0.04	0.02	0.12	0.33	0.39	0.65	0.31	0.13	1.02	2.49
	V	13.97	21.65	3.17	2.45	13.05	54.29	0.07	0.09	0.04	0.02	0.12	0.33	0.39	0.65	0.31	0.13	1.02	2.49
16 Storey	II	10.94	13.87	2.15	2.46	13.09	42.50	0.07	0.09	0.04	0.02	0.12	0.34	0.36	0.65	0.31	0.13	1.02	2.47
	III	10.94	15.03	2.23	2.46	13.09	43.75	0.07	0.09	0.04	0.02	0.12	0.34	0.36	0.65	0.31	0.13	1.02	2.47
	IV	11.22	17.49	2.40	2.46	13.09	46.66	0.07	0.09	0.04	0.02	0.12	0.34	0.36	0.65	0.31	0.13	1.02	2.47
	V	13.32	20.95	3.17	2.46	13.09	52.99	0.07	0.09	0.04	0.02	0.12	0.34	0.36	0.65	0.31	0.13	1.02	2.47
14 Storey	II	8.65	13.69	2.04	2.48	13.31	40.17	0.05	0.09	0.04	0.02	0.13	0.32	0.33	0.65	0.31	0.13	1.02	2.44
	III	8.65	14.94	2.16	2.48	13.31	41.53	0.05	0.09	0.04	0.02	0.13	0.32	0.33	0.65	0.31	0.13	1.02	2.44
	IV	10.30	16.39	2.39	2.48	13.31	44.87	0.05	0.09	0.04	0.02	0.13	0.32	0.33	0.65	0.31	0.13	1.02	2.44
	V	12.71	19.52	3.18	2.48	13.31	51.20	0.05	0.09	0.04	0.02	0.13	0.32	0.33	0.65	0.31	0.13	1.02	2.44
12 Storey	II	8.22	12.98	2.03	2.48	13.31	39.01	0.05	0.09	0.04	0.02	0.13	0.31	0.32	0.65	0.31	0.13	1.03	2.44
	III	8.22	14.28	2.09	2.48	13.31	40.37	0.05	0.09	0.04	0.02	0.13	0.31	0.32	0.65	0.31	0.13	1.03	2.44
	IV	9.52	16.15	2.41	2.48	13.31	43.87	0.05	0.09	0.04	0.02	0.13	0.31	0.32	0.65	0.31	0.13	1.03	2.44
	V	12.16	18.29	3.17	2.48	13.31	49.42	0.05	0.09	0.04	0.02	0.13	0.31	0.32	0.65	0.31	0.13	1.03	2.44

Once the bill of quantities is worked out, the cost of the structural elements is worked out based on the unit rates of construction items available in Delhi schedule of rates for building works [5]. An enhancement of 15% is considered over the year 2014 rate to account for the current rates. The effect of increased rates for higher floor levels are also considered as per the practice. Finally, the structural system cost per square meter of the built up area with considerations of building heights and seismic zones are arrived to provide the cost modelling of the structural system and the results are shown in the Table 3. This cost model calculation also brings out the cost premium considering the different levels of seismic effects in the design.

Table 3. Cost modelling of structural systems of buildings in different seismic zones

Bldg.	Zone	Steel reinforcement (Rs/sqm)						Concrete (Rs/sqm)						Shuttering (Rs/sqm)						Total cost Rs/sqm)
		COL	MB	SW	SB	SLAB	TOTAL	COL	MB	SW	SB	SLAB	TOTAL	COL	BEAM	SW	SB	SLAB	TOTAL	
20 Storey	II	960	1012	164	188	1005	3329	670	789	379	143	1146	3127	222	185	172	52	205	836	7291
	III	960	1139	168	188	1005	3460	670	789	379	143	1146	3127	222	185	172	52	205	836	7422
	IV	975	1315	186	188	1005	3668	670	789	379	143	1146	3127	222	185	172	52	205	836	7630
	V	1081	1523	208	188	1005	4004	670	789	379	143	1146	3127	222	185	172	52	205	836	7966
18 Storey	II	860	1021	161	187	998	3227	627	784	371	142	1138	3062	215	184	171	52	204	825	7115
	III	860	1157	166	187	998	3368	627	784	371	142	1138	3062	215	184	171	52	204	825	7256
	IV	895	1348	176	187	998	3606	627	784	371	142	1138	3062	215	184	171	52	204	825	7493
	V	1048	1557	229	187	998	4019	627	784	371	142	1138	3062	215	184	171	52	204	825	7907
16 Storey	II	822	950	162	186	991	3110	656	777	376	141	1129	3080	201	182	170	51	202	807	6997
	III	822	1138	167	186	991	3304	656	777	376	141	1129	3080	201	182	170	51	202	807	7191
	IV	994	1225	179	186	991	3574	656	777	376	141	1129	3080	201	182	170	51	202	807	7461
	V	994	1587	235	186	991	3992	656	777	376	141	1129	3080	201	182	170	51	202	807	7879
14 Storey	II	641	925	152	186	997	2902	434	774	348	141	1137	2834	179	181	169	51	201	781	6518
	III	641	1120	161	186	997	3105	434	774	348	141	1137	2834	179	181	169	51	201	781	6721
	IV	762	1228	349	186	997	3523	434	774	348	141	1137	2834	179	181	169	51	201	781	7138
	V	938	1463	365	186	997	3949	434	774	348	141	1137	2834	179	181	169	51	201	781	7565
12 Storey	II	606	944	150	184	988	2872	415	764	341	140	1127	2787	174	179	168	51	194	766	6424
	III	606	1060	155	184	988	2993	415	764	341	140	1127	2787	174	179	168	51	194	766	6545
	IV	700	1200	177	184	988	3249	415	764	341	140	1127	2787	174	179	168	51	194	766	6802
	V	850	1294	221	184	988	3537	415	764	341	140	1127	2787	174	179	168	51	194	766	7089

7. Structural quantities in constructed buildings

The structural quantities adopted for some of the constructed buildings in India designed for seismic effects are compiled and shown in Table 4. This data broadly compares with the results of the present study and the variations could be attributed to the variation in the structural configurations adopted.

Table 4 – Structural quantities from existing buildings.

Building with seismic zone location	Structural concrete (cum. per sq.m.)	Steel reinforcement (kg per sq.m.)
21 storeyed commercial building in Zone IV	0.43	--

21 storeyed residential building Zone IV	0.33	59.20
27 storeyed residential building Zone IV	0.38	62.00
14 storeyed office building in Zone IV	0.30	50.80

8. Results of the study

The study carried out on the quantity and cost modelling of the structural system of reinforced concrete shear wall buildings in the range of 12 to 20 storeys in different seismic zones of India has brought out the following results.

On the aspect of quantity modelling, the requirement of structural concrete varies from 0.31 to 0.34 cum per sq.m of the built up area of the building with higher values attributed to taller buildings due to increased member sizes for load resistance. The requirement of shuttering material shows little variation and the average value is 2.47 sq.m. per sq.m. of the built up area. Fig. 3 shows graphically the requirements of structural concrete and shuttering material.

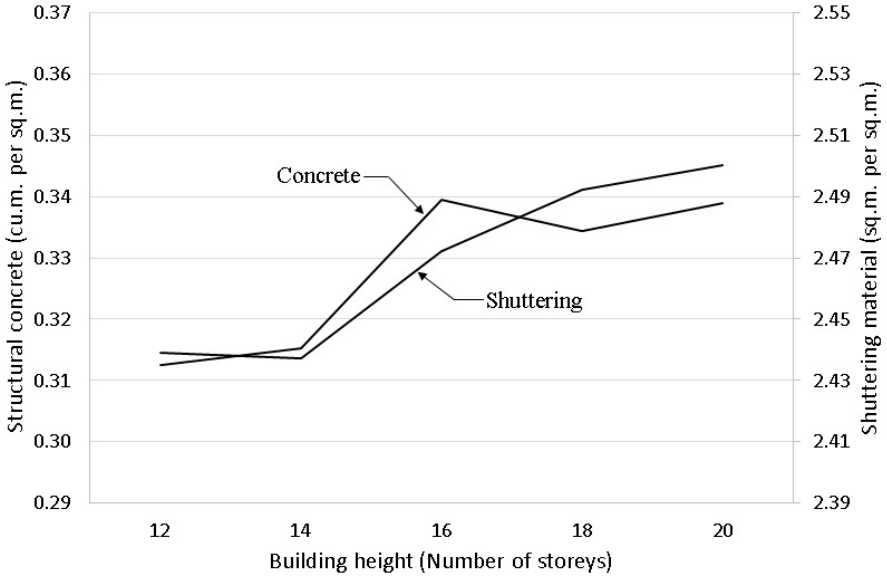

Fig. 3 –Requirement of structural concrete and shuttering material per sqm. of built up area

The requirement of steel reinforcement for the individual structural members and for the total structural system for the five different height of the buildings in low to very severe seismic zones are shown in Table 2 and graphically shown in Fig. 4. The value varies in the range of 40 to 55kg per sq.m. of the built-up area. The value increases with increase in number of storeys and increase in seismic severity from seismic zone II to V. The highest value is in the order of 54.87 kg per sq.m. for 20 storey building in seismic zone V.

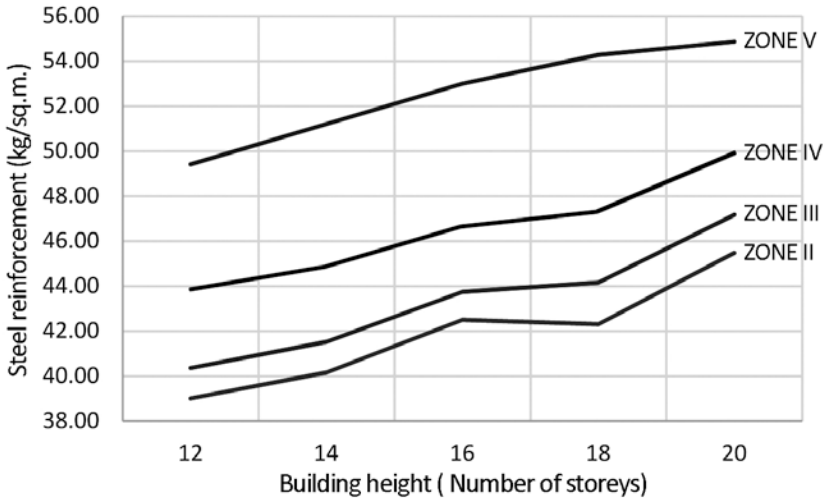

Fig. 4. Requirement of steel reinforcement per sqm. of built up area for different seismic zones

The study has brought out that the frame shear wall combination is more economical compared to the structural system only with moment resisting frames since the structural quantities arrived for a 10 storeyed building with same column grid layout with moment resisting frames showed more or less same requirement of structural quantities per unit built up area as that for the 20 storeyed building with shear walls. [1]

The study has brought out the aspect of larger demand of steel reinforcement in the ground storey which gets reduced towards the upper storeys due to the reduction in seismic demand towards the top. Fig.5 and Fig 6 show these variations for 20 and 16 storeyed buildings considered. In the case of 20 storeyed building the steel requirement at the ground storey is around 72 kg per sq.m. which reduces to about 50 kg per sq.m. at the top storey.

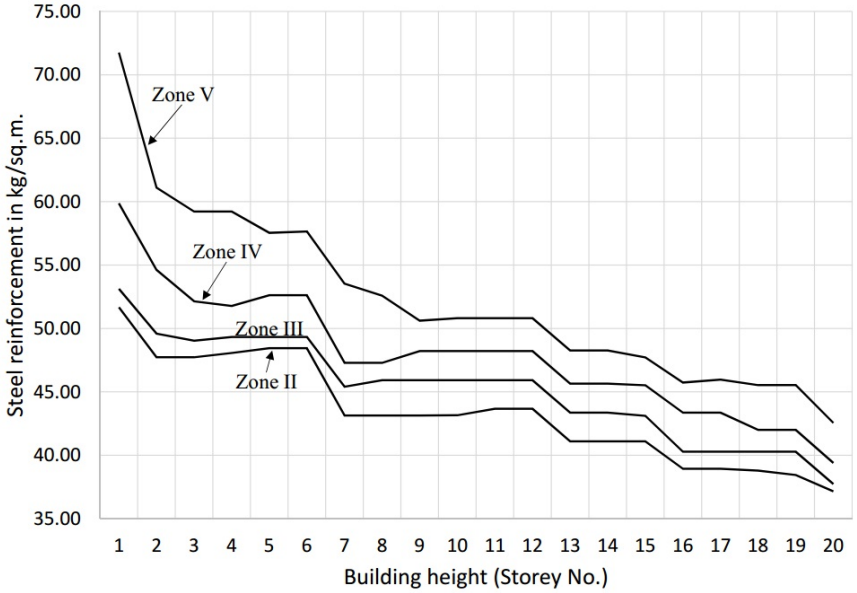

Fig. 5. Requirement of storey wise steel reinforcement for 20 storey building in different seismic zones.

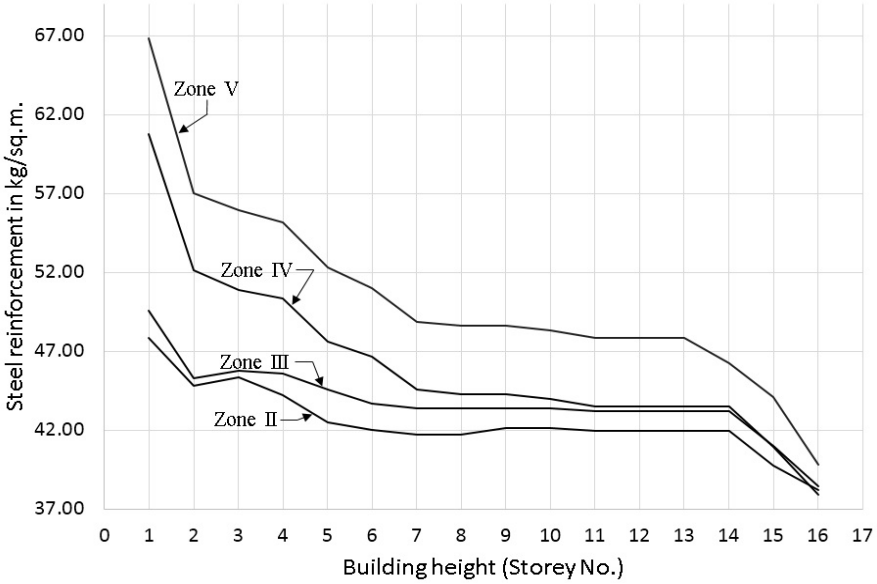

Fig 6. Requirement of storey wise steel reinforcement for 16 storey building in different seismic zones.

Through the proposed cost modelling approach, the structural system cost per square meter of the built up area are determined accounting low to very severe seismic conditions for five building heights considered. These costs arrived as square meter cost of built up area are based on the current rates of construction. The values obtained are shown in Table 3 and graphically presented in Fig 6.

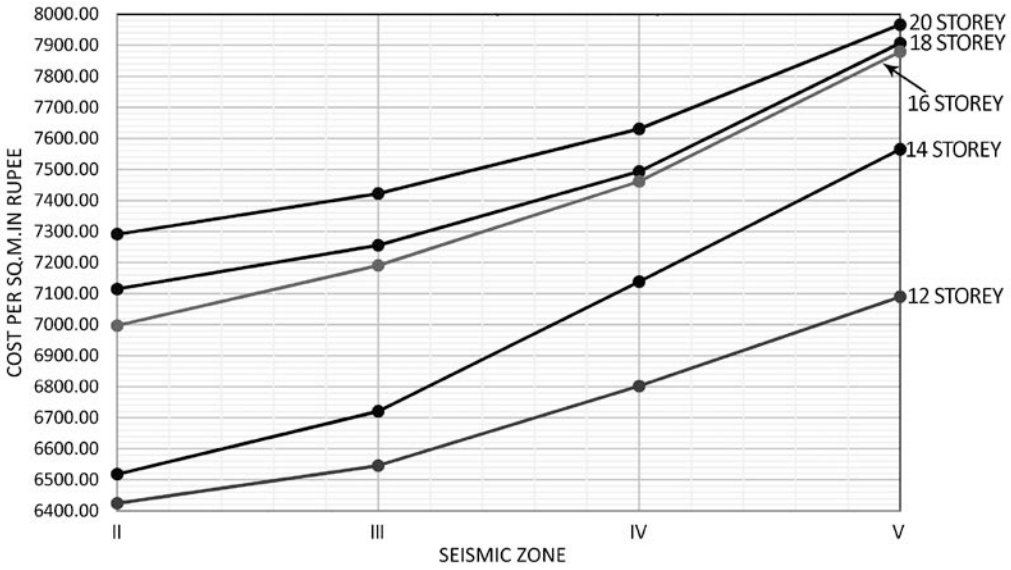

Fig.7- Cost of structural systems in different seismic zones (Rs per sqm of built up area)

These results quantify the aspect of cost premium for incorporating different levels of seismic forces. For the 20 storeyed building the cost of structural system is more about 10 %, 5 % and 2 % in seismic zones V, IV and III respectively compared to the cost in a low seismic condition, i.e. seismic zone II.

Table 5 – Cost premium for incorporating seismic resistance as percentage over seismic zone II design

Zone	20 storey	18 storey	16storey	14storey	12storey
III	1.80	1.98	2.77	3.11	1.88
IV	4.65	5.32	6.64	9.52	5.88
V	9.26	11.13	12.61	16.06	10.35

The storey wise quantification of structural quantities provides a useful input for the resource planning and time estimation processes in the area of construction management of multi-storeyed building projects.

5. Conclusions

The study has contributed towards the quantity and cost modelling aspects of reinforced concrete structural systems designed for different levels of seismic effects and quantifies the cost premium for incorporating the seismic safety. It has been brought out that such extra cost implications are not likely to exceed about 10 to 16% for the very severe seismic zone for the building systems studied. The study presented is considered useful for the cost estimation processes in the early stages of design and provides an approach for evaluating the cost economics of alternate structural systems designed for seismic effects. The results of the study are also useful for the time and resource planning aspects in the area of construction management.

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