STEPS FOR SAFE DESIGN AND CONSTRUCTION OF MULTISTOREY REINFORCED CONCRETE BUILDINGS

1. Introduction:

A large number of reinforced concrete multistoreyed frame buildings were heavily damaged and many of them collapsed completely in Bhuj earthquake of 2001 in the towns of Kachchh District (viz., Bhuj, Bhachao, Anjar, Gandhidham and Rapar) and other district towns including Surat and Ahmedabad. In Ahmedabad alone situated at more than 250 kilometers away from the Epicentre of the earthquake, 69 buildings collapsed killing about 700 persons. Earlier, in the earthquake at Kobe (Japan 1995) large number of multistoreyed RC frame buildings of pre 1981 code based design were severely damaged due to various deficiencies. Such behaviour is normally unexpected of RC frame buildings in MSK Intensity VIII and VII areas as happened in Kachchh earthquake of January 26, 2001. The aim of this paper is to bring out the main contributing factors which lead to poor performance during the earthquake and to make recommendations which should be taken into account in designing the multistoreyed reinforced concrete buildings so as to achieve their adequate safe behaviour under future earthquakes. The Indian Standard Code IS:1893 was suitably updated in 2002 so as to address the various design issues brought out in the earthquake behaviour of the RC Buildings. The paper highlights the main provisions of this code.

2. Causes of the Collapse of RC Frame Buildings and Recommendations

2.1 Ignorance of the Architects and Structural Engineers about the Contents of the relevant earthquake resistant Building Codes :

Recommendation:-
The following BIS Standards will be mainly required for the design of RCC Buildings. Architect's and Structural engineer's design office should have the current copies of these standards available in their offices and all their staff should fully familiarize with the contents of these codes:-

1. IS: 456 -2000 "Code of Practice for Plain and Reinforced Concrete"
2. IS: 875 Part 1 "Unit weights of materials".
3. IS: 875-1987Design loads (other than earthquake) for buildings and structures, Part2 Imposed Loads
4. IS: 875-1987Design loads (other than earthquake) for buildings and structures ,Part 3 Wind Loads
5. IS: 1904-1987 "Code of Practice for Structural Safety of Buildings: Foundation"
6. IS: 1498-1970 Classification and identification of soils for general engineering purposes (First Revision)
7. IS: 2131-1981 Method of Standard Penetration Test for soils (First Revision)
8. IS: 1905-1987, Code of Practice for Structural Safety of Buildings: Masonry
9. IS:1893(Part-I)-2002 "Criteria for Earthquake Resistant Design of Structures (Fifth Revision)".
10. IS:13920-1993, "Ductile Detailing of Reinforced Concrete Structures subjected to Seismic Forces - Code of Practice"
11. IS: 4326-1993, "Earthquake Resistant Design and Construction of Buildings - Code of Practice (Second Revision)"
12. IS-NBC-2005: National Building Code of India.

Note: The design offices should keep in touch with BIS-CE division to keep track of any amendments issued or further revisions.

2.2 Softness of Base Soil:

The soft soil on which most buildings in Ahmedabad were founded would have affected the response of the buildings in three ways:

(i) Amplification of the ground motion at the base of the building;
(ii) Absence of foundation raft or piles;
(iii) Relative displacement between the individual column foundations vertically and laterally, in the absence of either the foundation struts as per IS: 4326 or the plinth beams;
(iv) Resonance or, semi-resonance of the whole building with the long period ground waves;
(v) In the absence of the beam at plinth or, ground level, the length of ground storey columns gets increased, which increases the flexibility of the ground storey and if the columns become 'long' the buckling moments due to P- Δ effect will increase bonding to cause collapse of the columns.
(vi) If the soil is sandy and water table is high, it may liquify. See IS:1893-2002 Cl 6.3.5.2 and Table 1 for minimum N (corrected values) for safety and carryout soil liquefaction analysis by standard procedures available in the literature. The adverse effects of liquefaction may be seen in Figs. 1, 2 & 3.

Fig. 1
The Building Sank evenly about 1 m due to soil liquefaction. The displaced soil caused a bulge in the road.

Fig. 2
This inclined building sank unevenly and leans against a neighbouring building

Fig. 3
The solid building tilted as a rigid body and the raft foundation rises above the ground

Recommendation:-
Soil exploration at the buildings site must be carried out at sufficient points and to sufficient depth so as to give the following data:

(i) Soil classification in various layers and the properties like grain size distribution, fields density, angle of internal fritting and cohesion a plastic and liquid limits and coefficient of consolidation of cohesive sites.
(ii) Position of water table just before and just after monsoon.
(iii) SPT values and CPT values.
(iv) The output results should include liquefaction potential, safe bearing capacity and the type of foundation to be adopted, viz. (i) individual column footing of given width (ii) combined row footing or (iii) raft foundation or (iv) Pile foundations.
(v) Chemical analysis of soil to find if it has any harmful elements to the concrete, if so, precautions to be taken in making the foundations.
(vi) Chemical analysis of water to be used in making the Concrete mixtures.

2.3 Soft-first Storey:

Open ground storey (stilt floor) used in most severely damaged or, collapsed R.C. buildings, introduced 'severe irregularity of sudden change of stiffness' between the ground storey and upper storeys since they had infilled brick walls which increase the lateral stiffness of the frame by a factor of three to four times. Such a building is called a building with '*soft' ground storey*, in which the dynamic ductility demand during the probable earthquake gets concentrated in the soft storey and the upper storeys tend to remain elastic. Hence whereas the 'soft' storey is severely strained causing its total collapse, much smaller damages occurs in the upper storeys, if at all.

Behaviour of soft first storey buildings (buildings on *stilts* or with *open plinth*) during earthquakes may be seen in Figs. 4, 5 & 6.

Fig. 4
Sway mechanisms with soft storey ground floors (Izmit, Turkey 1999

Fig. 5
Soft first storey collapsed, upper part of the building fall onto the ground, (kachchh, 2001)

Fig. 6
Soft Storey (Open Plinth), Vertical Split between two blocks (Bhuj)

Recommendation:-
In view of the functional requirements of parking space under the buildings, more and more tall buildings are being constructed with stilts. To safeguard the soft first storey from damage and collapse, clause **7.10 of IS: 1893-2002 (Part 1)** provides two alternative design approaches

(i) The dynamic analysis of the building is to be carried out which should include the strength and stiffness effects of infills as well as the *inelastic deformations* under the design earthquake force disregarding the Reduction Factor R.

(ii) The building is analysed as a bare frame neglecting the effect of infills and, the dynamic forces so determined in columns and beams of the soft (stilt) storey are to be designed for 2.5 times the

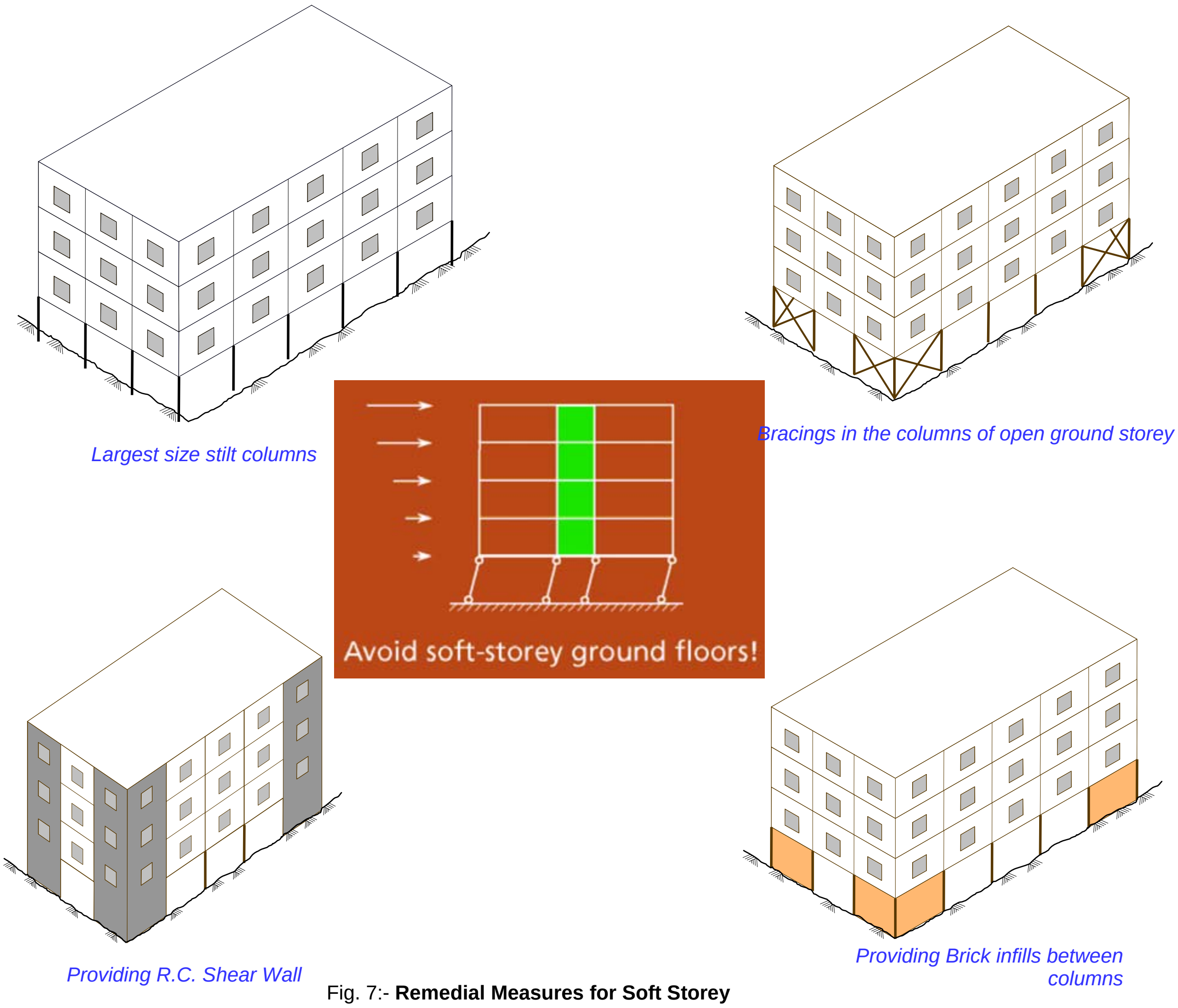
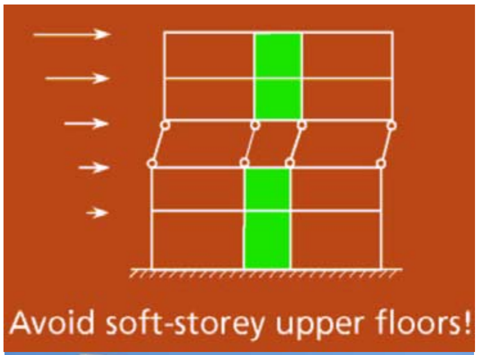


Fig. 7:- **Remedial Measures for Soft Storey**

storey shears and moments: OR the shear walls are introduced in the stilt storey in both directions of the building which should be designed for 1.5 times the calculated storey shear forces.

Some remedial measures to counter the bad performance are shown in Fig. 7.



Some times a soft storey is created some where at mid-height of the multi-storey building, for using the space as restaurant or gathering purposes, *see fig.8*. Such soft storey in building also collapsed in Kutch and Kobe earthquakes. For such a case also, the storey columns should be designed for the higher forces OR a few shear walls introduced to make up for the reduced stiffness of the storey.

Fig.8:- Collapse of soft middle storey in a building at Bhuj.

2.4 Bad Structural System:

The structural system adopted using floating columns, for reasons of higher FSI is very undesirable in earthquake zones of moderate to high intensity as in Zone III, IV & V since it will induce large vertical earthquake forces even under horizontal earthquake ground motions due to overturning effects.

Recommendation:-
The structural engineer should provide for the *load path* in the building from roof to the foundation. For example, a building with floating columns requires transfer of the floating column loads to horizontal cantilever beams through shear forces. The *load path,* therefore, is not vertical but changes from vertical to horizontal members before reaching the foundation. Sometimes similar situations arise within the frames where, for any reason, either the beam is missing or a column is missing. These are structural discontinuities and should better be avoided as far as possible. Other irregularities such as those defined in Table 4 & 5 of IS: 1893-2002 (Part 1) become the cause for large *torsional moments* and *stress concentration* in the buildings which should better be avoided by the architect and structural engineer in the initial planning of the building configuration. Otherwise, they should be carefully considered in structural analysis and properly detailed in the structural design.

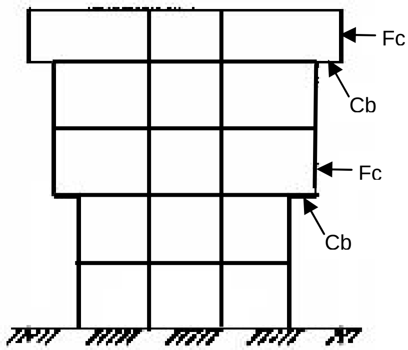


Fig.9:-Floating columns
Fc= Floating Columns
Cb= Cantilever Beams

2.5 Heavy Water Tanks on the Roof:

Heavy water tanks add large lateral inertia forces on the building frames due to the so called ‘whipping’ effect under seismic vibrations, but remain unaccounted for in the design. See the fall of such water tank in Fig.10

Recommendation:-
All projected systems above the roof top behave like secondary elements subjected to *roof level horizontal earthquake motions* which act as base motions to such projecting systems. To

Fig.10
5 storey R.C., collapse of open plinth, water tank at top dislocated (Bhuj)

account for such heavy earthquake forces, IS:1893-2002 (Part 1) provides in clause **7.12** that their support system should be designed for *five times* the design horizontal seismic co-efficient A_h specified in clause **6.4.2.** Similarly any horizontal projections as the balconies or the cantilevers supporting floating columns, the cantilevers need to be designed for *five times* the *design vertical co-efficient* as specified in clause **6.4.5** of IS: 1893-2002 (Part 1)

2.6 Lack of Earthquake Resistant Design:

All the upper floors weak in long directions (Izmit, Turkey 1999)

Many buildings in Gujarat were not designed for the earthquake forces specified in IS:1893, which was in existence from 1962, revised in 1970, 1976 & 1984. The applicable seismic zoning in Gujarat had remained the same as adopted in 1970 version. It is the same even in 2002 version of IS:1893 (Part I).

Inspite of that, the structural designers ignored the seismic forces in design. It may also be stated that most buildings are designed against lateral load in the *transverse direction*. Hence they collapse in the *longitudinal directions*.

Proper arrangement of columns is shown in Fig. 11 which would give adequate seismic resistance along both axes of the building.

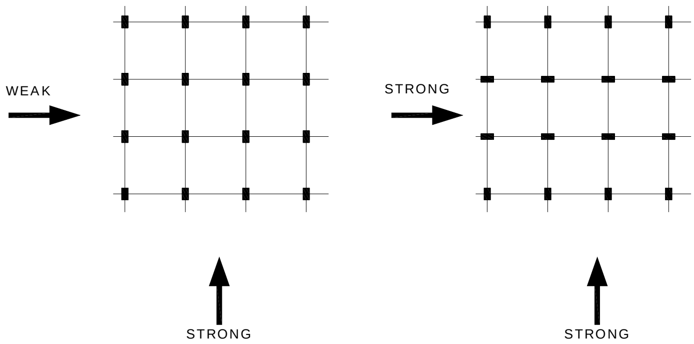
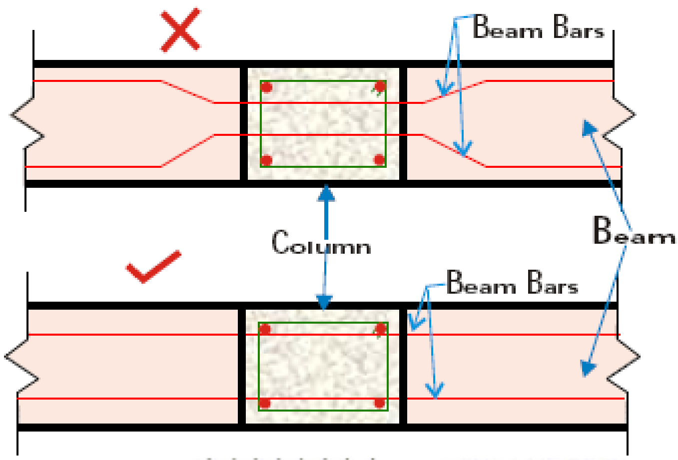


Fig.11:- Lateral Strength of Building Frame

Recommendation:-
It does not need emphasizing that all buildings including the multistoried buildings should be designed in accordance with IS: 1893 (Part 1) and IS: 4326 – 1993. The salient features of the design will be presented in Para 3.0 in this guide.

2.7 Improper Dimensioning of Beams & Columns:



The structural dimensioning of beams and columns was inadequate in terms of provisions in IS: 13920-1993 and also for proper installation of reinforcements in Beam-Column joints as per IS: 456 and IS: 13920.

Recommendation:
The relative dimensions of beams & columns become very important in tall buildings from the point of view of provision of longitudinal & transverse reinforcement in the members as well as the reinforcement passing through and anchored in the beam-column joints, permitting enough space for proper concreting and without involving any local kinking of the reinforcing bars. The practice of using small dimension columns like 200 or

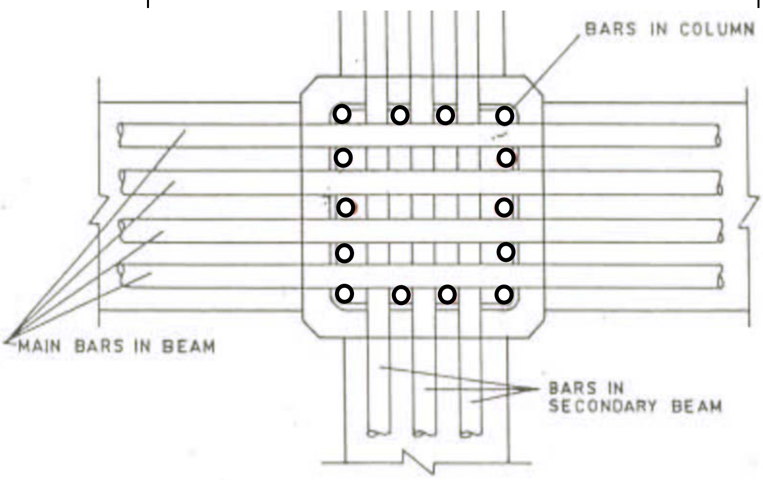


Fig.13:- Plan of Reinforcement in Beams & Columns

230 mm and *beams of equal width* is totally unacceptable from the reinforcement detailing view point. Infact for permitting the beam bars passing through the columns, without any local bending then straightening (introducing kinks), the proper scheme would be to use wider columns than the beams. Minimum dimensions of beams and columns, also limiting aspect ratios of the two members, are specified in IS: 13920 which need to be adhered to.

2.8 Improper Detailing of Reinforcement:

In detailing the stirrups in the columns, no conformity appeared to satisfy lateral shear requirements in the concrete of the joint as required under IS 4326- 1976 and IS: 13920-1993. The shape and spacing of stirrups seen in collapsed and severely damaged columns with buckled reinforcement was indicative of non-conformity even with the basic R.C. Code IS: 456-1978.

Recommendation:
In respect of proper detailing of reinforcement in beams, columns, beam-column joints as well as shear walls, all the provisions in IS:13920 have to be carefully understood and adopted in design. The *philosophy of over-design of beams in shear to force flexural hinge formation before shear failure, confining of highly compressed concrete in columns* and the use of properly shaped *shear stirrups with 135 degree hooks* are some low-cost but extremely important provisions. For overall safety of the frame, design based on the concept of *strong-column, weak-beam* system should be adopted as far as practical. It may be mentioned that the full ductility details as specified in IS: 13920 permit the use of the High Reduction Factor R=5 which would make the design economical. But if such ductility details are not adopted, the Reduction Factor is permitted as only 3.0, which means that the design force will become 1.67 times the case when full ductile detailing is adopted which may indeed turnout to be more expensive and at the same time brittle and relatively unsafe (see fig.13).

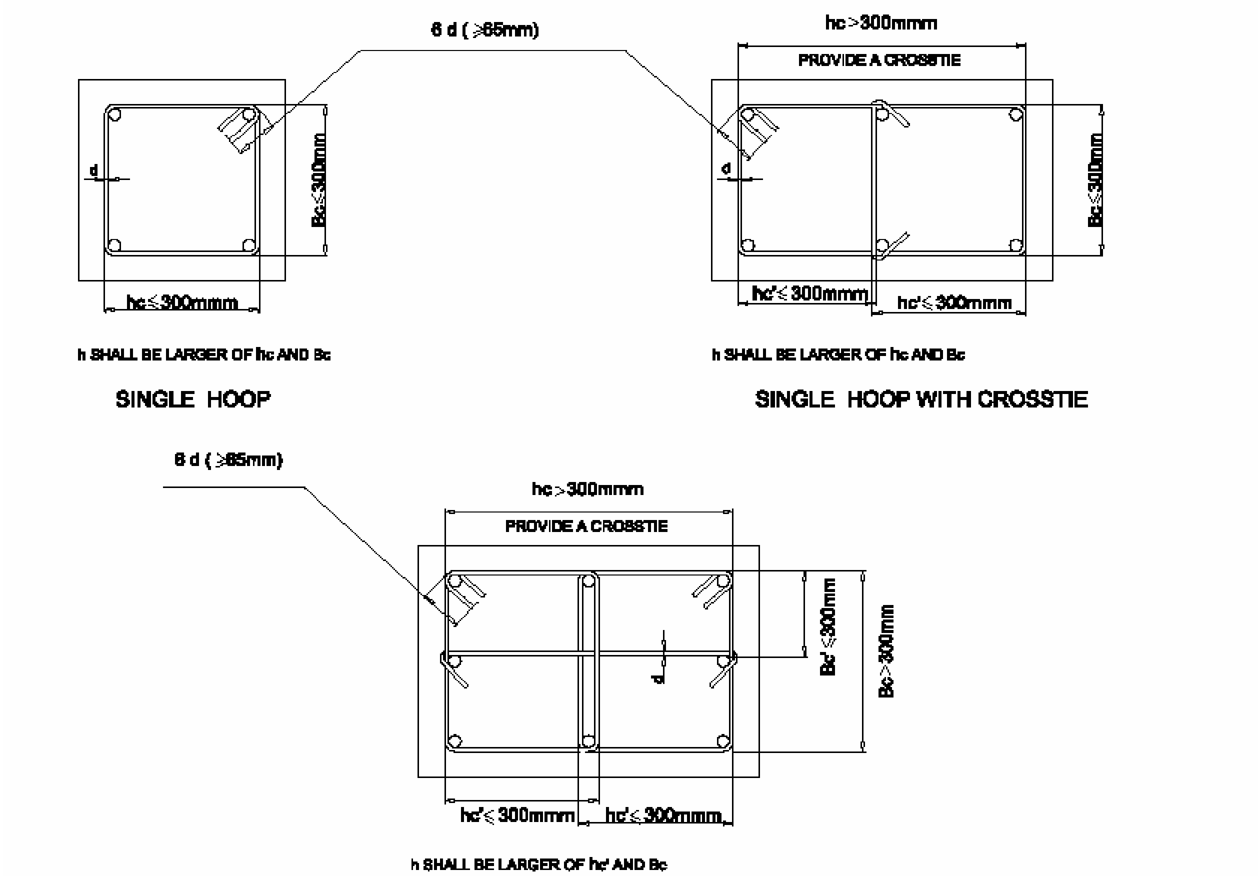


Fig.13:- Detailing of reinforcement (Overlapping Hoops & Crosstie)

2.9 Short Column Detailing

In some situations the column is surrounded by walls on both sides such as upto the window sills and then in the spandrel portion above the windows but it remains exposed in the height of the windows. Such a column behaves as a short column under lateal earthquake loading where the shear stresses become much higher than normal length columns and fail in shear. (See fig. 14)

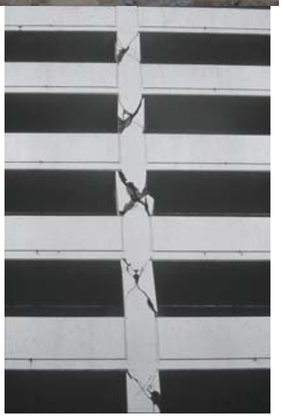


Fig.14:- Damage to buildings due to short column effect on columns

Recommendation:
To safe guard against this brittle shear failure in such columns the special confining stirrups should be provided throughout the height of the column at short spacing as required near the ends of the columns.

2.10 Torsional Failures

Torsional failures are seen to occur where the symmetry is not planned in the location of the lateral structural elements as for example providing the lift cores at one end of the building or at one corner of the building or unsymmetrically planned buildings in L shape at the street corners. Large torsional shears are caused in the building columns causing there torsional shear failures (See fig.15).

Fig.15:- Very unsymmetrical building

Recommendation:
Where site requirements of from functional requirements control the building plan shape, either it should be split into two symmetrical rectangular blocks by providing separation sections of appropriate with between the blocks or the structural elements should be so adjusted that the centre of stiffness and the centre of mass should coincide along both axis of the building needless to say that any non-coincidence of the centre of mass and centre of stiffness should be taken into design calculations as per IS:1893

2.11 Pounding Damage of Adjacent Buildings

Severe damage even leading to collapse are seen due to severe impact between two adjacent buildings under earthquake shaking if the adjacent blocks of a building or two adjacent buildings are of different heights with floors at different levels and with inadequate separation. Such buildings can vibrate out of phase with each other due to very different natural frequencies thus hitting each other quite severely (see fig.16).

Fig.16:- Pounding damage of adjacent buildings

Recommendation:

To avoid such pounding damage the amount of separation between them should be liberally provided so as to cater for the combined maximum out of phase displacements. A simple recommendation is given in IS:4326 (Cl.5.1.2) for flexible as well as stiff buildings which must be adopted as a minimum to avoid the possibility of pounding between two unsimilar buildings/blocks

2.12 Lack of Stability of Infill Walls

Fig. 17:- Infill wall damage

The infill walls were not properly attached either to the column or the top beams for stability against out-of-plane bending under horizontal earthquake forces. Their cracking and falling was widespread (See Fig. 17).

Recommendation:
Stability of infill walls is important in two ways: first, they introduce their brittle failure due to the diagonal compression in the panel and or diagonal tension cracking; secondly, and more important is their lateral stability under out of plane earthquake force acting on their own mass. While conducting the retrofitting studies of three lifeline buildings in Delhi, the *114 mm thick brick infill walls* have turned out to be one of the main issues to handle while retrofitting the building so as to save the inmates and the property inside from damage due to the failure of the infill walls. It has been found that such walls will have to be contained with in pairs of vertical angles spaced at 1.2 – 1.5 m apart. Therefore, while designing a new multistoried building, the stabilisation of the infill wall panels should be properly considered either by providing confining angles near the top or by providing slits on the vertical sides and stabilising by the means of vertical angles or channels.

2.13 Poor Construction Quality:

The construction quality of the damaged R.C. buildings was found to be much below that desired, as seen by the cover to reinforcement in the damaged members and the bad quality of concrete in the columns in 150 to 300 mm length just below the floor beams and within the beam column joints.

Recommendation:
Needless to say that if the quality of construction is not commensurate with the quality of design, even a well planned and a well designed building can show extremely bad behavior under earthquake shaking. It should be remembered that during earthquake shaking all bad quality constructions will be revealed and nothing can be kept hidden. Good quality of construction will include: *proper mixing and quantity of water, good quality sand and aggregates, designed quantity of cement in the mix, proper mixing of all the ingredients with control on water cement ratio, adequate compaction in the placement of concrete preferably by using vibrators, proper placement of steel with control on the cover to steel and adequate curing* before striking of the form work. The engineer incharge of the construction should personally be present at site to supervise all operations. He should have appropriate sampling and testing of materials carried out in a recognized laboratory, the results of test being kept in well maintained register for inspection by quality audit team. He should organize the taking of sample of steel reinforcement & concrete cubes in adequate numbers which should be tested at the specified age of testing.

3. Some Important Codal Design Provisions:

In the last few years the author has had the opportunity of reviewing many reinforced concrete building designs prepared by well-established consulting companies as well as individual consultants and felt the need of preparing brief guidelines so that no important Codal provisions are missed out and the various design details for achieving better construction in the field and better ductile performance in the event of a great earthquake are ensured. Thus a safe and ductile building could be achieved.

3.1 Building Configuration

For achieving basic structural safety of buildings under postulated earthquake forces the first important requirement is that the building should be designed with symmetrical configuration both horizontally and vertically. In any case the seismic force resisting elements must be planned symmetrically about the centre of the mass of the building. IS:1893 (Part 1-2002) presents in detail in cl.7.1 the various types of irregularities which should be avoided as far as possible or corrected by planning the structural resisting elements. The present day requirements of large column free spaces inside can be met by designing strong frames on the periphery of the building so as to resist most of the horizontal design seismic forces and relieving the internal columns relatively from the earthquake forces. For this purpose shear walls may be provided in the building perimeter to increase the stiffness in both principal axes of the building as compared with the internal columns which could be designed basically for vertical loads.

3.2 Calculation of Loads

The loads will include the following:

(i) *Dead Loads*: These will include the weight of all components at each level, viz., *roof* including water tanks, *Barsatis*, Parapets, roof finishes, slabs, beams, elevator machine room etc. and including all plasters and surface cladding etc., and each *floor level* including fixed masonry or other partitions, infill walls, columns, slabs and beams, weight of stairs, cantilever balconies, parapets and plastering or cladding wherever used. The unit weights may be taken from IS:875 (Part 1) or ascertained from the manufacturer.

(ii) *Imposed Floor Loads*: IS 875 (Part 2) deals with the imposed loads on roofs, floors, stairs, balconies, etc., for various occupancies. There is a provision for reduction in the imposed loads for certain situations, e.g. for large span beams and number of storeys above the columns of a storey. The earthquake code IS: 1893 (Part 1)-2002 permits general reduction in roof and floor imposed load when considering the load combination with the earthquake loading. But the two types of reductions, that is, in IS: 875 (Part 2) and IS: 1893 (Part 1) are *not* to be taken together.

3.3 The Earthquake Load:

For working out the earthquake loading on a building frame, the dead load and imposed load and weights are to be lumped at each column top on the basis of contributory areas. The imposed load is to be reduced as specified in IS: 1893 (Part1)-2002 for seismic load determination. Let us call them W_i at ith floor and W_n at the nth level at the roof level for a n-storey building. Hence the total load at the base of the building just above the foundation will be

$$W = \sum_{i=1}^{n} W_i + W_o$$

where W_o is the weight of elements in the ground storey.

3.4 Earthquake Resistant Design

Now the following steps may be taken:

(a) <u>Estimate fundamental time period Ta using empirical expressions given in the Code IS: 1893-</u>

2002.

$T_a = 0.075\ H^{0.75}$, IS: 1893 Cl.7.6.1 for bare frame along each axis
$T_{ax} = 0.09h/\sqrt{d}$ along x-axis IS: 1893 Cl.7.6.2 for frame with substantial infills
$T_{az} = 0.09h/\sqrt{b}$, along z-axis, IS: 1893 Cl.7.6.2 for frame with substantial infills

where h is the height of the building and d and b are the base dimensions of the building along x and z axis respectively.

(b) Calculate the design horizontal Seismic coefficient A_h

Now compute the fundamental time periods T'_x and T'_z for the bare frame along the two axes by dynamic analysis. These are generally found to be higher than T_{ax} and T_{az} respectively.
The design horizontal coefficient A_h is given by

$$A_h = (Z/2).\ (I/R).\ (S_a/g)$$

Take Z for the applicable seismic zone	(IS: 1893 Cl.6.4.2),
Take I for the use importance of the building	(IS: 1893 Table 2),
Take R for the lateral load resisting system adopted	(IS: 1893 Table 7),

and take Sa/g for the computed time period values T'_x, T_{ax}, T'_z and T_{az} with 5% damping coefficient using the response spectra curves IS: 1893 Fig 2 for the soil type observed. Thus four values of A_h will be determined as follows:-

In x-direction A'_{hx} for T'_x & A_{hax} for T_{ax}
In z-direction A'_{hz} for T'_z & A_{haz} for T_{az}

(c) Calculate the total horizontal shear (the base shear)
The design value of base shear V_B

$$V_B = A_h\ W$$

as per 1893 Cl.7.5.3.
For design of the building and portions thereof, the base shear corresponding to *higher* of A_{hax} and A'_{hx}, similarly between A_{haz} and A'_{hz} will be taken as minimum design lateral force.

(d) Seismic Moments and Forces in Frame Elements:

Calculate the seismic moments and axial forces in the columns, shears and moments in the beams by using the seismic weights on the floors/(column beam joints) through an appropriate computer software (*having facility for using floors as rigid diaphragm and torsional effects as per IS: 1893:2002).*

It may be performed by Response Spectrum or Time History analysis. The important point is that according to IS: 1893 Cl.7.8.2., the base shear computed in either of the dynamic method, say V'_B shall not be less than V_B calculated under Cl.7.5.3 using A_{hax} and A_{haz}. If so, then all shears, moments, axial forces etc worked out under dynamic analysis will be increased proportionately, that is, in the ratio of V_B/V'_B.

(e) Soft Ground Storey

It must be designed according to Cl.7.10 of IS: 1893-2002.

4. Method of Design

Structural design of various members has to be done by Limit State Method, as per IS 456-2000 for which the following load combinations should be used to work out the maximum member forces:-

Using

DL	for	DEAD LOAD
LL	for	LIVE LOAD
EQX	for	SEISMIC LOAD (X) DIRECTION
EQZ	for	SEISMIC LOAD (Z) DIRECTION

The load combinations for analysis and design will be taken as follows:

1. (DL+LL)*1.5
2. (DL+LL+EQX)*1.2
3. (DL+LL+EQZ)*1.2
4. (DL+LL-EQX)*1.2
5. (DL+LL-EQZ)*1.2
6. (DL+EQX)*1.5
7. (DL+EQZ)*1.5
8. (DL-EQX)*1.5
9. (DL-EQZ)*1.5
10. 0.9DL+EQX*1.5
11. 0.9DL+EQZ*1.5
12. 0.9DL-EQX *1.5
13. 0.9DL-EQZ*1.5

The members (beams, columns, shear walls etc.) and their joints will be designed for the worst combination of loads, shears and moments.

MATERIALS:

a) *Cement:* Ordinary portland cement conforming to IS 269 - 1976 shall be used along with fly ash after carrying out the design mix from approved consultant.

b) *Reinforcement:* Cold twisted high yield strength deformed bars grade Fe 415 conforming to IS: 1786-1985, or preferably TMT bars of standard manufacturer e.g. TATA Steel, SAIL or equivalent shall be used.

The following grades of concrete mix may be adopted or as required for safe design:

(a) For RCC columns in lowest few storeys	:	M35
(b) For RCC columns in the middle few storeys	:	M30
(c) For RCC columns in the top few storeys	:	M25
(d) For beams, slabs, staircase etc.	:	M20
(e) For raft foundation	:	M 20 or 25
(f) Max. Water cement Ratio	:	0.45
(g) Minimum cement content	:	300 kg/m^3 of concrete.

(h) Admixtures of approved brand may be used as per mix design

CLEAR COVER TO ALL REINFORCEMENT:

For mild Exposure and fire rating of 1 hr. following clear covers may be adopted

(a) For foundation R.C.C.:

i) Footings : 60 mm.

ii) Raft : 60 mm.

(b) For columns : 40 mm

(c) For Beams : 25 mm or main bar dia. whichever is more.

(d) For Slab : 20 mm.

4.1 Ductile Detailing

After designing the frame column-beam, shear walls and foundation by limit state theory as per IS: 456:2000, all details of longitudinal steel, overlaps, shear capacities, confining reinforcement requirements, stirrups and ties etc. shall be worked out using the provisions of IS: 13920-1993.

The drawings should clearly show all the adopted details.

5. Concluding Remarks

In a nut-shell, the seismic safety of a multi-storeyed reinforced concrete building will depend upon the initial architectural and structural configuration of the total building, the quality of the Structural analysis, design and reinforcement detailing of the building frame to achieve stability of elements and their ductile performance under severe seismic lading. Proper quality of construction and stability of the infill walls and partitions are additional safety requirements of the structure as a whole. Any weakness left in the structure, whether in design or in construction will be fully revealed during the postulated maximum considered earthquake for the seismic zone in the earthquake code IS: 1893.

Acknowledgement:

The figures have been taken from various sources to suit the text message and are anonymously acknowledged.
