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COST MODELING OF REINFORCED CONCRETE BUILDINGS DESIGNED FOR SEISMIC EFFECTS

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SUMMARY

The paper deals with structural cost modeling of seismically designed and detailed reinforced concrete framed structures for medium rise buildings in various seismic zones of Indian subcontinent. The model provides the total and componentwise quantities of structural concrete, steel reinforcement and shuttering material per unit area of floors. The structural system cost and the cost premium for seismic safety are presented. The study is broadly validated from the historic data of seismically designed and constructed buildings. The results of the study would be useful for design professionals and quantity surveyors.

INTRODUCTION

The most commonly adopted structural system for medium rise buildings in developing countries has been the cast-in-situ reinforced concrete moment resisting frames coupled by solid floor slabs. These bare frames are infilled with non-structural brick or concrete block masonry panel walls for creating the external enclosure and internal partition walls. The buildings with regular architectural and structural configurations having moment resisting frames with adequate beam-column sizes for joint rigidity and reinforcement detailing satisfying ductility requirements are proved to be quite capable of resisting high seismic forces as demonstrated in the recent major earthquakes in the Indian subcontinent.

For the reinforced concrete buildings in the range of 4 to 10 storeys with moment resisting framed structural system with shallow foundations on reasonably good soil conditions, the cost of the structural components including foundation would constitute the major components of the building cost and usually in the range of 40 to 50 % of the building civil cost (excluding the services) depending upon the specifications of the other non-structural components and finishes of the building.

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While the cost of the foundation system is site specific depending upon the building loads and subsoil characteristics, the structural cost of the superstructure would depend upon the structural configuration and loading characteristics including the importance of the building based on its utility. The structural configuration which is evolved from architectural and functional requirements refers to the overall building geometry, column spacing with the resulting beam spans and slab systems. The loading characteristics are influenced by gravity loads due to self weight, occupancy loads and lateral loads arising out of wind and earthquake effects. The durability requirements under the given exposure conditions also influence the structural cost.

As the structural cost forms the major component of the building cost, there is need to evolve appropriate cost modeling techniques to project the structural cost at the early stages of the planning and design. Most of the quantity surveyors project the structural cost based on their experiences and historical data on constructed buildings. Most of theses approaches are approximate and are to be rationalized based on the parametric study of the cost influencing factors such as; structural and architectural configuration, wind and seismic effects, soil parameters, exposure conditions deciding durability requirements, construction technology, importance of building utility etc.

Seismic effect is one of the relatively less understood parameter on the cost implications of the structural components. Although studies have been reported on the premium for earthquake resistance comprehensive cost models are needed for the cost management studies. In developing countries many buildings in seismic zones are constructed without considering seismic effects due to lack of awareness and wrongly presuming to be expensive. Hence there is a need to focus comprehensively on the issue of cost implications to incorporate seismic resistance in buildings. The study presented herein aims to present the structural cost modeling of reinforced concrete framed buildings with moment resisting frames, a commonly adopted structural system for low to medium rise buildings. The structural configuration considered in this study is for the office occupancy. These buildings are completely designed and reinforcement detailing done as per the seismic codal requirements for the moderate, high and very high seismic zones of the Indian subcontinent [1, 2, 3]. The cost models proposed are only for the superstructure of the buildings and a separate study is being done for the foundation systems.

The historical data on the details of the reinforced concrete moment resisting framed buildings with quantities of their structural components for different categories of building occupancies constructed in the last 15 years in the different seismic zones of the Indian subcontinent are compiled and presented in this paper for the broad validation of the proposed cost model.

PROPOSED COST MODEL

The proposed cost model for the structural system of the superstructure of the building is expressed as the quantum and cost of structural concrete, reinforcement steel and shuttering material per square meter of the floors as under and illustrated in fig [1] for a typical building.

(i) The quantities of structural concrete, reinforcement steel and shuttering material for slabs, beams and supporting columns for a particular floor area are expressed as equivalent volume of concrete, weight of steel reinforcement and equivalent shuttering area per square meter of the floor area respectively for individual components as well as their combined value.

(ii) With the known quantities of the structural materials as above and their prevailing unit rates of construction, the structural cost per square meter of the individual floors as well as the average structural cost per square meter of the floor area of the entire building is arrived.

(iii) If the structural member sizes are kept same in all the floors, the equivalent volume of structural concrete and equivalent area of shuttering remain same but the quantum of reinforcement steel per square of floor area will generally gets reduced towards the upper floors due to the reduction in earthquake induced storey shears towards the upper storeys.

BUILDINGS STUDIED

The structural system with moment resisting frames considered for this study is based on the actual buildings constructed for central government offices in various cities in India. The system consists of three bay frames (3 X 6m) placed at 6.5m spacing as shown in fig [2].For the purpose of this study the number of storeys are varied from two to ten storeys. While the slab thickness is kept same for all the cases, the sizes of beams and columns are decided based on the number of storeys and keeping in the view the maximum percentage of steel is restricted to avoid reinforcement congestion and to ensure proper concreting especially at beam-column junctions. The column sizes adopted are ranging from 400 X 400mm for two storied building and up to 650 X 650mm for ten storied buildings. Similarly the beam sizes are in the range of 300X 500 to 350 X 600 mm. The 28 days characteristic compressive strength of concrete and the yield strength of steel reinforcement adopted are 25 N/sq.mm and 415 N/sq.mm respectively.

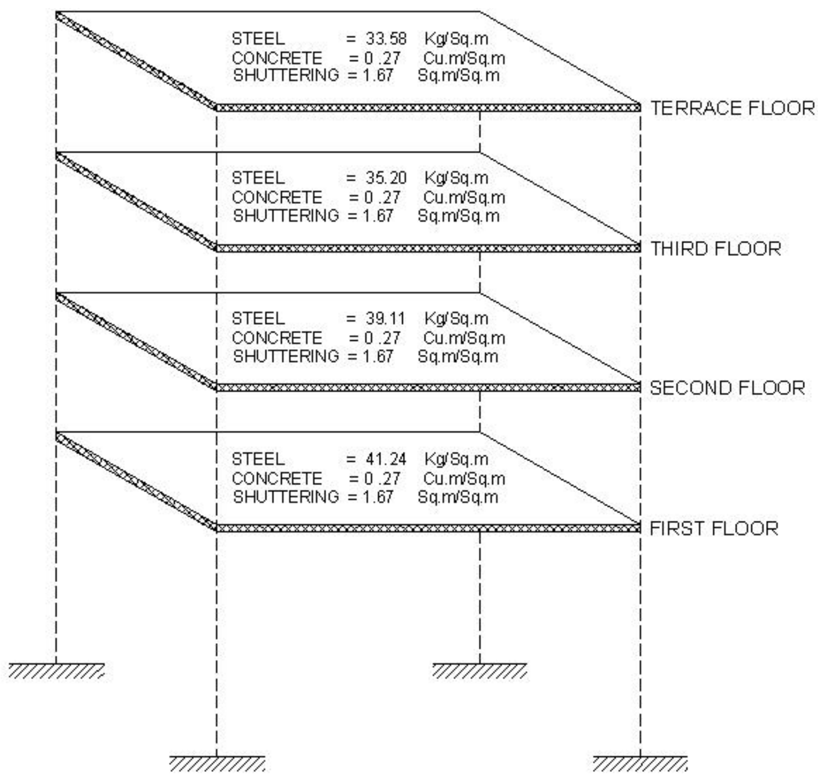

Fig.1.Cost model for a four storyed building in seismic zone IV

Seismic effects considered

In order to study the effect of different levels of seismic forces, the buildings are considered in different seismic zones of India as per I.S.1893-2002[1]. Each seismic zone is assigned with a seismic zone factor characterizing the maximum peak ground acceleration that can occur in the maximum considered earthquake (MCE) in the zone (table .1).In order to present the cost model in a generalized manner, the seismic effects on different buildings in each zone is expressed as design horizontal seismic (base shear) co-efficient expressed as a fraction of acceleration due to gravity. These design base shear co-efficients are obtained as per the code specified formula for the base shear determined as a function of zone factor, importance factor of the building, average response acceleration based on time period of the building, soil characteristics and response reduction factor based on the lateral load resisting system of the building.

Table 1. Intensities of seismic forces considered

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

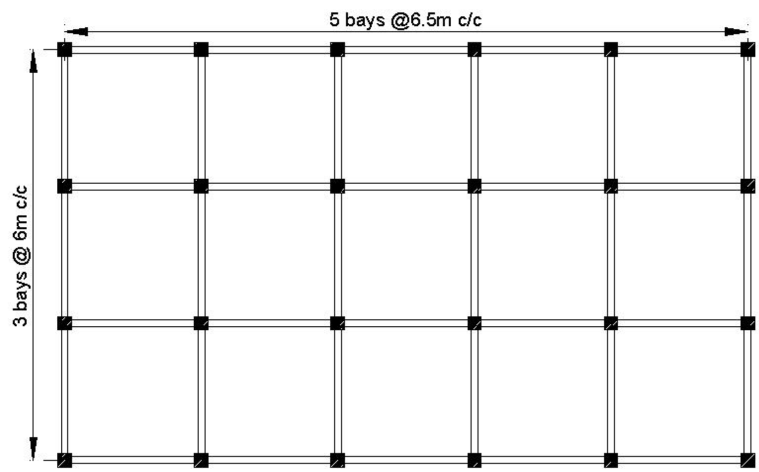

Fig.2. Structural configuration of a typical office building

Seismic analysis, design and detailing

Three dimensional earthquake analyses were carried out for the representative office buildings with number of storeys varying from two to ten storeys and considering them situated in all four seismic zones mentioned in table 1. The buildings being simple and of regular configurations, equivalent static load approach was adopted for the determination of the seismic forces. The entire analysis, design and detailing were done as per the codal provisions of Bureau of Indian Standards (1, 2, 3, 4). Besides satisfying the detailing for ductility in high seismic zones, durability requirements and easiness of construction were also taken care in the design and detailing (4).

Determination of time period

Time period is one of the major influencing parameter deciding the seismic forces in the buildings. The code specifies two types of empirical formula for the time period determination, one for the building with bare frames and another with brick infilled frames as well as shear wall buildings. Compared to structures with bare frames, the buildings with brick infilled frames have shorter time periods due to the stiffening effects of the infills resulting higher values of base shears. A comparison of the base shear co-efficients under these two situations is shown in fig.3. As the brick masonry infills are considered as non-structural due to many uncertainties like door/window openings, absence of positive connections between the frames and infills and resulting in the unpredictable behavior, it was not considered appropriate to use the formula for the brick infilled frames. At the same time it is necessary to consider initial stiffening effect of the brick infills that would produce higher seismic forces in the building. Once the unbonded infill cracks and gets detached from the frames after the initial shaking, the stiffening effects of the infills substantially get reduced. From these considerations it was considered reasonable to adopt an average time period between the bare frame and the infilled frame in the earthquake analysis. This aspect requires detailed considerations for the guidance of the designers.

Determination of cost model

From the final designs and detailing of the structural members (columns, beams and slabs) of the individual buildings, the actual quantities of structural concrete, steel reinforcement and shuttering areas required for the structural members at different floor levels are worked out in detail by standard quantity surveying methods. Provisions for reinforcement anchorage and laps, spacer bars etc. are accounted. Also provision for reinforced concrete non-structural components like lintels, sills and fins are also accounted based on the available data to project the cost model more realistic and usable in practice. Finally the concrete, reinforcement and shuttering quantities of the three structural components for different floor levels are worked out and expressed as the requirement per unit area of the individual floors as well the average quantity for the unit floor area of the entire building.

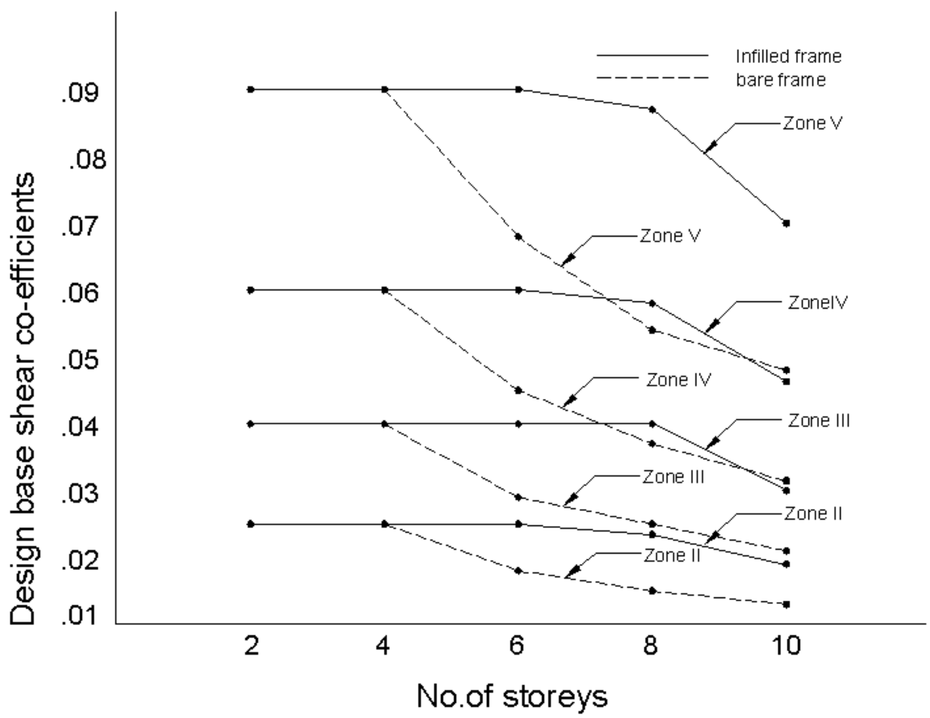

Fig.3.Design base shear co-efficients for buildings with bare frames and infilled frames

The total structural cost of the buildings designed for different levels of seismic forces are worked out from the bill of quantities of the structural components and their prevailing unit construction cost and the unit cost of the structural system is expressed as cost per square meter of the floors constructed. The details are presented in figs 4, 5 and 6. The componentwise break up of the structured quantities per square meter of the floor area is presented in table 2 for two to ten storied buildings in different seismic zones.

STRUCTURAL QUANTITIES IN THE EXISTING BUILDINGS

The actual structural quantities used in the R.C.C buildings with moment resisting frames constructed in the last 15 years are compiled in the proposed cost model format from the structural drawings and co-related with the final bill of quantities executed. These buildings are of different occupancy categories and are located in different seismic zones of India. The results of this compilation are shown in table 3, which broadly validates the reasonability of the proposed cost model.

Table 2: Quantities of structural components of R.C.C.buildings in seismic zones of India.

Blg	Zone	Steel (Kg/sq.m)				Concrete(cu.m/sqm)				Shuttering(Sq.m/sq.m)			
		col.	beam	slab	total	col.	beam	slab	total	col.	beam	slab	total
2storeyed	NS	2.93	11.09	14.21	28.23	0.02	0.06	0.18	0.26	0.21	0.43	1.02	1.66
	II	3.58	11.09	14.21	28.88	0.02	0.06	0.18	0.26	0.21	0.43	1.02	1.66
	III	4.46	11.24	14.21	29.91	0.02	0.06	0.18	0.26	0.21	0.43	1.02	1.66
	IV	5.19	14.28	14.21	33.68	0.02	0.06	0.18	0.26	0.21	0.43	1.02	1.66
	V	6.57	14.61	14.21	35.39	0.02	0.06	0.18	0.26	0.21	0.43	1.02	1.66
4storeyed	NS	3.62	10.82	14.27	28.71	0.03	0.06	0.18	0.27	0.24	0.42	1.01	1.67
	II	4.2	11.7	14.27	30.17	0.03	0.06	0.18	0.27	0.24	0.42	1.01	1.67
	III	5.73	12.98	14.27	32.98	0.03	0.06	0.18	0.27	0.24	0.42	1.01	1.67
	IV	7.36	15.65	14.27	37.28	0.03	0.06	0.18	0.27	0.24	0.42	1.01	1.67
	V	11.78	18.17	14.27	44.22	0.03	0.06	0.18	0.27	0.24	0.42	1.01	1.67
6storeyed	NS	5.18	8.65	14.19	28.02	0.04	0.06	0.18	0.28	0.25	0.5	1.01	1.76
	II	5.77	11.58	14.19	31.54	0.04	0.06	0.18	0.28	0.25	0.5	1.01	1.76
	III	7.36	13.99	14.19	35.54	0.04	0.06	0.18	0.28	0.25	0.5	1.01	1.76
	IV	8.46	19.33	14.19	41.98	0.04	0.06	0.18	0.28	0.25	0.5	1.01	1.76
	V	11.22	20.91	14.19	46.32	0.04	0.06	0.18	0.28	0.25	0.5	1.01	1.76
8storeyed	NS	6.11	9.97	14.19	30.27	0.05	0.07	0.18	0.30	0.26	0.49	1.01	1.76
	II	6.61	12.52	14.19	33.32	0.05	0.07	0.18	0.30	0.26	0.49	1.01	1.76
	III	8.6	15.19	14.19	37.98	0.05	0.07	0.18	0.30	0.26	0.49	1.01	1.76
	IV	9.68	20.21	14.19	44.08	0.05	0.07	0.18	0.30	0.26	0.49	1.01	1.76
	V	12.64	24.47	14.19	51.3	0.05	0.07	0.18	0.30	0.26	0.49	1.01	1.76
10storeyed	NS	9.58	8.94	14.13	32.65	0.05	0.08	0.18	0.31	0.27	0.49	1.01	1.77
	II	9.58	12.72	14.13	36.43	0.05	0.08	0.18	0.31	0.27	0.49	1.01	1.77
	III	11.63	14.66	14.13	40.42	0.05	0.08	0.18	0.31	0.27	0.49	1.01	1.77
	IV	12.85	21.15	14.13	48.13	0.05	0.08	0.18	0.31	0.27	0.49	1.01	1.77
	V	14.44	26.5	14.13	55.07	0.05	0.08	0.18	0.31	0.27	0.49	1.01	1.77

Table 3: Structural quantities in buildings designed and constructed for seismic effects in India

Building Description	Concrete (cu.m/sqm)	Steel (Kg/sq.m)	Shuttering (Sq.m/sq.m)
14-storeyed office building Seismic zone IV.	0.30	50.80	1.80
8-Storeyed office building seismic Zone IV.	0.28	47.20	1.75
6- Storeyed Hospital building seismic zone IV.	0.23	43.00	1.95
6-storeyed Hospital building seismic zone IV (revised)	0.25	48.0	1.95
8-storeyed residential building seismic zone IV	0.29	55.8	2.2
5-storeyed office building non-seismic zone II.	0.24	42.00	1.70
2-storeyed residential building seismic zone V.	0.21	43.30	2.31
2-storeyed hospital building seismic zone V.	0.21	35.75	1.85
4-storeyed laboratory building, seismic zone IV.	0.26	41.30	1.90

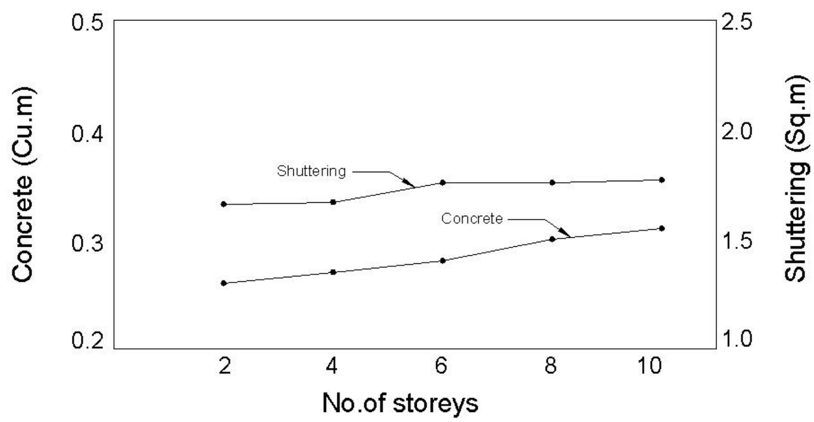

Fig.4.Requirement of structural concrete and shuttering materials per sq.m of floor area.

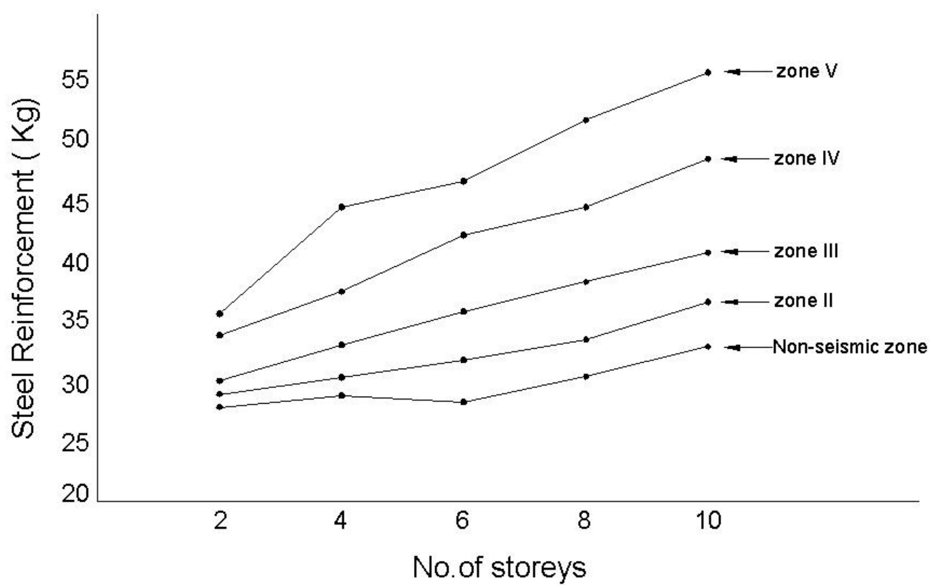

Fig.5.Reqirement of steel reinforcement (kg/sq.m of floor area)

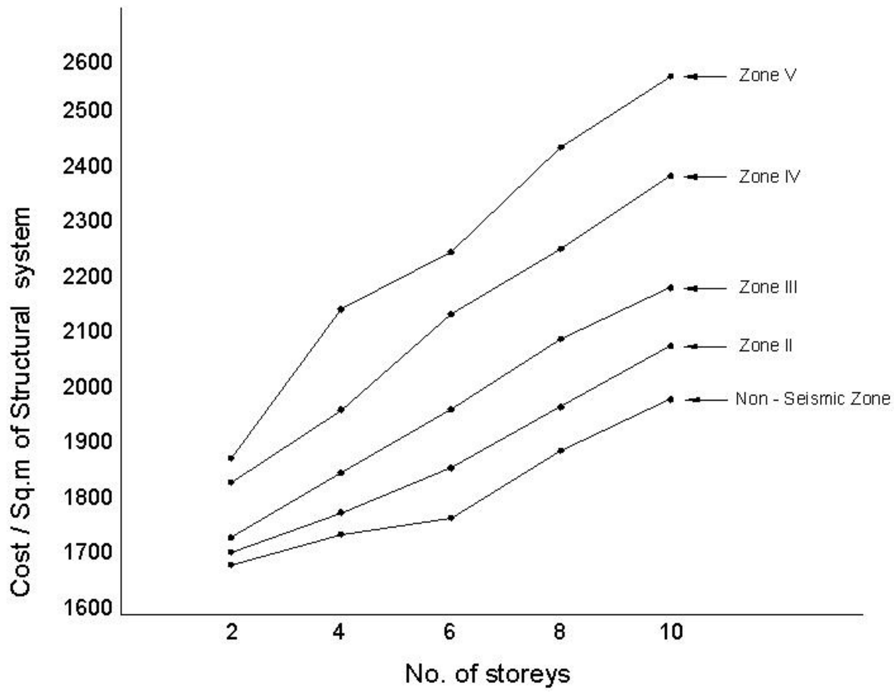

Fig.6. Cost of structural systems in different seismic zones (Rupees / Sq. m of floor area)

RESULTS AND DISCUSSIONS

From the seismic resistant design and cost estimation of the representative office buildings in the range of two to ten storeys under various levels of seismic forces in different seismic zones of Indian subcontinent, the following inferences are made:

(i) The requirement of structural concrete and shuttering materials per sq.m of floor area varies from 0.26 cu.m to 0.31 cu.m and 1.66 sq.m to 1.77 sq.m for 2 to 10 storeys respectively. These requirements need not be very sensitive to the seismic zones because structural member sizes are usually kept same except column sizes which could be reduced in the upper storeys of the buildings.

(ii) The effects of increasing levels of seismic forces are taken care in the design by increasing the steel requirements in column and beams. The steel requirements per square meter of floor area vary from 28 kg to 55 kg depending upon the number of storeys and seismic zones as shown in fig.5. For an eight storeyed building located in seismic zone V, a percentage increase of 69% in steel reinforcement is observed compared to non-seismic design.

(iii) The cost premium for incorporating earthquake resistance as a percentage of the structural cost of the building varies from 2 to 30 % depending upon the number of storeys and seismic zones as shown in fig.6. For a ten storeyed building this premium works out to 5%, 10%, 20% and 30% for seismic zones II, III, IV and V respectively. For buildings with normal specification this cost premium in relation to the total cost of the superstructure would be in the range of 3 to 15 % from low to high seismic zones.

CONCLUSIONS

The study has focused the important aspect of cost implications to incorporate seismic resistance in buildings. The cost modeling methodology with quantified values for low to medium rise reinforced concrete multistoried office buildings incorporating the various levels of seismic resistance depending upon the seismic zones is presented. The broad validation of the study is made by comparing the parameters of the cost model with historic data of seismically designed and constructed buildings in various seismic zones of the Indian subcontinent. Further studies are required to investigate and quantify the effect of different structural systems and configurations, occupancy types, soil condition and foundation systems. The study, besides creating awareness on the cost implications for seismically safe designs, would be useful for evaluating structural alternatives under different seismic intensities and related cost management studies.

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