TITLE :	DESIGN OF COLUMN
SUB -TITLE :	DESIGN OF COLUMN FOR CRACK WIDTH WITH AXIAL FORCE AND BIAXIAL MOMENTS
CODE OF PRACTICE :	IS 456:2000

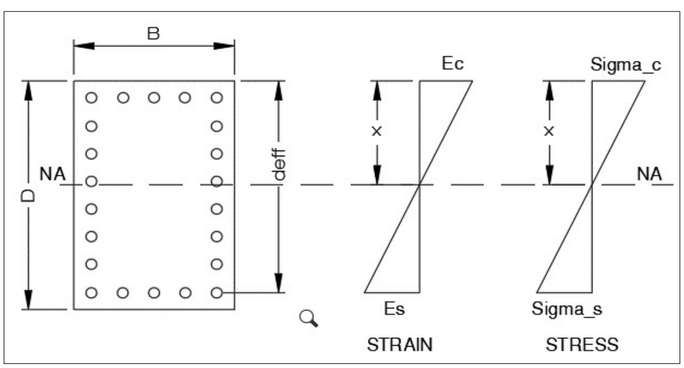
User Input

Column Number	=	**C1**	
Width of Column, B	=	**600**	mm
Depth of column,D	=	**900**	mm
Grade Of Steel,Fy	=	**500**	N/sqmm
Grade of Concrete,Fck	=	**50**	N/sqmm
Clerar Cover,Cc	=	**50**	mm

Final Critical Design Forces

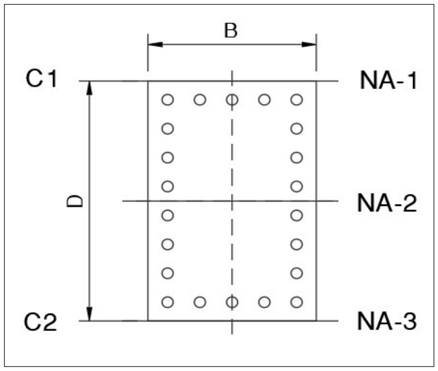
Axial force,Pu	=	**1000**	kN
Moment about X axis,Mux	=	**-900.12**	kNm
Moment about Y axis,Muy	=	**50.007**	kNm
Reinforcement Provided	=	**22-T32**	
Pt Calculated	=	**3.28**	%
No of rebars along D	=	**8**	Nos
No of rebars along B (Including corner bebars)	=	**5**	Nos
Corner Reinforcement - Dia	=	**32**	mm
Permissible Crack width	=	**0.2**	mm
Elastic Modulus of steel	=	**200000**	
Critical location	=	**'op Joint**	
Area of corner reinforcement,Ast	=	PI()/4x32^2	
	=	804.25	sqmm
Cover to centre of rebar	=	50+32/2	
	=	66	mm
c/c distance between rebars along Width	=	(600-66x2) /(5-1)	
	=	117.00	mm
c/c distance between rebars along Depth	=	(900-66x2) /(8-1)	
	=	109.71	mm
Effective depth of the section, deff	=	900-66	
	=	834.00	mm
Resultant Moment,Mud-x	=	SQRT(-900.1209^2 + 50.0067^2)	
	=	901.51	kNm

Stress Strain Diagram:



Maximum Permissble compressive stress in cor	=	50/3		Table 21 (IS 456-2000)
		16.67	N/sqmm	
Maximum Permissble tension stress in Steel	=	00x 0.55		Table 22 (IS 456-2000)
	=	275.00	N/sqmm	

Above is the stress-strain diagram used for computation of crack width.



The neutral axis location is calculated iteratively, based on the principles of equilibrium as below –

1. For the final position of the neutral axis, the sum of axial forces of the section is equal to the applied axial force,
   Fc (concrete) + Fc (Steel) + Ft (Steel) = P
2. For the final position of the neutral axis, the sum of moments about the neutral axis is equal to the moment of the applied force about the neutral axis,
   Mc (concrete) + Mc (Steel) + Mt (Steel) = P * N

Computing Procedure:

The software works on an iterative algorithm, which calculates the equilibrium position of the neutral axis and establishes the force equilibrium. While performing calculations, stress is assumed to vary linearly from C1 to C2
For the NA-1 condition, stress at C1 is tensile and minimum. For the NA-2 condition, stress at C1 is compressive and maximum
The following are the principles for the calculation of section forces –

1. M = Modular Ratio = 280 / (3 x σcbc)
   where,
   σcbc = Permissible compressive stress due to bending in concrete in N/sqmm
   = 16.67 N/sqmm Table-21 (IS 456-2000)
2. Ec = Elastic modulus of concrete = 5000 x Sqrt (fck)
3. The concrete in tension is neglected.
4. The stress in bars in compression = M * Ec * Equivalent stress in concrete at that location
5. The stresses in individual bars of reinforcement are calculated as per their actual location and their perpendicular distance from the neutral axis

There are three possible locations of NA -

1. NA-1 = Neutral axis is beyond the section - Column is in tension
2. NA-2 = Neutral axis is within the section - Column is in partial tension
3. NA-3 = Neutral axis is below the section - Column is in compression

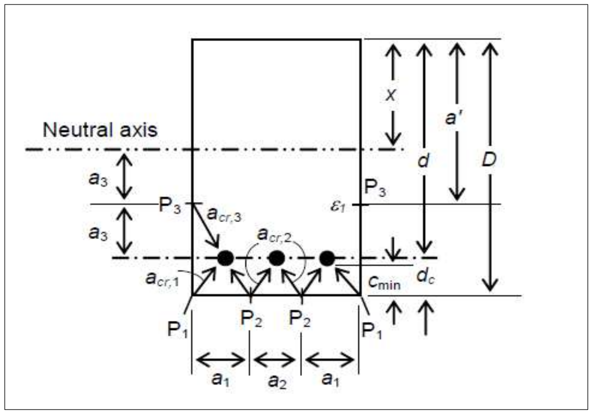
From the above conditions, it is clear that for NA-3, the section is uncracked. For NA-1 and NA-2, the following checks are performed before calculating crack-width –

1. Stress at corner/level C1 = Maximum compressive stress = This should be less than permissible
2. Stress in corner bar near C2 = Maximum tensile stress in reinforcement = This should be less than permissible

After finding the NA position, and confirming that stresses at C1 and for a bar near C2 are within the permissible limit, the following calculations are performed for calculating crack width and defining the adequacy –

1. Epsilon (strain) at C2 is calculated from NA position and stress at C2
2. Crack-width is calculated as = Wcr = 2.3 * Acr * Epsilon at C2
3. Crack-width check at C2 = This should be less than the permissible value of crack-width.

The formula in step 2 above is available in the technical paper
"crackwidth calculation for column subjected to Biaxial Bending_R. Gong and S. Cao".
Example showing calculation of Acr



As the above process is iterative, For the Validation of this example, section capacity is calculated for a given column size and reinforcement arrangement and section capacity is calculated as per the available stress in the concrete and reinforcement.
Based on the available stress in concrete and steel, we can check the section capacity and match with the design forces.
If the capacity and the design forces are same, then it can be considered that the stresses calculated in the concrete and steel are correct.

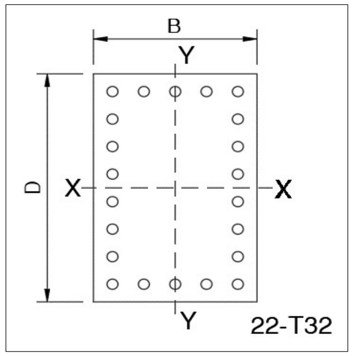
Crack width Design calculation report from RCDC,

Crack Width Check as per IS 456 + IS 13920 - 2016

Location	Bottom	Top
Critical Load Combination	10001	10001
Member Force		
P (kN)	1000.3998	1000.3998
Mx (kNm)	900.1209	900.1209
My (kNm)	50.0067	50.0067
Reinforcement-Total	22-T32	22-T32
Corner Reinforcement - Dia	32	32
Ast - corner reinforcement - mm2	804.2477	804.2477
Neutral Axis Angle (Deg)	86.8202	86.8202
Neutral axis location from compressive corner (mm)	343.9969	343.9969
acr (mm)	77.3381	77.3381
Check for Stress in Steel		
Fst (N/sqmm)	-128.451	-128.451
FstPerm (N/sqmm)	275	275
Check for Stress in Concrete		
Fc (N/sqmm)	15.2226	15.2226
FcPerm (N/sqmm)	16.6667	16.6667
Crack Width Check		
Epsilon-deff, ε1	0.0007	0.0007
Wcr (mm)	0.1235	0.1235
WcrPerm (mm)	0.2	0.2

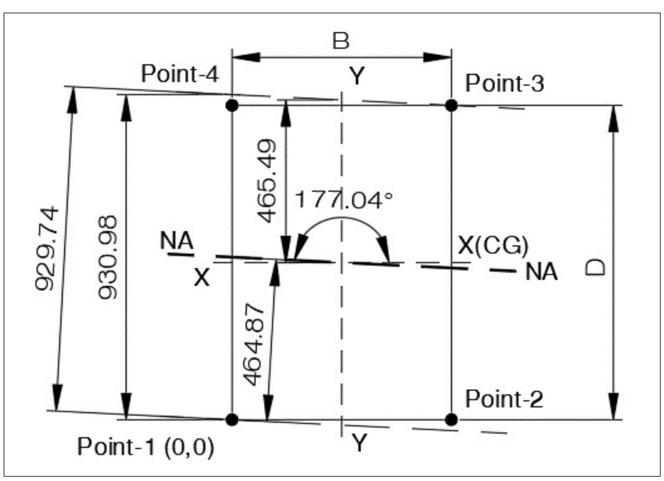
Check for Stress in Concrete	=	15.223	N/sqmm	
Check for Stress in steel	=	128.45	N/sqmm	
NA locaiton	=	343.99	mm	
depth below NA	=	834-343.99		
	=	490.01	mm	
moduluar ratio	=	280/(3x50/3)		Clause B-1.3 (IS 456-2000)
	=	5.6		

Column Reinforcement arrangement

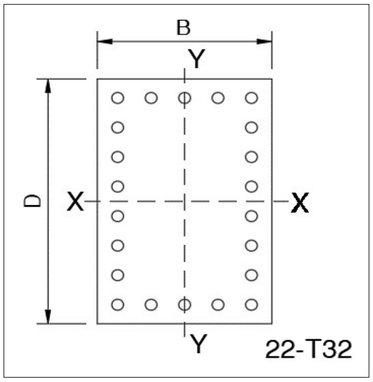


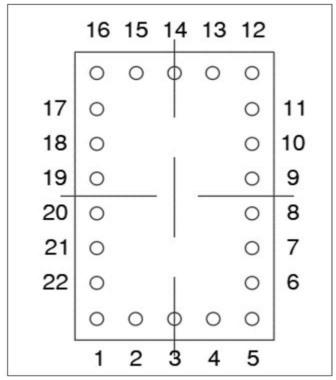
Calculation of Section Capacity:

Load Angle -Radian	=	atan (abs (-900.1209/50.0067))	
	=	1.52	Radian
Load Angle (Degree)	=	1.5153x180/Pi()	
	=	86.82	Degree
NA angle-radian (approximate)	=	1.5153+Pi()/2	
	=	3.09	Radian
NA angle-Degree	=	3.09x180/Pi()	
	=	177.04	Degree
slope of NA	=	tan(3.09)	
	=	-0.052	
Sin (Pi - NA)	=	sin(Pi()-3.09)	
	=	0.052	
Area of concrete	=	00x900	
	=	540000.00	sqmm
Cg-x	=	600/2	
	=	300.00	mm
Cg-y	=	900/2	
	=	450.00	mm
Y-intersection of line passing through Pt-3 =	=	900 - (-0.0516385) x600	
	=	930.98	mm
Y-intersection of line passing through cg =	=	450 - (-0.0516385) x300	
	=	465.49	mm
Perpendiculat distance bet'n Line through Pt-3 and (0,0)	=	(0-930.9831)/-0.0516385x0.0515698	
	=	929.74	mm
X-intersection of line passing through Pt-3	=	(0-930.9831)/-0.0516385	
	=	18028.86	mm
X-intersection of line passing through cg	=	(0-465.49155)/-0.0516385	
	=	9014.43	mm
Perpendicular distance bet'n Line through CG and (0,0)	=	9014.4282x0.0515698	
	=	464.87	mm

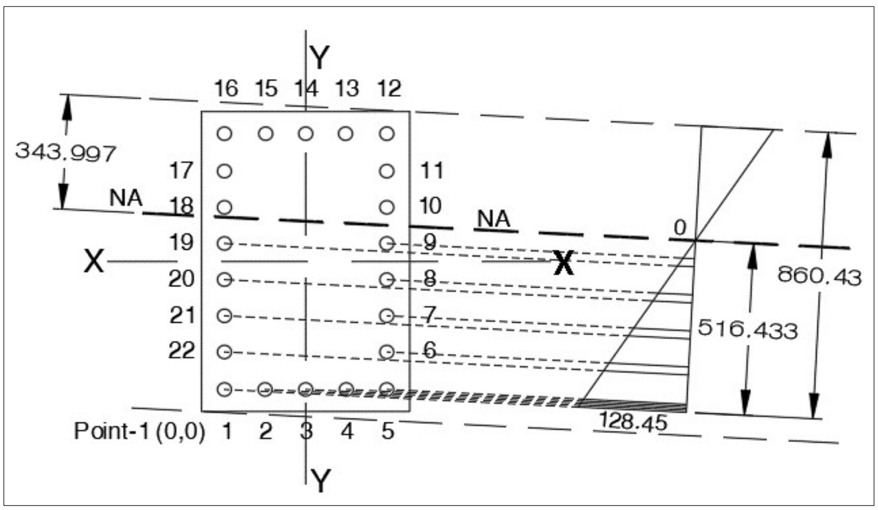


Rebar Arrangement:





Calculation of Rebar axial and moment capacity (Rebars Below the NA)



Rebar below and above the NA are shown in the above sketch

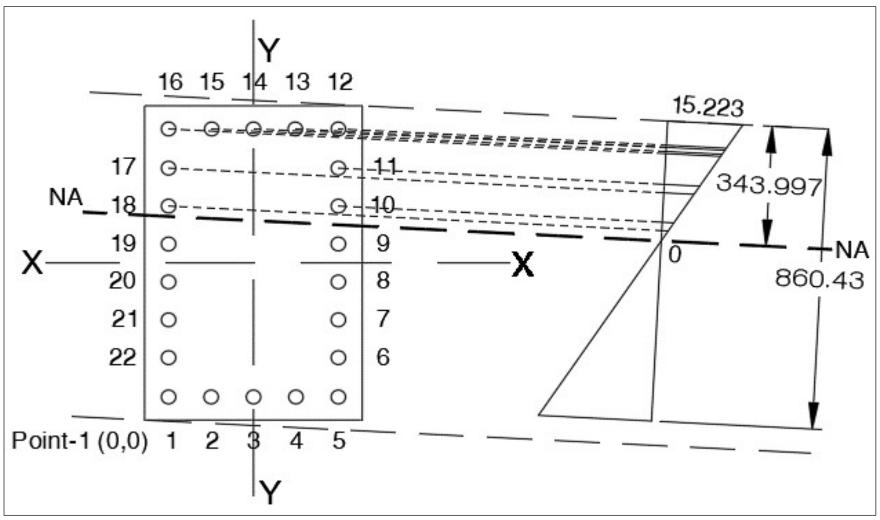
Tensile Stress at center of rebar -1 = 128.45 N/sqmm
As stress variation is linear, stress at each rebar center is calculated with respect to NA the location.
Stress in each rebar is multiplied by the area of the rebar to get the axial force in each rebar.
Summation of axial force in each rebar below the NA gives the axial tension force.
to get the Moment capacity,force in each rebar is multipled with the perpendicular distance between rebar center and CG

Rebar Location from left bottom corner and anti-clockwise

Sr.No	X-coordinate from Point-1 (mm)	Y-coordinate from Point-1 (mm)	Diameter	Area (sqmm)	For Line parallel to NA (mm)	X-intersection from 0,0 (mm)	Y-intersection from 0,0 (mm)	Distance from point-3 (mm)	Distance from NA (mm)	Distance from CG line (mm)	Stress @ CG (N/sqmm)	Stress @ NA (N/sqmm)	Force @ CG (kN)	Moment @ CG (kN-m)
1	66.0	66.0	32.0	804.2	69.41	1344.12	69.32	860.43	-516.4	-395.6	128.5	128.45	103.3064	-40.86352
2	183.0	66.0	32.0	804.2	75.45	1461.12	75.35	854.40	-510.4	-389.5	126.5	126.95	102.0995	-39.77007
3	300.0	66.0	32.0	804.2	81.49	1578.12	81.38	848.36	-504.4	-383.5	124.5	125.45	100.8925	-38.69118
4	417.0	66.0	32.0	804.2	87.53	1695.12	87.42	842.33	-498.3	-377.5	122.6	123.95	99.68557	-37.62686
5	534.0	66.0	32.0	804.2	93.57	1812.12	93.45	836.29	-492.3	-371.4	120.6	122.45	98.47862	-36.5771
6	534.0	175.7	32.0	804.2	203.29	3936.78	203.02	726.73	-382.7	-261.9	85.0	95.196	76.56099	-20.04776
7	534.0	285.4	32.0	804.2	313.00	6061.44	312.59	617.16	-273.2	-152.3	49.5	67.943	54.64336	-8.321373
8	534.0	395.1	32.0	804.2	422.72	8186.10	422.16	507.59	-163.6	-42.7	13.9	40.691	32.72573	-1.39794
9	534.0	504.9	32.0	804.2	532.43	10310.76	531.72	398.02	-54.0	66.9	-21.7	13.439	8.885131	0.593984

10	534.0	614.6	32.0	804.2	642.15	12435.42	641.29	288.45	55.5	176.4	-57.3	-13.81	0	0
11	534.0	724.3	32.0	804.2	751.86	14560.08	750.86	178.88	165.1	286.0	-92.9	-41.07	0	0
12	534.0	834.0	32.0	804.2	861.57	16684.74	860.43	69.32	274.7	395.6	-128.5	-68.32	0	0
13	417.0	834.0	32.0	804.2	855.53	16567.74	854.40	75.35	268.6	389.5	-126.5	-66.82	0	0
14	300.0	834.0	32.0	804.2	849.49	16450.74	848.36	81.38	262.6	383.5	-124.5	-65.32	0	0
15	183.0	834.0	32.0	804.2	843.45	16333.74	842.33	87.42	256.6	377.5	-122.6	-63.82	0	0
16	66.0	834.0	32.0	804.2	837.41	16216.74	836.29	93.45	250.5	371.4	-120.6	-62.32	0	0
17	66.0	724.3	32.0	804.2	727.69	14092.08	726.73	203.02	141.0	261.9	-85.0	-35.06	0	0
18	66.0	614.6	32.0	804.2	617.98	11967.42	617.16	312.59	31.4	152.3	-49.5	-7.811	0	0
19	66.0	504.9	32.0	804.2	508.27	9842.76	507.59	422.16	-78.2	42.7	-13.9	19.442	12.85397	0.549081
20	66.0	395.1	32.0	804.2	398.55	7718.10	398.02	531.72	-187.7	-66.9	21.7	46.694	37.55354	-2.51051
21	66.0	285.4	32.0	804.2	288.84	5593.44	288.45	641.29	-297.3	-176.4	57.3	73.946	59.47117	-10.49189
22	66.0	175.7	32.0	804.2	179.12	3468.78	178.88	750.86	-406.9	-286.0	92.9	101.2	81.3888	-23.27623
												Total	868.55	-258.43

Calculation of Rebar axial and moment capacity (Rebars above the NA)



Compressive Stress at extreme edge of concret = 15.22 N/sqmm

As stress variation is linear, stress at each rebar center is calculationcalculated with respect to NA location.

Stress in each rebar is multiplied by the modulus of elasticity (M) and the area of the rebar to get the axial force in each rebar.

The summation of axial force in each rebar above the NA gives the axial compressive force. The concrete stress is deducted from the reinforcement stress at the rebar location to avoid duplication of force.

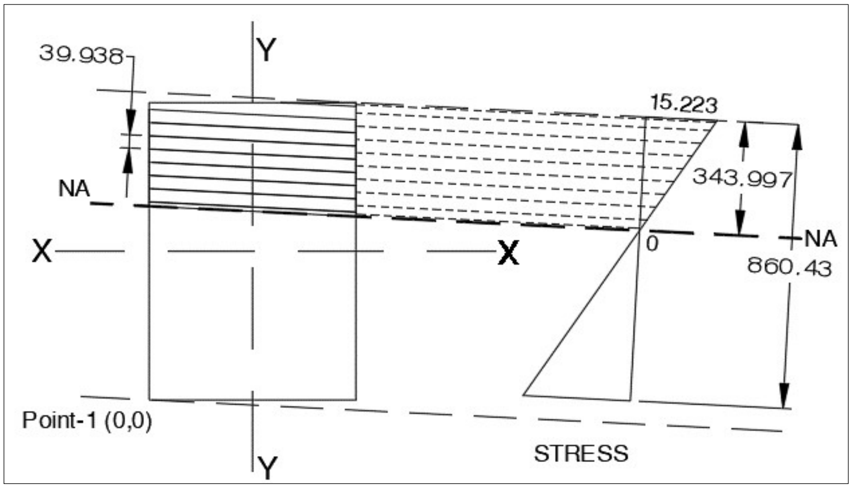
To get the Moment capacity,force in each rebar is multipled with the perpendicular distance between rebar center and CG

Rebar Location from left bottom corner and anti-clockwise

Sr.No	X-coordinate from Point-1 (mm)	Y-coordinate from Point-1 (mm)	Diameter	Area (sqmm)	For Line parallel to NA (mm)	X-intersection from 0,0 (mm)	Y-intersection from 0,0 (mm)	Distance from point-3 (mm)	Distance from NA (mm)	Distance from CG line (mm)	Stress @ NA (N/sqmm)	Stress @ NA (N/sqmm)	Force @ CG (kN)	Moment @ CG (kN-m)
1	66.0	66.0	32.0	804.2	69.41	1344.12	69.32	860.43	-516.4	-395.6	0.0	0	0	0
2	183.0	66.0	32.0	804.2	75.45	1461.12	75.35	854.40	-510.4	-389.5	0.0	0	0	0
3	300.0	66.0	32.0	804.2	81.49	1578.12	81.38	848.36	-504.4	-383.5	0.0	0	0	0
4	417.0	66.0	32.0	804.2	87.53	1695.12	87.42	842.33	-498.3	-377.5	0.0	0	0	0
5	534.0	66.0	32.0	804.2	93.57	1812.12	93.45	836.29	-492.3	-371.4	0.0	0	0	0
6	534.0	175.7	32.0	804.2	203.29	3936.78	203.02	726.73	-382.7	-261.9	0.0	0	0	0
7	534.0	285.4	32.0	804.2	313.00	6061.44	312.59	617.16	-273.2	-152.3	0.0	0	0	0
8	534.0	395.1	32.0	804.2	422.72	8186.10	422.16	507.59	-163.6	-42.7	0.0	0	0	0
9	534.0	504.9	32.0	804.2	532.43	10310.76	531.72	398.02	-54.0	66.9	-2.4	0	0	0
10	534.0	614.6	32.0	804.2	642.15	12435.42	641.29	288.45	55.5	176.4	2.5	18.187	12.65026	2.231757
11	534.0	724.3	32.0	804.2	751.86	14560.08	750.86	178.88	165.1	286.0	7.3	54.068	37.60758	10.75532
12	534.0	834.0	32.0	804.2	861.57	16684.74	860.43	69.32	274.7	395.6	12.2	89.948	62.56489	24.74795

13	417.0	834.0	32.0	804.2	855.53	16567.74	854.40	75.35	268.6	389.5	11.9	87.972	61.19055	23.83511
14	300.0	834.0	32.0	804.2	849.49	16450.74	848.36	81.38	262.6	383.5	11.6	85.997	59.81621	22.93887
15	183.0	834.0	32.0	804.2	843.45	16333.74	842.33	87.42	256.6	377.5	11.4	84.021	58.44187	22.0592
16	66.0	834.0	32.0	804.2	837.41	16216.74	836.29	93.45	250.5	371.4	11.1	82.045	57.06753	21.19613
17	66.0	724.3	32.0	804.2	727.69	14092.08	726.73	203.02	141.0	261.9	6.2	46.164	32.11022	8.408172
18	66.0	614.6	32.0	804.2	617.98	11967.42	617.16	312.59	31.4	152.3	1.4	10.284	7.152905	1.089281
19	66.0	504.9	32.0	804.2	508.27	9842.76	507.59	422.16	-78.2	42.7	-3.5	0	0	0
20	66.0	395.1	32.0	804.2	398.55	7718.10	398.02	531.72	-187.7	-66.9	0.0	0	0	0
21	66.0	285.4	32.0	804.2	288.84	5593.44	288.45	641.29	-297.3	-176.4	0.0	0	0	0
22	66.0	175.7	32.0	804.2	179.12	3468.78	178.88	750.86	-406.9	-286.0	0.0	0	0	0
												Total	388.60	137.26

Strip Thickness = 39.94 mm (Assumed which gives more accurate capacity of the section)



Compressive Stress at extreme edge of concret = 15.22 N/sqmm

As stress variation is linear, stress at each strip center is calculationcalculated with respect to NA location.

Stress in each strip is multiplied by thearea of the strip to get the axial force in each strip. The summation of axial force in each strip above the NA gives the axial compressive force.

to get the Moment capacity,force in each strip is multipled with the perpendicular distance between strip center and CG

Concrete Capacity

No	Y-axis-intersection (mm)	length of strip (mm)	Area (sqmm)	Perpendicular distance from Point-1 (mm)	Distance from Point-3 (mm)	Distance from NA line (mm)	Distance from CG line (mm)	Stress in concrete (N/sqmm)	Force in Strip (kN)	Moment (kN-m)
1	20	360.56	14400	19.969	909.78	-565.79	-444.90	0	0	0
2	60	600.93	24000	59.908	869.84	-525.85	-404.96	0	0	0
3	100	600.93	24000	99.846	829.90	-485.91	-365.03	0	0	0
4	140	600.93	24000	139.78	789.96	-445.97	-325.09	0	0	0
5	180	600.93	24000	179.72	750.02	-406.03	-285.15	0	0	0
6	220	600.93	24000	219.66	710.08	-366.09	-245.21	0	0	0
7	260	600.93	24000	259.6	670.14	-326.15	-205.27	0	0	0
8	300	600.93	24000	299.54	630.21	-286.22	-165.33	0	0	0
9	340	600.93	24000	339.48	590.27	-246.28	-125.40	0	0	0
10	380	600.93	24000	379.41	550.33	-206.34	-85.46	0	0	0
11	420	600.93	24000	419.35	510.39	-166.40	-45.52	0	0	0
12	460	600.93	24000	459.29	470.45	-126.46	-5.58	0	0	0
13	500	600.93	24000	499.23	430.51	-86.52	34.36	0	0	0
14	540	600.93	24000	539.17	390.58	-46.59	74.30	0	0	0

15	580	600.93	24000	579.11	350.64	-6.65	114.23	0	0	0
16	620	600.93	24000	619.05	310.70	33.29	154.17	1.4732	35.357	5.4511
17	660	600.93	24000	658.98	270.76	73.23	194.11	3.2406	77.775	15.097
18	700	600.93	24000	698.92	230.82	113.17	234.05	5.008	120.19	28.131
19	740	600.93	24000	738.86	190.88	153.11	273.99	6.7754	162.61	44.553
20	780	600.93	24000	778.8	150.95	193.04	313.93	8.5428	205.03	64.363
21	820	600.93	24000	818.74	111.01	232.98	353.86	10.31	247.44	87.562
22	860	600.93	24000	858.68	71.07	272.92	393.80	12.078	289.86	114.15
23	900	600.93	24000	898.61	31.13	312.86	433.74	13.845	332.28	144.12
								Total	1470.5	503.43

Check for Axial force capacity

Axial force from rebars below NA	=	868.55	kN
Axial force from rebars above NA	=	388.60	kN
Axial force from concrete above NA	=	1470.6	kN
Total Axial force capacity of section	=	1470.55-868.55+388.6	
	=	990.6	kN
Axial force on section	=	1000	kN
Check		Ok	

Check for Bending Moment Capacity

Moment capacity from rebars below NA	=	-258.43	kN-m
Moment capacity from rebars above NA	=	137.26	kN-m
Moment capacity from Concrete above NA	=	503.43	kN-m
Total Axial force in section	=	503.43--258.43+137.26	
	=	899.1	kN-m
Resultant Moment,Mud-x	=	901.51	kN
Check		Ok	

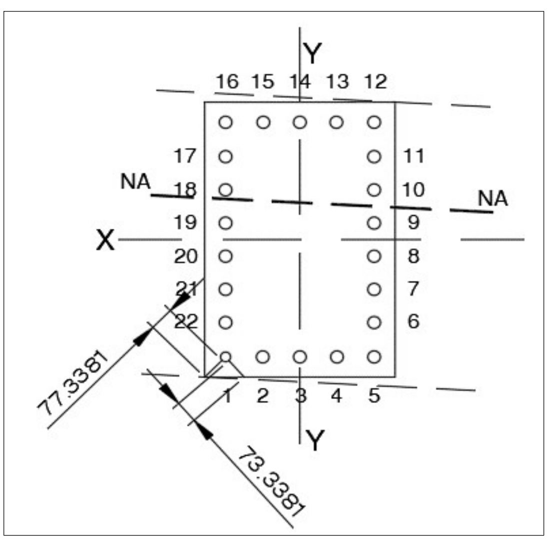
Note:

The variation in the axial force and moment capacity is due to rounding off the stress values and due to strip thickness.
The top most strip CG lies outside the section thus ignored in the capacity calculation.
The margin for error is kept less than the 1% for the validation

Computation of Crack Width

acr calculation:

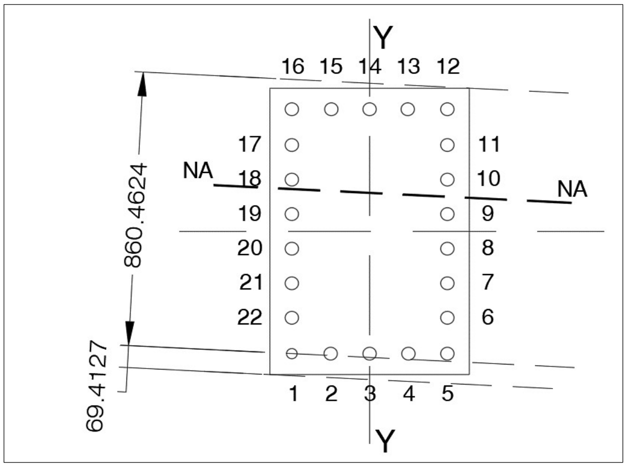
The maximum stresses are at rebar no.01, thus acr value would be calculated for this rebar.
acr value would be maximum distance from concrete surface to edge of rebar.



acr	=	SQRT(66^2+66^2)-32/2	
	=	77.338	mm

Strain in rebar calculation:

Stress in the rebar-1	=	128.45 N/sqmm	
Strain in the rebar-1	=	128.451/200000	
	=	0.0006423	
Strain at edge of concrete	=	0.000642255x(69.4127+860.4624)/860.4624	
	=	0.0007	Annex F (IS 456-2000)



Computation of crackwidth	=	2.3x0.00069407x77.3381	
	=	0.1235	mm
Permissible Crack width	=	0.2	mm
Check		Ok	