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REINFORCED CONCRETE BEAM AND COLUMN PROGRAMMING BASED ON SNI:2847-2019 ON SMARTPHONE USING TEXAS INSTRUMENTS

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ABSTRACT

The development of technology in the last few years can not be denied that it has developed very rapidly. In building construction, reinforced concrete beam and columns calculations also utilizing that technology development. Input data used to calculate reinforcement of beam and column are material property, section property and internal forces. Calculation of reinforcement beam using quadratic equation method and reinforcement column using Newton-Raphson method and divided-by-two method.Calculation results are flexural reinforcement As (longitudinal compression area) and As' (longitudinal tension area), shear reinforcement Av (transversal area) and S (distance of Av), torsional reinforcement Avt (transversal area due to torsional and/or shear), S (distance of Avt), Along (longitudinal area due to torsional buckling), column circular reinforcement Atot (total of longitudinal area), column rectangular two faces reinforcement Atot (total of longitudinal area), column rectangular four faces reinforcement Atot (total of longitudinal area), column biaxial reinforcement Atot (total of longitudinal area). The program determines As, As' and Atotal, the code is written using the Texas Instruments programming language, so that it can be applied to smartphones. Smartphone and manual calculation, for all cases not more than 5%, the calculation using Texas Instrument is accurate.

Keywords: smartphone; texas instruments; Newton-Raphson method; divided by two method; beam and column reinforcement.

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INTRODUCTION

Reinforced concrete beams are assumed to be multi-layered, which consists of layers of concrete and layers of reinforcement, analyzed with an element model, using the FORTRAN language (Abdi.FN, 2008). STAAD software, to analyze and design concrete beams and columns and compiled in Excel to summarize the results of STAAD (Fernandez.RJ, et.al, 2017). The mix design program, written in the Borland Delphi programming language, but does not discuss concrete reinforcement (Vectoriarda.US, et.al, 2014). Other researchers discuss reinforcing concrete columns, without using programming (Kriastianto,A.et.al, 2012; Bagio.TH, Kusuma.B, 2012; Nawy, et.al, 2010). Multiple reinforcement with optimum design, using annealing simulation, which discusses the design of reinforced concrete with the ultimate strength design method (Bagio.TH, Kusuma.B, 2012; Ferguson,PM,et.al, 1986).

Constraints used in this study were bending beam, minimum beam width, and deflection, while the optimization was using annealing simulation method (GalebAC, 2018). Program for special reinforcement for columns, [9]. Analysis and design of beam column joints based on SNI 2847-2019 (Bagio.TH, Kusuma.B, 2012; Nawy, et.al, 2010; LeungCK, Simmonds,SH, 1984bhatt,P, et.al, 2006; McCormac,JC, Brown,RH, 2014; Kadarningsih,R.et.al, 2017). Column reinforcement, based on the column equivalence concept, where the axial load on the column, indirectly gives an additional moment, assuming eccentricity (Afefy,HM, El-Tony,TM, 2016).

A computer program for concrete reinforcement in portals, based on cracked beams, discusses iterative procedures, ACI (American Code) and CEB (Euro Code) models are compared (ACI, International, 201; ACI Comittee318, 2014; Computers & Structures Inc, 2004; Computers & Structures Inc, 2004). Reinforced concrete with and without limitation (curtailment) of reinforcement for shear and bending, using Code IS 456-2000 (Ponanda,MR, MohsinM, 2017). Computer program about sectional analysis and design of beams, using visual basic programming language. Discussion about beams, columns, footings and designs on bending, shear, axial and torsion (ACI Comittee318, 2014; Muhammad,I, Mahmood,A, 2004).

General programs for calculating concrete reinforcement for beams and/or columns are all using a PC or a laptop, in the new era, smartphone is not only to call, but it will come to replacing PC in your hand, with Wabbitemu applications and using the TI (Texas Instruments) programming language (Texas Instrument, 2019; Texas Instruments, 2019).

BASIC THEORY

Flexural of beam.

Calculation of reinforced concrete beam due to bending moment, the properties of the beam and the moment from the results of the structural analysis are needed, figure 1.

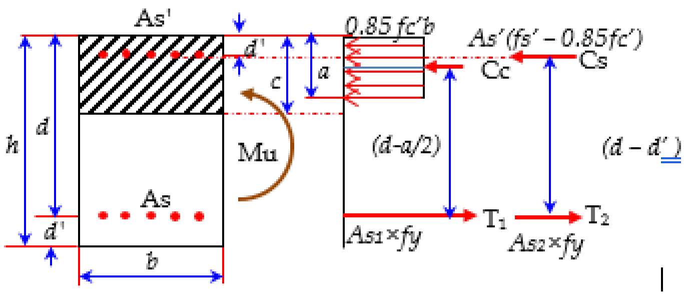

Figure 1. Beam internal forces at ultimate condition. (*Source: McCORMAC, 2014*)

Property of flexural beam, fc' = compressive strength of concrete (MPa), fy = yield strength of steel (MPa), fs' = compressive strength of steel (MPa), b = width of rectangular beam (mm), h = height of rectangular beam (mm), d = effective height of beam (mm), Mu = bending moment at the beam (kNm), As = tension reinforcement (mm2), As' = compression reinforcement (mm2), see figure 1.

$$\beta_1 = 0.85 - \frac{(fc' - 28)}{140} \qquad (0.65 \leq \beta_1 \leq 0.85) \qquad (1)$$

$$f_s' = 600\frac{c - d'}{c} \leq f_y \qquad (2)$$

$$a = \frac{As\,fy - As'\,(fs' - 0.85\,fc')}{0.85\,fc'\,b} \qquad (3)$$

$$Mn = \frac{Mu}{\phi} \;\; ; \;\; \phi = 0.9 \qquad (4)$$

$$Mn = [As\,fy - As'(fs' - 0.85\,fc')]\left[d - \frac{a}{2}\right] + As'(fs' - 0.85\,fc')(d - d') \qquad (5)$$

Shear Beam Reinforcement

Inclined cracks can develop in the webs of reinforced concrete beams, either as extensions of flexural cracks or occasionally as independent cracks. The first of these two types is the flexure – shear cracks.

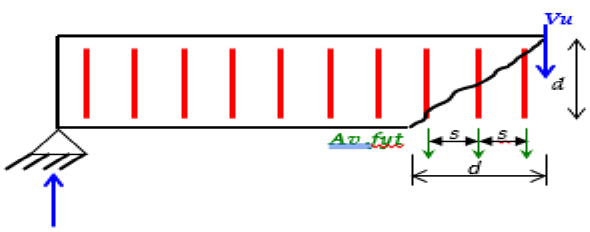

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Figure 2. Beam with vertical stirrups (*Source: McCORMAC, 2014*)

Property of beams same as flexural beam, *fc', fy, b, d, h, fyt* = yield strength of stirrups (MPa), *Vu* = shear force of beam (kN), *Av* = Area of stirrups (mm^2), *s* = space of stirrups (mm), ds = diameter of stirrups, *nk* = numbers of stirrups legs (≥ 2)

$$V_n = \frac{V_u}{\phi}\ ;\ \phi = 0.75 \tag{6}$$

$$V_c = \lambda \frac{\sqrt{f_c'}}{6} \times b_w \times d \tag{7}$$

$$Av = nk \times 0.25 \times \pi \times ds^2 \tag{8}$$

Torsion Beam Reinforcement

Reinforced concrete members are subjected to pure torsion, they will crack along 45° spiral lines when the resulting diagonal tension exceeds the design strength of the concrete.

Property of torsional beams same as beam with shear, *fc', fy, fyt, bw, d, h, Vu, Av, s, ds, At* = torsional stirrups (mm^2), *Tu* = torsional moment (kNm), *Vn, Vc* from equation (6), and equation (7)

$$T_n = \frac{T_u}{\phi}\ ;\ \phi = 0.75 \tag{9}$$

$$At = 2 \times 0.25 \times \pi \times ds^2 \tag{10}$$

$$X = bw\ ;\ Y = h \tag{11}$$

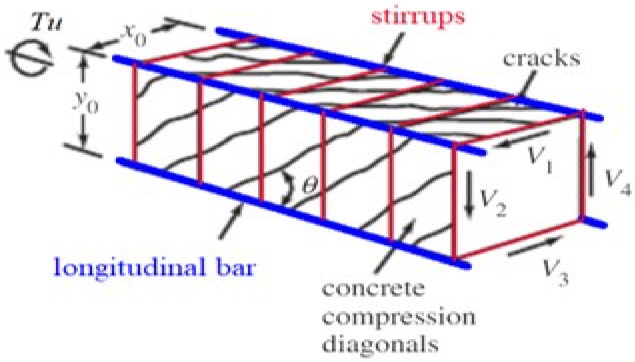

Figure 3. Imaginary space truss (*Source: McCORMAC, 2014*)

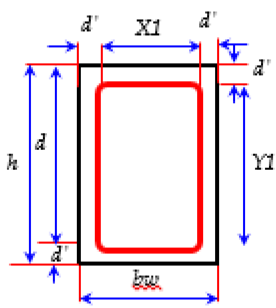

Figure 4. Cross section of beam (*Source: Bagio, 2019*)

$$X_1 = X - 2 \times \left(d' + \frac{ds}{2} \right)\ ;\ Y_1 = Y - 2 \times \left(d' + \frac{ds}{2} \right) \tag{12}$$

$$A_{cp} = X \times Y\ ;\ A_{oh} = X_1 \times Y_1\ ;\ A_o = 0.85 \times A_{oh} \tag{13}$$

$$P_{cp} = 2\times(X+Y) \;\; P_h = 2\times(X_1+Y_1) \tag{14}$$

$$T_c = \frac{\sqrt{f_c'}}{12}\times\frac{A_{cp}{}^2}{P_{cp}} \tag{15}$$

IF $T_n \le T_c$ THEN $T_n = 0$;

Column Reinforcement

All columns are subjected to some bending as well as axial forces, and they need to be proportioned to resist both. Property of rectangular column and circular same as flexural beam *fc', fy, b, d, h, Mu*, special for circular column $b = 0$, and Pu = Axial load (kN).

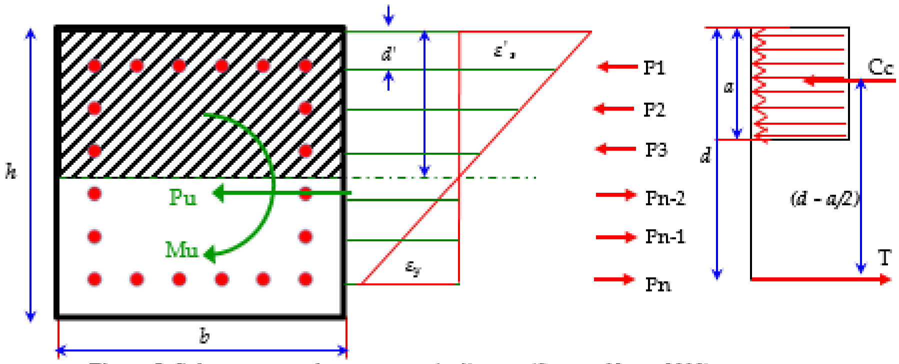

Figure 5. Column rectangular stress - strain diagram (*Source: Nawy, 2010*)

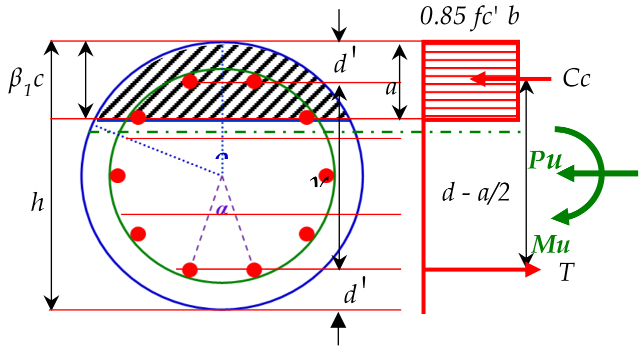

Figure 6. Column circular stress diagram (*Source: Nawy, 2010*)

Rectangular column (**Figure 5**)
Moment capacity and forces capacity in concrete area

$a = \beta 1\times c$ (16)

$Cc = 0.85\times fc'\times b\times a$ (17)

$Mc = Cc\times(h-a)/2$ (18)

Cicular column (**Figure 6**)
Moment capacity and forces capacity in concrete area

$z = (1-2\times\beta 1\times c/h)$ (19)

$\theta = \text{ArcCos}(z)$ (20)

$Ac = 0.25\times h^2\times[\theta - 0.5\times\text{Sin}(2\times\theta)]$ (21)

$y = [h\times\text{Sin}(\theta)]^3 / (12\times Ac)$ (22)

$Cc = 0.85\times fc'\times Ac$ (23)

$Mc = 0.85\times fc'\times Ac\times y$ (24)

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Column Biaxial Bending

Many columns are subjected to biaxial bending, that is, bending about both axes. Corner columns in buildings where beams and girders frame into the columns from both directions are the most common cases.

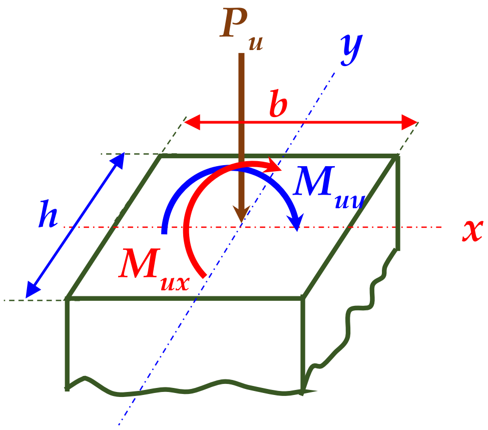


Figure 7. Column biaxial bending and axial load (Source: *Nawy, 2010)*

Property of biaxial bending moment for column same as rectangular column *fc', fy, b, h*, *Pu*, *Mux* = Moment at x-direction (kNm), *Muy* = Moment at y-direction (kNm)

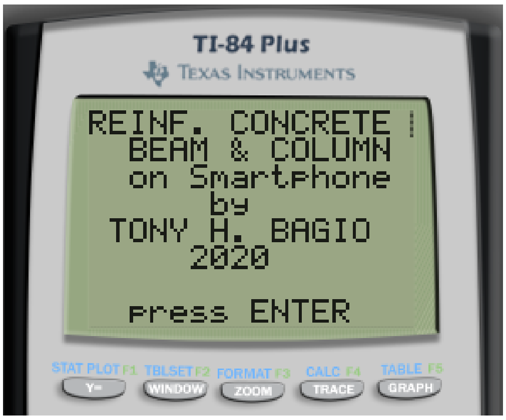
Interaction formula load contour modified method,

$$\left(\frac{Pn - Pnb}{Pno - Pnb}\right) + \left(\frac{Mnx}{Mnbx}\right)^{1.5} + \left(\frac{Mny}{Mnby}\right)^{1.5} \approx 1 \qquad (25)$$

Texas Instrument

Programming using TI (Texas Instrument) difference with programing using PC. The variables on TI , only 27 variables (PC unlimited variables). Display on TI84 Plus C Silver Edition has 8 lines and 24 columns, and TI 84 Plus has 8 lines and 16 columns.

(a)



(b)

Figure 8. Texas Instruments display (a) TI84 Plus C Silver, (b) TI-84 Plus

RESEARCH METHODS

Research method to calculate beam reinforcement due to bending, shear and torsion as well as calculating uniaxial or biaxial column reinforcement is fc', fy, b, h, and external forces such as Mu, Vu, Tu, and for columns Mux, Muy, Pu . It will be explained in detail in the next chapter.

Flexural Design of Beams.

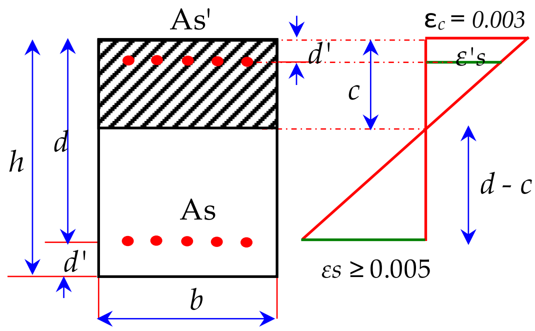


Figure 9. Strain diagram on beam (Source*: Bagio,2019)*

$$c_{max} = \frac{3}{8} d \tag{26}$$

$$a_{max} = \frac{3}{8} \beta_1 \, d \tag{27}$$

IF $d < \sqrt{\dfrac{M_n}{0.425 \cdot f_c{}' \cdot b}}$ THEN “CHANGE DIMENSION”

$$a = d - \sqrt{d^2 - \frac{M_n}{0.425 \cdot f_c{}' \cdot b}} \tag{28}$$

IF $a > a_{max}$ THEN $a = a_{max}$

$$\lambda = f_y \times \left(d - \frac{a}{2} \right) \tag{29}$$

$$\gamma = (f_s{}' - 0.85 \, f_c{}') \times \left(\frac{a}{2} - d' \right) \tag{30}$$

$$C_c = 0.85 \times f_c{}' \times a \times b \tag{31}$$

$$\delta = \frac{M_n \times f_y - C_c \times \lambda}{M_n \times f_s{}' + C_c \times \gamma} \tag{32}$$

$$As = \frac{M_n}{\lambda + \delta \times \gamma} \tag{33.a}$$

$$As' = \delta \times As \tag{33.b}$$

Shear Cracking of Reinforced Concrete Beams.

$$V_s = V_n - V_c \tag{34}$$

$$A_{vmin} = \kappa \times \frac{b_w \times s}{f_{yt}} \; ; \; \kappa = \frac{\sqrt{f_c{}'}}{16} \geq 0.35 \tag{35}$$

Zone area and $\lambda = 1$:

Zone 1 : $V_n \leq 0.5 \cdot V_c$; $\dfrac{A_v}{s} = 0$ (36.a)

Zone 2 : $0.5 \cdot V_c < V_n \leq V_c$; $\dfrac{A_v}{s} = \kappa \dfrac{b_w}{f_{yt}}$; $\kappa = \dfrac{\sqrt{f_c{}'}}{16} \geq 0.35$; $s = d/2 \leq 600$ (36.b)

Zone 3 : $V_c < V_n \leq 3 \cdot V_c$; $\dfrac{A_v}{s} = \dfrac{V_s}{f_{yt} \times d}$; $s = d/2 \leq 600$ (36.c)

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Zone 4 : $3 \cdot V_c < V_n \le 5 \cdot V_c$; $\dfrac{A_v}{s} = \dfrac{V_s}{f_{yt} \times d}$; $s = d/4 \le 300$ (36.d)

Zone 5 : $V_n > 5 \cdot V_c$; "CHANGE DIMENSION" (36.e)

Design of Torsional Reinforcing.
section get shear and torsion forces (from **figure 3** and **figure 4**)

$$VarL = \sqrt{\left(\frac{V_n}{b_w \times d}\right)^2 + \left(\frac{T_n \times P_h}{1.7 \times A_{oh}{}^2}\right)^2} \quad ; \quad VarR = \frac{V_c}{b_w \times d} + \frac{2\sqrt{f_c{}'}}{3} \tag{37}$$

IF $VarL > VarR$ THEN "CHANGE DIMENSIONS"

$$\frac{A_{vt,min}}{s} = \kappa \frac{b_w}{f_{yt}} \; ; \; \kappa = \frac{\sqrt{f_c{}'}}{16} \ge 0.35 \tag{38}$$

$$A\ell_{mn} = \frac{5}{12} \frac{\sqrt{f_c{}'}}{f_{yt}} A_{cp} - \frac{A_t}{s} P_h \frac{f_{yt}}{f_y} \tag{39}$$

$$\frac{A_t}{s} = \frac{T_n \times tan\,(\theta)}{2 \times A_o \times f_{yt}} \quad ; \quad \frac{A_v}{s} = \frac{V_s}{f_{yt} \times d} \tag{40}$$

$$\frac{A_{vt}}{s} = 2\frac{A_t}{s} + \frac{A_v}{s} \tag{41}$$

$$A\ell = \frac{A_t}{s} P_h \frac{f_{yt}}{f_y} cot^2\,\theta \tag{42}$$

Design of Column with Axial Load and Bending Moment

Rectangular column (**Figure 10.a**)

Number of rows' layer = N, number of columns' layer = Nk; Nk = INT $(b/h \times N) + 1$
Number of total bars (ntot) = $2(Nk + N - 2)$
Section area, $Agr = b \times h$
Rebar area, $As(i) = \rho t \times Agr \times nb$, where:
If (i = 1 or i = N) THEN $nb = Nk/ntot$, ELSE nb = 2

Cicular column (**Figure 10.b**)

Number of bars = N
Number of total bars (ntot) = 2 ×N
Section area (Agr) = $0.25\,\pi \times h^2$
Rebar area as(i) = ρt × Agr × 2

General

Astotal = ρt × Agr, 1% ≤ ρt ≤ 8%
Spacing of rebars, $s(i) = d' + (i - 1)(d - d')/(N - 1)$
Rebar stressing, $fss(i) = 600 \times (c - s(i))/c$

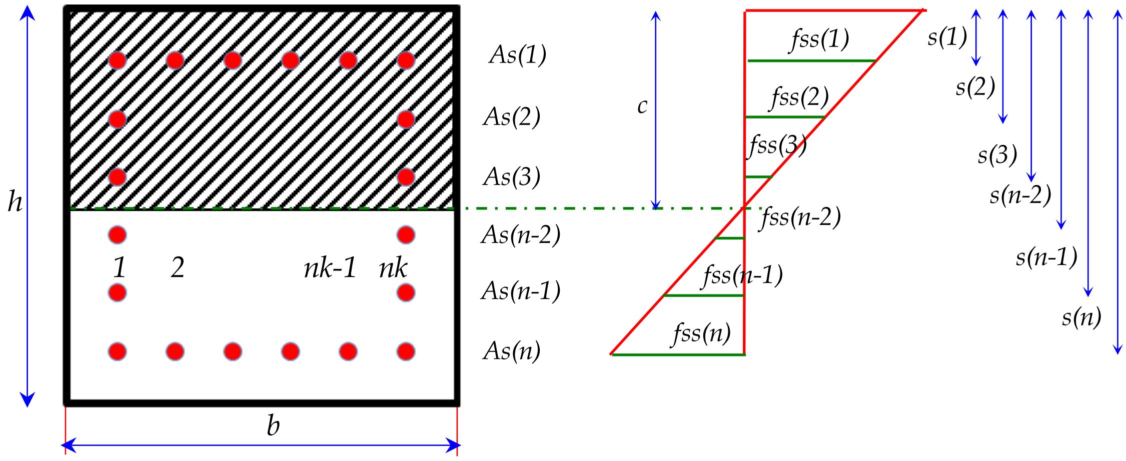

Figure 10.a. Column rectangular with area, depth and stress (*Source: Nawy, 2010*)

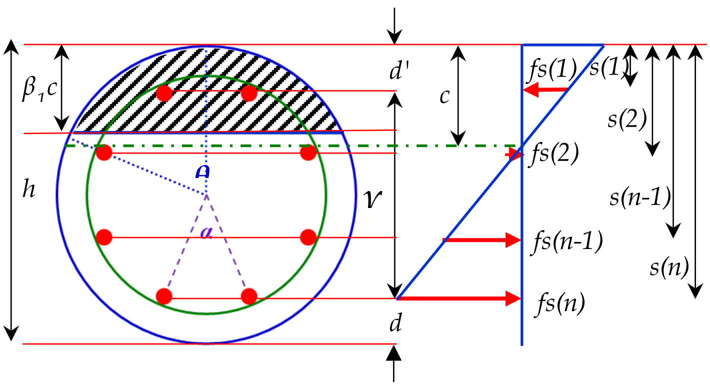

Figure 10.b Column circular with depth (d_i) and stress (fs_i) (Source: *Nawy, 2010*)

Compression force and tension force in the reinforcement and moment of the internal forces of the column concrete

$$Cs = \sum_{i=1}^{N} fss(i) \times As(i) \tag{43}$$

$$Ms = \sum_{i=1}^{N} fss(i) \times As(i) \times \frac{(h - s(i))}{2} \tag{44}$$

Internal force total, IF rectangular column, *Cc* from equation (17), *Mc* from equation (18), IF circular column *Cc* from equation (23), *Mc* from equation (24)

$$P_o = C_c + C_s \tag{45}$$

$$M_o = M_c + M_s \tag{46}$$

$$e_u = \frac{M_u}{P_u} \tag{47}$$

$$e_o = \frac{M_o}{P_o} \tag{48}$$

Using Newton-Raphson method until, $e_u \approx e_o$, to get c value

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Design reinforcement column with Biaxial Bending.

Notation of **Figure 11.**

nb = number of bars x direction
nh = number of bars y direction = INT(h/b×nb)
ntot = total numbers of bars = 2× (nb + nh -2)
Asx OR Asy = rebar area in x-direction OR in y-direction
dx = effective height ; dy = effective width
ρt = Astot / (b × h); 1% < ρt ≤ 8% (49)

see **figure 12.a**, and **figure 12.b**

ρx = ρt / (h/b +1) ; *ρy* = *ρt / (b/h +1)*

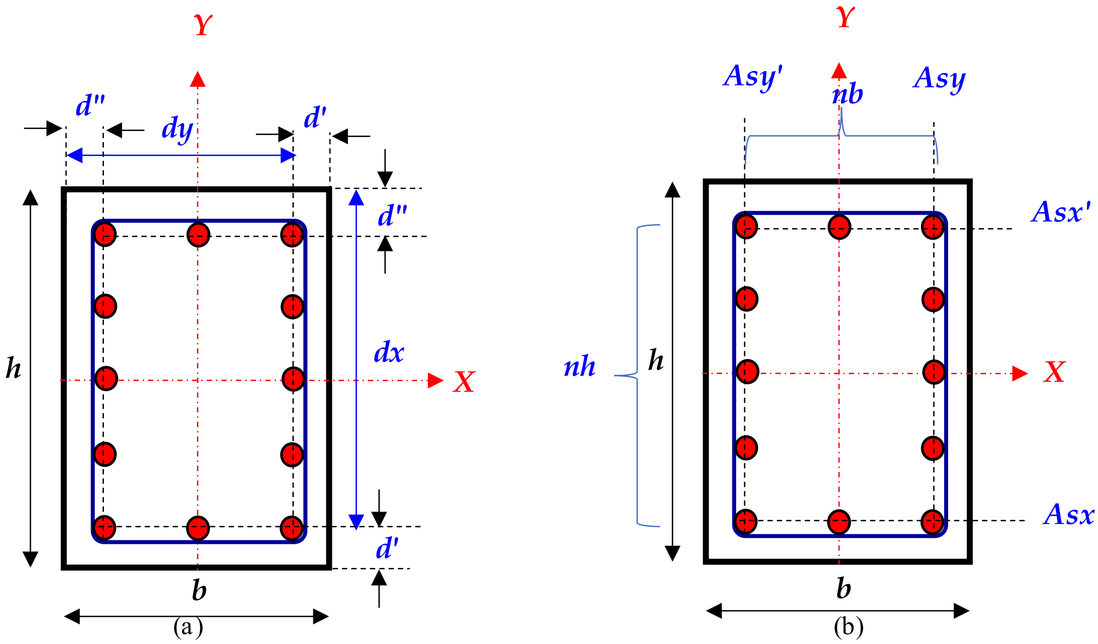

Figure 11. (a) dimension of column, (b) bars in column

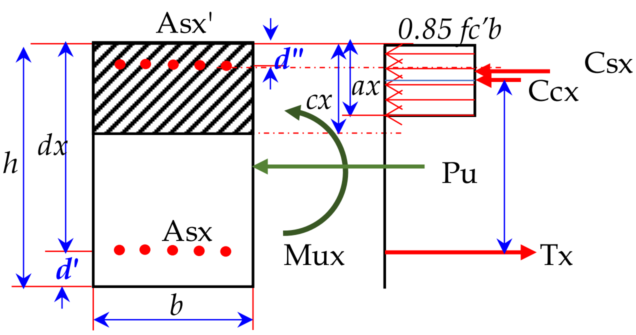

Figure 12.a. Moment and Axial in y-direction

Asx'	=	$Asx = 0.5\times\rho x\times b\times h$	;	Asy'	=	$Asy = 0.5\times\rho y\times b\times h$
cbx	=	$(600\times dx) / (600 + fy)$	;	cby	=	$(600\times dy) / (600 + fy)$
ax	=	$\beta 1\times cbx$	;	ay	=	$\beta 1\times cby$
fsx'	=	$600\times (1 - d'/cbx)$	;	fsy'	=	$600\times (1 - d'/cby)$
Ccx	=	$0.85\times fc'\times b\times ax$	;	Ccy	=	$0.85\times fc'\times h\times ay$
Csx	=	$Asx'\times (fsx' - 0.85\times fc')$	;	Csy	=	$Asy'\times (fsy' - 0.85\times fc')$
Tx	=	$Asx\times fy$	;	Ty	=	$Asy\times fy$
Ø	=	$0.65 + (fy/200\,000 - 0.002) \times (250/3)$				

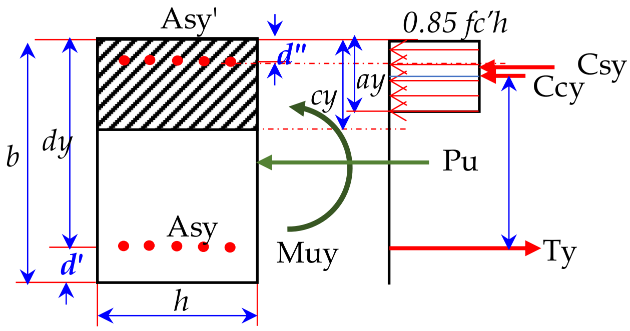

Figure 12.b. Moment and Axial in y-direction

For Interaction formula using equation (25)

$$\left(\frac{Pn-Pnb}{Pno-Pnb}\right)+\left(\frac{Mnx}{Mnbx}\right)^{1.5}+\left(\frac{Mny}{Mnby}\right)^{1.5}\approx 1 \tag{50}$$

where :

Pn	=	$Pu/Ø$	(51)
Mnx	=	$Mux/Ø$	(52)
Mny	=	$Muy/Ø$	(53)
Pno	=	$0.85 \times fc' \times (Agr - Ast) + fy \times Ast$	(54)
$Pnbx$	=	$Ccx + Csx - Tx$	(55)
$Pnby$	=	$Ccy + Csy - Ty$	(56)
Pnb	=	MAX ($Pnbx, Pnby$)	(57)
$Mnbx$	=	$Ccx \times (dx - d'' - ax/2) + Csx \times (dx - d' - d'') + Tx \times d''$	(58)
$Mnby$	=	$Ccy \times (dy - d'' - ay/2) + Csy \times (dy - d' - d'') + Ty \times d''$	(59)

RESULTS AND DISCUSSIONS

Smartphone Application

Initial information will appear first, when the smartphone is turned on, followed by the initial selection menu.

Figure 13. Opening menu on smartphone

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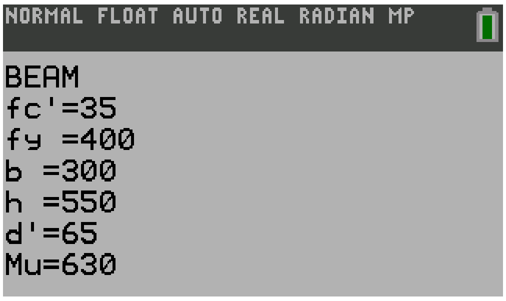

Figure 14.a. Flexure beam Input

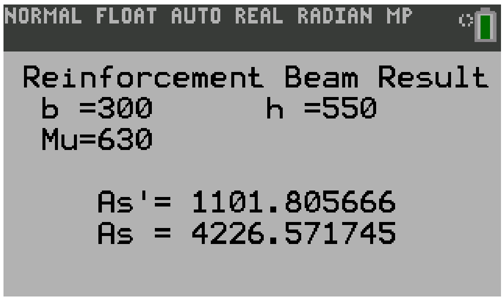

Figure 14.b. Flexure beam Output

Figure 15.a. Shear beam Input

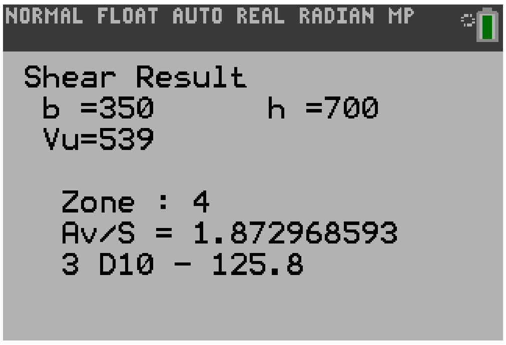

Figure 15.b. Shear beam Output

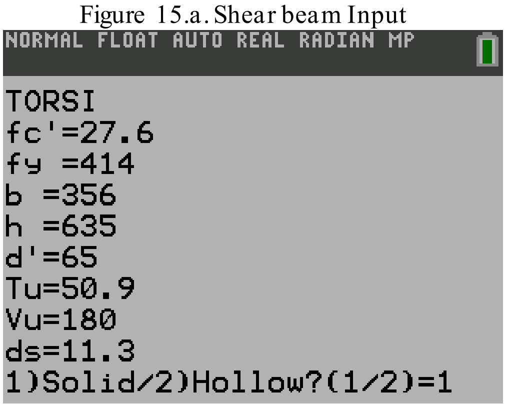

Figure 16.a. Torsion beam Input

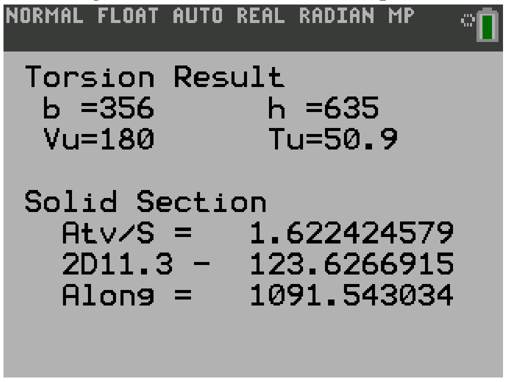

Figure 16.b. Torsion beam Output

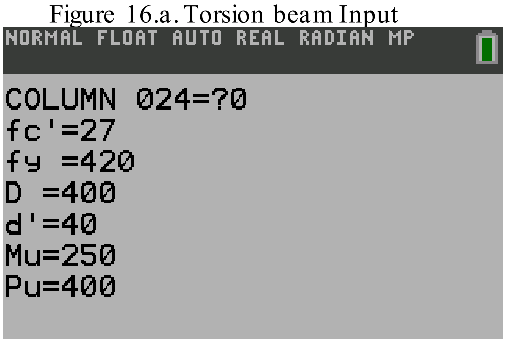

Figure 17.a. Circular column Input

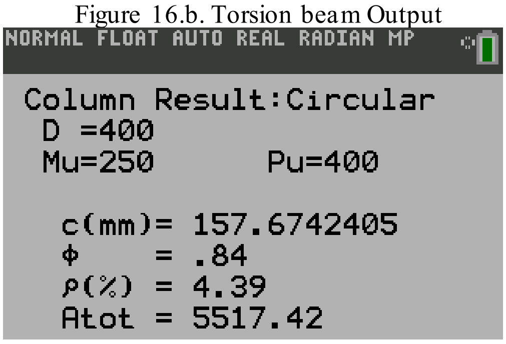

Figure 17.b. Circular column Output

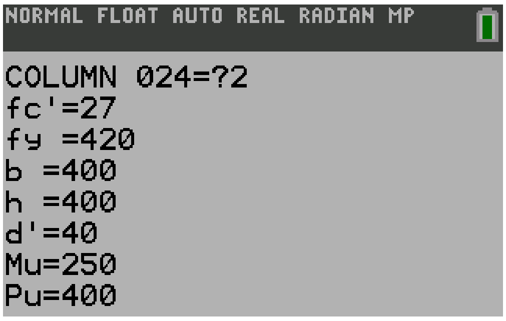

Figure 18.a. Column two faces Input

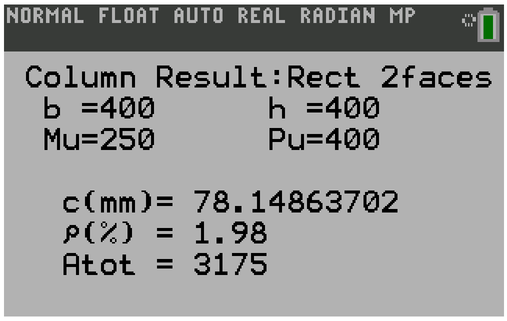

Figure 18.b. Column two faces Output

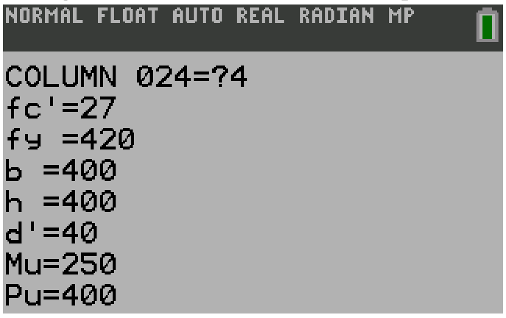

Figure 19.a. Column four faces Input

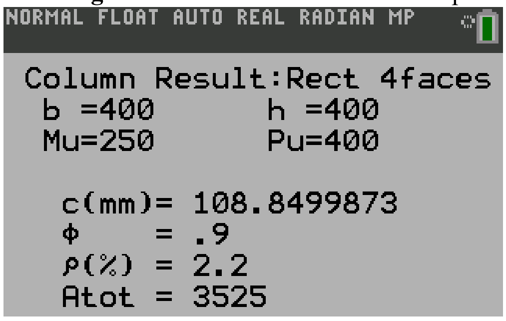

Figure 19.b. Column four faces Output

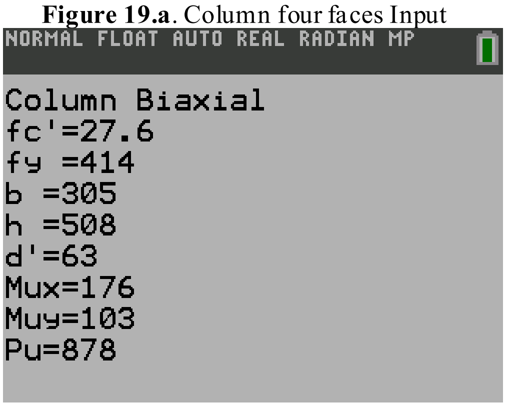

Figure 20.a. Column biaxial Input

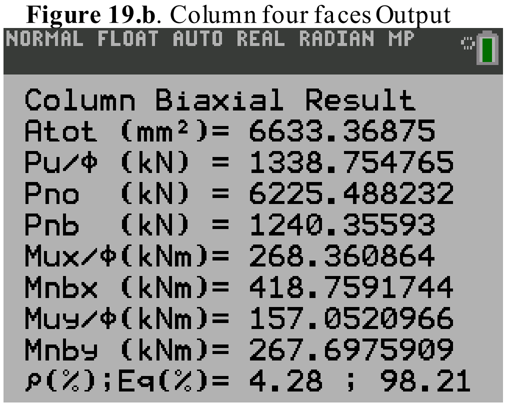

Figure 20.b. Column biaxial Output

Figure 14 to figure 20, consists of 2 (two) parts, namely part a) is input data and part b) is output result. respectively are beam reinforcement designs namely flexural bending reinforcement (figure 14), shear reinforcement (figure 15), torsion reinforcement (figure 16), and column reinforcement design circular column (figure 17), rectangular column two faces (figure 18), rectangular column four faces (figure 19) and biaxial bending column (figure 20)

Manual Calculation

Calculation of reinforcement for beams and columns manually using the formula for reinforcement of concrete due to bending, shear, torsion, axial and biaxial bending.

1 Flexural reinforcement
Initial data required : fc' = 35 MPa; fy = 400 MPa; b = 300 mm; h = 550 mm; d' = 65 mm; Mu = 450 kNm. The results of manual calculations are obtained as follows
Result: As (Eq. 33) = 1100 mm^2; As'(Eq. 34) = 4227 mm^2

2 Shear reinforcement
Initial data required : fc' = 35 MPa; fy = 420 MPa; b = 350 mm; h = 700 mm; d' = 65 mm; nk = 3; ds = 10 mm; Vu = 539 kN.
The results of manual calculations are obtained as follows
Result: S (Eq. 36.a to 36.e) = 125.7 mm

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3 Torsion reinforcement
Initial data required : fc' = 27.6 MPa; fy = 414 MPa; b = 356 mm; h = 635 mm; d' = 65 mm; ds = 11.3 mm; Vu = 180 kN; Tu = 50.9 kNm; Solid . The results of manual calculations are obtained as follows
Result: S (Eq. 41) = 125 mm; Along (Eq. 42) = 1086 mm^2

4 Column uniaxial
Initial data required : fc' = 27 MPa; fy = 420 MPa; h = 400 mm; b = 400 mm; d' = 40 mm; Pu = 400 kN; Mu = 250 kNm. The results of manual calculations are obtained as follows.
Result: a) Cicular: Atot (Eq. 47 & 48) = 5348 mm^2; b) Rectangular two faces: Atot (Eq. 47 & 48) = 3189 mm^2; c) Rectangular four faces: Atot (Eq. 47 & 48) = 3522 mm^2

5 Column biaxial
Initial data required :fc' = 27.6 Mpa ; fy = 414 MPa; b = 508 mm; h = 305 mm; d' = 63 mm; Pu = 878 kN; Mux = 176 kNm; Muy = 103 kNm. The results of manual calculations are obtained as follows.
Result : As (Eq. 49) = 6710 mm2 ; Interaction (Eq. 51) = 98.99%

CONCLUSION

Smartphone calculation and manual calculation are flexural reinforcement, shear reinforcement, torsional reinforcement, column circular reinforcement, column rectangular two faces reinforcement, column rectangular four faces reinforcement, column biaxial reinforcement such as:

Flexural reinforcement: difference As = 0%; difference As' = 0.18%
Shear reinforcement: difference S = 0.08%
Torsional reinforcement: difference S = 1.12%; difference Al = 0.51%
Column circular reinforcement: difference Astot= 3.16%
Column rectangular two faces reinforcement: difference Astot = 0.44%
Column rectangular four faces reinforcement: difference Astot = 0.09%
Column biaxial reinforcement: difference = 1.15%
for all cases less than 5%, the calculation of smartphone using Texas Instrument is accurate

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