Bull. Ind. Soc. Earth. Tech., Paper No.307, Vol.28, No.2, June 1991, pp. 17 to 31

DESIGN AND COST IMPLICATIONS OF I.S. CODE PROVISIONS FOR ASEISMIC DESIGN OF R.C. FRAME BUILDINGS

By

Sudhir K. Jain
Assistant Professor
Deptt. of Civil Engg.
Indian Institute of Technology
KANPUR

and

Anil K. Patnaik
Engineers India Ltd.
NEW DELHI

ABSTRACT

With the introduction of performance factor, K, in IS:1893-1984, a R.C. frame building may be detailed as ordinary concrete frame (with K = 1.6) as per IS:456-1978 or as ductile concrete frame (with K = 1.0) as per IS:4326-1976. Three real-life multistorey R.C. frame buildings have been designed for seismic zones I, III and V. The frames have been detailed as ordinary frames with K = 1.0 and 1.6 and as ductile frames. Quantity of reinforcement steel and the cost implications for different zones and detailing criteria have been compared. It is seen that with the introduction of K, cost of construction has gone up especially in zones II and III. In zones III to V it is more economical to provide ductile frame than the ordinary frame.

INTRODUCTION

A reinforced concrete frame building in India may have frames with two types of detailing, i.e., frames with member design conforming to special ductility detailing of IS:4326-1976 (Ref. 6), hereafter referred to as Ductile Concrete Frame (DCF) and frames with members conforming to requirements of IS:456-1978 (Ref. 2), hereafter referred to as Ordinary Concrete Frame (OCF). In IS:1893-1984 (Fourth Revision) (Ref. 5) performance factor, K, has been introduced for calculation of design seismic loads for a building. Prior to this, in IS:1893-1975 (Third Revision) (Ref. 4), with the absence of K it was in effect equal to unity for all structures and as per IS:4326-1976 DCF was to be provided for design seismic coefficient, α_h, as 0.05 or more. However, now the code IS:1893-1984 allows designer a choice to either provide DCF with same lateral loads that existed before 1984 (i.e., K = 1.0), or to provide an OCF with sixty percent enhancement of lateral loads as compared to what existed earlier (i.e., K = 1.6). The choice of type of frames to be provided in a structure and its cost implications will vary widely with seismic zone, soil-foundation system, utility, structural system of building, dead and live loads, etc. It may be mentioned here that if DCF is provided, lateral loads are less which may lead to saving in main reinforcement, while due to ductile detailing quantity of transverse steel and sometimes compression steel is more. However, if OCF is provided the lateral loads are higher, hence main reinforcement in structure increases. Thus, there is a clear need to study and understand steel quantity and cost implications if one were to opt for OCF or DCF. It is also of interest to know the relative increase in cost with the fourth revision of IS:1893 due to K = 1.6 for OCF even when α_h is less than 0.05. Besides, one would like to have an idea of premium involved in providing earthquake resistance in buildings in different seismic zones. These aspects have been investigated in this paper by carrying out complete analysis and design of three practical buildings as DCF and OCF in zones I, III and V.

COST OF EARTHQUAKE RESISTANT CONSTRUCTION

Some government organizations, such as CPWD, recommend extra cost for resisting earthquake forces for preliminary cost estimates. However, this is not done with due consideration of seismic zone, structural system, etc. and thus as such no systematic study seems to have been made for evaluating the premium involved for earthquake resistant construction in Indian conditions. A committee of experts set-up by the Structural Engineer Association of California (SEAOC) has evaluated such additional costs for U.S. conditions (Degenkolb, et al., 1970). Table 1 summarises the estimates increase in cost to provide earthquake resistance according to this committee. These are based on extensive work as well as expert judgement of the committee. The assumptions on which this study was based are quoted below :-

1) That the minimum non-earthquake resistant structure in various localities is nevertheless properly designed to resist vertical load and wind load forces as recommended by the Uniform Building Code (UBC) or other comparable model code, and the construction inspection is sufficient to assure this level of quality of construction.

2) The tabulated costs include the extra design and inspection costs required in earthquake prone areas, but that the normal costs of design and inspection have been provided for on a professional basis for comparable non-earthquake resistant structures.

3) The building including seismic resistant provision is of comparable quality, material, durability, fire resistance, etc. as the building without seismic provisions.

4) The increased cost in percentage is to be applied to the complete engineering and architectural building, including structure, foundation, walls, architectural treatment, mechanical and electrical facilities, etc. It does not apply to site such as streets, sidewalks, paving, landscaping, drainage, etc. nor does it apply to tenants' improvements.

The committee report also highlighted that the extra cost of design is an appreciable portion of the total increase since more analysis, drafting and field inspections are customarily required in seismic areas.

PRESENT WORK

Three buildings have been designed with the aid of computer programs and the quantity and cost of materials compared. These are all real structures in either completion, construction or planning stages. One is a four-storey institutional building, other an eight-storey residential building and the third a three-storey industrial building. These form a representative group of three different classes of practical structures. All the three buildings are of reinforced concrete framed construction and do not have shear walls. Seismic forces in each building have been obtained using seismic coefficient method. The buildings have been designed for the following four load cases for zones I, III and V and the material quantities and cost of construction have been evaluated and compared. The results obtained can be interpolated for zones II and IV.

(i) Only dead and live loads
(ii) Vertical loads and seismic forces for OCF (K = 1.0), i.e., equivalent to design conforming to IS:1893-1975 and disregarding the ductility requirement even when $\alpha_h \geqslant 0.05$.

(iii) Vertical loads and seismic forces for DCF (K = 1.0)
(iv) Vertical loads and seismic forces for OCF (K = 1.6).

Load case (ii) has been included to see effect of recent introduction of performance factor on the cost of construction. The premium for seismic resistance has been calculated over and above the cost of structure with only dead and live loads applied but not including wind loads. This study does not account for the additional cost involved in analysis, drafting, detailing and field inspections for DCF due to non-availability of reliable data on these costs. Ductility provisions of IS:4326 will mainly influence design of columns and beams. Hence cost of slabs, foundations and other structural and non-structural members has not been considered in this study. The results reported here are for soil - structure coefficient, β , as 1.5 for the institutional building and 1.0 for the other two buildings and importance factor, I, as 1.0 for all the three buildings. The beam and column size in a building have not been varied in different seismic zones.

ANALYSIS AND DESIGN

Three dimensional linear elastic analysis of the buildings considered has been done using computer package ETABS (Ref. 10). ETABS is a special purpose analysis package for building systems. With proper modelling, the program treats the entire structure as a three dimensional frame. It ignores axial deformation of beams and assumes floors to be rigid in their own plane. It accounts for rigid zones at ends of columns and beams and has the option to output member forces at the centre lines or at beam and column faces. It can also include shear deformations of members. It has provision for analysis of buildings with shear walls and bracings also.

Analysis of each of the buildings was done for the following four load cases (i) only dead load (DL); (ii) only live loads (LL); (iii) forces due to earthquake in X-direction (ELX); (iv) forces due to earthquake in Y-direction (ELY). With member forces for these four load cases, following nine load combinations as recommended by IS:456 for limit state method of design, are generated within each of the design programs described subsequently.

a) 1.5 (DL + LL)
b) 1.5 (DL + ELX)
c) 1.5 (DL - ELX)
d) 1.5 (DL + ELY)
e) 1.5 (DL - ELY)
f) 1.2 (DL + LL + ELX)
g) 1.2 (DL + LL - ELX)
h) 1.2 (DL + LL + ELY)
i) 1.2 (DL + LL - ELY)

Four design programs have been developed in FORTRAN to design and detail beams and columns by limit state method using output of ETABS. This enabled a fairly comprehensive and reliable estimation of reinforcement quantities. These programs have been named BEAM1, BEAM2, COLUM1 and COLUM2. BEAM1 and COLUM1 design flexural members and columns, respectively, for OCF; BEAM2 and COLUM2 design flexural members and columns, respectively, for DCF. These programs also calculate quantity of main and transverse steel using centre line lengths of members and sectional dimensions, but ignoring laps, anchorage lengths, wastage etc. The programs also write information on governing load case (from among the nine load cases listed above) for each member for main and transverse steel separately. The programs for DCF write if provisions of IS:4326 govern in design of tension, compression or transverse steel. In BEAM1 and BEAM2, flange effect of slabs (i.e., T-beam action) has been ignored.

Shear reinforcement in beams is obtained for shear force at distance d (effective depth) from face of the column. BEAM1 checks for minimum limits on transverse steel as specified by IS:456 and provides a minimum bar diameter of 6 mm. For detailing main reinforcement in beams, this program uses available diameters of steel ranging from 12 mm to 28 mm and provides a set of arrangement that is closest to theoretical area of steel required. If two members are on either side of a column and are continuous in alignment, the program provides same reinforcement on both sides of the column by picking up the higher steel area. With the above detailing method, steel quantities obtained are fairly close to those for practical detailing.

In addition to detailing of beams as in BEAM1 above, BEAM2 ensures minimum and maximum reinforcement requirements of IS:4326. With area of steel actually provided, it calculates negative and positive plastic moment capacities of sections at ends of each beam following the procedure outlined by Patnaik and Jain (1989). It considers strain hardening in main reinforcement by using tensile stress as 1.25 times the yield stress of steel (f_y) and with partial safety factor for material (γ_m) as unity. With these plastic moments the program calculates design shear force at ultimate load condition (i.e., loading condition corresponding to the stage at which plastic hinges are formed). It also ensures the spacing requirements of IS:4326 for transverse steel.

For design axial forces and biaxial moments generated within the program for columns, COLUM1 chooses a steel arrangement corresponding to minimum required area of steel from within its library of arrangements, after checking adequacy for biaxial bending by generating interaction curves for a section. SP:16(S & T) - 1980 (Ref. 9) has given interaction curves by approximating sections as having twenty bars, equally distributed on all four sides of sections. However, in COLUM1 interaction curves are generated for each section separately for each steel arrangement, making the column design exact and economical. It designs transverse steel as per IS:456 using bar diameter of 6 mm as a minimum.

In addition to design and detailing of columns as in COLUM1 above, COLUM2 calculates confinement steel as required by IS:4326 and provides the same over the required length at the ends of columns.

ASSUMED COST OF R.C. CONSTRUCTION

To assess the difference in cost of structural framing systems, approximate current market rates of reinforced concrete construction have been assumed. The assumed cost of M15 concrete is Rs. 750.00 per cubic metre, Fe415 steel reinforcement is Rs. 8,000.00 per ton and shuttering for concrete is Rs. 60.00 per square metre. Variation of unit rates with vertical lead has not been considered. The cost of concrete skeletons (only columns and beams) has been given as the overall cost, without consideration of cost of slabs, foundations, and other structural and non-structural elements.

RESULTS

Schematic plans of the three buildings considered are given in Figs. (1-3). Table (2) gives break-up of reinforcement steel required in terms of main and transverse reinforcement for beams and columns for each zone and design criteria. The cost of skeleton frame, excluding cost of foundation, floor slabs, and other structural and non-structural items, is given in Table (3) and plotted in Fig. (4).

The premium for earthquake resistant design over and above the skeleton cost due to vertical loads alone is given in Table (4). It is seen that premium for the institutional building is much more than that for the other two buildings. This is due to higher value of factor β (= 1.5) for this building.

Four-Storey Institutional Building

This is an educational building with lecture halls and laboratories (Fig. 1). It has a base dimension of 15.8 m by 38.4 m and rises to a height of 16.25 m. The structural system consists of thirteen frames in transverse direction and four frames in longitudinal direction. The building has 100 mm thick solid slab at roof level and 120 mm thick solid slabs at other floor levels. The foundation system consists of isolated footings. The load class 400 of IS:875 (Ref. 3) has been used in the lecture halls and laboratories, and load class 300 has been used in the cabins and corridors. The total dead load of structure is about 2500 tons and live load is about 400 tons. The following observations may be made from the results :

(i) ZONE I : DCF requires 3.36 ton more steel (13.4% higher) than OCF (K = 1.6) while the difference between OCF (K = 1.6) and OCF (K = 1.0) is 0.54 tons (2.6%). DCF involves Rs.0.27 lakhs more cost than OCF (K = 1.6) which amounts to 4.2 percent of the total cost of skeleton. The difference of cost between OCF (K = 1.6) and OCF (K = 1.0) is only about Rs. 0.04 lakhs (0.7%). The premium of seismic resistance is about Rs. 10.00 per square metre of plinth area per floor (OCF, K = 1.6).

(ii) ZONE III : Steel in DCF is 7.40 tons (23.0%) less than that in OCF (K = 1.6) and OCF (K = 1.6) involves 11.14 tons (39.2%) more steel than OCF (K = 1.0). DCF is cheaper by Rs. 0.59 lakhs (8.5%), as compared to the cost of OCF (K = 1.6). Cost of OCF (K = 1.6) is about Rs. 0.89 lakh (13.4%) more than that of OCF (K = 1.0). The difference between DCF and OCF(K=1.0) is Rs. 0.30 lakhs (4.3%). The premium for seismic resistance in Zone III is about Rs. 45.00 (DCF) to Rs. 70.00 (OCF, K = 1.6) per square metre of plinth area per floor.

(iii) ZONE V : DCF results in a saving of 17.89 tons (35.2%) of steel over OCF (K = 1.6) while OCF (K = 1.6) involves 21.71 tons (46.2%) more steel than OCF (K = 1.0). DCF is cheaper than OCF (K = 1.6) by Rs. 1.43 lakhs (16.7%) and costlier than OCF (K = 1.0) by Rs. 0.31 lakhs (3.8%). Premium per square metre of plinth area per floor for seismic resistance in Zone V is Rs. 107.00 with DCF and about Rs. 161.00 with OCF (K = 1.6).

Eight - Storey Residential Building

This is an H-shaped residential building. Structural separation joints have been provided (Fig. 2) to avoid interaction of central core with each of the wings. One wing of the building has been analyzed in this study. It has a base dimension of 5.20 m by 21.6 m and rises to a height of 25.65 m. The structural system for each wing consists of seven frames in transverse direction and two frames in longitudinal direction. The floors consist of solid slabs ranging from 90 mm to 130 mm in thickness. The foundation system consists of isolated footings. This being a residential building, load class 200 of IS:875 has been used throughout the building. 115 mm thick brick walls have been provided by the architect for all partitions and external walls. With thin slabs, half brick walls and inter-storey height of 3.15 m, this structure is a relatively lightly loaded structure. Total dead load of the structure is about 1300 tons and total live load is about 175 tons. A comparison of results for different detailing criteria shows the following trends :

(i) **ZONE I :** OCF (K = 1.6) involves 1.45 tons (12.6%) less steel as compared to DCF (K = 1.6) and 0.14 tons (1.4%) more steel than OCF (K = 1.0). It is costlier by Rs 0.12 lakhs (4.1%) to provide DCF as compared to OCF (K = 1.6). The premium for earthquake resistance is about Rs 2.00 per square meter of plinth area per floor.

(ii) **ZONE III :** Difference in quantity for DCF and OCF (K = 1.6) is very nominal with DCF requiring 0.24 tons (2%) less steel as compared to OCF (K = 1.6). OCF (K = 1.6) involves about 1.85 tons (17.2%) more steel as compared to OCF (K = 1.0). The difference in cost between DCF and OCF (K = 1.6) is very nominal, while OCF (K = 1.6) is costlier by Rs 0.15 lakhs (5.4%) as compared to OCF (K = 1.0). The premium for earthquake resistance is about Rs. 22.00 to Rs. 24.00 per square metre of plinth area per floor.

(iii) **ZONE V :** By providing DCF, 3.50 tons (21.7%) less steel is needed as compared to that for OCF (K = 1.6). Use of OCF (K = 1.6) increased the steel quantity by 5.16 tons (35.7%) as compared to OCF (K = 1.0). In financial terms, DCF is cheaper by Rs 0.28 lakhs (8.8%) as compared to OCF (K = 1.6). Premium per square metre per floor for earthquake resistance is about Rs 55.00 if DCF is provided and Rs 86.00 if OCF (K = 1.6) is provided.

Three-Storey Industrial Building

In this building the basement is a storage godown, the ground floor a machine room housing light machines which do not produce significant vibrational disturbance and the first floor is an office space. The intermediate storey height is much more than height of the other storeys (Fig. 3). Thus, this is an irregular building and it does not fulfill requirements for use of seismic coefficient method given in the code. However, as has been seen elsewhere (Patnaik, 1988), the code provisions for seismic coefficient and response spectrum methods yield significantly different level of design seismic forces. Hence, to ensure consistancy with results of the other two buildings considered, this building also was designed using seismic coefficient method. Moreover, in the absence of overall lack of earthquake engineering background among many designers in the country such irregular buildings continue to be designed by seismic coefficient method. The building has base dimension of 42.0 m by 28.0 m and rises to a height of 14.15 m above foundation level. The structural system consists of four frames of 42.0m length and a fifth frame of 35.0 m length in transverse direction and six frames of 28.0 m length and one of 21.0 m in longitudinal direction. Loading of 10 kN per square metre on ground floor and 3 kN per square metre on first floor were used. Total dead load of the structure is about 2700 tons and live load is about 1500 tons. Results for this building show the following :

(i) **ZONE I :** DCF involves 3.43 tons (12.9%) more steel as compared to OCF (K = 1.6). OCF (K = 1.6) involves negligibly more amount of steel than is required by OCF (K = 1.0). DCF becomes costlier by Rs. 0.28 lakhs (4.3%) as compared to OCF (K = 1.6). There is practically no difference in cost between OCF (K = 1.6) and OCF (K = 1.0). The premium for earthquake resistance in Zone I is negligible.

(ii) **ZONE III :** DCF requires 3.72 tons (11.8%) less steel than OCF (K = 1.6), which in turn involves 7.30 tons (26.0%) more steel than OCF (K = 1.0). DCF is cheaper by Rs. 0.30 lakhs (4.3%) as compared to OCF (K = 1.6). The difference between OCF (K = 1.6) and OCF (K = 1.0) is about Rs. 0.58 lakhs

(8.7%). Premium for earthquake resistance per square metre of plinth area per floor is about Rs. 21.00 (DCF) to Rs. 30.00 (OCF K = 1.6).

(iii) ZONE V : DCF involves 16.99 tons (36.9%) less steel than OCF (K = 1.6), which in turn requires 21.34 tons (51.2%) more steel as compared to OCF (K = 1.0). DCF is cheaper by Rs. 1.36 lakhs (16.8%) as compared to OCF (K = 1.6). There is a difference of Rs. 1.70 lakhs (22.8%) between OCF (K = 1.6) and OCF (K = 1.0). Premium for earthquake resistance per square metre of plinth area per floor is about Rs. 55.00 if DCF is provided and Rs. 95.00 if OCF (K = 1.6) is provided.

DISCUSSION AND CONCLUSIONS

Three practical buildings have been thoroughly analyzed and designed to study steel quantity and cost implications for ductile as well as non-ductile construction in Zones I, III and V. The cost of structures designed as per the earlier edition of the code, i.e., IS:1893-1975, has also been shown. Besides, design for only dead and live loads has also been carried out and premium for earthquake resistance for these buildings given. An experienced designer can judiciously utilize the percentage increase in cost of structures and quantity of steel reported here, in planning and preliminary design stages of similar structures. Since no two designers are likely to arrive at the same final design and detailing, the figures given in this study may vary considerably but these may be treated as rough guidelines for similar structures.

From Table (2), it is seen that as one moves from lower seismic zone to higher seismic zone, increase in transverse reinforcement is not significant, in main reinforcement of beams it is moderate while the increase is most significant for main reinforcement in columns. This trend is so prominent that while in Zone I, the quantity of main reinforcement in columns is of the same order or significantly less than that in beams; in Zone V quantity of main reinforcement in columns is significantly more than that in beams. In the present study beam and column sizes were not varied for different zones. However, it is obvious that in higher seismic zones, the column size must be increased substantially, while the beams may not require much upward revision. The rather low share of transverse steel in the overall reinforcement quantity and the fact that transverse steel improves seismic performance of a structure very substantially, once again indicate the desirability of liberal use of transverse steel in R.C. frames, especially when the building is to be located in an active seismic area.

Besides the results reported, some interesting observations were made during this study. It was seen that, in general, for low values of live loads on the structure, load condition 1.5 (DL ± EL) usually governs the design. However, some of the members are governed by the load condition 1.2 (DL + LL ± EL) also. In beams of DCF for usual sizes and loads (i) maximum limit of longitudinal reinforcement as specified by IS:4326 occassionally governs the design, (ii) minimum longitudinal steel condition of IS:4326 often governs at sections where only hanger bars are required, and (iii) limit on maximum spacing for transverse steel (i.e., d/4 for distance 2d from face of column and d/2 for remaining length) almost always governs. Thus, for moderately reinforced sections with normal spans, design of shear reinforcement with consideration of plastic moment capacities does not govern the design very often. It was also seen that the quantity of steel and premium for earthquake resistant design are very sensitive to the column sizes used, especially in high seismic zones.

The three buildings considered belong to three different classes of building and have different number of storeys, but the trend of results has been quite similar. For a proposed building with values of β and I different from the ones used in this study this trend may be interpolated from Fig. (4). It is seen that in Zones III to V, it is more economical to provide DCF rather than OCF with K = 1.6. In Zone I, DCF is more expensive and in Zone II DCF and OCF (K = 1.6) almost break even. With the introduction of performance factor in the fourth revision of IS:1893, cost of construction has gone up in Zones II and III substantially and in Zone I nominally. Zones IV and V in any case were governed by DCF design as per IS:4326. A significantly higher premium for the institutional building due to higher value of β (= 1.5) indicates that for economy in structural design the foundation system should be chosen to keep this factor low to the extent possible especially in the higher seismic zones.

On the basis of this study the following recommendations are also made:

(i) The code should allow only ductile detailing for Zones IV and V. This not only makes economic sense (over OCF with K = 1.6) but will also ensure better performance of buildings during an earthquake. However, it is important to take necessary measures to educate designers as well as contractors in ductile detailing. In Zone III the code should allow relaxed ductile detailing but with K = 1.0. Buildings in Zones I and II should be required to be designed only as per IS:456-1978 with performance factor K = 1.0 since in any case the seismic risk to buildings in these zones is quite low.

(ii) This study has been based on three buildings all of which are framed structures. Maximum number of storeys was eight. More such systematic studies are needed on buildings more number of storeys, varying configuration and design features, and those with shear walls. The cost implications of R.C. frame versus shear wall construction in Indian conditions for different zones should also be investigated on similar lines.

(iii) An appropriate expert committee, on lines with the SEAOC Committee (Ref. 1), consisting of researchers, designers and construction engineers, should be constituted to evaluate financial implications of earthquake resistant construction for various types of building in different seismic zones of the country. This kind of information will be very useful in ensuring implementation of code provisions for aseismic design.

REFERENCES

1. Degenkolb, H.J., Gizienski, S.F., Meehan, J.F., Messinger, D.L. and Pinkham, C.W. (1970), Report of the Ad Hoc Committee on Cost of Design for Earthquake. Appendix - B, Proceedings of Structural Engineers Association of California, 171 Second Street, San Francisco, California 94105.

2. IS:456-1978, Indian Standard Code of Practice for Plain and Reinforced Concrete. Bureau of Indian Standards, New Delhi.

3. IS:875-1964, Indian Standard Code of Practice for Structural Safety of Buildings : Loading Standards. Bureau of Indian Standards, New Delhi.

4. IS:1893-1975, Indian Standard Criteria for Earthquake Resistant Design of Structures (Third Revision). Bureau of Indian Standards, New Delhi.

5. IS:1893-1984, Indian Standard Criteria for Earthquake Resistant Design of Structures (Fourth Revision). Bureau of Indian Standards, New Delhi.

6. IS:4326-1976, Indian Standard Code of Practice for Earthquake Resistant Design and Construction of Buildings. Bureau of Indian Standards, New Delhi.

7. Patnaik, A.K. (1988), A Study of Provisions of Indian Standards for Aseismic Design of Buildings. M. Tech. Thesis, Department of Civil Engineering, Indian Institute of Technology, Kanpur.

8. Patnaik, A.K. and Jain, S.K. (1989), Ductility Requirements in Indian Codes for Aseismic Design of R.C. Frame Structures : A Review. Bulletin of the Indian Society of Earthquake Technology (communicated for publication).

9. SP:16 (S&T) - 1980, Design Aids for Reinforced Concrete to IS:456-1978, Bureau of Indian Standards, New Delhi.

10. Wilson, E.L., Hollings, J.P. and Dovey, H.H. (1979), Three Dimensional Analysis of Building Systems (Extended Version) - ETABS, Report No. EERC 75-13, College of Engineering, University of California, Berkeley, California, U.S.A.

TABLE 1: ESTIMATED INCREASED COSTS TO PROVIDE EARTHQUAKE RESISTANCE IN STRUCTURES IN THE U.S.A. (Adapted from Ref. 1)

Area (Zone) / Type of building	Areas which now enforce design for hurricane, cyclone, tornado or abnormally high winds	Other U.S. areas to meet Zone 3 requirements	Other U.S. areas located in Zones 0, 1 & 2 to provide minimum requirements
1 & 2 storey wood frame	0.5%	2%	1%
1, 2, 3 storey brick or conc. block	4%	8%	4%
4 storey & up brick or conc. block	5%	10%	5%
Concrete frame	2%	5%	2%
Steel frame	0.5%	3%	1%

TABLE 2: QUANTITY OF REINFORCEMENT STEEL (in tons)

BUILDING		THE INSTITUTIONAL BUILDING			THE RESIDENTIAL BUILDING			THE INDUSTRIAL BUILDING		
		O.C.F. (K=1.0) (1)	D.C.F. (K=1.0) (2)	O.C.F. (K=1.6) (3)	O.C.F. (K=1.0) (1)	D.C.F. (K=1.0) (2)	O.C.F. (K=1.6) (3)	O.C.F. (K=1.0) (1)	D.C.F. (K=1.0) (2)	O.C.F. (K=1.6) (3)
					Z O N E I					
Beams	Main	11.30	11.44	11.59	3.95	3.95	4.03	12.58	12.79	12.62
	Hoop	2.38	3.93	2.38	0.71	1.38	0.71	3.03	5.24	3.03
Columns	Main	6.36	6.36	6.60	4.65	4.65	4.65	6.60	6.60	6.82
	Hoop	1.13	3.33	1.13	0.63	1.55	0.69	0.79	2.06	0.79
T o t a l		21.16	25.06	21.70	9.94	11.53	10.08	23.00	26.69	23.26
					Z O N E III					
Beams	Main	13.19	13.19	15.22	4.42	4.49	4.92	14.06	14.16	15.81
	Hoop	2.38	3.94	2.44	0.72	1.40	0.74	3.03	5.32	3.04
Columns	Main	11.63	11.63	20.07	4.89	4.89	6.19	10.13	10.13	15.50
	Hoop	1.23	3.41	1.84	0.70	1.56	0.73	0.85	2.03	1.01
T o t a l		28.43	32.17	39.57	10.73	12.34	12.58	28.06	31.64	35.36
					Z O N E V					
Beams	Main	16.43	17.00	20.03	5.27	5.60	6.20	17.16	18.11	18.21
	Hoop	2.58	4.25	3.16	0.77	1.45	1.18	3.09	5.74	3.44
Columns	Main	25.96	25.96	42.43	7.38	7.38	11.20	20.10	20.10	38.65
	Hoop	2.02	3.60	3.08	1.02	1.67	1.02	1.32	2.07	2.71
T o t a l		46.99	50.81	68.7	14.44	16.10	19.60	41.67	46.02	63.01

TABLE 3: COST OF SKELETON FRAME (in Lakh Rupees)

Building	Zone	DL+LL only (0)	O.C.F. (K=1.0) (1)	D.C.F. (K=1.0) (2)	O.C.F. (K=1.6) (3)
The Institutional Building	I III V	5.88 5.88 5.88	6.08 6.66 8.14	6.39 6.96 8.45	6.12 7.55 9.88
The Residential Building	I III V	2.70 2.70 2.70	2.70 2.76 3.06	2.83 2.89 3.19	2.71 2.91 3.47
The Industrial Building	I III V	6.23 6.23 6.23	6.24 6.65 7.74	6.54 6.93 8.06	6.26 7.23 9.44

TABLE 4: PREMIUM FOR EARTHQUAKE RESISTANT DESIGN (in Rs per square metre per floor)

Building	Zone	O.C.F.(K=1.0)	D.C.F.(K=1.0)	O.C.F.(K=1.6)
The Institutional Building	I III V	8.00 33.00 94.00	21.00 45.00 107.00	10.00 70.00 161.00
The Residential Building	I III V	0.00 7.00 40.00	14.00 22.00 55.00	2.00 24.00 86.00
The Industrial Building	I III V	0.00 12.00 45.00	9.00 21.00 55.00	0.00 30.00 95.00

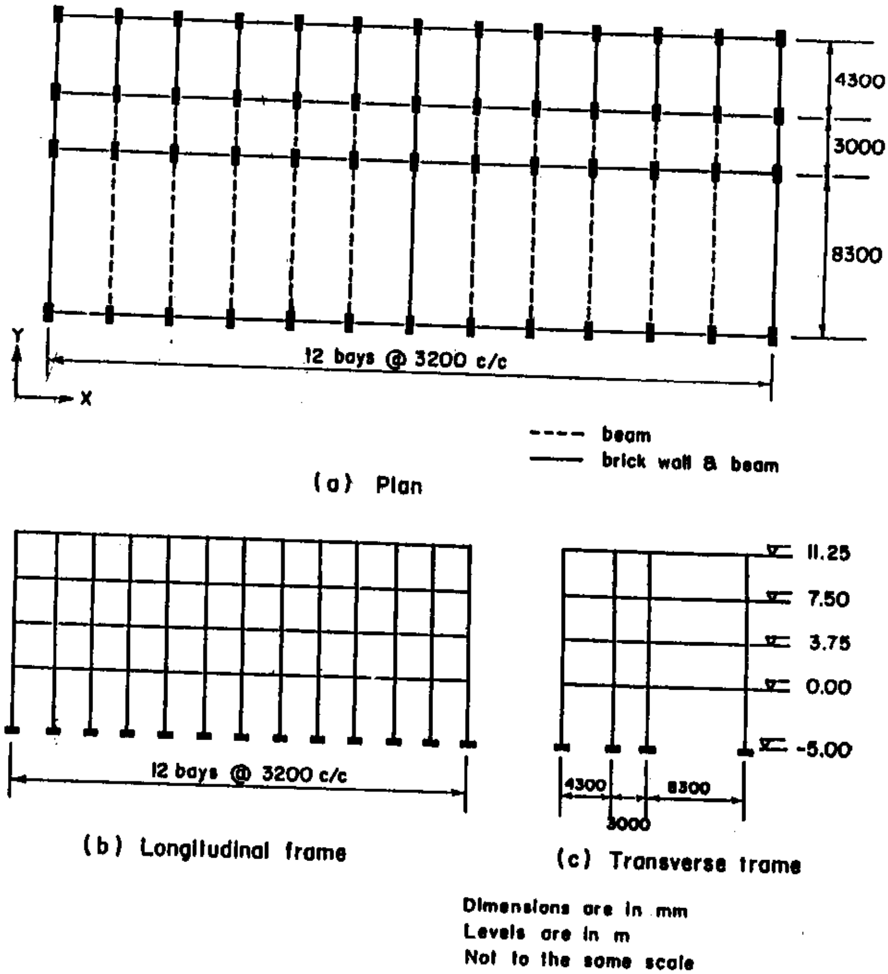

FIG. 1 SCHEMATIC PLAN OF THE INSTITUTIONAL BUILDING

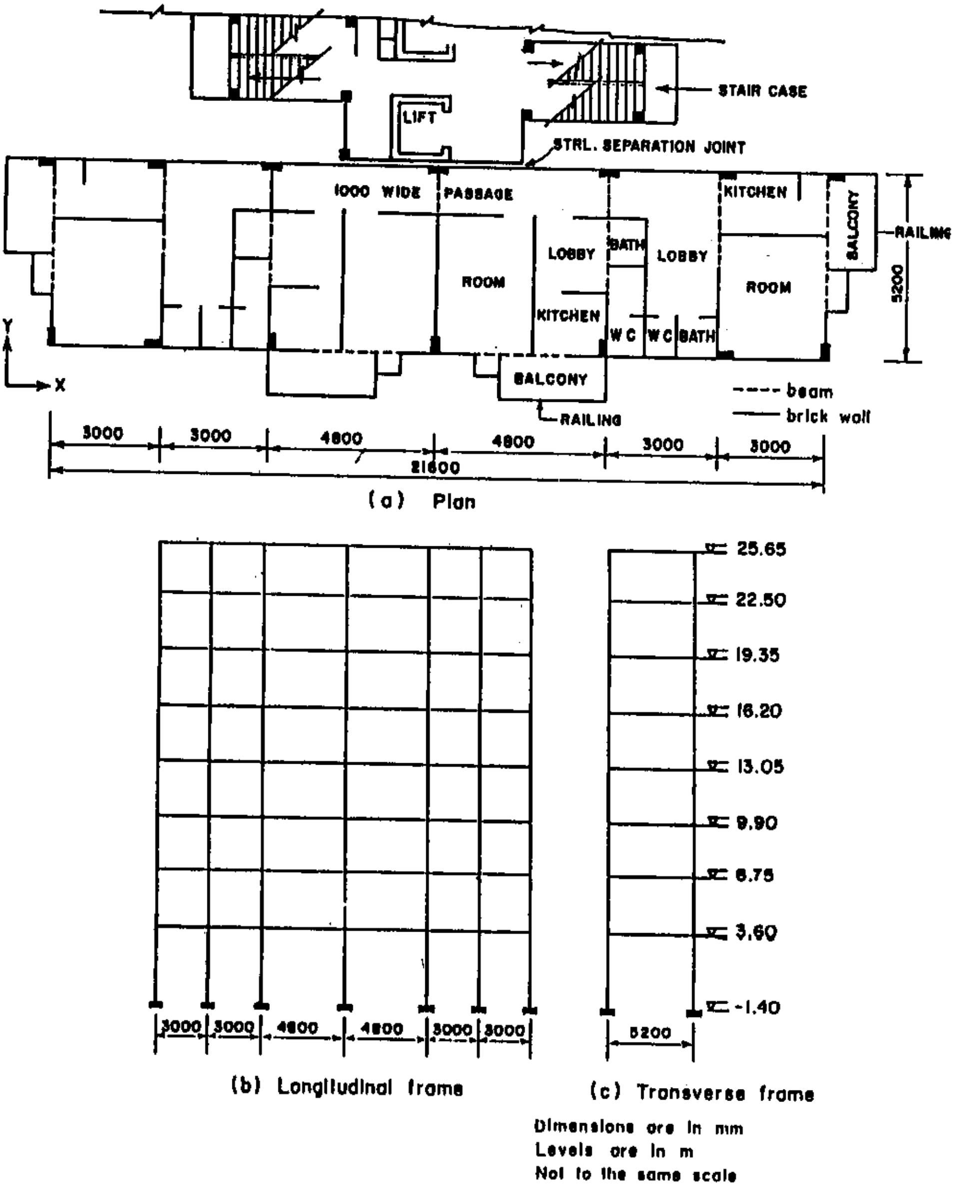

FIG. 2 SCHEMATIC PLAN OF THE RESIDENTIAL BUILDING

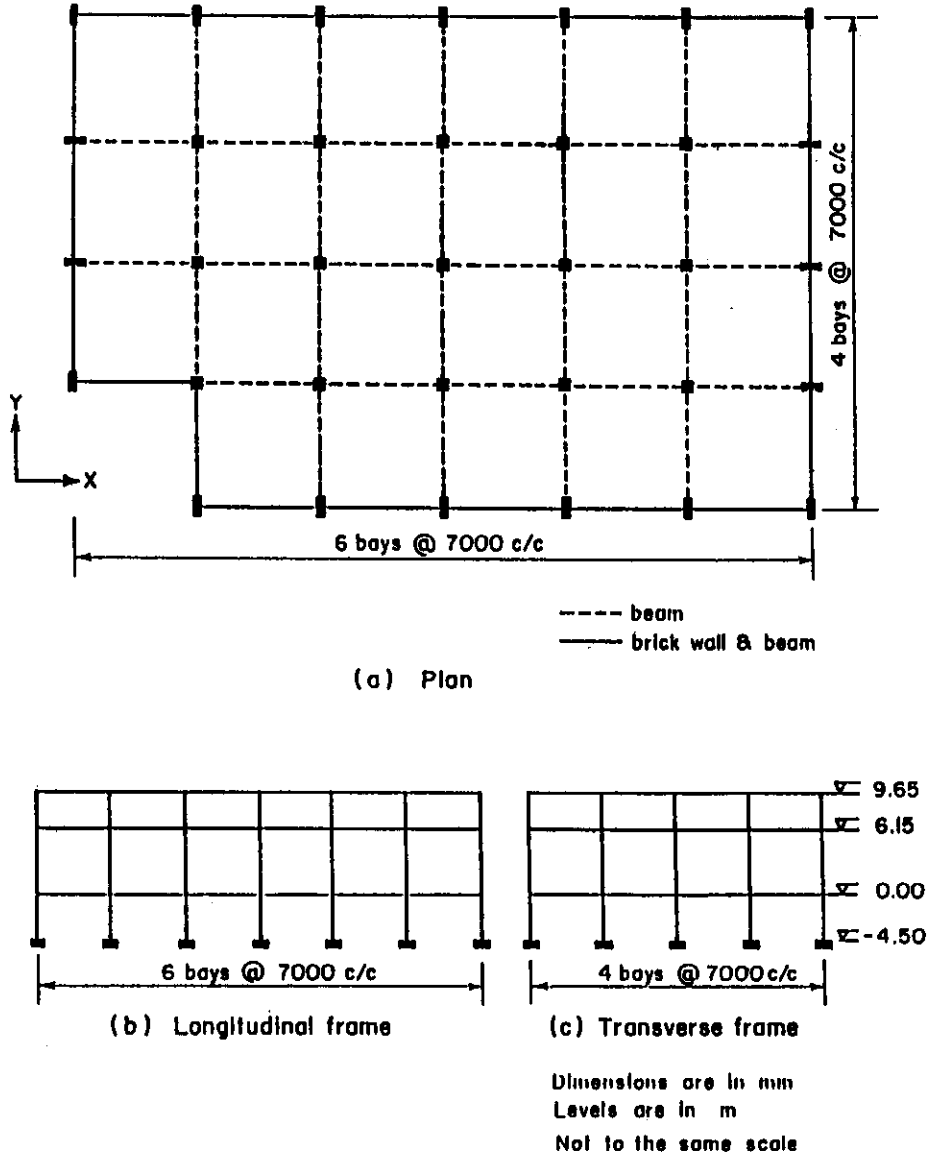

FIG. 3 SCHEMATIC PLAN OF THE INDUSTRIAL BUILDING

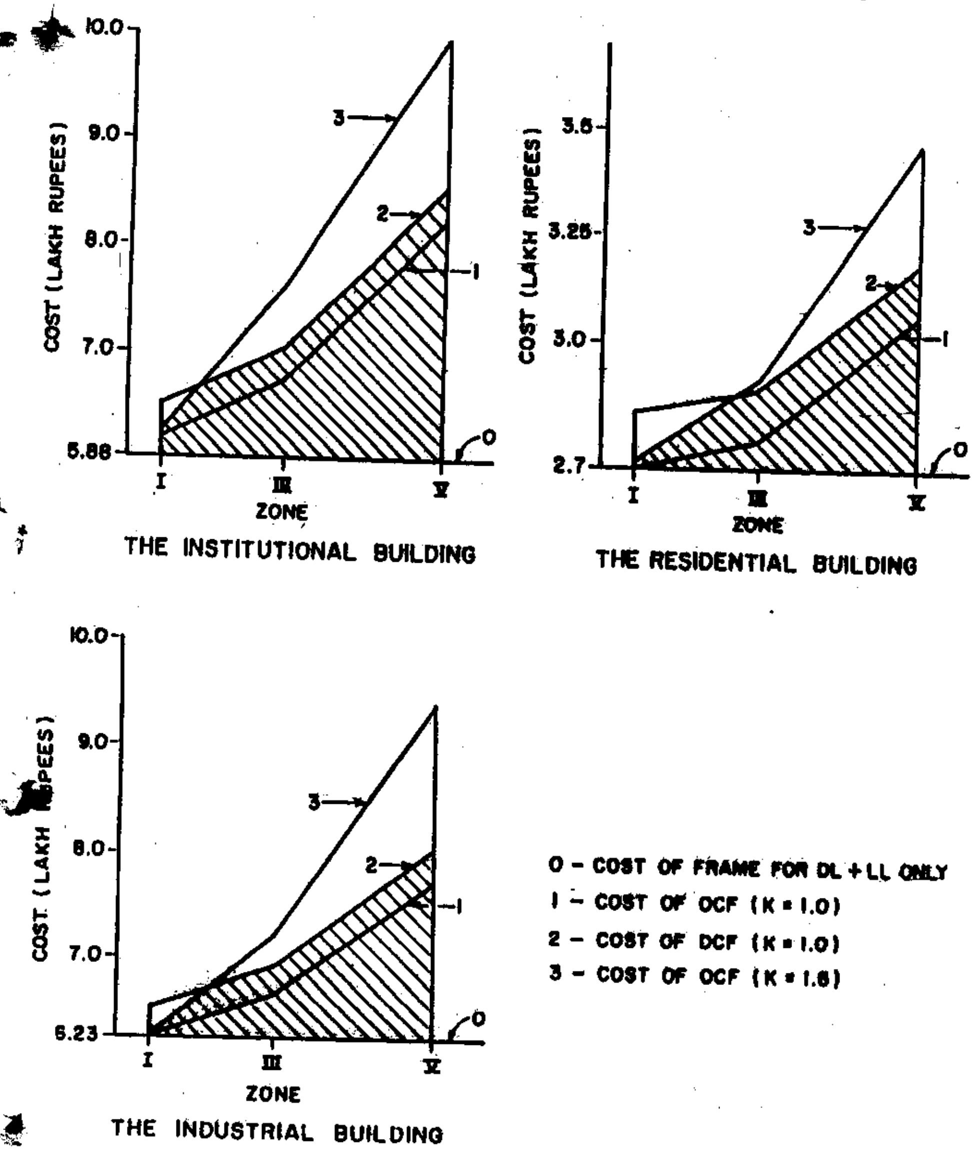

FIG. 4 COST OF EARTHQUAKE RESISTANT CONSTRUCTION