Review of Special confining links in column as per IS13920-2016 and ACI318-2014

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From the past earthquake records and observations, it has been seen that many column failures during earthquake occurred due to buckling of main bars near beam column junction as there was no adequate lateral restrain. Even during the structural audit and repair works, it has been observed that confining reinforcement has not been provided in the beam column junction of RCC frames. Either in the design or during construction, some how, the confining reinforcement is missing in the junctions of beam and column and near the joints. For anticipated ductile behaviour of framed structures, confining reinforcement plays very important role and can't be ignored. The diameter of confinement reinforcement, its spacing and detailing of joints must be paid special attention for improving performance of structure during earthquake. We need to create more awareness amongst structural engineers and site engineers regarding this important provision in the code.

For ductile design and detailing of reinforced concrete structures, calculations of special confining reinforcement as per clause 7.6 of IS13920:2016 is required.

A) Factors affecting quantum of confinement reinforcement : There are various parameters that affect the amount of confinement reinforcement as cited in reference 3 like -

1.**Ratio of concrete strength to tie strength fck/ fy** : With the increase in concrete strength, more confinement steel is required.

2. **Axial stress in concrete** : Other codes consider this parameter in calculating confining steel. IS code does not account for this effect in the equation for confining reinforcement. However, IS13920 clause 7.1 puts cap on maximum axial stress in column Pu/fck. B.d to 0.4. This may be to avoid crushing failure.

3. **Unconfined cover concrete thickness** : This is considered through Ag/Ak parameter where Ag is gross concrete area and Ak is area of confined concrete core.

4. **Longitudinal reinforcement and its spacing** – IS code does not account for this effect.

5. **Curvature ductility factor** – Amount of confining reinforcement in plastic hinge zone of columns has significant effect on curvature ductility as suggested by many researchers.

American code, New Zealand code, Canadian codes consider effect of axial stress in column and higher grade of concrete in calculation of confining reinforcement.

With some sample examples, comparison of confinement reinforcement in columns with IS13920:2016 and ACI318-2014 has been made.

Equating two equations given in IS code for confinement reinforcement Ash for rectangular links

Ash /(Sv. h) = 0.18 * fck/fy *(Ag/Ak -1) ..... Eq (1)

or Ash /(Sv. h)= 0.05 * fck/fy ..... Eq(2) whichever is higher

equating the equations, Ag/Ak >=1.27

It means second equation will govern the area of confinement links for large column sizes where ratio of Ag/Ak<1.27

As the ratio of Ag/Ak is more than 1.27, it indicates effective core concrete area is less and column will not be efficient to resist the load after loss of cover concrete. Thus, the area of link is more for higher ratio of Ag/Ak.

IS code defines Ash as cross section of bar forming link where as ACI code defines volumetric ratio of area of links along each face of column considering concrete core dimension and spacing of links.

ACI : Ash / (s. Bc) = 0.3 * (f'c/fyt) (Ag/Ac -1) or 0.09 (f'c/fyt) whichever is higher.

Writing the equations in IS code on similar lines of ACI code by replacing h by Bc

IS : Ash /(s. Bc) = 0.18 * fck/fy *(Ag/Ak -1) or 0.05 * fck/fy whichever is higher

Where f'c is cylindrical compressive strength and fck is cube compressive strength.

By substituting f'c = 0.8 * fck in the expression of ACI code the factor will be 0.3*0.8 = 0.24.

Thus , it can be seen that confinement steel as per ACI is around 33% more than that given in IS (0.24/ 0.18 = 1.33) if volumetric ratio is compared from the above equations.

ACI also considers effect of axial stress ratio or higher grade of concrete in calculation of confinement steel. If the axial stress ratio Pu/(Ag*f'c) > 0.3 or f'c>70 Mpa, area of hoops is further enhanced based on the number of longitudinal bars and concrete strength factor and given by expression Ash /(s. Bc) = 0.2*kf*kn*Pu/(fyt*Ach) . This is not considered in the present IS code.

B) Effect of Ag/Ak ratio for various column sizes :

It is interesting to see the effect of Ag/Ak ratio for different column shapes. Assuming clear cover to links as 40mm, it can be seen that for square columns of size more than 700mmx700mm, the ratio of Ag/Ak < 1.27, thus second equation of IS code governs the area of link bar. For column size less than 700x700mm, first equation governs. The trend of Ag/Ak for square columns can be seen from Fig 1.

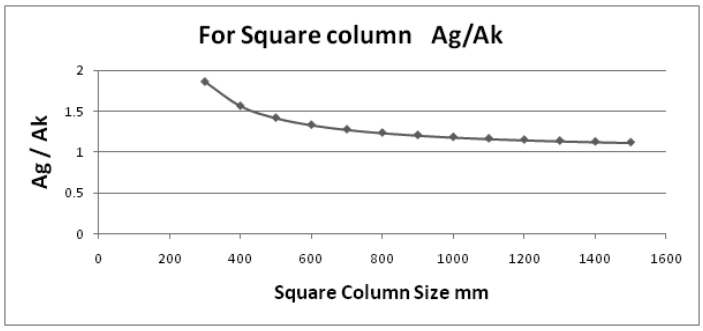

Fig 1 Variation of Ag/Ak for square columns

Considering minimum lateral dimension as 300mm as per latest code, variation of Ag/Ak can be seen for walls of 300mm thickness and 400mm thickness from Fig2. It can be seen from the figure that the ratio does not go below 1.27 though it reduces as the wall length is increased. Since the ratio of Ag/ Ak does not fall below 1.27, equation 1 as given in IS13920 will always govern for confining reinforcement for all the walls.

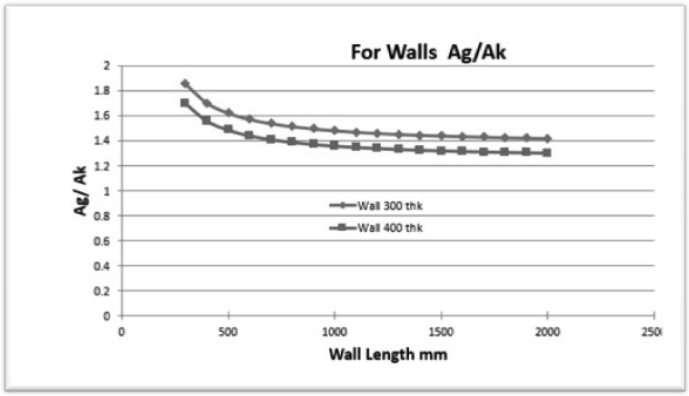

Fig 2 Variation of Ag/Ak for walls of 300mm thickness and 400mm thickness.

c) Sample calculations for confining reinforcement as per IS and ACI code for different columns

Case 1) Column of dimension 400mm x 1100mm

Consider following column details as shown in Fig3.

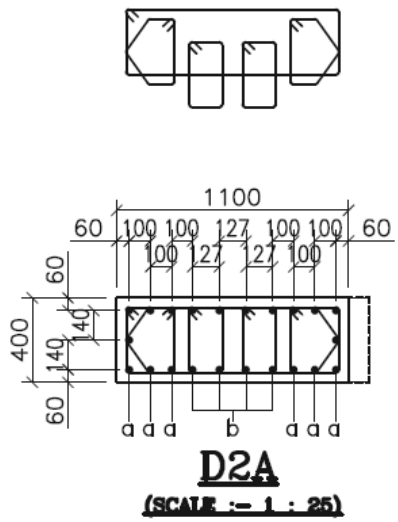

Fig 3 Rectangular column 400mm x1100mm

From consideration of ease of concreting, spacing of links should not be less than 100mm. Thus, considering spacing of links as 100mm. As per the equation given in code IS13920:2016 Clause 7.6

Ash area of bar forming link is given by higher of

Ash = 0.18 * Sv * h * fck/fy *(Ag/Ak -1)

Or = 0.05 *Sv * h * fck/fy

Considering M35 concrete, Fy=500 Mpa

Sv = 100mm minimum (considering ease of placing of concrete)

Ag = 400*1100=440000mm2

Ak= (400-2*40) * (1100-2*40) = 326400 mm2

Ag/Ak =440000/326400=1.348

IS Code mentions h as longer dimension of rectangular link but does not exceed 300mm which is a bit confusing. It should have been distance between the longitudinal bars which are tied by cross link as per ACI which sounds more rational.

In the above case, distance between longitudinal bars varies from 100mm to 140mm. Code should clarify on value of h to be considered in the calculations. If the main bar distances are variable for a given column bar arrangement, whether one should consider average of all the bar distances for calculations of h which is more logical.

h(average) = (2*140+3*127+6*100) /10 = 126mm

Value of Ash is influenced by value of h.

Ash = 0.18*100*h*35/500 * (1.34-1) = 0.43h

For different values of h, value of Ash is as below –

For 100mm Ash = 43.8mm2 (8mm link is Ok)

For 126mm Ash = 54mm2 (10mm link is required)

For 140mm, Ash = 61.3mm2 (10mm diameter of link is required)

For 200mm Ash=87.6mm2 (12mm link is required)

For 3000mm, Ash =131 mm2 (16mm diameter link is required.)

In short, we will not be able to use 8mm links any more in most of the cases.

Calculations checked with ACI318-2014 provisions –

As per Table 18.7.5.4

For rectangular hoop Rst = n * Ab /s. Bc = 0.3 (f'c/fyt) (Ag/Ac -1) or 0.09 (f'c/fyt) which ever is higher.

Where n = number of legs of hoop

Ab = area of one link bar

S = spacing of links

Bc = width of column perpendicular to link

f'c = cylindrical strength = 0.8*fck

Calculations to be performed along the width and length of column face and higher value is to be considered.

Considering calculations along the width =400 - 2*40 cover = 320mm = Bc

Number of effective legs of link in width n1 = 2 straight +0.7*2 inclined =3.4 nos

Considering link spacing of 100mm = S

Using above equation

3.4*Ab/(100*320) = 0.3* (0.8*35/500)(1.34-1)

Thus Ab = **53 mm2**, Thus 8mm link is just OK at 100mm spacing.

Considering calculations along the length Bc =1100+2*40= 1020

n2= 8 straight +2 inclined*.7=9.4

Using the same equation

9.4*Ab/(100*1020) = 0.3* (0.8*35/500)(1.34-1)

Thus Ab = **62 mm2.**

Higher value of 62 mm2 is to be considered. Thus, 10mm link is required at 100mm spacings.

Comparing volumetric ratio of links as per both codes -

Volumetric ratio as per ACI Ash/ S. Bc = 0.3 (f'c/ fyt) (Ag/Ac -1) =

= 0.3* (0.8*35/500)(1.348-1) = 0.005846

Volumetric ratio as per IS code Ash/S. Bc = 0.18 * fck/fy *(Ag/Ak -1)

= 0.18*35/500 * (1.348-1) = 0.00438

As per ACI318 , If the axial stress ratio Pu/Ag*f'c > 0.3 volumetirc ratio is governed by

Ash /(s. Bc) = 0.2*kf*kn*Pu/(fyt*Ach) which means , confining reinforcement is increasing with increasing axial stress ratio.

Plotting the values for the same column as given in Figure 4

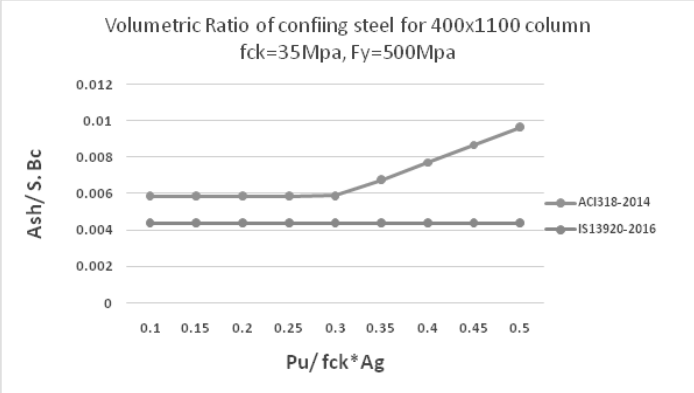

Fig 4 Volumetric ratio of confining steel v/s axial stress ratio in column

Case 2) For 600mm x 600mm column

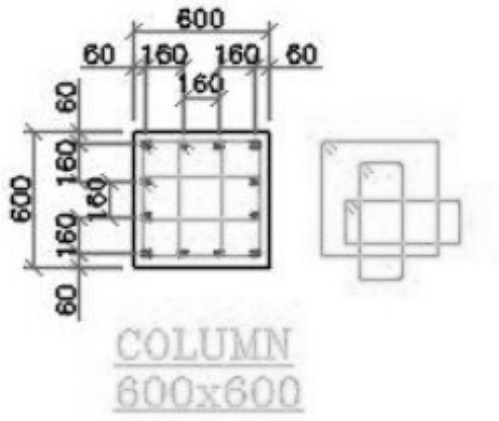

Fig 5 quare column of 600mm x600mm size

Main longitudinal bars 12 nos as shown in the arrangement. The link required can be calculated as

Ag = 600x600 = 360000 mm2

Ak = (600-80)*(600-80) =270400 mm2

Ag/Ak =360000/270400 =1.33

M35, Fe500, Sv=100mm, longer side of link h=160mm+20mm main bar +8 link*2 = 196mm

Area of link Ash = 0.18 * 100*196*35/500 (1.33-1) = 81.4mm2 (we need more than 10mm diameter as link)

If area of link is calculated considering volumetric ratio as per ACI Concept

h= average spacing of long bar in the width = (600-2*40) / 4 legs of link =130mm av

Area of link Ash= = 0.18 * 100*130*35/500 (1.33-1) = 55 mm2

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Considering calculations as per ACI318-2014 for 100mm spacing of links -

n=4

Bc = 600-2*40=520mm

Ag/Ac= 1.33

Using the equation for area of link -

n * Ab /s. Bc = 0.3 (f'c/fst) (Ag/Ac -1)

4*Ab/(100*520) = 0.3* (0.8*35/500)(1.33-1)

Thus , area of link required Ab= 72mm2

Case 2 A For 300x300mm column

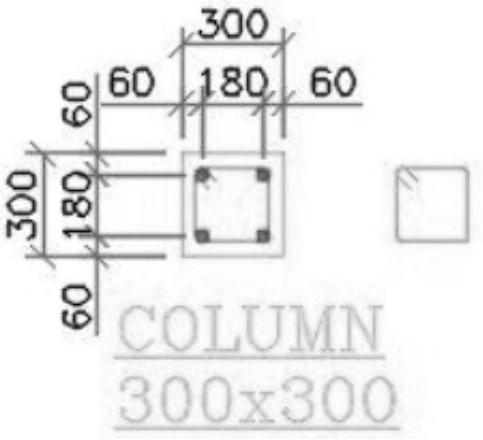

Fig 6 Square column 300mm x300mm

with 4 main bars of 25mm diameter, the link required can be calculated as

Ag = 300x300 = 90000 mm2

Ak = (300-80)*(300-80) =48400 mm2

Ag/Ak =90000/48400 =1.85

M35, Fe500, Sv=100mm, h=300-2*40cover = 220mm

Ash = 0.18 * 100*220*35/500 (1.85-1) = 235mm2 (we need more than 16mm diameter as link … which is not feasible to provide at site)

If the same calculations are done on volumetric ratio based on ACI concept, i.e. two legs of link in the width of 220mm, effective width of each link = 220/2 = 110mm and Ash=235/2= 120mm2 which sounds more rational.

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Considering calculations as per ACI318-2014 for 100mm spacing of links -

n=2

Bc = 300-2*40=220mm

Ag/Ac= 1.85

Using the equation for area of link -

n * Ab /s. Bc = 0.3 (f'c/fst) (Ag/Ac -1)

2*Ab/(100*220) = = 0.3* (0.8*35/500)(1.85-1)

Thus Ab= 157mm2

Case 3) For 600mm diameter circular column

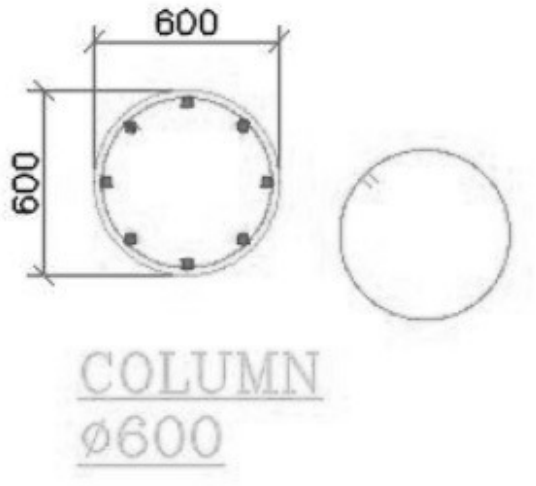

Fig 7 Circular column 600mm diameter

Fck =35 Mpa ; Fy=500 MPa ; Cover 40mm to link and pitch of spiral assumed as 100mm

Ag= 3.142/4 * 600^2 =282780mm2

Dk = 600-2*40 =520mm

Ac= 3.142/4 * (600-2*40)^2 = 212399mm2

Ag/Ac= 282780/212399 = 1.33

As per IS13920-2016

Ash= 0.09* s* Dk * fck /fy * (Ag/Ac -1)

= 0.09 * 100 * 520* 35/500 * (1.33-1) = 108mm2

As per ACI 318-2014

Rst = n*Ab/(S*Dk) = 0.45 *(f'c/fyt)(Ag/Ac -1)

n=4

S= 100mm spacing, Dk=520mm, f'c = 0.8Fck

4*Ab/(100*520) = 0.45* (0.8*35/500) (1.33-1)

Thus, area of hoop Ab =108 mm2 , same as that of IS code calculations.

D) Trends for confining reinforcement as per IS code equations

A graph for value of Ash for circular column can be plotted for various parameters like Fck =35 MPA, Fy= 500Mpa and considering pitch of spiral as 75mm. It can be seen from the graph that the direction of graph changes at 700mm diameter where Ag/Ak=1.27. Beyond 700mm diameter, Ash increases with the diameter of column. More than 10mm diameter hoop will be required.

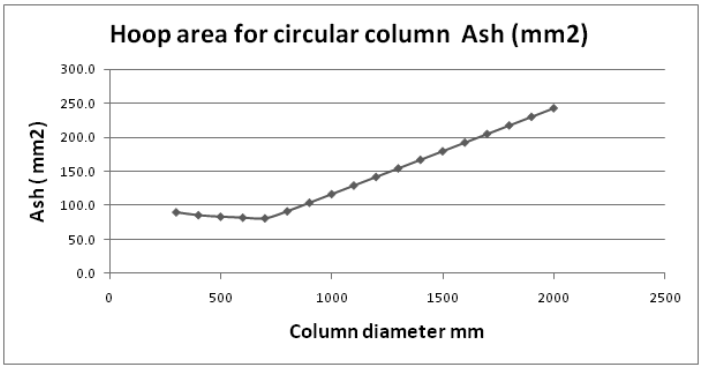

Fig 8 Hoop area for circular column with 75mm pitch, Fck= 35 MPa, Fy=500Mpa

Similarly, trend for confining reinforcement for square column can be plotted considering Fck =35 MPA, Fy= 500Mpa. Area of link Ash will be a function of h (which is the distance between the

longitudinal bars but less than 300mm). In IS code it is defined as longer dimension of rectangular link but does not exceed 300mm.

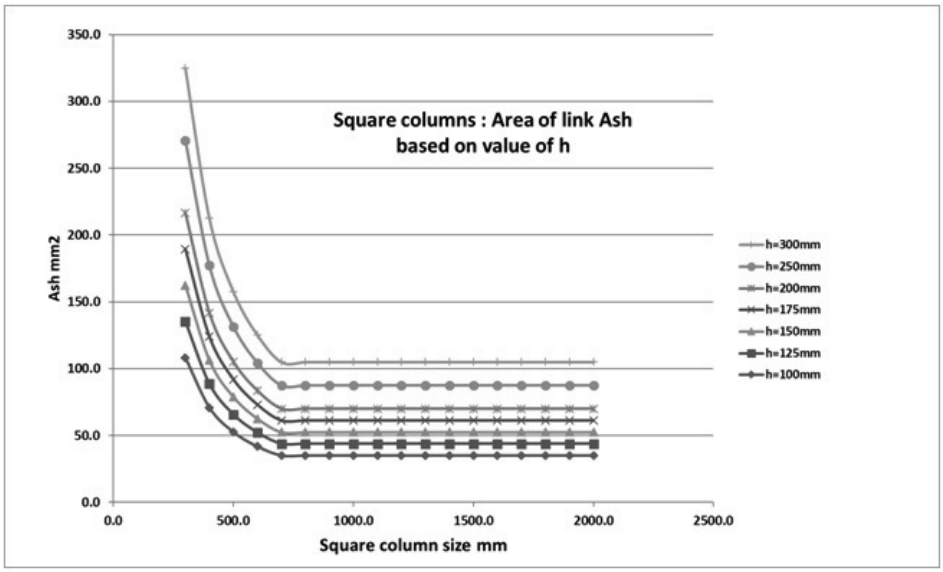

Fig 9 Area of link Ash for square columns with variable h for Fck=35Mpa , Fy=500Mpa, link spacing 100mm

Thus, from the graphs in Fig 9, it can be observed that for the main bar spacing up to 200mm, hoop of 10mm diameter will be required for column size above 600mm and 8mm hoop may be enough if the main bar spacing is less than 150mm.

Trend for confining reinforcement for columns / walls of 300mm thickness has been shown in Fig10 for various values of h (which is the distance between the longitudinal bars but less than 300mm) and for Fck=35Mpa , Fy=500Mpa

It can be seen from Fig10 that 8mm diameter link is not enough for walls. Minimum 10mm diameter link will be required if the spacing of main bars is restricted to 125mm. Higher diameter links will be required if spacing of main reinforcement is increased. Thus, to restrict the link diameter , it is necessary to keep spacing of main bars within 150mm.

For the same cross section area of column (concrete area 0.36m2) and same main steel (around 1.65%) , theoretical consumption of confining reinforcement is compared as per IS code considering various shapes of columns considering parameters like spacing of links as 100mm, cover 40mm, Fck=35Mpa , Fy=500MPa and h as centre to centre distance between main bars. The calculations are presented in Table1 . Similar comparison can be done for various column shapes and bar arrangements.

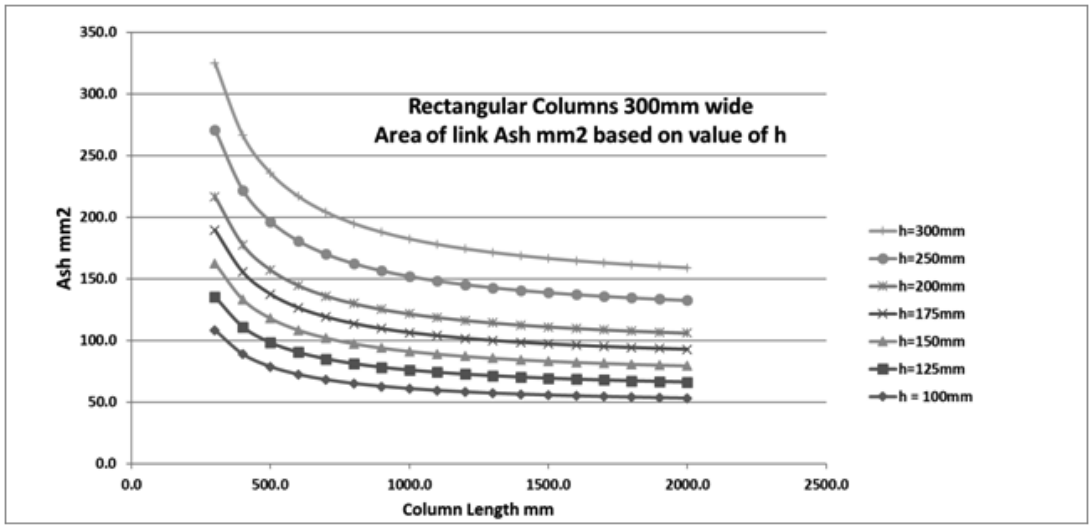

Fig 10 Area of link Ash for 300wide column / walls with varying h for Fck=35Mpa, Fy=500Mpa, spacing of links Sv=100m

Table 1 : Consumption of confining reinforcement in columns.

Sr.no	Column size	Main steel	Area of link Ash mm2	Length of links in m	Weight of links steel Kg / m3 of conc.
1	Circular 677mm diameter	12 nos Tor 25	108 mm2	1.82 m	**44 kg/m3**
2	Square column 600mmx600mm	12 nos Tor 25	67 mm2	5.33 m	**77 kg/m3**
3	Rectangular 300mm x1200mm Main bars on long side	20 nos Tor 20	70 mm2	5.67 m	**96 kg/m3**
4	Rectangular 300mm x1200mm Main bars on long side	12 nos Tor 25	156 mm2	4.77 m	**177 kg/m3**

Order of preference for column shape for having minimum weight of links will be circular, square, rectangular and walls with minimum spacing of main bars. Circular columns will require minimum weight of links and walls will have maximum.

Conclusions :

1. For rectangular and square columns, it is necessary to simplify the IS code equation of confining reinforcement on volumetric basis as given in ACI which leads to more rational calculations.
2. More clarity is required in the definition of h in IS 13920 for calculation of confining reinforcement. In practice, spacing between the main column bars is not constant. To avoid any confusion on longer side of link , h can be considered to be the average distance between the longitudinal column bars which are laterally tied.
3. For circular column, hoop diameter increases with diameter of column. Links of 10mm and higher diameters will be required.
4. In most of the building projects, 8mm diameter links are still being used for columns and walls which is not sufficient as per the code guidelines. We need to switch to 10mm diameter and higher bars for links as per the requirements. Link diameter is governed by spacing of main column bars.
5. For the same cross section of concrete and main steel, weight of links will be minimum for circular sections and will be maximum for walls.
6. It is necessary to create more awareness among structural engineers and site engineers to provide correct confinement reinforcement which will improve performance of our RCC structures.

References :

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4. Design of Reinforced concrete Structures – By N. Subramanian , Oxford university Press Published in 2013.

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