Gravity Columns and Floating Columns

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Introduction

Gravity Columns are Columns which are designed to resist only vertical loads and are not designed for effects of lateral loads like wind and EQ. In metros like Mumbai with the small sizes of plots especially in redevelopment projects, floating of few columns or shear walls on transfer girders to give clear spaces for parkings, driveway, ramps etc. at lower levels becomes inevitable. But in the latest IS codes there are severe restrictions on providing Gravity columns or floating columns/walls which are a part of lateral load resisting system. U.S. codes do not have such severe restrictions. Authors views on these two aspects are discussed in this paper.

Gravity Columns

In design of buildings under vertical and lateral loads, columns, shear walls along with beams framing into them resist the lateral loads due to wind and earthquake. There could be some columns which do not have beams framing into them or when they are supporting flat slabs. Such columns will not give much resistance to lateral loads due to wind and EQ. Such columns called Gravity columns could then be designed to only carry vertical loads.

There are conflicting views about design of Gravity columns. Design of such columns is discussed below considering the provisions of IS codes, ASCE 07-05 and ACI 318.

Clause 3.6 of IS 13920-2016 defines Gravity Columns in Buildings as "It is a column which is not part of the lateral load resisting system and designed only for force actions (that is, axial force, shear force and bending moments) due to gravity loads. But it should be able to resist the gravity loads at lateral displacement imposed by the earthquake forces."

Clause 11 of IS 13920-2016 states that Gravity Columns "shall be detailed according to Cl. 11.1 and 11.2 for bending moments induced when subjected to 'R' times design lateral displacement under the factored equivalent static design seismic loads". This is in line with philosophy of EQ resistance design which requires building structure to have sufficient ductility to withstand with some deformation or damage but without collapse the maximum expected EQ during its lifetime of magnitudes R times the design EQ. Hence, gravity columns should also be able to withstand the large displacement in such earthquake.

It is not clarified in the code how the moments due to R times design lateral displacements under the factored equivalent static design seismic loads are to be calculated. Some designers then consider Gravity columns in the 3-D analysis of the building, obtain moments/shears in them under design seismic loads and multiply them by R value assumed for the building to get the values of moments specified in Cl. 11 of IS 13920.

The above procedure seems irrational – because then the Gravity columns will have to be designed for 3 to 5 times the moment/shears for which they would be designed if they were considered part of lateral load resisting structure. It would then be better and economical not to consider them as Gravity columns but as lateral load resisting members and include them in the 3-D structure analysis – in which case they are not required to be designed for R times the corresponding moments.

Cl. 12.12.5 of ASCE 07-2016 also requires that members not included in seismic force resisting system to be adequate for gravity load effects plus "Seismic forces resulting from displacement due to the design storey drift (∆)”. Here, ∆ is taken equal to drift under factored EQ load multiplied by deflection amplification factors Cd given in the code and divided by the importance factor (Cl. 12.8.6 of ASCE 07). Generally values of Cd are equal to or less than corresponding R values for the type of structure of the building. Considering that ∆ is drift under factored EQ loads, the resulting drift to be considered for calculating the seismic forces (after multiplication by Cd) will be about R times the drift under factored EQ loads i.e. the provision is similar to that in Cl. 11 of IS 13920-2016.

Cl. 12.12.5 of ASCE 07 specifies that “RC concrete frame members not designed as part of the seismic force resisting system shall comply with section 18.14 of ACI 318”.

Cl. 18.14 of ACI 318-14 entitled “Members not designated as part of the Seismic–Force– Resisting System” states that frame members, not assumed to contribute to lateral resistance (such as Gravity columns), shall be designed to support the gravity loads while subjected to the “design displacements”. Cl. 2.2 and commentary of the code defines design displacement äu as that calculated considering effects of cracked sections, effects of torsion, effects of vertical forces acting through lateral displacements (i.e. P - ∆ effect), effect of deformation of diaphragm etc. with modification factors to account for expected inelastic response.

Obviously, if a Gravity column has to be designed for moments/shears arising out of design displacement äu plus those due to gravity loads then it will require much bigger size and reinforcement than if it were designed only for gravity loads. Then there is no advantage of designing a Gravity column.

However, Cl. 18.14.3.3 of ACI-14 permits that moments/shears under äu plus those due to gravity loads can exceed capacity of the Gravity columns. It even permits such moments/shears due to äu not be calculated at all provided that in either case the reinforcement in the Gravity column is provided as per ductile detailing requirements of code. This clause states:

18.14.3.3 Where the induced moments or shears exceed ϕM_n or ϕV_n of the frame member, or if induced moments or shears are not calculated, (a) through (d) shall be satisfied:

(a) Materials, mechanical splices, and welded splices shall satisfy the requirements for special moment frames in 18.2.5 through 18.2.8.
(b) Beams shall satisfy 18.14.3.2(a) and 18.6.5.
(c) Columns shall satisfy 18.7.4, 18.7.5, and 18.7.6.
(d) Joints shall satisfy 18.8.3.1.

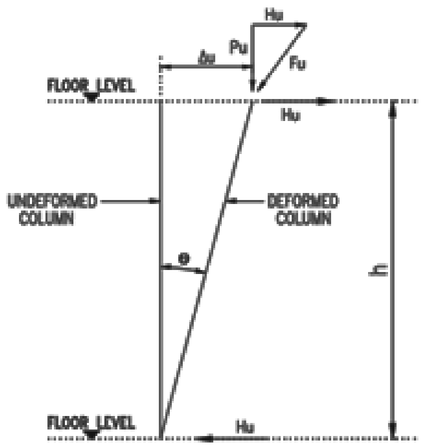
IS 13920 – 2016 also has a similar provision for Gravity Columns –

Its clause 11.2 states “When induced bending moments and shear forces under said lateral displacement combined with factored gravity bending moment and shear force exceed design moment and shear strength of the frame, 11.2.1 and 11.2.2 shall be satisfied”.

The principle behind this, as per commentary on Cl. 18.14.3.3 of ACI-14, is that with ductile detailed reinforcement the Gravity column will yield under äu but will continue to sustain the gravity loads as expected.

Figure 1 shows a Gravity column which is designed only for gravity loads and so in the lateral load analysis it may be considered as hinged at its top and bottom floor levels by giving moment releases to it at such joints (or by giving it a very low value of moment of inertia). As a Gravity column the column will be designed for the resulting vertical loads plus moments/shears from gravity load analysis plus those due requirement of minimum eccentricity and slenderness as per code.

Such column under lateral loads will develop plastic hinges at top and bottom but still will be able to sustain displacements äu without failure provided its reinforcement is as per ductile detailing requirements of code. It will be able to sustain the gravity load as per equilibrium of forces shown in figure 1.



$Fu = Pu/\cos\theta$, $Hu = Pu \tan\theta = Pu \,.\, \Delta u/h$

Hu transferred to lateral load resisting frames/walls by floor diaphragm.

Table 9, v) Note 4 of IS1893-2016: $\Delta/h \leq 0.001$ For Flat slab buildings

Hence: As per Cl. 11 IS 13920: $\Delta u/h \leq 0.003$ For R = 3

Gives $Hu \leq 0.3\%$ of Pu

Also then Increase in axial load in column from Pu to Fu is small.

From the force diagram in Fig. 1 it is seen that even after displacement äu, equilibrium is achieved with a nominally increased axial force in the column and small horizontal forces in the floors (forming a couple to resist moment due to äu) which will be transferred to lateral load resisting frames/walls by the floor diaphragms.

In a typical building with flat slab floors the lateral loads may be resisted by core walls and moment frames on the facades. The intermediate columns between central cores and facade which support the flat slabs could be designed as Gravity columns to resist only the vertical loads (plus any moments under gravity loads including those due to min. eccentricity, slenderness etc.). These columns should however be provided with links as per ductile detailing requirement of code.

Sizes and reinforcements in columns designed thus as Gravity columns can be smaller than if they were included in the 3-D frame to resist lateral loads. Reduction of sizes of such columns helps in increasing carpet area, facilitating parking and reduced cost. Hence, consultants can consider designing some columns as Gravity columns to get the benefits.

It is imperative that flat slabs supported on Gravity columns should be provided with shear reinforcement near the columns as per code to prevent shear failure under äu.

Floating Columns or Shear walls

In many multistoried buildings in metro cities, there are residential or commercial floors at upper levels while on the lower "podium" floors and basements there are open plazas, retails areas, parkings, driveways. Hence, it may not be possible to continue some of the columns or shear walls of upper floors through the lower floors to foundation and inevitably they have to be floated on transfer girders at a suitable floor level such as first residential floor. Otherwise planning the building with all structural columns/wall continuing to foundation may not be possible for the architects and then project may not be viable to satisfy especially the parking requirements.

As per clause 10.1.10 of IS-13920-2016 (please see snapshot below) Special Shear Walls cannot be discontinued to rest on transfer beams and columns. Special Shear Walls are walls with ductile detailing.

10.1.10 Special shear walls shall be founded on properly designed foundations and shall not be discontinued to rest on beams, columns or inclined members.

The above clause does not apply to Ordinary Shear Walls (which have no ductile detailing) and they could be floated on transfer beams. But then as per Cl. iv) Note 1 of Table 9 of IS1893 (part 1) – 2016 (Please see snapshot below) RC structures in Zones III, IV, V have to be designed with ductile detailing i.e. ordinary shear walls cannot be used in a building which is in Zone III and above.

iv) **Dual Systems** (*see* Note 3)

a)	Buildings with ordinary RC structural walls and RC OMRFs (*see* Note 1)	3.0
b)	Buildings with ordinary RC structural walls and RC SMRFs (*see* Note 1)	4.0
c)	Buildings with ductile RC structural walls with RC OMRFs (*see* Note 1)	4.0
d)	Buildings with ductile RC structural walls with RC SMRFs	5.0

NOTES

1 RC and steel structures in Seismic Zones III, IV and V shall be designed to be ductile. Hence, this system is not allowed in these seismic zones.

As per Cl. VI of Table 6 of IS1893-2016 (please see snapshot below) even floating columns which are part of lateral load resisting system are prohibited.

vi) **Floating or Stub Columns**
Such columns are likely to cause concentrated damage in the structure.

This feature is undesirable, and hence should be prohibited, if it is part of or supporting the primary lateral load resisting system.

From the above it seems that a designer cannot provide a floating (discontinuous) column or wall in a building which are part of lateral load resisting system.

However, Sr. no. iv) of Table 5 of IS1893:2016 seems to indeed permit out of plane offsets in column/walls resisting lateral loads (which means upper column/wall are floating) even in zones III, IV, V subject to lower permissible drift in the storey below.

ASCE7-16 does not have such stringent restrictions. Its clause 12.3.3.3 gives forces for which members supporting discontinuous walls or frames have to be designed. Figures C12.3-2, C12.3-4 and C12.3-5 in its commentary show such discontinuous walls. Cl. 12.3.3.3 requires the supporting members to be designed to resist the seismic effects including over strength factor of its Cl. 12.4.3. The over strength factor of ASCE is generally 2.5.

Thus, if a wall or column is discontinuous on a transfer girder then to comply with ASCE7 requirements the transfer girder should be designed for about 2.5 times the design EQ loads. EQ in vertical direction has to be added or subtracted to give the most critical results for, say, tensile steel at bottom and top of the RCC transfer girder.

It is does not seem that ASCE code requires the columns supporting the transfer girder and its framing beams to be designed with the over strength factor Ù all the way to the foundation. But this can be done to be on the conservative side.

IS 1893-2002 did have a clause 7.10.3 a) in which it permitted columns and beams of a soft storey to be designed for 2.5 times the shears and moments calculated under design seismic loads, besides other requirements. But this has been deleted in the latest IS1893-2016.

Thus, in the authors opinion if the transfer girder and other structure below a discontinuous wall/column are properly designed as per ASCE7-16 code then the structural consultant could permit few columns/wall to be floated in a building even if they are part of lateral load resisting system – notwithstanding the very stringent provision of IS code to the contrary which need to be reviewed and revised.

Conclusions

The authors' views as per the above discussion can be summarized as below:

1. Gravity columns could be used without designing them for bending moments/shears due to 'R' times the lateral displacements under the factored static design seismic loads required by Cl. 11 of IS 13920-16. But then they should be detailed for ductility as per code.

2.Floating columns should be avoided. But where they are unavoidable with small plots and parking requirements in cities like Mumbai, floating columns even if they are a part of lateral load resisting system, could be permitted. But then the transfer girders and columns supporting them should be designed for Omega times (about 2.5 times) the moments/shears under design EQ loads as per ASCE.

3.IS code committee may consider amendments in code provisions considering the above.

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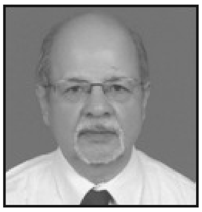

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