TITLE :		DESIGN OF Shear Wall with Boundary Element						
SUB -TITLE :		DESIGN OF WALL FOR FLEXURE AND SHEAR						
CODE OF PRACTICE :		IS 456-2000 + 13920-2016						
DESIGN TYPE :		LIMIT STATE DESIGN						
NOTE :- 1) User to Input data in cell marked as Blue.								
2) Design follows Limit State Method.								
User Input							**Reference / Comments**	
PARAMETERS :		RCDC	SYMBOL		INPUT	UNITS		
Wall					W7			
Level					4.2 m To 7.858 m			
Width of Wall		Wall B	B	=	250	mm	User Input	
Depth of Wall		Wall D	D	=	1,100	mm	User Input	
Grade of Concrete		Grade Of Concrete	fck	=	25	N/mm^2	User Input	
Grade of Steel (Main Steel)		Grade Of Steel	fy	=	415	N/mm^2	User Input	
Grade of Steel (Shear reinforcement)		Grade Of Steel	fyshear	=	415	N/mm^2	constant	
Cover to reinforcement		Clear Cover	Cc	=	50	mm	User Input	
Floor to floor height of the wall			hw	=	15,800	mm	User Input	
Beam depth along D (left side)			db1	=	800	mm	User Input	
Beam depth along D (Right side)			db2	=	800	mm	User Input	
Beam depth along B (left side)			bb1	=	800	mm	User Input	
Beam depth along B (right side)			bb2	=	800	mm	User Input	
Maximum % steel			ptmax	=	4.00	%	User Input	
Partial Factor of Safety for Material Concrete			γ_c	=	1.50	constant	User Input	
Partial Factor of Safety for Material Steel			γ_s	=	1.15	constant	User Input	
Wall Type		Wall Type		=	UnBraced		User Input	
Minimum eccentricity check		Minimum eccentricity check		=	One Axis at a Time		User Input	
Code defined D/B ratio		Code defined D/B ratio		=	4			
Effective Length Factor along Major Axis				=	0.93		User Input	
Effective Length Factor along Minor axis				=	0.75		User Input	
Minimum % reinforcement in wall (User defined)				=	0.25	%		
Spacing Round Factor for Links				=	25.00	mm		
Clear Floor Height @ B		Clear Floor Height @ B		=	15,000	mm	=H-(bb1,bb2)	
Clear Floor Height @ D		Clear Floor Height @ D		=	15,000	mm	=H-(db1,db2)	
Flexural Design (Analysis Forces)								
Critical Analysis Load Combination					19			
Load Combination				=	[9] : 1.5 (LOAD 1: LOAD CASE 1) -1.5 (LOAD 4: LOAD CASE 4 EQ-Y)			
Critical Location				=	Top Joint			
Axial force			Pu	=	603.09	kN	User Input	
Bending Moment along D			Mux	=	20.45	kNm	User Input	
Bending Moment along B			Muy	=	-9.66	kNm	User Input	
Shear force from Analysis along D			Vux	=	-207.97	kN	User Input	
Shear force from Analysis along B			Vuy	=	14.02	kN	User Input	
Load Combination for Boundary Element Length								
Load Combination Containing EQ where Axial Force is Maximum.								
Axial force			Pu	=	724.19	kN	User Input	
% reinforcement considered for BE length calculation				=	300.70	%		
Load Combination for Boundary Element Check								
Most Favouring Pu			Pu (Fav)	=	724.19	kN	User Input	
Bending Moment along D			Mux	=	300.70	kNm	User Input	
Most Un-favouring Pu			Pu (Un-fav)	=	147.69	kN	User Input	
Bending Moment along D			Mux	=	-259.66	kNm	User Input	

Shear Design (Analysis Forces)							
Along D							
Critical Analysis Load Combination				20			
Load Combination				[10] : 0.9 (LOAD 1: LOAD CASE 1) +1.5 (LOAD 3: LOAD CASE 3 EQ-X			
Shear force from Analysis along D		Vux	=	104.47	kN		
Axial force		Pu	=	680.86	kN		
Along B							
Critical Analysis Load Combination				23			
Load Combination				[13] : 0.9 (LOAD 1: LOAD CASE 1) -1.5 (LOAD 4: LOAD CASE 4 EQ-Y)			
Shear force from Analysis along B		Vux	=	228.84	kN		
Axial force		Pu	=	534.14	kN		
Reinforcement Provided in Wall							
Boundary Zone							
Diameter of longitudinal reinforcement		dia	=	16	mm	User Input	
Numbers of Rebars at Each End Zone		Nos	=	4	Nos	User Input	
No of Rebars Along B		Nos	=	2	Nos	User Input	
No of Rebars Along D		Nos	=	2	Nos	User Input	
Mid Zone							20-T16 + 8-T10
Diameter of longitudinal reinforcement		dia	=	8	mm	User Input	
Numbers of Rebars at Each End Zone		Nos	=	10	Nos	User Input	
Total area of Longitudinal reinforcement				2111.15	sqmm		
Shear Links							
Boundary zone Links							
Link Diameter			=	16	mm		
Link Spacing			=	100	mm		
Other Links							
Link Diameter			=	16	mm		
Link Spacing			=	175	mm		
No of Links			=	2	mm		
Step 1) Check Code Defined D/B Ratio							
D/B Ratio				4.4			
Check	D/B Ratio		=	Hence, Design as Wall			
Step 2) Check For Requirement Of Boundary Element							
Check For Maximum Compressive Stress Along Height of Wall							
Level where Maximum Stress exists				At level (4.2 m)			
Load Combination		[7] : 1.5 (LOAD 1: LOAD CASE 1) -1.5 (LOAD 3: LOAD CASE 3 EQ-X)					
Axial Force		Pu	=	724.19	kN		
Moment along Major Axis		Mx	=	300.70	kNm		
Area Of Concrete (BxD)		A	=	275000	sqmm		
Section Modulus (B x D^2/6)		Zxx	=	50416666.67	mm3		
Pu/A			=	2.633	N/mm^2		
Mx/Zxx			=	5.96	N/mm^2		
Maximum Stress (P/A +Mx/Zxx)			=	8.60	N/mm^2		
0.2 x Fck			=	5	N/mm^2		
Check For Maximum Compressive Stress				Maximum Stress in Wall > 0.2 x Fck			
Check For Maximum Compressive Stress at level Considered							
Load Combination		[7] : 1.5 (LOAD 1: LOAD CASE 1) -1.5 (LOAD 3: LOAD CASE 3 EQ-X)					
Axial Force		Pu	=	724.19	kN		
Moment along Major Axis		Mx	=	300.70	kNm		
Pu/A			=	2.63	N/mm^2		
Mx/Zx			=	5.96	N/mm^2		
Maximum Stress (P/A +Mx/Zxx)			=	8.60	N/mm^2		
0.15 x Fck			=	3.75	N/mm^2		
Check For Maximum Compressive Stress				Hence Boundary Element is applicable			

10 SPECIAL SHEAR WALLS

10.1 General Requirements

10.1.3 The minimum ratio of length of wall to its thickness shall be 4.

10.4 Boundary Elements

Boundary elements are portions along the wall edges that are strengthened by longitudinal and transverse reinforcement even if they have the same thickness as that of the wall web. It is advantageous to provide boundary elements with dimension greater than thickness of the wall web.

10.4.1 Boundary elements shall be provided along the vertical boundaries of walls, when the extreme fibre compressive stress in the wall exceeds $0.2 f_{ck}$ due to factored gravity loads plus factored earthquake force. Boundary elements may be discontinued at elevations where extreme fiber compressive stress becomes less than $0.15 f_{ck}$. Extreme fibre compressive stress shall be estimated using a linearly elastic model and gross section properties.

Step 2) Calculation of Boundary Element Length			
Load Combination	1.2 (LOAD 1: LOAD CASE 1) +1.2 (LOAD 2: LOAD CASE 2) +1.2 (LOAD 4: LOAD CASE 4 EQ-Y)		
Axial force	Pu	2566.22	kN
Ast for for BE length calculation (0.8% assumed)	pt	826925	sqmm
Maximum Possible Axial Force in the wall	Po	0.8 x (0.85 x Fck x Ac + Fy x Ast)	
		265156.375	kN
Ratio of Design axial force / Maximum axial force Permissible	Pu/Po	0.010	
Ratio for Boundary		0.150	
Boundary Element Length at Each End	BE Length	200	mm

Ductile Wall design

Boundary elements are provided for ductile walls as per IS 13920. Zoning of reinforcement is done around the boundary element. The initial length of the boundary element is arrived at as per following procedure:

i. Value Po is calculated Po = 0.8 x (0.85 x Fck x Ac + Fy x Ast)

ii. The largest axial force Pu in earthquake combination is determined

iii. Length of boundary element is determined based on the above two values as

a. If Pu< 0.15 x Po then length of the boundary element = 0.15 x Lw.

b. If Pu> 0.35 x Po then length of the boundary element = 0.25 x Lw.

c. If 0.15 x Po <Pu< 0.35 x Po the interpolate between 0.15 to 0.25 Lw .

The above is based on a few international papers and recommendations in the ACI code.

Reference has also been made to an IIT-Kanpur publication IITK-GSDMA-EQ22-V3.03, example 9.

Step 4) Effective Length Calculation		
Effective Length Factor along Major Axis	0.93	
Effective Length Factor along Minor axis	0.75	
Step 5) Minimum Eccentricity Check		
Check	Since Axial Force is compressive, Min. Eccentricity check to be performed	
Most critical case is with Min. Eccentricity	Y-direction	
Actual Eccentricity Along D :	-	
	0	mm
	Max (Actual Eccentricity,20)	
Minimum Eccentricity Along D :	0.00	mm
Mminx	-	
	0.00	kNm
Actual Eccentricity Along B :	Clear Floor Height @ B / 500 + B / 30	
	38.33	mm
Minimum Eccentricity Along B :	Max (Actual Eccentricity,20)	
	38.33	mm
Mminy	Pu x Minimum Eccentricity	
	23.12	kNm

25.4 Minimum Eccentricity

All columns shall be designed for minimum eccentricity, equal to the unsupported length of column/ 500 plus lateral dimensions/30, subject to a minimum of 20 mm. Where bi-axial bending is considered, it is sufficient to ensure that eccentricity exceeds the minimum about one axis at a time.

25.3 Slenderness Limits for Columns

25.3.1 The unsupported length between end restraints shall not exceed 60 times the least lateral dimension of a column.

Step 5) Slenderness Check

Max Slenderness Ratio(Clear Floor Height @ B/B)			15000/250		
			60.00		
Check			<= 60, Hence OK		
Column Is Unbraced Along D					
Slenderness Check Along D:					
Effective Length Factor along Major Axis			0.93		
Effective Length (Unsupported Length x Effective Length Factor)			15000X0.93		
			13950.00	mm	
Slenderness Ratio			Effective Length / D		
			12.68		
			Wall Slender Along D		
Slenderness moment along D			(Pu D/ 2000) (Ley/D)^2		
			53.35	kNm	
Calculation of Slenderness Moment	Pu	=	603.09	kN	
	Pd	=	1558.89	kN	User Input
	Puz	=	3727.10	kN	
Reduction factor 'k' for slenderness moment			(Puz - Pu) / (Puz - Pd) < = 1		
			1.44		
	k		1.00		
Slenderness Moment along D	MsIndx		53.35	kNm	
Column Is Unbraced Along B					
Slenderness Check Along B:					
Effective Length Factor along Major Axis			0.75		
Effective Length (Unsupported Length x Effective Length Factor)			15000X0.75		
			11250.00	mm	
Slenderness Ratio			Effective Length / B		
			45.00		
			Wall Slender Along B		
Slenderness moment along B			(Pu D/ 2000) (Ley/D)^2		
			152.66	kNm	
Calculation of Slenderness Moment	Pu	=	603.09	kN	
	Pb	=	1194.05	kN	
	Puz	=	3727.10	kN	
Reduction factor 'k' for slenderness moment			(Puz - Pu) / (Puz - Pd) < = 1		
			1.23		
	k		1.00		
Slenderness Moment along B	MsIndy		152.66	kNm	

Calculation of Design Moment

Direction	Manalysis	Mmin (Abs)	Mdesign	MsIndx (Abs)	Mdesign-final
	A	B	C	E	F
Major Axis - Mux	20.45	0.00	20.45	53.35	73.80
Minor Axis - Muy	-9.66	23.12	-23.12	152.66	-175.78

Where

A	=	Moments directly from analysis
B	=	Moments due to minimum eccentricity
C	=	Maximum of analysis moment and min. eccentricity = Max (A,B)
E	=	Moment due to slenderness effect
F	=	Final design Moment = Max(C- Top Bottom , D- Top Bottom) + E

25.1.2 ***Short and Slender Compression Members***

A compression member may be considered as short when both the slenderness ratios $\frac{l_{ex}}{D}$ and $\frac{l_{ey}}{b}$ are less than 12:

39.7.1 The additional moments M_{ax} and M_{ay} shall be calculated by the following formulae:

$$M_{ax} = \frac{P_u D}{2\,000}\left\{\frac{l_{ex}}{D}\right\}^2$$

$$M_{ay} = \frac{P_u b}{2\,000}\left\{\frac{l_{ey}}{b}\right\}^2$$

where

P_u = axial load on the member,

l_{ex} = effective length in respect of the major axis,

l_{ey} = effective length in respect of the minor axis,

D = depth of the cross-section at right angles to the major axis, and

b = width of the member.

39.7.1.1 The values given by equation **39.7.1** may be multiplied by the following factor:

$$k = \frac{P_{uz} - P_u}{P_{uz} - P_b} \leq 1$$

$$P_{uz} = 0.45 f_{ck} \cdot A_c + 0.75 f_y \cdot A_{sc}$$

10.3 Design for Axial Force and Bending Moment

10.3.1 Design moment of resistance M_u of the wall section subjected to combined bending moment and compressive axial load shall be estimated in accordance with requirements of limit state design method given in IS 456, using the principles of mechanics involving equilibrium equations, strain compatibility conditions and constitutive laws.

The moment of resistance of slender rectangular structural wall section with uniformly distributed vertical reinforcement may be estimated using expressions given in Annex A. Expressions given in Annex A are not applicable for structural walls with boundary elements.

Final Critical Design Forces						
Pu	=	603.09	kN			
Mux	=	73.80	kNm			
Muy	=	-175.78	kNm			
Minimum % steel						
User defined pt min1				=	0.25	
Vertical reinforcement as per type of wall						
Floor to Floor height of wall			hw	=	15800	mm
Depth of Wall			Lw = D	=	1100	mm
hw/Lw			hw/Lw	=	14.36	
Type of wall					hw/Lw > 2 Hence, Slender wall	
Width of Wall			tw = B	=	250	mm
Minimum % of Horizontal Reinforcement			Ph	=	0.0025	
Minimum % of Web Reinforcement			Pvweb	=	0.0025	
Ptv min2			Ptv min2	=	0.005625	%
Ptmin			Ptmin	=	Max(Pvweb,Ptv min2)	
				=	0.005625	
				=	0.5625	%
Resultant Moment (Combined Action)						
Moment Capacity Check						
Pt Calculated				=	0.77	
Reinforcement Provided				=	8-T16 + 10-T8	
Load Angle				=	Tan^{-1}(Muy/Mux)	
				=	-67.23	deg
MRes				=	190.64	kNm
MCap				=	222.9	kNm
Capacity Ratio				=	MRes/ MCap	
				=	0.86	
Check					0.86<=1	
Check For Boundary Element						
Calculation of vertical reinforcement in BE zone						
Area Of Concrete (BxD)			A	=	275000	sqmm
Section Modulus (B x D^2/6)			Z	=	50416666.67	mm3
Maximum Compressive Force in BE						
Most Favouring Pu			P (Fav)		724.19	kN
Bending Moment along D			M		300.70	kNm
P/A			P/A	=	2.63	N/mm^2
M/Z			M/Z	=	5.96	N/mm^2
Depth of Wall			Lw = D	=	1100	mm
Stress Slope,S1				=	((P/A + M/Z) - (P/A - M/Z)) / Lw	
				=	10.84	N/mm^2
Stress - 1				=	(P/A + M/Z) - S1 X (BE length) / 2	
				=	7.51	N/mm^2
Stress - 2				=	(P/A - M/Z) + S1 X (BE length) / 2	
				=	-2.25	N/mm^2
Maximum compressive force				=	Maximum (Stress-1, Stress-2) x BE length	
				=	375.66	kN
Pt required			pt1	=	0	%

39.6 Members Subjected to Combined Axial Load and Biaxial Bending

The resistance of a member subjected to axial force and biaxial bending shall be obtained on the basis of assumptions given in **39.1** and **39.2** with neutral axis so chosen as to satisfy the equilibrium of load and moments about two axes. Alternatively such members may be designed by the following equation:

10.1.4 Special shear walls shall be classified as squat, intermediate or slender depending on the overall height h_w to length L_w ratio as

a) Squat walls: $h_w / L_w < 1$,

b) Intermediate walls: $1 \le h_w / L_w \le 2$, and

c) Slender walls: $h_w / L_w > 2$.

Table 1 Minimum Reinforcement in RC Shear Walls

(*Clause* 10.1.6)

Sl. No.	Type of Wall	Reinforcement Details
i)	Squat walls	$(\rho_h)_{min} = 0.002\,5$ $(\rho_v)_{min} = 0.002\,5 + 0.5\left(1 - \frac{h_w}{t_w}\right)(\rho_h - 0.002\,5)$ $(\rho_{v,net}) = (\rho_{v,web}) + \left(\frac{t_w}{L_w}\right).[0.02 - 2.5(\rho_{v,web})]$ $(\rho_v)_{provided} < (\rho_h)_{provided}$
ii)	Intermediate walls	$(\rho_h)_{min} = 0.002\,5$ $(\rho_{v,be})_{min} = 0.008\,0$ $(\rho_{v,web})_{min} = 0.002\,5$ $(\rho_{v,net})_{min} = 0.002\,5 + 0.013\,75\left(\frac{t_w}{L_w}\right)$.
iii)	Slender walls	$(\rho_v)_{min} = 0.002\,5 + 0.5\left(\frac{h_w}{L_w} - 2\right)(\rho_h - 0.002\,5)$ $(\rho_{v,be})_{min} = 0.008\,0$ $(\rho_{v,web})_{min} = 0.002\,5$ $(\rho_{v,net})_{min} = 0.002\,5 + 0.013\,75\left(\frac{t_w}{L_w}\right)$.

Maximum Tensile Force in BE					
Most Un-Favouring Pu	Pu (Un-Fav)		147.69	kN	
Bending Moment along D	Mux		-259.66	kNm	
Pu/A	Pu/A	=	0.54	N/mm^2	
Mx/Zx	M/Z	=	-5.15	N/mm^2	
Stress Slope,S1		=	((P/A + M/Z) - (P/A - M/Z)) / Lw		
		=	-9.36	N/mm^2	
Stress - 1		=	(P/A + M/Z) - S1 X (BE length) / 2		
		=	-3.68	N/mm^2	
Stress - 2		=	(P/A - M/Z) + S1 X (BE length) / 2		
		=	4.75	N/mm^2	
Maximum compressive force		=	Minimum (Stress-1, Stress-2) x BE length		
		=	-183.84	kN	
Pt required	pt2	=	1.02	%	
Design pt in BE					
Minimum pt		=	0.8	% (Constant)	Clause 10.4.3 (IS 13920-2016)
Pt required in BE		=	=Maximum (0.8, pt1, pt2)		
		=	1.02	%	
Check For Compression Capacity Of BE					
PT provided in BE		=	1.61	%	
Ast provided in BE	Ast	=	804.25	sqmm	
Capacity of BE in compression		=	0.4 x Fck x Aconcrete + 0.67 x Fy x Ast		
		=	715.58	kN	
			715.58 > 375.66		
			715.58 Hence OK		
Check For Tension Capacity Of BE					
PT provided in BE		=	1.61	%	
Ast provided in BE	Ast	=	804.25	sqmm	
Capacity of BE in Tension		=	0.87 x Ast X Fy		
		=	290.37	kN	

10.4.2 A boundary element shall have adequate axial load carrying capacity, assuming short column action, so as to enable it to carry axial compression arising from factored gravity load and lateral seismic shaking effects.

10.4.2.1 The load factor for gravity load shall be taken as 0.8, if gravity load gives higher axial compressive strength of the boundary element.

10.4.3 The vertical reinforcement in the boundary elements shall not be less than 0.8 percent and not greater than 6 percent; the practical upper limit would be 4 percent to avoid congestion.

Wall Configuration

	Boundary Element	Mid	Boundary Element
Length (mm)	200	700	200
Reinforcement	4-T16	10-T8	4-T16
Ast provided	804.25	502.65	804.25
Pt as % of entire wall	0.29%	0.18%	0.29%
Pt as % of zone	1.61%	0.29%	1.61%

Shear Design (Analysis Forces)				
Design for shear along D				
Critical Analysis Load Combination		:	20	
Critical Load Combination	[10] : 0.9 (LOAD 1: LOAD CASE 1) +1.5 (LOAD 3: LOAD CASE 3 EQ			
Design shear force	Vuy	=	104.47	kN
Axial Force	Pu	=	680.86	kN
Shear Stress	Tvy	=	Vuy / (0.8 x B X D))	
		=	0.4749	N/mm^2
Pt (20% of vertical reinforcement)		=	0.154	%
Beta		=	18.906	
Design shear strength,	Tc	=	0.2940	N/mm^2
Shear Strength Enhancement Factor		=	1 + 3 x Pu / (B x D x Fck)	
		=	1.2971	
Shear Strength Enhancement Factor (max)		=	1.50	
Shear Strength Enhancement Factor		=	1.2971	
Enhanced shear strength (Tc x Enhancement Factor)	Tc-e	=	0.381	N/mm^2
Design shear check		=	Tvy > Tc x Enhancement factor	
			Shear Reinforcement required along D	

10.2 Design for Shear Force

10.2.1 Nominal shear stress demand τ_v on a wall shall be estimated as:

$$\tau_v = \frac{V_u}{t_w d_w},$$

where V_u is factored shear force, t_w thickness of the web, and d_w effective depth of wall section (along the length of the wall), which may be taken as 0.8 L_w for rectangular sections.

39.2 Design Shear Strength of Concrete

SP 24

$$\tau_c = \frac{0.85\sqrt{0.8 f_{ck}}\,(\sqrt{1.+5\beta}-1)}{6\beta}$$

where $\beta = 0.8\, f_{ck}/6.89\, p_t$, but not less than 1, and

$$P_t = \frac{100\, A_s}{b_w d}$$

Links for shear design along D				
Pt (20% of vertical reinforcement)		=	0.154	%
Effective Depth	Deff	=	880	mm
Shear resisted by concrete along D	VcD	=	83.90	kN
Shear to be resisted by shear reinforcement along D	VusD	=	20.57	kN
Area of shear reinforcement required,	Asv-d	=	64.78	sqmm
Master Link Rebar		=	16	mm
Number of legs provided		=	2	mm
Spacing of links prvd, Sv		=	175	mm
Asv Provided		=	2297.85	sqmm
Design for shear along B				
Critical Analysis Load Combination		:	23	
Critical Load Combination	[13] : 0.9 (LOAD 1: LOAD CASE 1) -1.5 (LOAD 4: LOAD CASE 4 EQ-Y)			
Design shear force	Vux	=	228.84	kN
Axial Force	Pu	=	534.14	kN
Shear Stress	Tvx	=	Vux / (0.8 x B X D))	
		=	1.0402	N/mm^2
Pt (20% of vertical reinforcement)		=	0.154	%
Beta		=	18.906	
Design shear strength,	Tc	=	0.2940	N/mm^2
Shear Strength Enhancement Factor		=	1 + 3 x Pu / (B x D x Fck)	
		=	1.2331	
Shear Strength Enhancement Factor (max)		=	1.50	
Shear Strength Enhancement Factor		=	1.2331	
Enhanced shear strength (Tc x Enhancement Factor)	Tc-e	=	0.363	N/mm^2
Design shear check		=	Tvy > Tc x Enhancement factor	
			Shear Reinforcement required along B	
Links for shear design along B				
Pt (20% of vertical reinforcement)		=	0.154	%
Effective Depth	Beff	=	192	mm
Shear resisted by concrete along B	VcD	=	76.57	kN
Shear to be resisted by shear reinforcement along B	VusD	=	152.27	kN
Area of shear reinforcement required,	Asv-d	=	2197.70	sqmm
Master Link Rebar		=	16	mm
Number of legs provided		=	2	mm
Spacing of links prvd, Sv		=	175	mm
Asv Provided		=	2297.85	sqmm

40.2.2 ***Shear Strength of Members under Axial Compression***

For members subjected to axial compression P_u, the design shear strength of concrete, given in Table 19, shall be multiplied by the following factor :

$$\delta = 1 + \frac{3P_u}{A_g f_{ck}} \text{ but not exceeding 1.5}$$

where

P_u = **axial compressive force in Newtons,**

A_g = **gross area of the concrete section in mm², and**

f_{ck} = **characteristic compressive strength of concrete.**

Design Of Links					
Main Links					
Links in the zone where special confining links are not required					
Normal Links					
Horizontal reinforcement as per type of wall					
hw			=	15,800	mm
Lw			=	1,100	mm
hw/Lw			=	14.36	
Type of wall				hw/Lw > 2 Hence, Slender wall	
tw			=	250	mm
Ph			=	0.0025	
Pvweb			=	0.0025	
Ptv min			=	0.5625	%
Area of Horizontal Links				625	sqmm
Diameter of main horizontal steel			=	16	mm
Spacing Required for Links				175	mm
Thus, Spacing			=	175	mm
Spacing of horizontal reinforcement is minimum of following					
D / 5			=	220	mm
3 x B			=	750	mm
Maximum			=	450	mm
Spacing considered			=	175	mm
Special confining reinforcement as per IS 13920 - 2016					
Min. Lateral dimension of column, B			=	250	mm
B/3			=	83.33	mm
6 X Smallest Longitudinal Bar Dia			=	48	mm
Spacing			=	150	mm
Hence Link spacing, Sv			=	100	mm
Hoop dimension, h				(B - 2 x Cover + 2 x Link Dia) / (No of Rebars Along B -1)	
Along B			=	182.00	mm
Along D				(BE Zone - Cover + Link Dia + Main Rebar Dia / 2 + Link Dia) / (No of Rebars Along D -1)	
			=	190.00	mm
		Max (Along B, Along D)		190.00	mm
Area of special confining link, Ash			=	0.05 x Sv x h x (Fck/Fy)	
			=	57.229	sqmm
Diameter of special confining link			=	16	mm
			=	Max. longitudinal bar dia / 4	
			=	4	mm
Area of horizontal steel provided				Area of bar provided x 1000 x 2 / spacing	
			=	4021.24	(sqmm)/ m height
			=	1.6085	
				> min. steel required 0.25%	
Special confining links to be provided along full height in BE.					
Table For Links					
Note: Ductile Design Of Links Is Applicable Only For Boundary Elements					

	Required			Provided	
	Normal Design	Shear Design	Ductile Design	Normal Zone	Ductile Zone
Link Dia.	16	---	16	16	16
Spacing	175	---	100	175	100

Secondary Links:	
In Boundary element	T8@100c/c
In Mid-zone	T8@125c/c

10.1.8 The largest diameter of longitudinal steel bars used in any part of a wall shall not exceed 1/10th of the thickness of that part.

10.1.9 The maximum spacing of vertical or horizontal reinforcement shall not exceed smaller of;

a) 1/5th horizontal length L_w of wall;
b) 3 times thickness t_w of web of wall; and
c) 450 mm.

10.4.4 Boundary elements, where required as per **10.4.1**, shall be provided with special confining reinforcement throughout their height, given by

$$A_{sh} = 0.05\ s_v\ h\ \frac{f_{ck}}{f_y}$$

and have a spacing not more than,

a) 1/3 of minimum member dimension of the boundary element;
b) 6 times diameter of the smallest longitudinal reinforcement bars; and
c) 100 mm but may be relaxed to 150 mm, if maximum distance between cross-ties/parallel legs of links or ties is limited to 200 mm,

but need not be less than 100 mm.