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A Review of Codes on Building Irregularities for Seismic Analysis

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***Abstract:*— Possibility of damage happening during earthquake ground motion is more where there are occurrences of structural weakness and this weakness generally produced because of the irregularity.The presence of structural irregularity changes the seismic response and the change in the seismic response depends upon the type of structural irregularities. In this paper, criteria and limits specified by IS 1893(Part 1) for different types of irregularities are discussed and standards defined by other countries (ASCE-7-10, NBCC2005, TEC2007, NZS1170 and EC8: 2004) have been compared. The code's main advice for the designers is to avoid irregularities altogether if possible.Alsoto avoid casualties, architects should design appropriately and understand the dynamic behavior. To do that, the basis of seismic codes which are substantial bases should be used in architectural studies.**

***Index Terms*— Horizontal and Vertical irregularity, Mass,Stiffness, strength, Setback, In-Plane Discontinuity, Torsional, Re-entrant Corners, Diaphragm Discontinuity, Out-of-Plane Offsets, Non-Parallel Lateral Force System.**

I. INTRODUCTION

Earthquakes are more unpredictable and devastating of all natural disasters.Because of which,it is very difficult to save over engineering properties and life.Possibility of damage happening during earthquake ground motion is more where there are occurrences of structural/geometrical weakness. To havebetter performance in an earthquake, the building should have four main characteristics, specifically simple and regular configuration, suitable lateral strength, stiffness and ductility.The building that lacks symmetry, has a discontinuity in load resisting elements, massorgeometry is entitled as irregular building. These irregularities may cause interruption of force flow and stress concentrations. Asymmetrical arrangements of mass and stiffness of elements may originate a large torsional force where the center of mass does not coincide with the center of rigidity.However, because of the day by day development in the modern era, it is very difficult for architectsto create simple regular structure.

The presence of structural irregularity changes the seismic response and the change in the seismic response depends upon the type of structural irregularities. The section 7 of IS 1893 (part 1): 2002 enlist the irregularity in the building configuration system. These irregularities may be broadly classified as (i)Vertical irregularity due to sudden change of strength, stiffness geometry and mass resulting inan irregular distribution of forces and (ii) horizontal irregularity associated to asymmetrical plan shape or discontinuities in the horizontal resisting elements (diaphragms) such as cutouts, large opening, re-entrant corners, out-of-plane offset and other abrupt changes resulting into torsion. Flow chart of irregularity category is as shown in Figure 1.Earthquake codes are authorized documents, the aim of which is to determine the minimum conditions for the production of seismically safe and functional buildings. In this paper, criteria and limits specified by IS 1893 for these irregularitiesare discussed and standards defined by other countries (ASCE-7-10, NBCC2005, TEC2007, NZS1170 and EC8: 2004) have been compared.

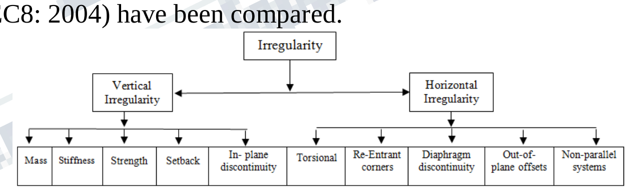

Figure 1: Different types of irregularity

II. VERTICAL IRREGULARITY

In the earlier versions of IS 1893 (BIS, 1962, 1966, 1970, 1975, 1984), there was no mention ofVertical irregularity in building frames. However, the recent version of IS 1893 (Part 1)-2002, different types of vertical irregularity have been listed below.

1) Mass Irregularity

It has to be considered to exist where the seismic weight of any storey as shown in Figure 2, is more than 200 percent of that of its adjacent storeys.Heavy mass can be brought by an intermediate service floor with water tanks and heavy equipment for air conditioning and/or back-up power generation, heavy storage etc.

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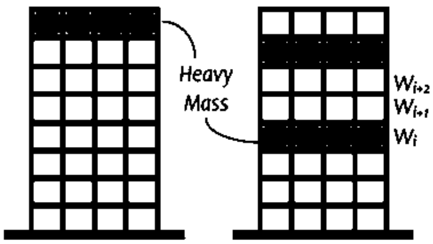

Figure 2: mass Irregularity (IS1893:2002)

2) Stiffness Irregularity

If the lateral stiffness of any considered storey is less than 70% of that in the adjacent storey or less than 80% of the average lateral stiffness of the 3 above story then stiffness irregularity has to be considered. As referred in Figure 3, when a column is discontinued in ground floor or story height more than average story height, then there will be a sudden change in story stiffness.

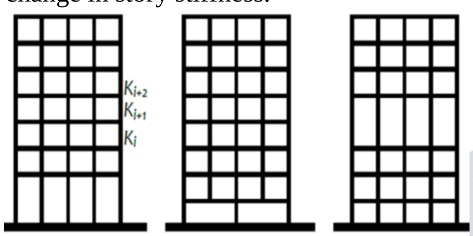

Figure 3: Stiffness Irregularity(IS1893:2002)

3) Strength Irregularity

It is to be present if the lateral strength of all seismic force resisting elements, distributing storey shear in theconsidered direction is less than 80% of that in the above storey. As shown in Figure 4, this type can also be considered as weak story.

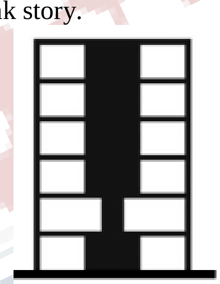

Figure 4: Strength Irregularity (https://civil-engg-world.blogspot.in)

4) Vertical Geometric Irregularity (Setback)

When the horizontal dimension of the lateral force resisting system in any storeyis more than 150 percent of that in its adjacent storey(for example$L_1$and L_2as shown in Figure5) then vertical geometric irregularity shall be considered to exist.

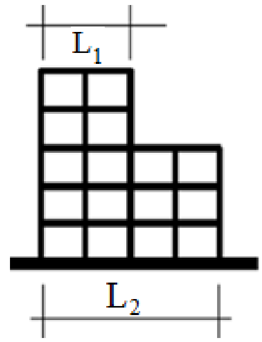

Figure 5: Setback (IS1893:2002)

1) In-Plane Discontinuity

In-plane discontinuity in vertical elements resisting lateral force shall be considered to exist when in-plane offset of the lateral force resisting elements greater than the length of those elements. As per Figure 6, offset is ‘b’ and length is ‘a’ of the lateral force resisting element.

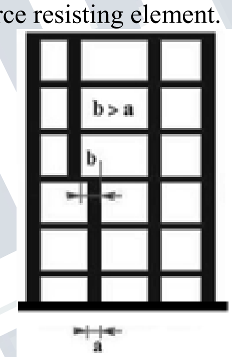

Figure 6: In-Plane Discontinuity (https://civil-engg-world.blogspot.in)

In the same way, the other international code of practice has also been referred and criteria defining limits of these irregularities are shown in Table 1.

Table 1: Vertical Irregularity Limits Established By International Codes

Sr. No.	Code Name	[1] Mass	[2] Stiffness	[3] Strength	[4] Setback
1	IS 1893:2002	M_i>200% M_{adj}	S_i< 70% of S_{i+1} **Or** S_i<80% (above 3 story average)	L.S. < 80% adjacent story	H.D. > 150% H.D.$_{adjacent}$ story
2	IS 1893 DRAFT	M_i>150% M_{adj}	Lateral stiffness less than the adjacent story	L.S. less than adjacent story	H.D. > 125% H.D.$_{adjacent}$ story
3	ASCE-7-10	M_i>150% M_{adj}	S_i< 70% of S_{i+1} **Or** S_i<80% (above 3 story average)	L.S. < 80% adjacent story	H.D. > 130% H.D.$_{adjacent}$ story
4	NBCC2005	M_i>150% M_{adj}	S_i< 70% of S_{i+1} **Or** S_i<80% (above 3 story average)	Story shear strength < adjacent Story	H.D. > 130% H.D.$_{adjacent}$ story
5	TEC2007	------	(Story drift)$_i$ > (S. drift)$_{i+1}$ or $_{i-1}$	Eff. shear area < 80% of adjacent Story	------
6	NZS1170	M_i>150% M_{adj}	S_i< 70% of S_{i+1} **Or** S_i<80% (above 3 story average)	L.S. < 90% adjacent story	H.D. > 130% H.D.$_{adjacent}$ story
7	EC8:2004	Abrupt change Should be avoided	S_i< 70% of S_{i+1} **Or** S_i<80% (above 3 story average)	------	a)Setback @ all story < 0.3 G.F.W b) I.S. <0.1 P.P.W

Mi–mass of any considered story, Madj– mass of adjacentstory, Si – stiffness of any considered story,

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Si+1-stiffness ofadjacentstory, L.S.- lateral strength of considered story, H.D. – horizontal dimension of considered story, G.F.W- ground floor width, I.S. – individual stetback, P.P.W- previous plan dimension

III. HORIZONTAL IRREGULARITY

As per the recent version of IS 1893 (Part 1)-2002, different types of horizontal irregularity have been listed as discussed below.

1) *Torsional Irregularity*

When floor diaphragms are stiff in their specific plan in relative to the vertical structural elements that resist the lateral forces and when the maximum storey drift, at one end of the structure as shown in Figure 7, is more than 1.2 times the average of the storey drifts at the two endsof the structure then torsionalirregularity considered to be exist.

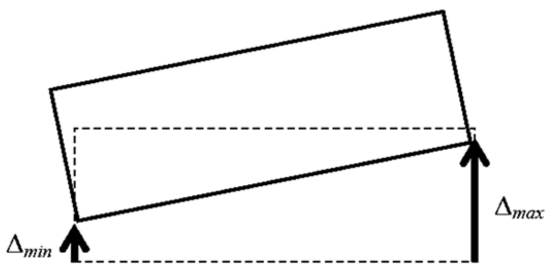

Figure 7:Torsional Irregularity (IS1893:2016 Draft)

2) *Re-entrant Corners*

If plan arrangements of a structure and its horizontalforce resisting system take account of re-entrant corners,wherever projections of the structure, are larger than 15 % ofits plan dimension in the particular considered direction then re-entrant corner irregularity to be considered. As per Figure 8, 'A' indicates the projections and 'L' indicates plan dimensions.

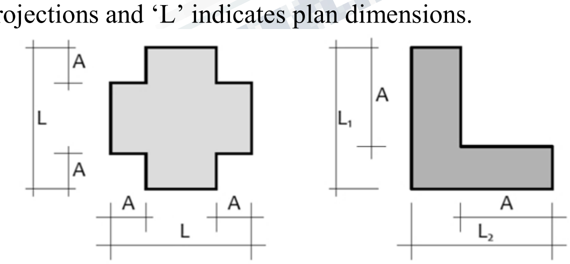

Figure 8:Re-entrant Corners(IS1893:2016 Draft)

3) *Diaphragm Discontinuity*

Diaphragms with sudden discontinuities in the form of cut-out or open areas and deviations in stiffness will be greater than 50 % of the total gross bounded diaphragm area then diaphragm discontinuity irregularity type to be present. Refer Figure 9 for more clarification.

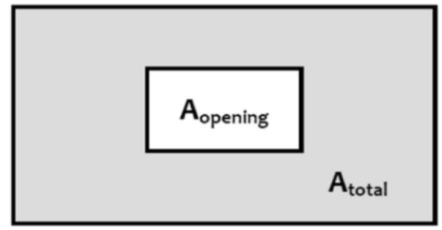

Figure 9: Diaphragm Discontinuity (IS1893:2016 Draft)

4) *Out-of-Plane Offsets*

As shown in Figure 10, when there will be discontinuities in a lateral force resistance path, then out-of-plane offsets of vertical elements to be reflected.

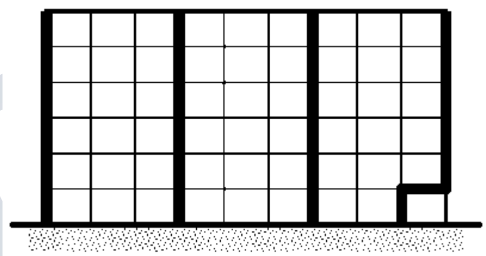

Figure 10:Out-of-Plane Offsets (IS1893:2016 Draft)

5) *Non-Parallel Lateral Force System*

When the vertical elements resisting the lateral forceare not parallel toor symmetric about the majororthogonal axesor the lateral force resisting elements, as shown in Figure 11, then non-Parallel lateral force system to be in existence.

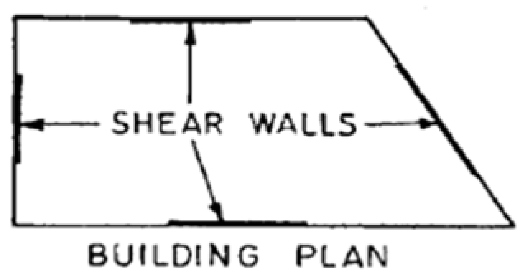

Figure 11: Non-Parallel Lateral Force System (IS1893:2002)

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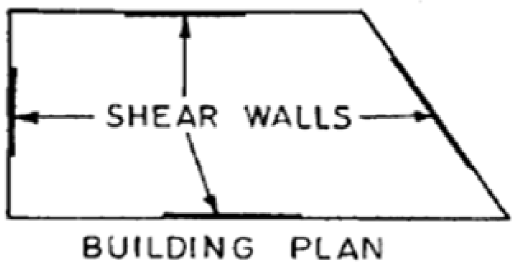

Figure 11: Non-Parallel Lateral Force System (IS1893:2002)

Correspondingly, the other country code has also been referred. Criteria defining limits of these horizontal irregularities as per different international code of practice are shown in Table 2

Table 2: Horizontal IrregularityLimits Established By International Codes

Sr. No.	Code Name	[1] Torsional	[2] Re-Entrant Corners	[3] Diaphragm Discontinuity
1	IS 1893:2002	$\Delta_{max} \geq 1.2\ \Delta_{avg}$	Re-entrant Corner ≥ 15% of Plan Dimension	Open area or change in diaphragm stiffness > 50%
2	IS 1893 DRAFT	$\Delta_{max} \geq 1.5\ \Delta_{min}$	Re-entrant Corner ≥ 15% of Plan Dimension	Open area or change in diaphragm stiffness > 50%
3	ASCE-7-10	$\Delta_{max} \geq 1.2\ \Delta_{avg}$	Re-entrant Corner ≥ 15% of Plan Dimension	Open area or change in diaphragm stiffness > 50%
4	NBCC2005	$\Delta_{max} \geq 1.7\ \Delta_{avg}$	------	------
5	TEC2007	$\Delta_{max} \geq 1.2\ \Delta_{avg}$	Re-entrant Corner ≥ 20% of Plan Dimension	Open area > 33%
6	NZS1170	$\Delta_{max} \geq 1.4\ \Delta_{avg}$	------	------
7	EC8:2004	$r_x > 3.33\ e_{ox}$ $r_y > 3.33\ e_{oy}$ r_x and $r_y > l_s$	Re-entrant Corner ≥ 5% of Plan Dimension	in-plan stiffness of the floors shall be sufficiently large

rx&ry-the square root of the ratio of the torsional stiffness to the lateral stiffness in the x and y direction, ls-The radius of gyration of the floor mass in plan, eox&eoy - the distance between the centre of stiffness(CS) and the centre of mass(CM) measured along the x and y directions respectively, Δmax – maximum story drift at one end,Δavg - average story drift at one end

IV. CONCLUSION

Earthquake resistant design of buildings is a continuing area of research since the earthquake engineering has started not only India but also in other developed countries. Earthquake codes are official documents, the objective of which is to define the minimum conditions for the construction of seismically safe and functional buildings. The basis of codalprovisions is to prevent architects and engineers from creating critical design errors that will compromise the life of their building occupiers.Since building design and construction is controlled by codes it is only usual that any relevant improvement be replicated in the constantly revised codes.The code's main advice for the designers is to avoid these irregularities altogether if possible, if analysis is done using a codal coefficient method.For irregular building, code recommended either response spectrum method or time history method.By the previous earthquakes, it has been agreed that there is a strong correlation between architectural design and building resistance.To avoidcasualties, architects should design appropriately and understand the dynamic behavior.To do that, the basis of seismic codes which are substantial bases should be used in architectural studies.From the above discussed different types, if a building is ensuring any one type of irregularity, then building to be considered as irregular. It is also noticed that the limits of both horizontal and vertical irregularities recommended by different country codes arewell comparable.

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