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QUANTITY ESTIMATION OF STRUCTURAL MATERIALS IN REINFORCED CONCRETE BUILDINGS DESIGNED FOR SEISMIC EFFECTS

V. THIRUVENGADAM[1], Thangmuansang GUITE[2], Rishi Kant THAKRE[3], J.C.WASON.[4]

ABSTRACT

The cost prediction of reinforced concrete structural systems with seismic resistant provisions is of research interest in building economics. The quantity estimation of structural materials forms the major effort in cost estimation process.
This study presents two quantity estimation methods using quantity modeling concepts accounting three major cost influencing parameters; number of storey, structural configuration and seismic hazard level. In the gross floor area method, approximate structural quantities are obtained based on the quantities used per unit floor area of constructed buildings. In the detailed bill of quantities method, structural concrete and shuttering materials are assessed from the structural framing plans and steel reinforcement quantities are assessed based on appropriate steel reinforcement coefficients that define the weight of reinforcement required per unit volume of concrete considering structural member type and seismic design requirements.
The quantity estimation process is carried out for the structural systems with 6m x6.5m column grids, heights varying from 2 to 20 storey and designed for four seismic zones. Depending on these variables, the quantities of structural concrete, steel reinforcement and shuttering per square meter of the gross floor area ranges between 0.25 to 0.35cum, 1.50 to 2.50sq.m and 25kg to 55kg respectively. The steel coefficient for the total structural system vary from 100 to 250 kg per cum of concrete. As built quantities are compiled for buildings constructed in seismic zones.
The proposed parametric quantity modeling is useful for evaluating the cost economics of structural systems besides the quantity surveying, project scheduling and material management applications.

Keywords: reinforced concrete; structural materials; quantity estimation; seismic design

1. INTRODUCTION

Building structural system constitutes as one of the major cost component of the building and could be in the range of 35 to 50% of the total building cost excluding the building services. The structural system for the reinforced concrete multi-storeyed building is broadly divided into super structure system consisting of framing system and floor system and substructure system with basement floors with retaining walls and foundation system. The superstructure cost is governed by the building architectural proportions, structural system configurations and design requirements for carrying gravity loads due to occupancy and lateral loads from earthquake and wind effects. The substructure cost depends on the structural arrangement of basement floors and type of foundation system adopted based on the geotechnical parameters of the substrata.

The cost prediction of reinforced concrete structural systems is of research interest in the area of building economics and in particular with design provisions for earthquake safety under different

[1]Visiting Professor, School of Planning and Architecture, New Delhi, India, thiruspa@gmail.com
[2]Design Engineer, New Delhi, India, gsangboi@gmail.com
[3]Project Manager, Mumbai, India, rishithakre@yahoo.com
[4]Design Engineer, New Delhi, India, jcwason@yahoo.com

levels of seismic hazards. The structural materials used for the construction of the cast-in-situ reinforced concrete structural system are; the structural concrete, steel reinforcement bars and the shuttering materials and the quantity estimation of these structural materials in slab, beam, column and shear wall components that constitutes the structural system is the major effort in the cost estimation process.

This paper deals with the methods of quantity estimation of structural materials in the super structure system of the commonly adopted cast-in-situ reinforced concrete framed buildings in the height range of 2 to 20 storey designed for different levels of seismic effects. In the first method, called floor area method, the approximate quantities per unit gross floor area (GFA) of the proposed building are assessed based on the quantities used in actually constructed buildings with similar structural and seismic parameters. In a more detailed approach, called bill of quantities method (BOQ), detailed bill of quantities are assessed from the floor wise framing plans of the structural system and with the use of steel coefficients for each component of the structural system. For the satisfactory earthquake performance the structural framing arrangement needs to be worked out incorporating the earthquake resistance features. In two earlier works, Thiruvengadam et al (2004) and Thiruvengadam and Thangmuansang (2017), the cost modelling and the cost premium for earthquake resistance are brought out. The quantity and cost estimation aspects of the foundation systems are taken up under a separate study.

2. STRUCTURAL FRAMING WITH EARTHQUAKE RESISTANCE FEATURES

Reinforced concrete framed buildings with masonry infill walls are commonly adopted in many parts of the world. For the height range of about 15 storey structural system with moment resisting frames coupled by solid floor slabs are used and for the increased heights up to about 35 storey shear walls in combination with the frames are adopted for providing the required lateral load resistance against earthquake and wind forces.

The floor level framing plans are evolved showing the configuration of structural elements in terms of their location, size, shape and orientation, floor heights, column grid spacing, spans and sizes of main and secondary beams and the proportions and thickness of the slab panels. The structural framing plans needs to be worked out in close coordination with architectural discipline to meet the functional requirements of the floor spaces and building services disciplines for accommodating the requirements of the building mechanical, electrical and plumbing services. The coordinated framing plans form the basis for proceeding with the detailed designs for all the disciplines including the detailed costing of the building structural systems.

The uniformity and symmetry in architectural, structural configurations and mass distribution developed during early stages of design contribute to the inherent seismic resistant capacity to the buildings and this has been amply demonstrated in a number post-earthquake damage studies. Some of the aspects that needs to be taken care while developing structural framing arrangements to ensure good seismic performance are: appropriate planning and positioning of seismic joints, symmetrical placements of structural elements avoiding undesirable torsional effects, member sizing of beams and columns considering the beam column joint behaviour including the reinforcement anchorage requirements in the joint zones, detailing for ductile behaviour, adequate lateral stiffness along the principal axes of the building, special care of structural arrangement in buildings with open ground storey and other considerations to ensure satisfactory seismic performance. The structural member sizes besides meeting the strength and stiffness criteria based on preliminary designs should also take in to considerations the avoidance of reinforcement congestion and easy placement of concrete during the construction process.

The floor level framing plans evolved with the earthquake resistant considerations with structural member sizes facilitates quantity estimation of structural concrete and the area of shuttering materials. As the requirement of structural concrete for the slab component forms the substantial portion of the total quantity it would be economical to provide optimum floor slab thicknesses. Provision of secondary beams in large sized slab panel would enable the adoption of lesser slab depths.

3.CONCEPT OF QUANTITY MODELLING OF STRUCTURAL SYSTEM

Under this concept of quantity modelling, the floor wise requirements of the structural quantities are expressed per unit area of the individual floors and the total structural system requirements are expressed per unit built up area of the building. Initially the quantities of structural concrete, steel reinforcement and shuttering materials required for the individual components of the structural system (slabs, beams, supporting columns and shear walls) in a particular floor are expressed as the volume of concrete, weight of steel reinforcement and area of shuttering materials per unit area of the floor under consideration. These floor wise structural quantities of the individual components are then combined to obtain equivalent volume of concrete, weight of steel reinforcement and area of shuttering materials per unit area of the floors as illustrated in Figure 1. The requirement of the structural quantities for the total structural system are obtained by dividing the total quantity requirements by the total built up area of the building structural system. In seismically designed buildings the floor wise quantities will be maximum in the lower most storey and would generally reduce towards the upper storey in buildings with regular configurations. If the structural member sizes are kept same in all the floors then the variation shall be only in steel reinforcement. These aspects of floor wise variations in quantities are brought by the proposed quantity model.

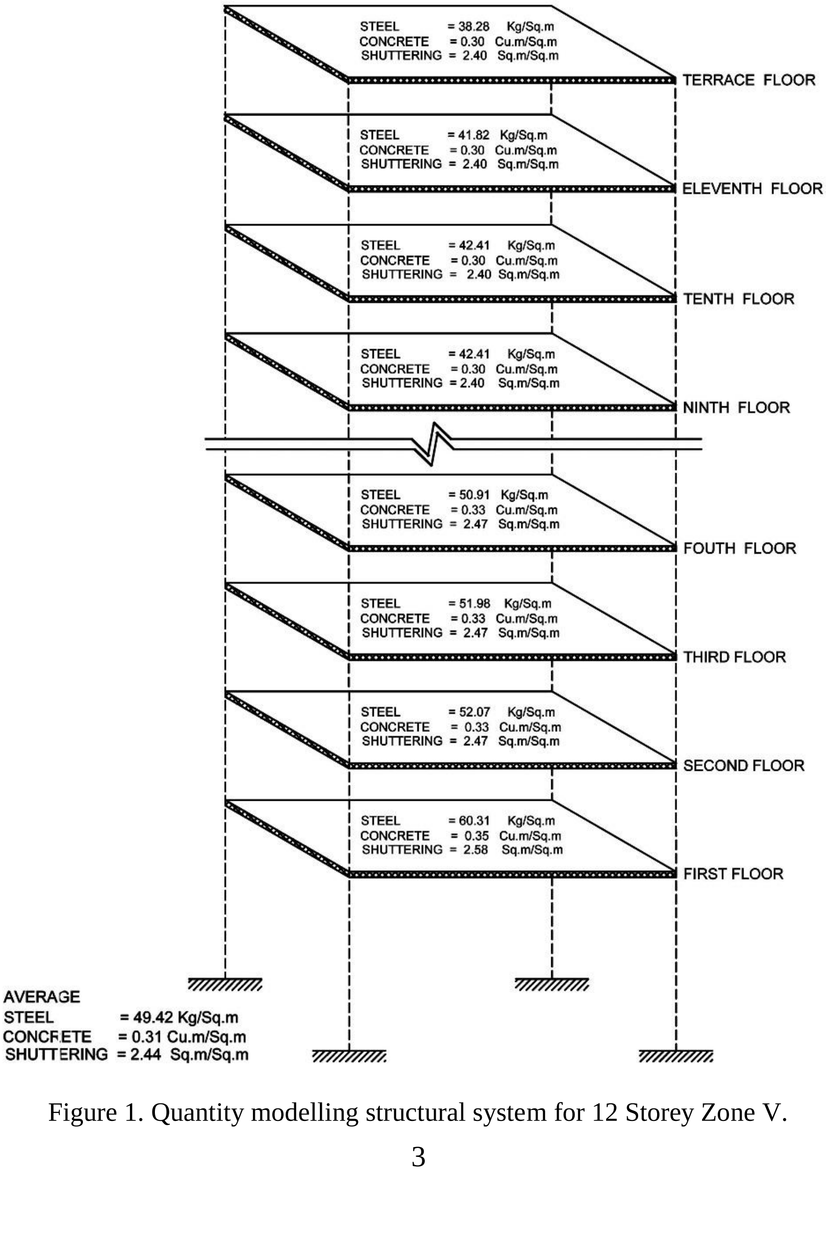

Figure 1. Quantity modelling structural system for 12 Storey Zone V.

The proposed quantity modelling besides forming the basis for determining the structural cost enables for the comparison of the structural materials requirements and cost economics of the comparable alternative structural systems. It also provides the extent of variations in structural quantities in structural system designed for the different levels of seismic hazards and for the evaluation of cost premium for seismic safety.

4. QUANTITY ESTIMATION BY FLOOR AREA METHOD

In this floor area method, the requirements of structural quantities for the proposed building structural system is obtained using the data base of the quantities used per unit built up area in the similar constructed projects. Similarity is considered in terms of occupancy type, number of storey, column grid spacing defining the beam spans, slab panel sizes and seismic zone of the building location. The total quantities of the structural concrete, steel reinforcement and shuttering requirements of the proposed structural system is obtained by multiplying the respective data base quantity with the total built up floor area of the proposed building. The data obtained from few constructed buildings are given and discussed subsequently in this paper. This method is analogous to the popular square meter cost estimation method used to obtain the building preliminary cost estimates based on the similar constructed building costs.

5. QUANTITY ESTIMATION BY BILL OF QUANTITIES METHOD

5.1 General

In this approach the quantities of structural concrete and the shuttering materials are worked out from the floor wise structural framing plans with the structural member sizes as discussed in the earlier section. The standard method of measurement (SMM) adopted in quantity surveying (QS) practice is used to calculate the volume of the structural concrete and the area of shuttering materials. For calculating the slab quantities the clear slab panel size between the supporting beams are considered. The beam length shall be the clear span between the supporting columns and the depth shall be inclusive of the portion of slab thickness over the beams. For the columns and shear walls, the height shall be taken inclusive of the beam depths in beam-column/shear wall junctions. For determining the required shuttering areas, the clear surface area of the structural members supporting the concrete casting are considered.

5.2 Estimation of steel reinforcement quantities

The steel reinforcement constitute substantial portion of structural cost compared to the cost of structural concrete and the cost ratio between steel reinforcement and concrete is about 60 per cubic meter of these materials. In the quantity surveying practice the steel reinforcement quantities are obtained by multiplying the volume of structural concrete by the appropriate steel coefficient considered for the structural member. The steel coefficient is defined as the weight of steel reinforcement required per cubic meter of the concrete in the structural member (kg/cum) and would depend on the type, design and detailing requirements of the structural member. Once the member wise concrete quantities and the applicable steel coefficients are known, the floor wise steel reinforcements are calculated and expressed per unit built up area of the floors. For the total structural system, the average steel consumption per cubic meter of concrete is obtained by dividing the total quantity of steel by the total quantity of the concrete used in the system. Use of appropriate steel coefficient for the structural members is an important aspect in the assessment of the steel reinforcement quantities.

Under the earthquake loads, the floor system with its large in plane stiffness provides diaphragm action for the transmission of lateral loads to the vertical framing system. The slab panels and the secondary beams are designed only for gravity loads and their concrete and steel reinforcement requirements and steel coefficients are not considered influenced by the earthquake loads. The beams, columns and shear walls, as earthquake resistance elements, require additional reinforcement over and above the requirements for the gravity load designs. Accordingly the steel coefficients these elements will gets increased with the increased level seismic hazards considered in the design. In high seismic zones, the reinforcement quantity gets increased due to the provision of ductility detailing with closely spaced stirrups.

In the absence of adequate data, quantity surveyors tend to use approximate steel coefficients without adequate considerations for seismic parameters. Any incorrectly assumed steel coefficients in estimation stage would result into variance with the actually executed quantities based on the final structural designs resulting into cost variations and contractual issues. Inaccuracy in the estimation of this major cost item would have bearings in the tender evaluations and final as built contract amount. No published data on this aspect of steel coefficients seems to be available and is generally confined in the documents of the constructed projects.

Keeping in view the above aspects, the present study aims to develop values of steel coefficients for different components of the structural system taking into account the framing arrangement, building heights and varying levels of design seismic forces. The results of the study are considered useful for the quantity estimation of similar structural systems and this type of information needs to be developed for different structural arrangements and occupancy types.

6. BUILDING STRUCTURAL SYSTEMS STUDIED

In this study, quantity estimation of structural materials for office buildings in the height range of 2 to 20 storey are considered. Structural system with moment resisting frames with solid floor slab system are adopted for 2 to 10 storey buildings and frames in combination with shear walls are adopted for 12 to 20 storey buildings. The column grid spacing adopted is 6mx6.5m which is commonly used for office buildings. Solid floor slab panels are provided with secondary beams to reduce the slab thickness. For 2 to 10 storey buildings, the column size varied from 750x750mm to 600x600 mm depending upon the building heights with the main and secondary beam sizes of 350x650 mm and 250mmx450mm respectively. The floor slab thickness adopted is 120mm.

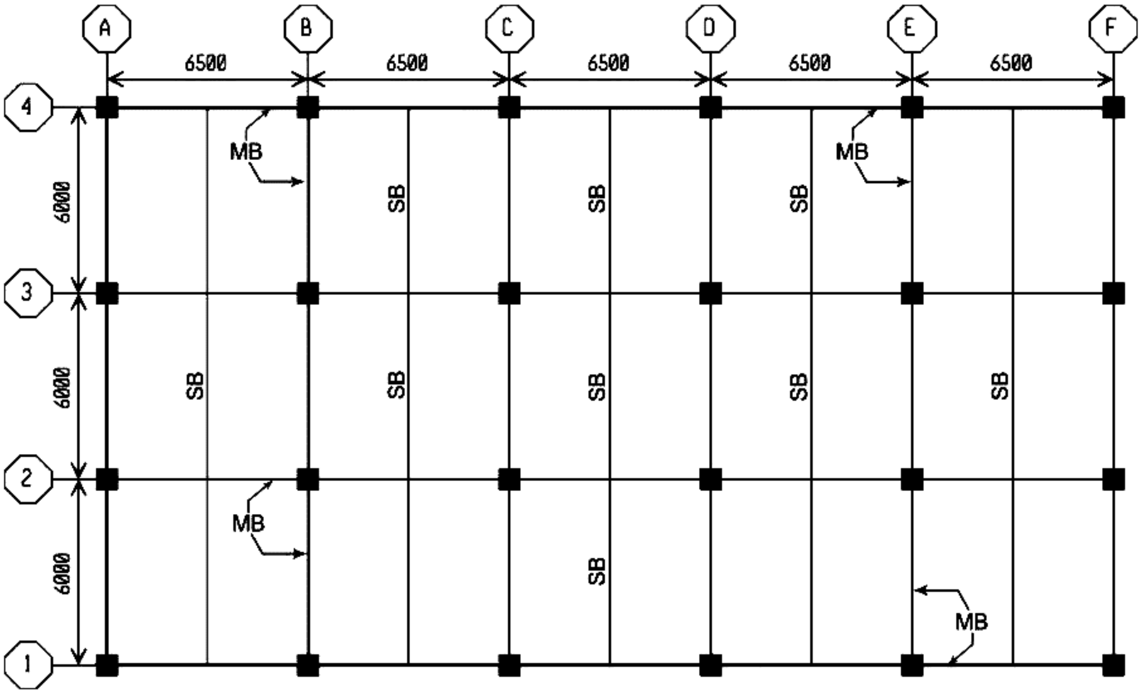

Figure 2. Structural framing plan for 2-10 storey.

The column sizes adopted for 12 to 20 storey building varied from 800mmx800mm to 500mmx500mm.The shear wall length is 3000mm with thickness along the height varying from 350mm to 250mm.The structural arrangement for the typical floor is shown for the two sets of buildings in Figure 2 and Figure 3. The concrete grade of M35 and M30 adopted for columns and shear walls and M25 for floor beams and slabs. The steel reinforcement grade used is Fe 500 and these material grades are as per Indian codes. The structural member sizes are based on preliminary analysis with considerations of reducing reinforcement congestion and durability aspects.

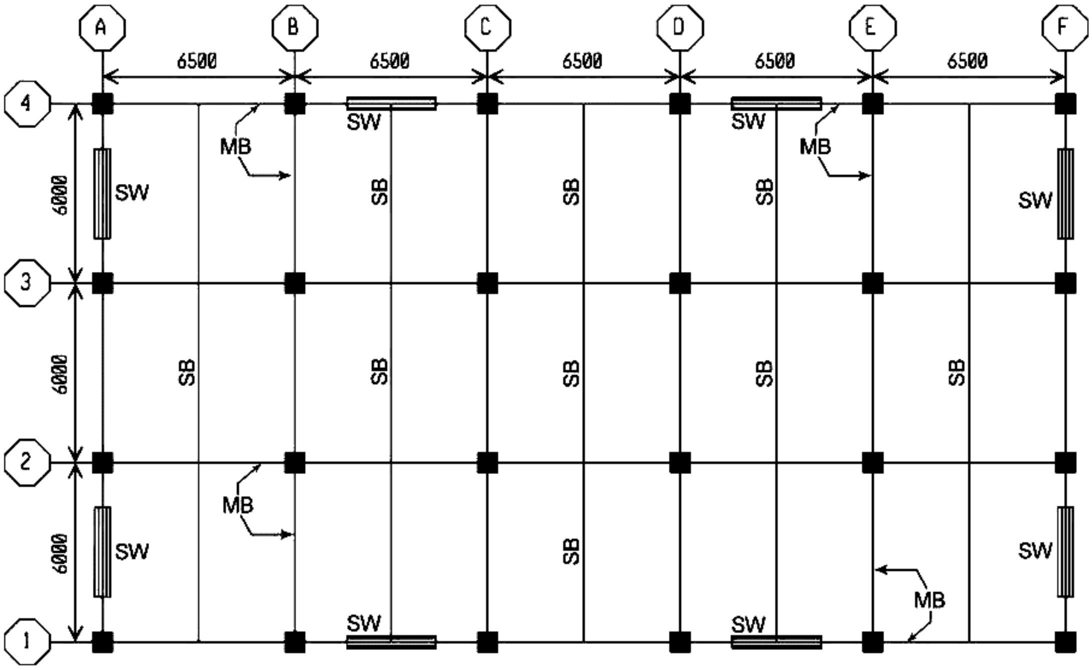

Figure 3. Structural framing plan for 12-20 storey.

7. SEISMIC HAZARDS CONSIDERED

The ten buildings in the range of 2 to 20 storey mentioned above are designed for four levels of earthquake effects by considering them located in four seismic zones of Indian subcontinent which vary from low to very severe seismic conditions. The seismic parameters of these zones as per Indian seismic code IS 1893 (2002) is shown in Table 1.

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, the design base shear is calculated as;

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

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.

Response spectrum method of earthquake analysis are carried out using ETABS software on the three dimensional modelling of the structural systems 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 individual member design and detailing for ductility for high seismic zones are done as per Indian seismic code IS 4326(2002). Based on the seismic design and detailing for the ten buildings in each of the four seismic zones, the quantities of structural concrete, steel reinforcement and shuttering materials are worked out for all the 40 cases and the results are tabulated and discussed in the following section.

8. DETERMINATION OF QUANTITIES OF STRUCTURAL MATERIALS

The requirements of structural concrete, steel reinforcement and shuttering materials per unit gross floor area of the buildings obtained through detailed design and detailing in four seismic zones are shown in Table 2 for 2 to 10 storey buildings and in Table 3 for 12 to 20 storey buildings. For each of the building heights, the increase in steel reinforcement requirements from low seismic (Zone II) to very severe seismic (Zone V) are shown. The increase in structural concrete requirements due to increase in building heights shown are due to increased sizes of columns and main beams. However for each of the building height, the quantities of structural concrete are same as the structural member sizes are kept same in all the seismic zones and only the steel requirement increases with increasing levels of seismic forces in the seismic zones. The results are also shown graphically in Figure 4.

Table 2. Quantity modelling for 2 to 10 storey buildings.

Build	**Zone**	**Steel Reinforcement (kg/sq.m)**					**Concrete (cum/sqm)**					**Shutering (sq.m./sq.m.)**				
		Col	**MB**	**SB**	**Slab**	**Total**	**Col**	**MB**	**SB**	**Slab**	**Total**	**Col**	**MB**	**SB**	**Slab**	**Total**
2 Storey	II	4.21	8.43	2.45	10.40	25.49	0.05	0.07	0.02	0.11	0.25	0.32	0.17	0.05	1.00	1.54
	III	5.05	9.95	2.45	10.40	27.85	0.05	0.07	0.02	0.11	0.25	0.32	0.17	0.05	1.00	1.54
	IV	6.44	10.69	2.45	10.40	29.98	0.05	0.07	0.02	0.11	0.25	0.32	0.17	0.05	1.00	1.54
	V	8.66	11.95	2.45	10.40	33.46	0.05	0.07	0.02	0.11	0.25	0.32	0.17	0.05	1.00	1.54
4 Storey	II	4.09	8.66	2.45	10.40	25.60	0.05	0.07	0.02	0.11	0.25	0.32	0.17	0.05	0.87	1.41
	III	5.41	10.22	2.45	10.40	28.48	0.05	0.07	0.02	0.11	0.25	0.32	0.17	0.05	0.87	1.41
	IV	6.50	12.14	2.45	10.40	31.49	0.05	0.07	0.02	0.11	0.25	0.32	0.17	0.05	0.87	1.41
	V	8.46	13.43	2.45	10.40	34.74	0.05	0.07	0.02	0.11	0.25	0.32	0.17	0.05	0.87	1.41
6 Storey	II	9.04	10.23	2.45	10.32	32.04	0.06	0.09	0.02	0.11	0.28	0.30	0.16	0.05	0.87	1.38
	III	11.09	12.90	2.45	10.32	36.76	0.06	0.09	0.02	0.11	0.28	0.30	0.16	0.05	0.87	1.38
	IV	12.55	14.06	2.45	10.32	39.38	0.06	0.09	0.02	0.11	0.28	0.30	0.16	0.05	0.87	1.38
	V	14.57	17.11	2.45	10.32	44.45	0.06	0.09	0.02	0.11	0.28	0.30	0.16	0.05	0.87	1.38
8 Storey	II	9.02	10.58	2.45	10.23	32.28	0.06	0.09	0.02	0.11	0.28	0.31	0.16	0.05	0.87	1.39
	III	11.95	13.23	2.45	10.23	37.86	0.06	0.09	0.02	0.11	0.28	0.31	0.16	0.05	0.87	1.39
	IV	13.87	14.57	2.45	10.23	41.12	0.06	0.09	0.02	0.11	0.28	0.31	0.16	0.05	0.87	1.39
	V	17.69	18.46	2.45	10.23	48.83	0.06	0.09	0.02	0.11	0.28	0.31	0.16	0.05	0.87	1.39
10 Storey	II	10.07	11.85	2.45	10.22	34.59	0.07	0.09	0.02	0.11	0.29	0.35	0.15	0.01	0.87	1.38
	III	12.65	14.08	2.45	10.22	39.40	0.07	0.09	0.02	0.11	0.29	0.35	0.15	0.01	0.87	1.38
	IV	15.05	17.29	2.45	10.22	45.01	0.07	0.09	0.02	0.11	0.29	0.35	0.15	0.01	0.87	1.38
	V	18.46	20.45	2.45	10.22	51.58	0.07	0.09	0.02	0.11	0.29	0.35	0.15	0.01	0.87	1.38

Table 3. Quantity modelling for 12 to 20 storey buildings.

Build	Zone	Steel reinforcement (kg/sq.m.)						Concrete(cu.m./sq.m.)						Shuttering (sq.m./sq.m.)					
		Col	MB	SW	SB	Slab	Total	Col	MB	SW	SB	Slab	Total	Col	MB	SW	SB	Slab	Total
12 Storey	II	8.22	12.98	2.03	2.48	13.31	39.02	0.05	0.09	0.04	0.02	0.13	0.33	0.32	0.65	0.31	0.13	1.03	2.44
	III	8.22	14.28	2.09	2.48	13.31	40.38	0.05	0.09	0.04	0.02	0.13	0.33	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	0.33	0.32	0.65	0.31	0.13	1.03	2.44
	V	12.16	18.29	3.17	2.48	13.31	49.41	0.05	0.09	0.04	0.02	0.13	0.33	0.32	0.65	0.31	0.13	1.03	2.44
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	0.33	0.33	0.65	0.31	0.13	1.02	2.44
	III	8.65	14.94	2.16	2.48	13.31	41.54	0.05	0.09	0.04	0.02	0.13	0.33	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	0.33	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	0.33	0.33	0.65	0.31	0.13	1.02	2.44
16 Storey	II	10.94	13.87	2.15	2.46	13.09	42.51	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
18 Storey	II	11.36	13.34	2.11	2.45	13.05	42.31	0.07	0.09	0.04	0.02	0.12	0.34	0.39	0.65	0.31	0.13	1.02	2.49
	III	11.36	15.12	2.18	2.45	13.05	44.16	0.07	0.09	0.04	0.02	0.12	0.34	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	0.34	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	0.34	0.39	0.65	0.31	0.13	1.02	2.49
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	47.18	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

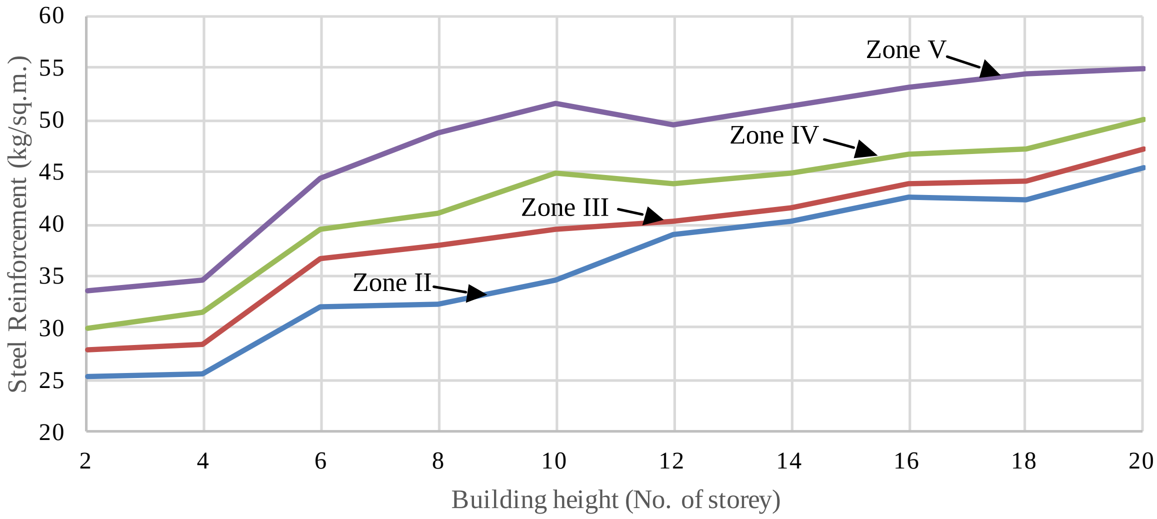

Figure 4. Requirement of steel reinforcement requirement (kg/sq.m.).

The Table 4 show the calculated values of the steel reinforcement coefficients for the individual components of the structural system for the four seismic zones. The average steel coefficient for the total structural system obtained by dividing the total steel reinforcement quantity by the total concrete quantity is also shown. It is important to recognize that the steel reinforcement requirements are sensitive to the structural member sizes adopted in the design. While the adoption of restricted member sizes will increase the quantity of steel reinforcement per unit floor area as well the steel coefficient for individual members, the adoption of somewhat liberal member sizes would reduce these values. The reported values are for the in between situation for the member sizes kept with a view to avoid higher cross sectional steel percentages in members for reducing the reinforcement congestion to ensure defect free concrete placement and dense concrete for durability.

Table 4. Calculated steel coefficients (kg/cum) for 2 to 20 storey buildings.

Bldg	**Zone**	**Col**	**MB**	**SB**	**Slab**	**Average ***	**Bldg**	**Zone**	**COL**	**SW**	**MB**	**SB**	**Slab**	**Average ***
2 Storey	II	84.20	120.43	122.50	94.55	101.96	**12 Storey**	II	164.40	50.75	144.22	124.00	102.38	118.40
	III	101.00	142.14	122.50	94.55	111.40		III	164.40	52.25	158.67	124.00	102.38	122.36
	IV	128.80	152.71	122.50	94.55	119.92		IV	190.40	60.25	179.44	124.00	102.38	132.93
	V	173.20	170.71	122.50	94.55	133.84		V	243.20	79.25	203.22	124.00	102.38	149.72
4 Storey	II	81.80	123.71	122.50	94.55	102.40	**14 Storey**	II	173.00	51.00	152.11	124.00	102.38	121.72
	III	108.20	146.00	122.50	94.55	113.92		III	173.00	54.00	166.00	124.00	102.38	125.88
	IV	130.00	173.43	122.50	94.55	125.96		IV	206.00	59.75	182.11	124.00	102.38	139.97
	V	169.20	191.86	122.50	94.55	138.96		V	254.20	79.50	216.89	124.00	102.38	155.15
6 Storey	II	150.67	113.67	122.50	93.82	114.43	**16 Storey**	II	156.29	53.75	154.11	123.00	109.08	125.02
	III	184.83	143.33	122.50	93.82	131.29		III	156.29	55.75	167.00	123.00	109.08	128.68
	IV	209.17	156.22	122.50	93.82	140.64		IV	160.29	60.00	194.33	123.00	109.08	137.24
	V	242.83	190.11	122.50	93.82	158.75		V	190.29	79.25	232.78	123.00	109.08	155.85
8 Storey	II	150.33	117.56	122.50	93.00	115.29	**18 Storey**	II	162.29	52.75	148.22	122.50	108.75	124.44
	III	199.17	147.00	122.50	93.00	135.21		III	162.29	54.50	168.00	122.50	108.75	129.88
	IV	231.17	161.89	122.50	93.00	146.86		IV	169.43	58.25	195.89	122.50	108.75	139.18
	V	294.83	205.11	122.50	93.00	174.39		V	199.57	79.25	240.56	122.50	108.75	159.67
10 Storey	II	143.86	131.67	122.50	92.91	119.28	**20 Storey**	II	180.86	53.50	169.00	122.00	108.58	133.76
	III	180.71	156.44	122.50	92.91	135.86		III	180.86	55.00	187.22	122.00	108.58	138.76
	IV	215.00	192.11	122.50	92.91	155.21		IV	183.71	61.00	212.56	122.00	108.58	146.76
	V	263.71	227.22	122.50	92.91	177.86		V	204.57	81.50	242.44	122.00	108.58	161.38

*Average steel coefficient (kg/cum) for the total structural system.

Another aspect that influences the steel reinforcement requirement unit floor area is the floor area factor. Although there is increase in quantum of steel reinforcement with increase in building height with associated increase in total floor area the increase in steel quantity is not in the same proportion as that of the quantum of floor area increase. For higher building height with more floor area the requirement of steel per unit floor area could come down in comparison with lower building height with lesser floor area.

Based on the present study, Table 5 shows the suggested values of average steel coefficient for the individual components of the structural system for four seismic zones for use in quantity estimation process. The average steel coefficient values for the total structural system is also shown in Table 5for different seismic zones. Although the suggested values have the limitation that they been derived for a specific column grid size, it is considered useful the quantity estimation for structural systems with similar structural parameters. More research is being done with other column grid sizes for improving the proposed quantity estimation approach.

Table 5. Suggested steel coefficients (kg/cum) for structural members.

Bldg	Zone	Col	Beams	Average*	Bldg	Zone	Col	SW	Beams	Average*
2 to 4 Storey	**II**	90	125	100	**12 to 14 Storey**	**II**	160	50	160	120
	III	110	150	115		**III**	180	50	170	125
	IV	130	175	130		**IV**	200	60	180	135
	V	175	200	140		**V**	200	80	220	155
5 to 7 Storey	**II**	150	150	115	**15 to 17 Storey**	**II**	170	60	170	125
	III	200	175	130		**III**	200	60	180	130
	IV	225	200	145		**IV**	200	80	200	140
	V	250	225	160		**V**	220	80	240	160
8 to 10 Storey	**II**	175	150	120	**18 to 20 Storey**	**II**	180	60	180	135
	III	200	175	140		**III**	200	60	190	140
	IV	250	200	160		**IV**	220	80	220	150
	V	300	225	180		**V**	230	80	250	160

*Average steel coefficient (kg/cum) for the total structural system.
Steel coefficients for solid slabs 100 kg/cum and for secondary beams 125 kg/cum.

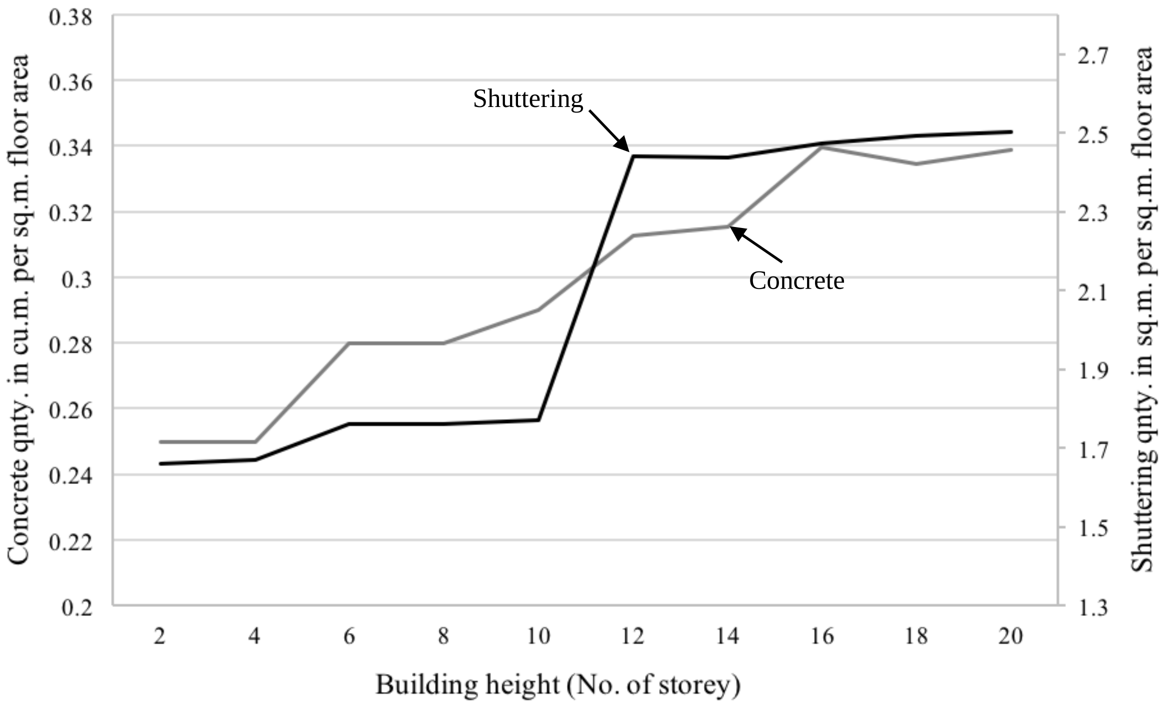

Figure 5. Requirement of structural concrete and shuttering per sq.m. of floor area.

9. QUANTITIES OF STRUCTURAL MATERIALS IN CONSTRUCTED BUILDINGS

A compilation of the quantities of the structural concrete and steel reinforcement used per square meter of the built up area of the buildings of different occupancy types designed and constructed in seismic zones of India is shown in Table 6. These buildings are in the height range of 4 to 23 storey and provided with moment resisting frames with solid floor slabs and some of the taller ones are with shear walls in combination with the frames.

The quantity of the structural concrete and steel reinforcement per square meter of the built up area vary between 0.25cum to 0.30 cum and 30 kg to 55 kg respectively and these values broadly fall in the range of values presented in the present study. Efforts are continuing to compile more such data from seismically designed and constructed buildings.

Table 6. Structural Quantities in constructed buildings.

Sl. No.	Building Height/ Seismic Zone	Structural Concrete cum/sq.m.	Steel Reinf. (kg/sq.m)	Sl. No.	Building Height/ Seismic Zone	Structural Concrete cum/sq.m.	Steel Reinf. (kg/sq.m)
1	Residential (B+G+28)/IV	0.32	59	**9**	Residential (B+G+11)/IV	0.27	--
2	Residential (B+G+19)/IV	0.33	59.20	**10**	Office 8 Storey/IV	0.25	48.00
3	Residential (B+G+22)/IV	0.27	53	**11**	Office 14 Storey/IV	0.30	51.00
4	Residential (B+G+25)/IV	0.38	62.00	**12**	Commercial (3B+G+4)/IV	0.30	47.00
5	Residential (B+G+18)/IV	0.29	--	**13**	Laboratory (B+G+4)/IV	0.28	42.00
6	Residential (B+G+11)/IV	0.25	--	**14**	Office (B+G+4)/II	0.24	42.00
7	Residential (B+G+18)/IV	0.27	--	**15**	Hospital (B+G+5)/IV	0.26	48.00
8	Residential (2B+G+17)/IV	0.29	--	**16**	Hospital (B+G+4)/IV	0.30	46.00

The structural system for above buildings are with Moment resisting frames with solid slabs.
The taller buildings are with shear walls.
B+G+16 indicate one basement +Ground floor +16 upper floors.

10. SUMMARY OF THE STUDY RESULTS

This study presents methods for the quantity estimation of structural materials in reinforced concrete building structural systems using simple parametric quantity modelling concepts accounting three major influencing parameters; number of storey, structural configurations and seismic hazard levels defined by the seismic zones. The application of these methods require data base on structural materials requirements generated through detailed analysis and design of structural systems and from the as built quantities data of seismically designed and constructed buildings.

Towards the objective, the study has considered structural systems for ten building heights from 2 to 20 storey, office type occupancy, with 6mx6.5m column grids and carried out seismic analysis and design for four seismic hazard levels as per the Indian seismic zones and generated data for the forty design cases on the requirement structural concrete, steel reinforcement and shuttering materials. The results of the study are summarized as under:

The requirement of the structural concrete per square meter of the gross floor area varies from 0.25 to 0.34 cum and the shuttering area varies from 1.35 to 2.50 sq.m corresponding to the building height variation of 2 to 20 storey. The percentage increase in concrete quantity for 10 storey and 20 storey buildings over the 2 storey building case are 16% and 40% respectively.

The requirement of steel reinforcement varies from 26 kg to 55kg per square meter of the gross floor area due to increase in building heights and seismic hazard levels and the specific values are shown in Tables 2 and 3. For 2 to 10 storey buildings with moment resisting frames the percentage increase from seismic zone II to zone V is between 31 to 51 % and for the 12 to 20 storey buildings with frame shear wall combination the corresponding percentage increase is between 21 to 28%.

The study has evolved suggested values of steel coefficient for the component wise quantification of the steel reinforcement. For the columns, the values vary from 100 to 200 kg/cum, for the beams, from 125 to 220 kg/cum, for the shear walls, from 50 to 80 kg/cum, and for the total structural system from 100 to 250 Kg/cum corresponding to the increase in building heights and the seismic hazard levels in the seismic zones.

For improving the applicability of the proposed quantity estimation methods similar studies are being carried out for increased column grid sizes 7.5mx7.5m and 10.5mx10.50m and for other occupancy types like residential buildings.

11. CONCLUSIONS

The study reported herein presents the methods for the quantity estimation of structural materials in reinforced concrete structural systems designed for different levels of seismic hazards which enables realistic cost estimation of such structural systems. A simple parametric quantity model is proposed to assess the structural materials requirements per unit gross floor area with the consideration of three influencing parameters; building height, structural framing and the seismic hazard level of the seismic zone. This approach is useful for evaluating the comparative economics of the alternative structural systems and for the bench marking the material consumptions in reinforced concrete structural systems including the assessment of premium for incorporating the seismic resistance. The proposed quantity estimation methods shall facilitate project schedule development and material management applications.

12. REFERENCES

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