ACI Fall Convention 2008

St. Louis

ACI 314 Committee Meeting
Sunday, November 2

ARGENTINA DOCUMENT

Developed for INTI-CIRSOC by

Eng. Daniel Ortega from
INTI -CIRSOC

Eng. Victorio Hernández Balat
Eng. Juan Francisco Bissio
from Quasdam Ingeniería

The main purpose of this document is to put forward a proposal for the development of new design aids based on ACI 318-08.

INTI-CIRSOC, which is the official institution in charge of national safety and structural codes in Argentina, wants to cooperate with the American Concrete Institute developing these aids in both US Customary and Metric Units.

This proposal contains four types of design aids:

- Flexure - Tension and Compression Reinforcement (when needed)
- Axial and Flexure
  - Uniaxial Bending
    - Symmetrical Reinforcement
    - Unsymmetrical Reinforcement
  - Biaxial Bending

All these design aids allow direct reading of reinforcement.

For each type of aids

- A Sample Design Aid
- Step by step procedures
- Step by step examples
- The proposed scheme for each set of aids

are presented.

If this proposal is accepted further discussion will be needed in order to coordinate details.

FLEXURE – OPTIMAL DESIGN

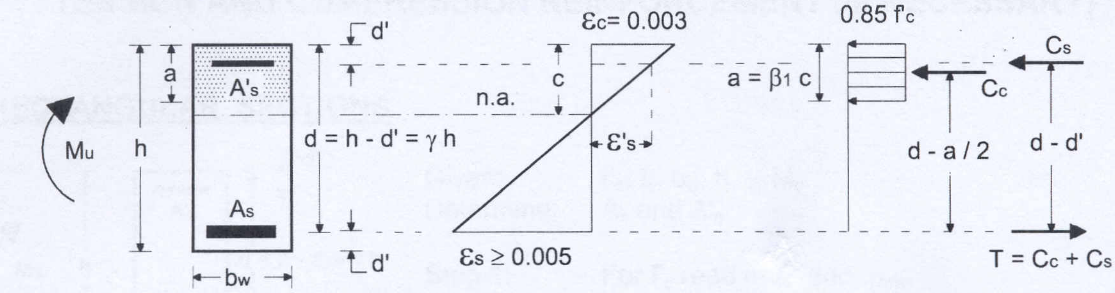
DESIGN AIDS FLE-XX

RECTANGULAR AND FLANGED SECTIONS WITH TENSION AND COMPRESSION REINFORCEMENT (IF NECESSARY)

Contents:

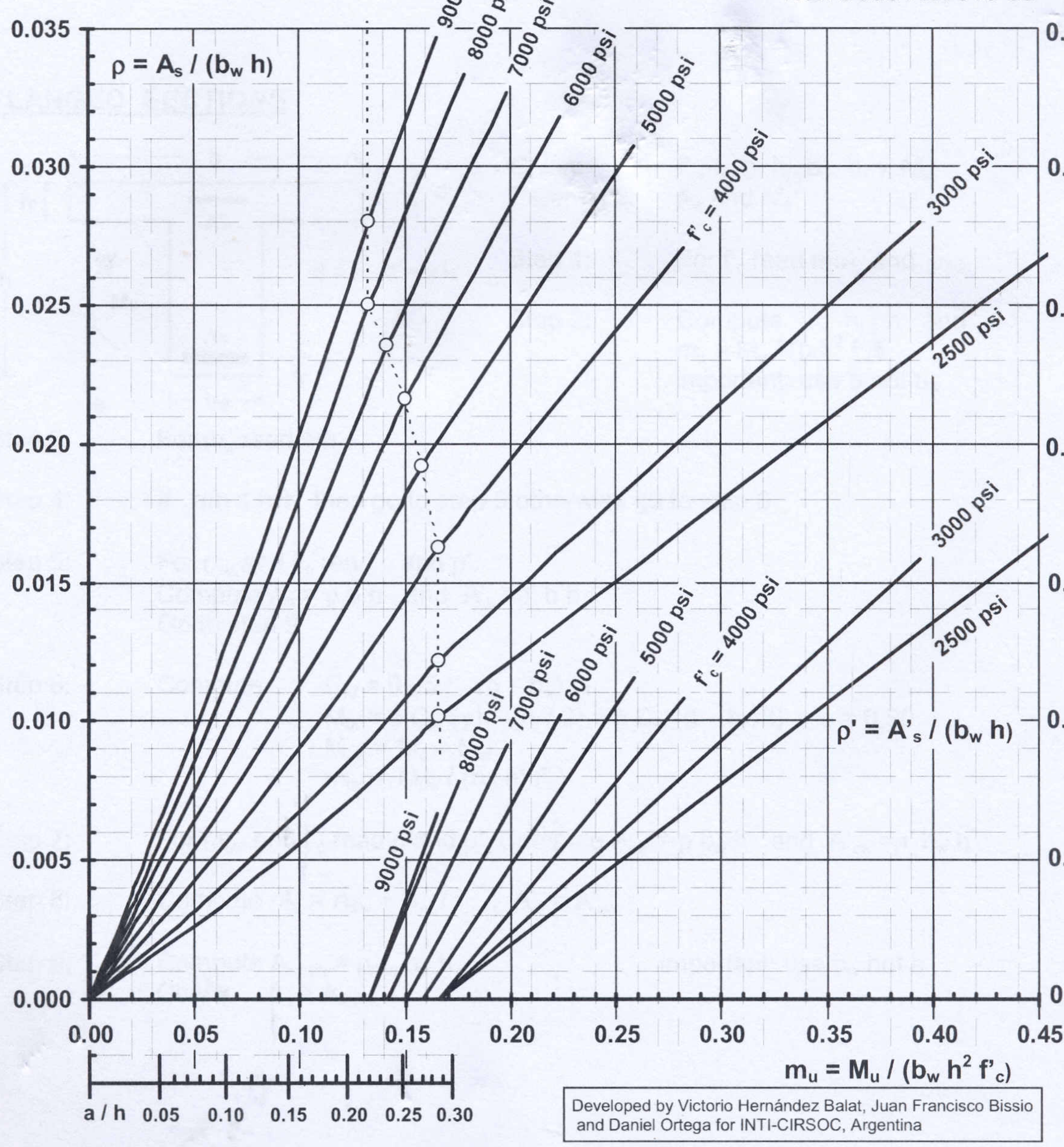
- Sample Design Aid
- Step by step procedures for rectangular and flanged sections
- Step by step examples for rectangular and flanged sections
- Proposed scheme for the whole set of aids

FLEXURE – OPTIMAL DESIGN - f_y = 60,000 psi - $\gamma = d / h = 0.90$ | FLE - XX



	f'c (psi)							
	2500	3000	4000	5000	6000	7000	8000	9000
m_{u1}	0.0564	0.0474	0.0359	0.0303	0.0277	0.0257	0.0241	0.0227
ρ_{min}	0.0030	0.0030	0.0030	0.0032	0.0035	0.0038	0.0040	0.0043
β_1	0.850	0.850	0.850	0.801	0.752	0.702	0.653	0.650

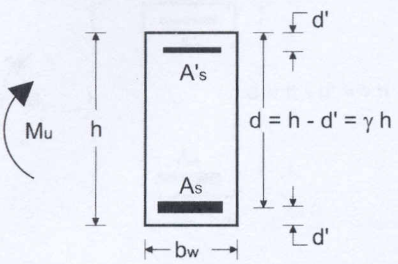
Ref. Code ACI 318-08



Developed by Victorio Hernández Balat, Juan Francisco Bissio and Daniel Ortega for INTI-CIRSOC, Argentina

FLEXURE – OPTIMAL DESIGN – DESIGN AIDS FLE-XX
PROCEDURES FOR RECTANGULAR AND FLANGED SECTIONS WITH TENSION AND COMPRESSION REINFORCEMENT (IF NECESSARY)

RECTANGULAR SECTIONS



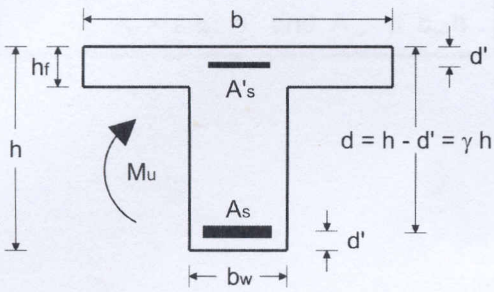
Given: f'_c, f_y, b_w, h, γ, M_u
Determine: A_s and A'_s

Step 1: For f'_c read mu_1 and ρ_{min}

Step 2: Compute $m_u = M_u / (b_w h^2 f'_c)$

Step 3:
- ► If $m_u \le m_{u1}$ then $A_s = \rho_{min} b_w h$ ($A'_s = 0$)
- ► If $m_u > m_{u1}$ then for m_u and f'_c read ρ and ρ' (ρ' could be zero)
  Compute $A_s = \rho\, b_w h$ and $A'_s = \rho'\, b_w h$

FLANGED SECTIONS



Given: f'_c, f_y, b, h_f, b_w, h, γ, M_u
Determine: A_s and A'_s

Step 1: For f'_c read mu_1 and ρ_{min}

Step 2: Compute h_f / h and
$m_u = M_u / (b\, h^2 f'_c)$
important: use b not b_w

Step 3: For m_u read a/h

Step 4: If $a/h \le h_f/h$ then go to step 5 otherwise go to step 6

Step 5: For m_u and f'_c read ρ and ρ'.
Compute $A_s = \rho\, b\, h$ and $A'_s = \rho'\, b\, h$
Go to step 9

Step 6: Compute
$C_{nf} = 0.85 f'_c (b - b_w) h_f$
$M_{uf} = \phi C_{nf} (\gamma h - h_f / 2) = \phi C_{nf} (d - h_f /2)$; $\phi = 0.90$
$M_{uw} = M_u - M_{uf}$
$m_{uw} = M_{uw} / (b_w h^2 f'_c)$

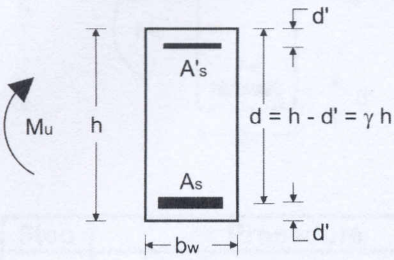
Step 7: For m_{uw} and f'_c read ρ and ρ'. Compute $A_{sw} = \rho\, b_w h$ and $A'_{sw} = \rho'\, b_w h$

Step 8: Compute $A_s = A_{sw} + C_{nf} / f_y$; $A'_s = A'_{sw}$

Step 9: Compute $A_{s\,min} = \rho_{min} b_w h$ — important: use b_w not b
Check $A_s \ge A_{s\,min}$

FLEXURE – OPTIMAL DESIGN – DESIGN AIDS FLE-XX
EXAMPLES FOR RECTANGULAR AND FLANGED SECTIONS WITH TENSION AND COMPRESSION REINFORCEMENT (IF NECESSARY)

RECTANGULAR SECTIONS



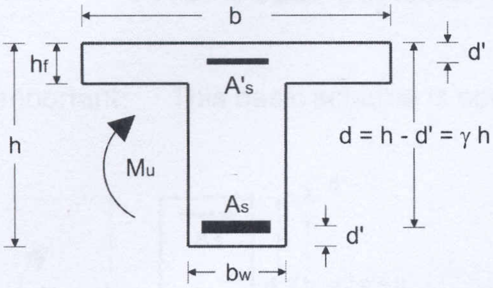
Given: f'_c = 4000 psi ; f_y = 60,000 psi
b_w = 14" ; h = 25" ; $\gamma = d / h \approx 0.90$

a) M_u = 95 ft-kips = 1140 in-kips
b) M_u = 205 ft-kips = 2460 in-kips
c) M_u = 598 ft-kips = 7175 in-kips

Determine: A_s and A'_s

Step	Procedure	Case a)	Case b)	Case c)
1	For f'_c read m_{u1} and ρ_{min}	m_{u1} = 0.0359, ρ_{min} = 0.0030		
2	$m_u = M_u / (b h^2 f'_c)$	0.0326	0.0703	0.205
3	Compare	$m_u \le m_{u1}$	$m_u > m_{u1}$	$m_u > m_{u1}$
	For m_{uw} and f'_c read ρ and ρ' or $\rho = \rho_{min}$ if $m_u \le m_{u1}$	ρ_{min} = 0.0030	ρ = 0.0062 ρ' = 0	ρ = 0.0198 ρ' = 0.0036
	$A_s = \rho b_w h$ and $A'_s = \rho' b_w h$	A_s = 1.05 in.^{2} A'_s = 0.00 in.^{2}	A_s = 2.17 in.^{2} A'_s = 0.00 in.^{2}	A_s = 6.93 in.^{2} A'_s = 1.26 in.^{2}

FLANGED SECTIONS



Given: $f'_c = 4000$ psi ; $f_y = 60{,}000$ psi
$b = 42"$; $h_f = 4"$
$b_w = 14"$; $h = 25"$; $\gamma = d / h \approx 0.90$

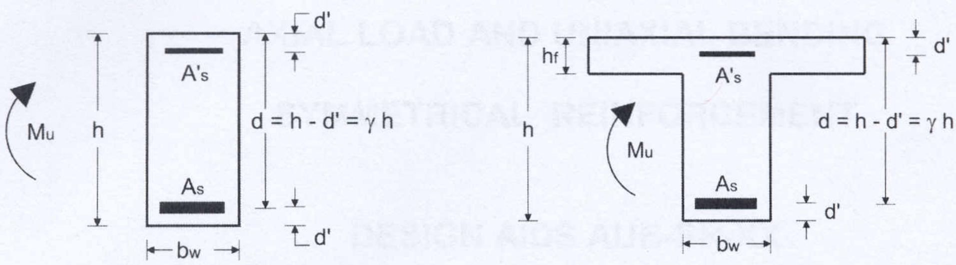
a) $M_u =$ 420 ft-kips = 5,040 in-kips
b) $M_u =$ 1000 ft-kips = 12,000 in-kips
c) $M_u =$ 1170 ft-kips = 14,040 in-kips

Determine: A_s and A'_s

Step	Procedure	Case a)	Case b)	Case c)
1	For f'_c read m_{u1} and ρ_{min}	$m_{u1} = 0.0359$, $\rho_{min} = 0.0030$		
2	h_f / h	0.16		
	$m_u = M_u / (b\, h^2\, f'_c)$	0.048	0.1143	0.1337
3	For m_u read a / h	0.072	0.185	0.225
4	Compare	$a / h < h_f / h$	$a / h > h_f / h$	$a / h > h_f / h$
	Action	go to step 5	go to step 6	go to step 6
5	For m_u and f'_c read ρ and ρ'	$\rho = 0.0041$ $\rho' = 0$	--------	--------
	$A_s = \rho\, b\, h$ and $A'_s = \rho'\, b\, h$	$A_s = 4.31$ in.^{2} $A'_s = 0.00$ in.^{2}	--------	--------
	Action	go to step 9	--------	--------
6	$C_{nf} = 0.85\, f'_c\, (b - b_w)\, h_f$	--------	380.80 kips	380.80 kips
	$M_{uf} = 0.90\, C_{nf}\, (\gamma h - h_f / 2)$	--------	7025.76 in-kips	7025.76 in-kips
	$M_{uw} = M_u - M_{uf}$	--------	4974.24 in-kips	7014.24 in-kips
	$m_{uw} = M_{uw} / (b_w\, h^2\, f'_c)$	--------	0.1421	0.2004
7	For m_{uw} and f'_c read ρ and ρ'	--------	$\rho = 0.0135$ $\rho' = 0$	$\rho = 0.0194$ $\rho' = 0.0032$
	$A_{sw} = \rho\, b_w\, h$ and $A'_{sw} = \rho'\, b_w\, h$	---------	$A_{sw} = 4.73$ in.^{2} $A'_{sw} = 0.00$ in.^{2}	$A_{sw} = 6.79$ in.^{2} $A'_{sw} = 1.12$ in.^{2}
8	$A_s = A_{sw} + C_{nf} / f_y$ and $A'_s = A'_{sw}$	--------	$A_s = 11.08$ in.^{2} $A'_s = 0.00$ in.^{2}	$A_s = 13.14$ in.^{2} $A'_s = 1.12$ in.^{2}
9	$A_{s\,min} = \rho_{min}\, b_w\, h$	1.05 in.^{2}		
	Check $A_s \geq A_{s\,min}$	Ok	Ok	Ok

FLEXURE – OPTIMAL DESIGN – DESIGN AIDS FLE-XX
PROPOSED SCHEME FOR THE WHOLE SET OF AIDS

Important: This basic scheme is open to discussion.



U.S. Customary Units Version

f'_c (psi): 2500, 3000, 4000, 5000, 6000, 7000, 8000, 9000
f_y (ksi): Grade 60 and 75
$\gamma = d / h$: 0.95, 0.90, 0.85

Total: 6 Aids

Metric Version

f'_c (MPa): 17, 20, 25, 30, 35, 40, 45, 50, 55, 60
f_y (MPa): Grade 420 and 520
$\gamma = d / h$: 0.95, 0.90, 0.85

Total: 6 Aids

AXIAL LOAD AND UNIAXIAL BENDING

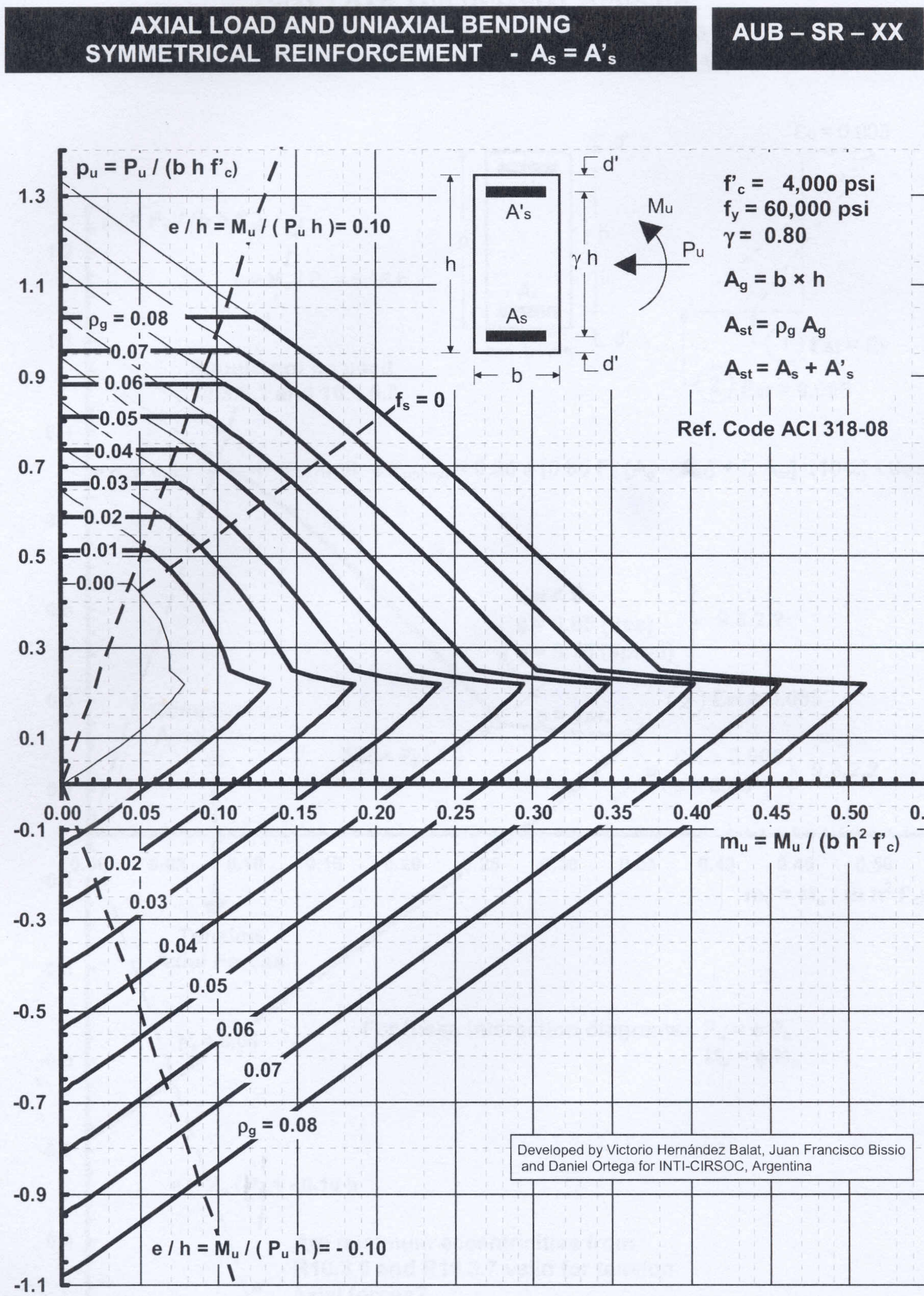
SYMMETRICAL REINFORCEMENT

DESIGN AIDS AUB-SR-XX

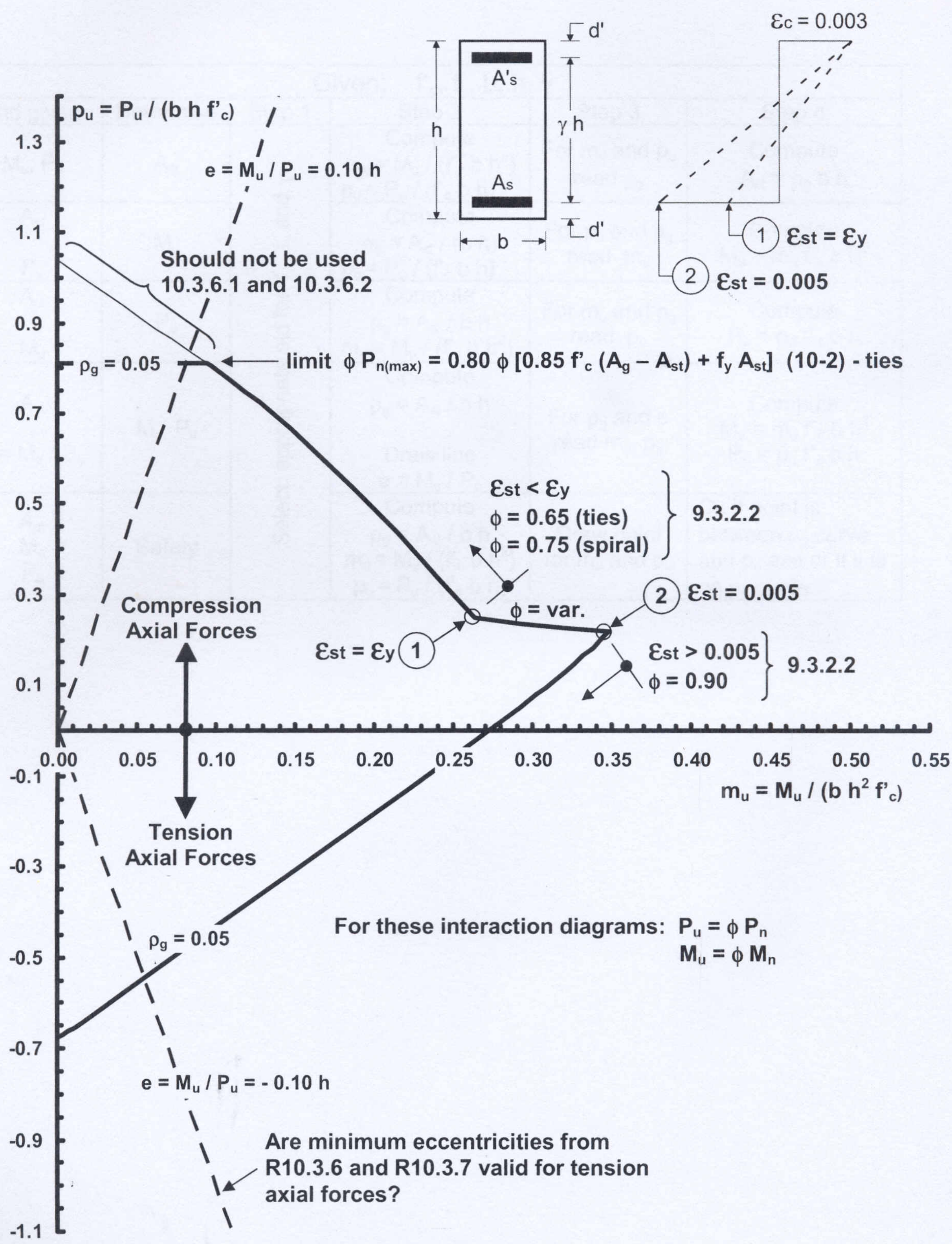
RECTANGULAR, CIRCULAR AND ANNULAR SECTIONS

Contents:

- Sample Design Aid
- Step by step procedures
- Step by step examples
- Proposed scheme for the whole set of aids


AXIAL LOAD AND UNIAXIAL BENDING
SYMMETRICAL REINFORCEMENT - As = A's
AUB – SR – XX
pu = Pu / (b h f'c)
e / h = Mu / (Pu h)= 0.10
ρg = 0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
fs = 0
h
γ h
A's
As
b
d'
Mu
Pu
f'c = 4,000 psi
fy = 60,000 psi
γ = 0.80
Ag = b × h
Ast = ρg Ag
Ast = As + A's
Ref. Code ACI 318-08
1.3
1.1
0.9
0.7
0.5
0.3
0.1
-0.1
-0.3
-0.5
-0.7
-0.9
-1.1
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
mu = Mu / (b h2 f'c)
ρg = 0.08
e / h = Mu / (Pu h)= - 0.10
Developed by Victorio Hernández Balat, Juan Francisco Bissio and Daniel Ortega for INTI-CIRSOC, Argentina

AXIAL LOAD AND UNIAXIAL BENDING
SYMMETRICAL REINFORCEMENT – $A_s = A'_s$
UNDERSTANDING INTERACTION DIAGRAMS



AXIAL LOAD AND UNIAXIAL BENDING
SYMMETRICAL REINFORCEMENT
DESIGN AIDS AUB-SR-XX
PROCEDURES FOR DESIGN AND VERIFICATION

Given: f'_c, f_y, b, h, γ					
and given	Determine	Step 1	Step 2	Step 3	Step 4
M_u, P_u	A_{st}	Select appropriate aid for f'_c, f_y and γ	Compute $m_u = M_u / (f'_c\ b\ h^2)$ $p_u = P_u / (f'_c\ b\ h)$	For m_u and p_u read ρ_g	Compute $A_{st} = \rho_g\ b\ h$
A_{st} P_u	M_u		Compute $\rho_g = A_{st} / (b\ h)$ $p_u = P_u / (f'_c\ b\ h)$	For p_u and ρ_g read m_u	Compute $M_u = m_u\ f'_c\ b\ h^2$
A_{st} M_u	P_u		Compute $\rho_g = A_{st} / b\ h$ $m_u = M_u / (f'_c\ b\ h^2)$	For m_u and ρ_g read p_u	Compute $P_u = p_u\ f'_c\ b\ h$
A_{st} $e = M_u / P_u$	M_u, P_u		Compute $\rho_g = A_{st} / b\ h$ Draw line $e = M_u / P_u$	For ρ_g and e read m_u, p_u	Compute $M_u = m_u\ f'_c\ b\ h^2$ $P_u = p_u\ f'_c\ b\ h$
A_{st} M_u P_u	Safety		Compute $\rho_g = A_{st} / b\ h$ $m_u = M_u / (f'_c\ b\ h^2)$ $p_u = P_u / (f'_c\ b\ h)$	Draw point for m_u and p_u	Ok if point is between ρ_g curve and p_u axe or if it is on ρ_g curve

AXIAL LOAD AND UNIAXIAL BENDING
SYMMETRICAL REINFORCEMENT
DESIGN AIDS AUB-SR-XX
EXAMPLES FOR DESIGN AND VERIFICATION

Given: f'_c = 4000 psi ; f_y = 60,000 psi ; b = 14" ; h = 25" ; $\gamma = (h - 2d')/h \approx 0.80$					
and given	**Determine**	**Step 1**	**Step 2**	**Step 3**	**Step 4**
M_u = 470 ft-kips M_u = 5640 in-kips P_u= 420 kips	A_{st}	Select appropriate aid for f'_c, f_y and γ	Compute $m_u = M_u / (f'_c\ b\ h^2)$ m_u = 0.161 $p_u = P_u / (f'_c\ b\ h)$ p_u = 0.300	For m_u and p_u read ρ_g = 0.026	Compute $A_{st} = \rho_g\ b\ h$ A_{st} = 9.10 in.^{2}
A_{st} = 12.25 in.^{2} P_u = -168 kips (tension)	M_u		Compute $\rho_g = A_{st} / (b\ h)$ ρ_g = 0.035 $p_u = P_u / (f'_c\ b\ h)$ pu = - 0.120	For p_u and ρ_g read m_u = 0.148	Compute $M_u = m_u\ f'_c\ b\ h^2$ M_u = 5180 in-kips
A_{st} = 12.25 in.^{2} M_u = 470 ft-kips M_u = 5640 in-kips	P_u		Compute $\rho_g = A_{st} / b\ h$ ρ_g = 0.035 $m_u = M_u / (f'_c\ b\ h^2)$ m_u = 0.161	For m_u and ρ_g read p_u = 0.430 p_u = -0.075	Compute $P_u = p_u\ f'_c\ b\ h$ P_u = 602 kips P_u = - 105 kips
A_{st} = 12.25 in.^{2} $e = M_u / P_u$ = 0.50 h	M_u, P_u		Compute $\rho_g = A_{st} / b\ h$ ρ_g = 0.035 Draw line $e = M_u / P_u$ = 0.5 h	For ρ_g and e read m_u = 0.18 p_u= 0.36	Compute $M_u = m_u\ f'_c\ b\ h^2$ M_u = 6300 in-kips $P_u = p_u\ f'_c\ b\ h$ P_u = 504 ips
A_{st} = 12.25 in.^{2} M_u = 470 ft-kips M_u = 5640 in-kips P_u= 665 kips	Safety		Compute $\rho_g = A_{st} / b\ h$ ρ_g = 0.035 $m_u = M_u / (f'_c\ b\ h^2)$ m_u = 0.161 $p_u = P_u / (f'_c\ b\ h)$ p_u = 0.475	Draw point for m_u and p_u	Point is exterior Given m_u, p_u combination is UNSAFE

AXIAL LOAD AND UNIAXIAL BENDING
SYMMETRICAL REINFORCEMENT
DESIGN AIDS AUB-SR-XX
PROPOSED SCHEME FOR THE WHOLE SET OF AIDS

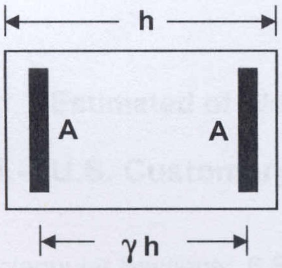
Important: This basic scheme is open to discussion.

1.- General

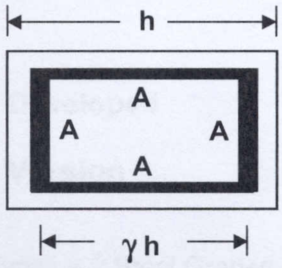
Only tied sections are considered (not spirally reinforced sections are considered)

2.- Concrete Sections and Reinforcement Arrangements to be Considered

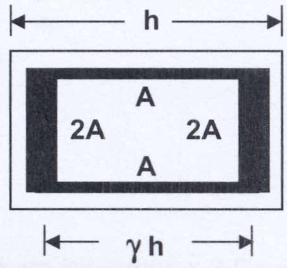
Section R1



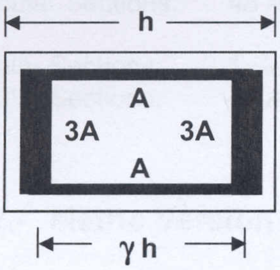
Section R2



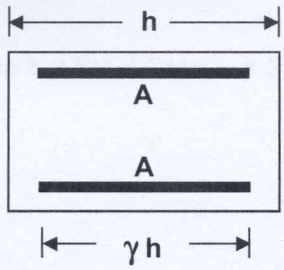
Section R3



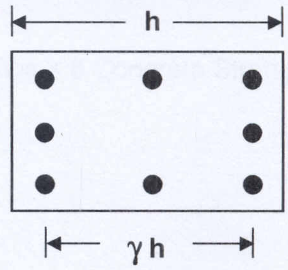
Section R4



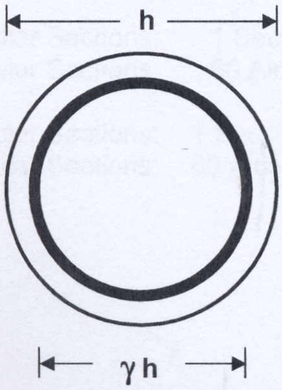
Section R5



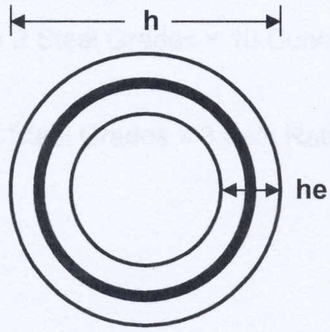
Section R6



Section C1



Section A1



3.- Other Parameters

3.1.- U.S. Customary Units Version

f'_c (psi):	2500, 3000, 4000, 5000, 6000, 7000, 8000, 9000
f_y (ksi):	Grade 60 and 75
γ :	0.90, 0.80, 0.70
he/h:	0.10, 0.20, 0.30

3.2.- Metric Version

f'_c (MPa):	17, 20, 25, 30, 35, 40, 45, 50, 55, 60
f_y (MPa):	Grade 420 and 520
γ :	0.90, 0.80, 0.70
he/h:	0.10, 0.20, 0.30

4.- Estimated of Aids to be Developed

4.1.- U.S. Customary Units Version

Rectangular Sections: 6 Section Types × 2 Steel Grades × 8 Concrete Strengths × 3 Covers
Rectangular Sections: 288 Aids

Circular Sections: 1 Section Type × 2 Steel Grades × 8 Concrete Strengths × 3 Covers
Circular Sections: 48 Aids

Anular Sections: 1 Section Tipe × 2 Steel Grades × 3 he/h Ratios × 8 Concrete Strengths
Anular Sections: 48 Aids

4.2.- Metric Version

Rectangular Sections: 6 Section Types × 2 Steel Grades × 10 Concrete Strengths × 3 Covers
Rectangular Sections: 360 Aids

Circular Sections: 1 Section Type × 2 Steel Grades × 10 Concrete Strengths × 3 Covers
Circular Sections: 60 Aids

Annular Sections: 1 Section Type × 2 Steel Grades × 3 he/h Ratios × 10 Concrete Strengths
Annular Sections: 60 Aids

AXIAL LOAD AND UNIAXIAL BENDING

UNSYMMETRICAL REINFORCEMENT

DESIGN AIDS AUB-NSR-XX

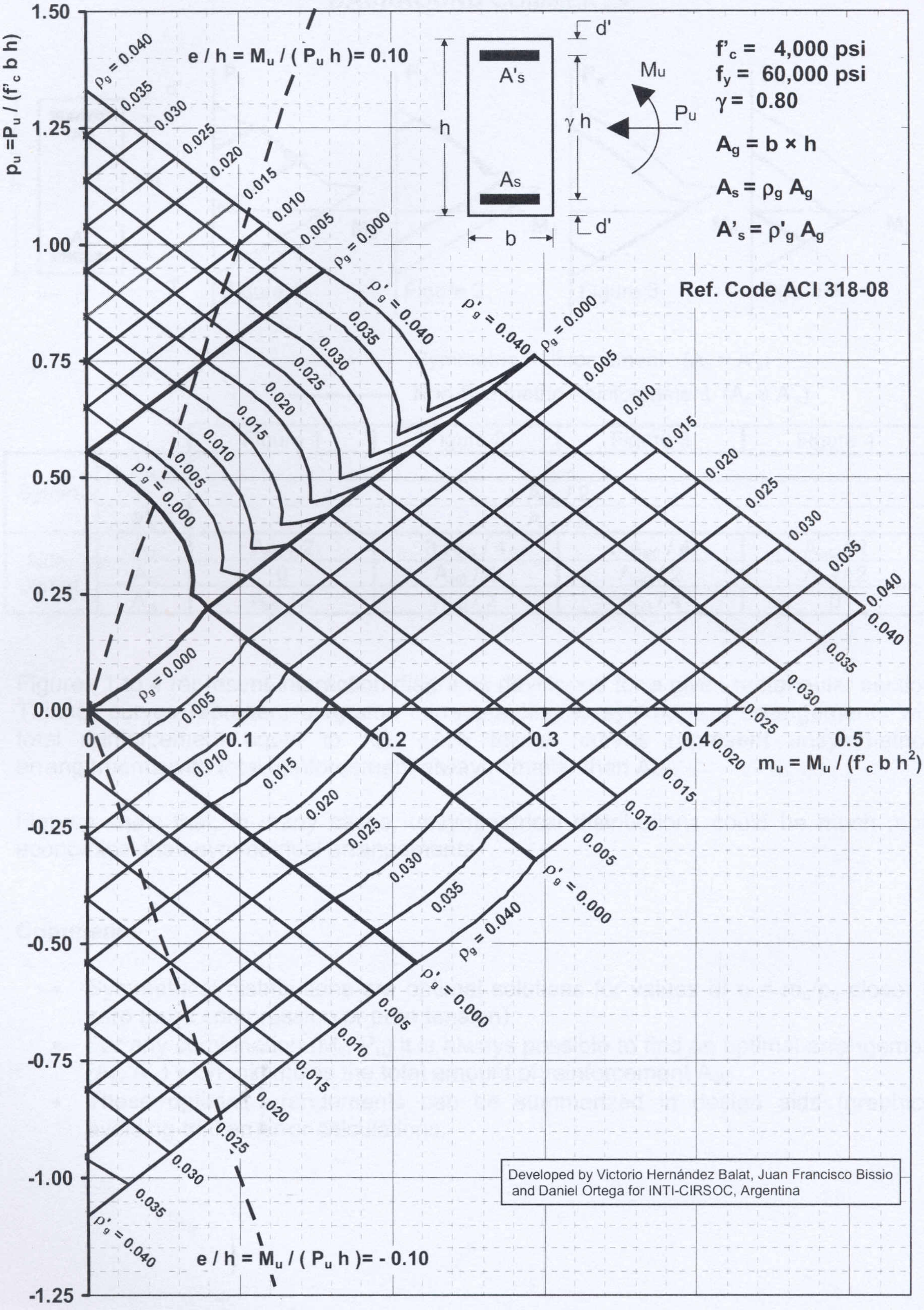
RECTANGULAR SECTIONS

Contents:

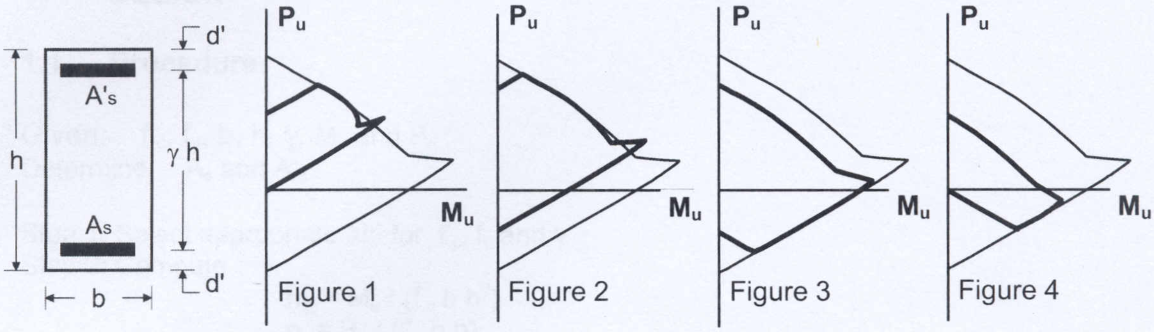
- Sample Design Aid
- Background comments
- Step by step procedures
- Step by step examples
- Proposed scheme for the whole set of aids

AXIAL LOAD AND UNIAXIAL BENDING UNSYMMETRICAL REINFORCEMENT

AUB – NSR – XX



AXIAL LOAD AND UNIAXIAL BENDING
UNSYMMETRICAL REINFORCEMENT
DESIGN AIDS AUB-NSR-XX
BACKROUND COMMENTS



Symmetric Reinforcement ($A_s = A'_s$)

Non-Symmetric Reinforcement ($A_s \neq A'_s$)

		Figure 1	Figure 2	Figure 3	Figure 4
Symm.	A_{st}	A_{st0}			
	A_s	A_{st0} / 2			
	A'_s	A_{st0} / 2			
Non-Symm.	A_{st}	A_{st0} / 2	3 A_{st0} / 4	3 A_{st0} / 4	A_{st0} / 2
	A_s	0	A_{st0} / 4	A_{st0} / 2	A_{st0} / 2
	A'_s	A_{st0} / 2	A_{st0} / 2	A_{st0} / 4	0

Figures 1 to 4 represent interaction diagrams developed for a given rectangular section. Thinner curves represent diagrams corresponding to symmetrical arrangements with total reinforcement equal to A_{st0} while thicker curves represent unsymmetrical arrangements with total reinforcement always smaller than A_{st0}.

Figures show that, in many cases, unsymmetrical distributions could be much more economical than symmetrical arrangements.

Comments

- Symmetrical distributions are optimal solutions for values of $e = m_u/p_u$ closer to zero (pure compression or pure tension).
- For any combination (M_u, P_u) it is always possible to find an optimal arrangement (A_s, A'_s) wich minimizes the total amount of reinforcement A_{st0}.
- These optimal arrangements can be summarized in design aids (graphics) avoiding trial an error calculations.

AXIAL LOAD AND UNIAXIAL BENDING
UNSYMMETRICAL REINFORCEMENT
DESIGN AIDS AUB-NSR-XX
PROCEDURES FOR DESIGN AND VERIFICATION

1. DESIGN

1.1. Procedure

Given: f'_c, f_y, b, h, γ, M_u and P_u
Determine: A_s and A'_s

Step 1: Select appropriate aid for f'_c, f_y and γ
Step 2: Compute

$$m_u = M_u / (f'_c\, b\, h^2)$$
$$p_u = P_u / (f'_c\, b\, h)$$

Step 3: For m_u and p_u read ρ_g and ρ'_g
Step 4: Compute

$$A_s = \rho_g\, b\, h$$
$$A'_s = \rho'_g\, b\, h$$

1.2. Examples

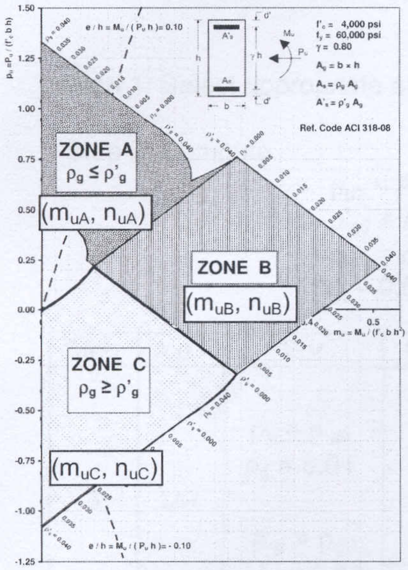
Given: f'_c = 4000 psi ; f_y = 60,000 psi ; b = 14" ; h = 25" ; $\gamma = (h - 2d') / h \approx 0.80$					
and given	Determine	Step 1	Step 2		
M_u = 470 ft-kips M_u = 5640 in-kips P_u= 420 kips (*)	A_s A'_s	Select appropriate aid for f'_c, f_y and γ	Compute $m_u = M_u / (f'_c\, b\, h^2)$ m_u = 0.161 $p_u = P_u / (f'_c\, b\, h)$ p_u = 0.300	For m_u and p_u read ρ_g = 0.0055 ρ'_g = 0.0105	Compute $A_s = \rho_g\, b\, h$ A_s = 1.93 in.^{2} $A'_s = \rho'_g\, b\, h$ A'_s = 3.68 in.^{2}
M_u = 205 ft-kips M_u = 2460 in-kips P_u= 0 kips (**)			Compute $m_u = M_u / (f'_c\, b\, h^2)$ m_u = 0.07 $p_u = P_u / (f'_c\, b\, h)$ p_u = 0	For m_u and p_u read ρ_g = 0.006 ρ'_g = 0	Compute $A_s = \rho_g\, b\, h$ A_s = 2.10in.^{2} $A'_s = \rho'_g\, b\, h$ A'_s = 0 in.^{2}
M_u 598 ft-kips M_u = 7175 in-kips P_u= 0 kips (***)			Compute $m_u = M_u / (f'_c\, b\, h^2)$ m_u = 0.205 $p_u = P_u / (f'_c\, b\, h)$ p_u = 0	For m_u and p_u read ρ_g = 0.020 ρ'_g = 0.0035	Compute $A_s = \rho_g\, b\, h$ A_s = 7.00 in.^{2} $A'_s = \rho'_g\, b\, h$ A'_s = 1.22 in.^{2}

(*) Data are the same as for First Example for Axial Load and Uniaxial Bending with Symmetrical Reinforcement. Results: A_s = 4.55 in.^{2} ; A'_s = 4.55 in.^{2} (A_{st} = 9.10 in.^{2})
(**) Data are the same as for Flexure example b. Results: A_s = 2.17 in.^{2} ; A'_s = 0 in.^{2}
(***) Data are the same as for Flexure example c. Results: As = 6.93 in.^{2} ; A's = 1.26 in.^{2}

2. VERIFICATION

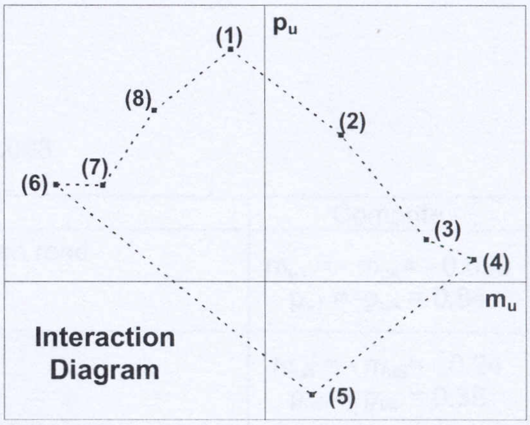
2.1 Procedure

Given: f'_c, f_y, b, h, γ, A_s and A'_s
Plot: Complete Interaction Diagram



Step 1: Select appropriate aids for f'_c, f_y, γ (symmetrical and unsymmetrical reinforcement aids). For these calculations unsymmetrical aid will be considered divided into three zones (see figure)

Step 2: Compute
$\rho_{g0} = A_s / (b\ h)$
$\rho'_{g0} = A'_s / (b\ h)$
$\rho_{gt0} = \rho_{g0} + \rho'_{g0}$
$\Delta = 0.65\ (\rho_{g0} - \rho'_{g0})\ f_y / f'_c$



Step	Aid	For	Point	Action	Compute
3	UR (*)	$\rho_g = \rho'_{g0}$ $\rho'_g = \rho_{g0}$	(1)	If $\rho_g \geq \rho'_g$ then read m_{uA} , p_{uA} else determine point from 4 (1)	$m_{u1} = -\ m_{uA}$ $p_{u1} = p_{uA}$
			(6)	Read m_{uB}, n_{uB}	$m_{u6} = -\ m_{uB}$ $p_{u6} = p_{uB}$
			(5)	If $\rho_g < \rho'_g$ then read m_{uC} , p_{uC} else determine point form 4 (5)	$m_{u5} = -\ m_{uC}$ $p_{u5} = p_{uC}$
4	UR (*)	$\rho_g = \rho_{g0}$ $\rho'_g = \rho'_{g0}$	(1)	If $\rho_g < \rho'_g$ then read m_{uA} , p_{uA} else determine point from 3 (1)	$m_{u1} = m_{uA}$ $p_{u1} = p_{uA}$
			(4)	Read m_{uB}, n_{uB}	$m_{u4} = m_{uB}$ $p_{u4} = p_{uB}$
			(5)	If $\rho_g \geq \rho'_g$ then read m_{uC} , p_{uC} else determine point from 3 (5)	$m_{u5} = m_{uC}$ $p_{u5} = p_{uC}$
5	SR (*)	$\rho_g = 2\ \rho'_{g0}$ $f_s = 0$	(2)	Read m_u, n_u	$m_{u2} = m_u$ $p_{u2} = p_u$
6	SR (*)	$\rho_g = 2\ \rho_{g0}$ $f_s = 0$	(8)	Read m_u, n_u	$m_{u8} = -\ m_u$ $p_{u8} = p_u$
7	SR (*)	$\rho_g = \rho_{g0} + \rho'_{g0}$ $\varepsilon_t = \varepsilon_y$	(3)	Read m_u, n_u	$m_{u3} = m_u$ $p_{u3} = p_u - \Delta$
			(7)		$m_{u7} = -\ m_u$ $p_{u7} = p_u + \Delta$

(*) SR: Design aid for Symmetrical Reinforcement
UR: Design aid for Unsymmetrical Reinforcement

2.2 Example

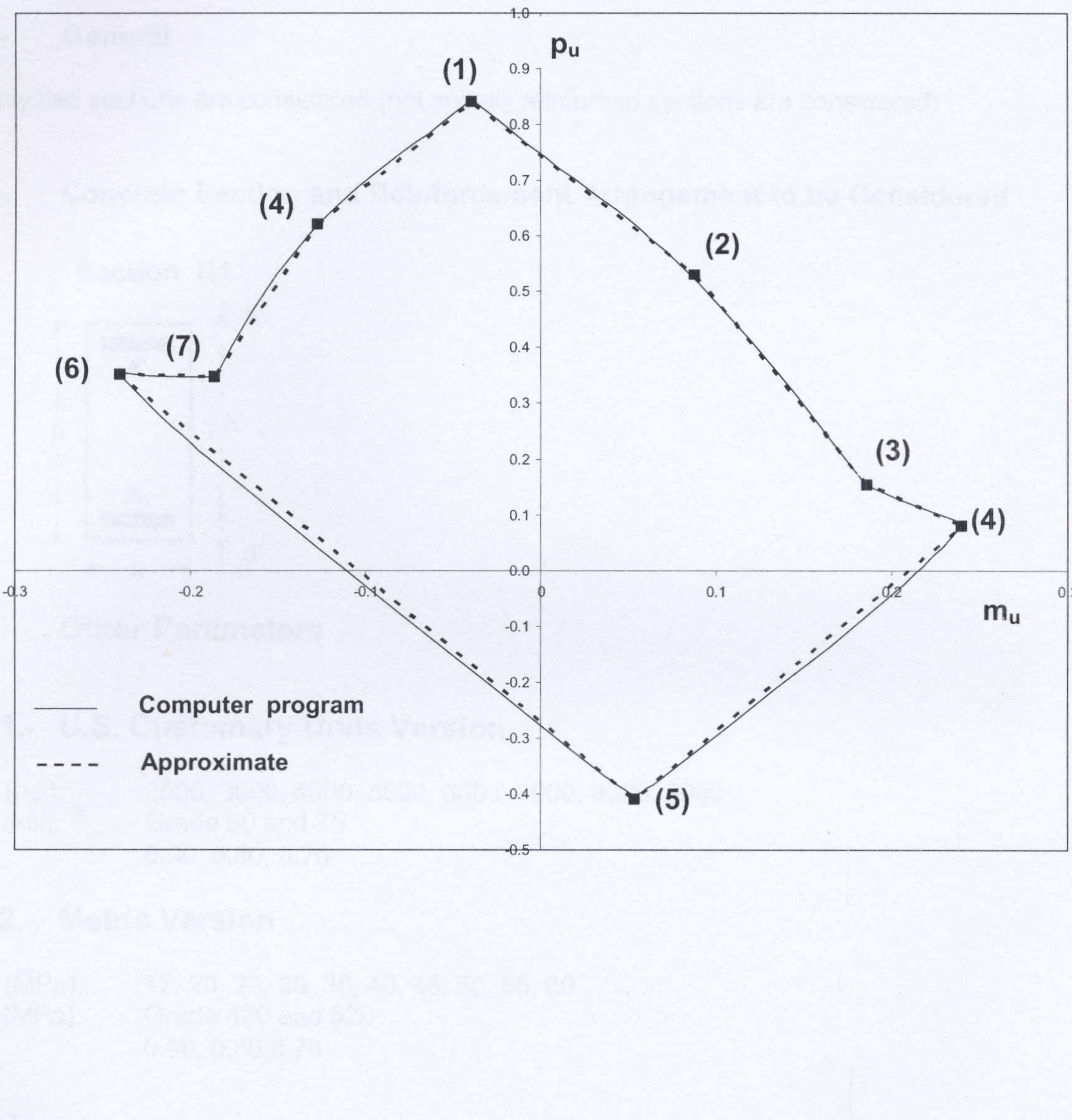
Given: f'_c = 4000 psi ; f_y = 60,000 psi ;
b = 14" ; h = 25" ; $\gamma = (h - 2d') / h \approx 0.80$
$A_s = 7.00$ in.^{2} ; $A'_s = 3.50$ in.^{2}

Step 1: Select appropriate aids for f'_c, f_y, γ (symmetrical and unsymmetrical reinforcement aids).

Step 2: Compute

$$\rho_{g0} = A_s / (b\,h) = 0.02$$
$$\rho'_{g0} = A'_s / (b\,h) = 0.01$$
$$\rho_{gt0} = \rho_{g0} + \rho'_{g0} = 0.03$$
$$\Delta = 0.65\,(\rho_{g0} - \rho'_{g0})\, f_y / f'_c = 0.098$$

Step	Aid	For	Point	Action	Compute
3	UR	$\rho_g = \rho'_{g0}$ $\rho_g = 0.01$ $\rho'_g = \rho_{g0}$ $\rho'_g = 0.02$	(1)	If $\rho_{g0} \geq \rho'_{g0}$ then read $m_{uA} = 0.039$ $p_{uA} = 0.84$	$m_{u1} = - m_{uA} = - 0.039$ $p_{u1} = p_{uA} = 0.84$
			(6)	Read $m_{uB} = 0.24$ $p_{uB} = 0.35$	$m_{u6} = - m_{uB} = - 0.24$ $p_{u6} = p_{uB} = 0.35$
			(5)	If $\rho_{g0} < \rho'_{g0}$ then read m_{uC} , p_{uC} else determine point form 4 (5)	----------
4	UR	$\rho_g = \rho_{g0}$ $\rho'_g = \rho'_{g0}$	(1)	If $\rho_{g0} < \rho'_{g0}$ then read m_{uA} , p_{uA} else determine point from 3 (1)	----------
			(4)	Read $m_{uB} = 0.24$ $p_{uB} = 0.08$	$m_{u4} = m_{uB} = 0.24$ $p_{u4} = p_{uB} = 0.08$
			(5)	If $\rho_{g0} \geq \rho'_{g0}$ then read $m_{uC} = 0.054$ $p_{uC} = - 0.41$	$m_{u5} = m_{uC} = 0.054$ $p_{u5} = p_{uC} = - 0.41$
5	SR	$\rho_g = 2\,\rho'_{g0}$ $f_s = 0$	(2)	Read $m_u = 0.088$ $p_u = 0.53$	$m_{u2} = m_u = 0.088$ $p_{u2} = p_u = 0.53$
6	SR	$\rho_g = 2\,\rho_{g0}$ $f_s = 0$	(8)	Read $m_u = 0.127$ $p_u = 0.62$	$m_{u8} = - m_u = 0.127$ $p_{u8} = p_u = 0.62$
7	SR	$\rho_g = \rho_{g0} + \rho'_{g0}$ $\varepsilon_t = \varepsilon_y$	(3)	Read $m_u = 0.186$ $p_u = 0.25$	$m_{u3} = m_u = 0.186$ $p_{u3} = p_u - \Delta = 0.153$
			(7)		$m_{u7} = - m_u = - 0.186$ $p_{u7} = p_u + \Delta = 0.348$



p_u
m_u
(1)
(2)
(3)
(4)
(5)
(6)
(7)
Computer program
Approximate

AXIAL LOAD AND UNIAXIAL BENDING
UNSYMMETRICAL REINFORCEMENT
DESIGN AIDS AUB-NSR-XX
PROPOSED SCHEME FOR THE WHOLE SET OF AIDS

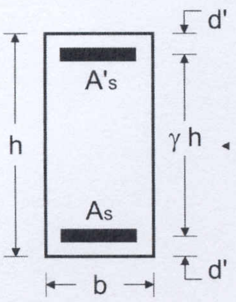
Important: This basic scheme is open to discussion.

1.- General

Only tied sections are considered (not spirally reinforced sections are considered)

2.- Concrete Section and Reinforcement Arrangement to be Considered

Section R1



3.- Other Parameters

3.1.- U.S. Customary Units Version

f'_c (psi): 2500, 3000, 4000, 5000, 6000, 7000, 8000, 9000
f_y (ksi): Grade 60 and 75
γ : 0.90, 0.80, 0.70

3.2.- Metric Version

f'_c (MPa): 17, 20, 25, 30, 35, 40, 45, 50, 55, 60
f_y (MPa): Grade 420 and 520
γ : 0.90, 0.80,0.70

4.- Estimated of Aids to be Developed

4.1.- U.S. Customary Units Version

1 Section Type × 2 Steel Grades × 8 Concrete Strengths × 3 Covers = 48 Aids

4.2.- Metric Version

1 Section Type × 2 Steel Grades × 10 Concrete Strengths × 3 Covers = 60 Aids

AXIAL LOAD AND BIAXIAL BENDING

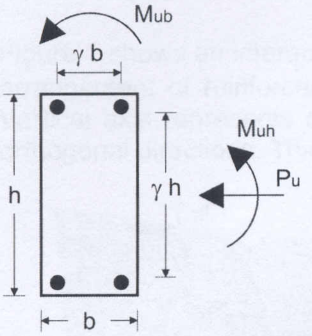
DESIGN AIDS ABB-XX

RECTANGULAR SECTIONS

Contents:

- Sample Design Aid
- Background comments
- Step by step procedures
- Step by step examples
- Proposed scheme for the whole set of aids

AXIAL LOAD AND BIAXIAL BENDING — ABB - XX



f'_c = 4,000 psi
f_y = 60,000 psi
γ = 0.80

$A_g = b \times h$

$A_s = \rho_g A_g$

$p_u = P_u / (b\, h\, f'_c)$

$m_{uh} = M_{uh} / (b\, h^2 f'_c)$

$m_{ub} = M_{ub} / (b^2 h\, f'_c)$

$m_{ux} = \max(m_{uh}, m_{ub})$

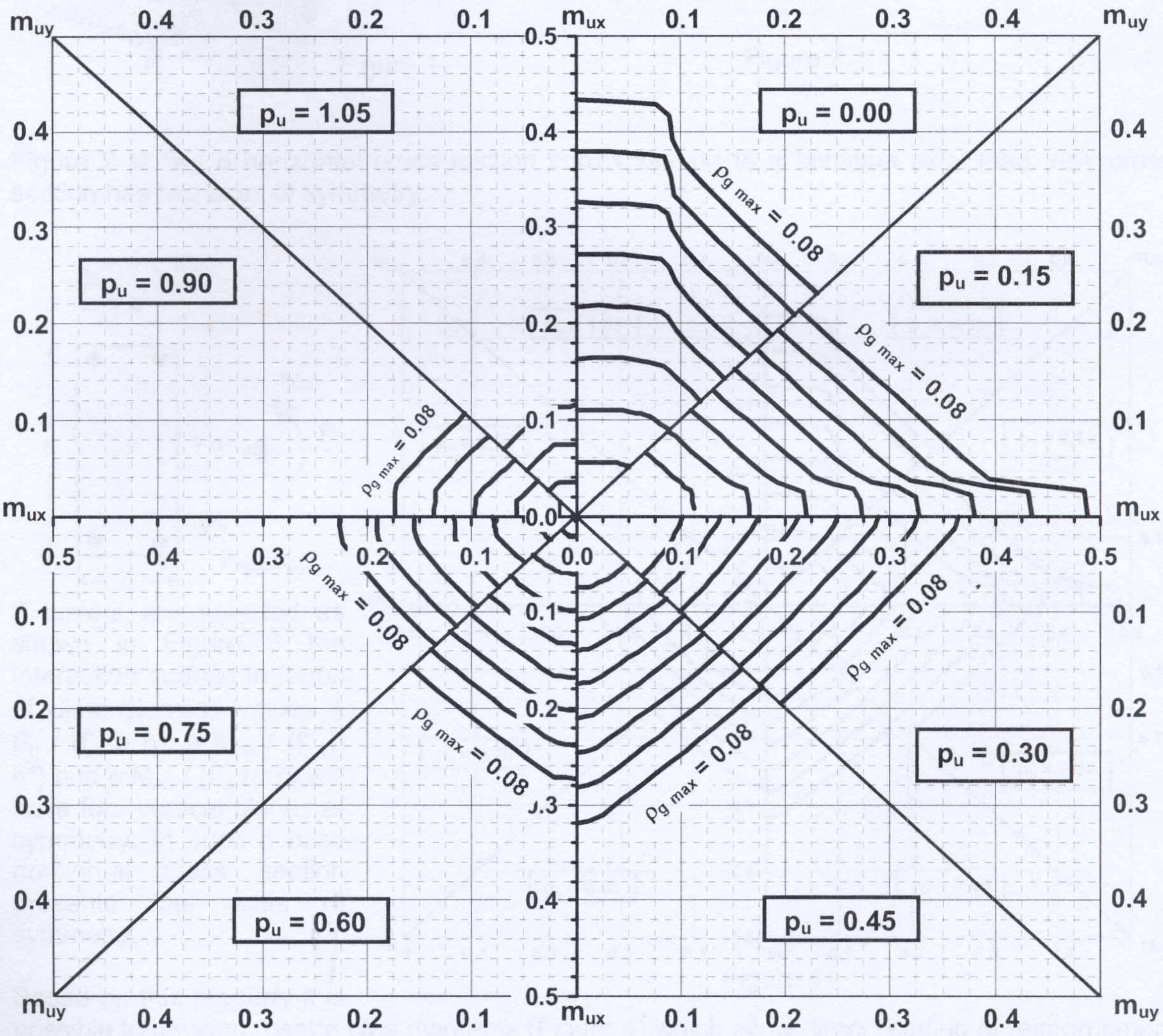
$m_{uy} = \min(m_{uh}, m_{ub})$

Curves:

$\rho_{g\,max} = 0.08$

$\Delta\rho_g = 0.01$ (equidistance)

Ref. Code ACI 318-08



Developed by Victorio Hernández Balat, Juan Francisco Bissio and Daniel Ortega for INTI-CIRSOC, Argentina

AXIAL LOAD AND BIAXIAL BENDING
DESIGN AIDS ABB - XX
BACKROUND COMMENTS

Figure 1 shows an interaction surface corresponding to a rectangular section with a symmetrical arrangement of reinforcement. The surface is expressed in terms of $\phi\ P_n$, $\phi\ M_{nh}$ and $\phi\ M_{nb}$. Vertical axis represents axial forces while horizontal axis represent bending moments in two orthogonal directions. This surface has two vertical planes of symmetry.

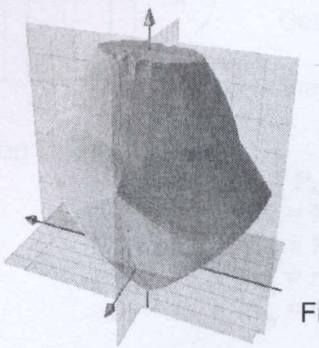


Figure 1

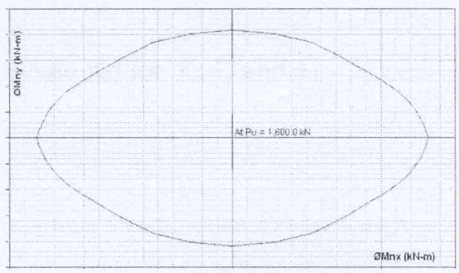


Figure 2

Figure 2 shows a horizontal cross section corresponding to a constant axial load. Any cross section has two axes of symmetry.

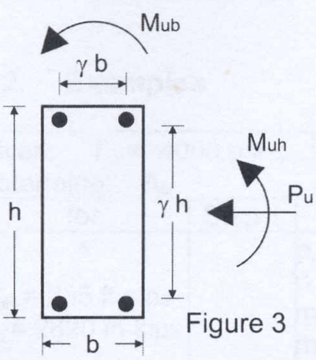


Figure 3

If covers are selected as shown in Figure 3 the interaction surface in terms of dimensionless values $\phi\ P_n$ / (f'_c b h), $\phi\ M_{nh}$ / (f'_c b h^2) and $\phi\ M_{nb}$ / (f'_c b^2 h) will have four vertical planes of symmetry. In such a case horizontal cross section presents four axes of symmetry.

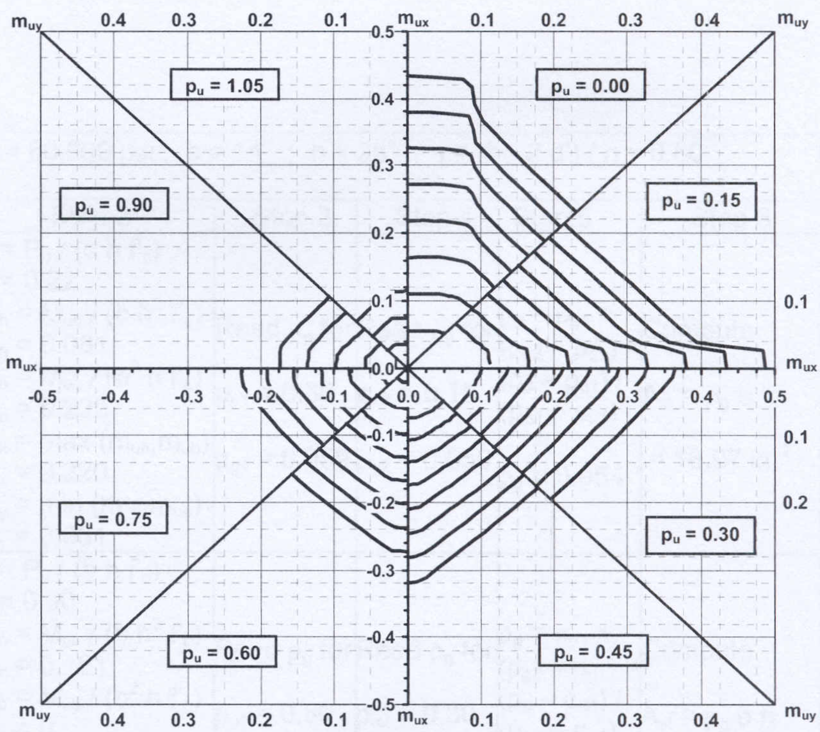
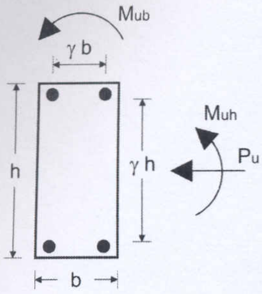


Figure 4

Based on this property it is possible to develop rosette type diagrams (Figure 4) which allow direct reading of reinforcement (in terms of ρ) for any given set of p_u, m_{uh} and m_{ub}. Each eight of the diagram represents a cross sections at a constant value of p_u . Many values of ρ are plotted on each eight.

AXIAL LOAD AND BIAXIAL BENDING
DESIGN AIDS ABB - XX
PROCEDURES FOR DESIGN AND VERIFICATION



1. DESIGN

1.1. Procedure

Given: f'_c, f_y, b, h, γ, M_{uh}, M_{ub} and P_u
Determine: A_{st}

Step 1: Select appropriate aid for f'_c, f_y and γ

Step 2: Compute

$$p_u = P_u / (b\, h\, f'_c)$$
$$m_{uh} = M_{uh} / (b\, h^2\, f'_c)$$
$$m_{ub} = M_{ub} / (b^2\, h\, f'_c)$$
$$m_{ux} = \max(m_{uh}, m_{ub})$$
$$m_{uy} = \min(m_{uh}, m_{ub})$$

Step 3: For the superior immediate value $p_{u1} \geq p_u$ and for m_{ux} and m_{uy} read ρ_{g1}
Step 4: For the inferior immediate value of $p_{u2} \leq p_u$ and for m_{ux} and m_{uy} read ρ_{g2}
Step 5: Interpolate $\rho_g = \rho_{g1} + (\rho_{g2} - \rho_{g1}) \times (p_u - p_{u1}) / (p_{u2} - p_{u1})$
Step 6: Compute $A_{st} = \rho_g\, b\, h$

1.2. Examples

Given: f'_c = 4000 psi ; f_y = 60,000 psi ; b = 14" ; h = 25" ; γ = (h - 2 d') / h ≈ 0.80
Determine: A_{st}

for	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
M_{uh} = 235 ft-kips M_{uh} = 2820 in-kips M_{ub} = 360 ft-kips M_{ub} = 4320 in-kips P_u= 308 kips	Select appropriate aid for f'_c, f_y and γ	$p_u = P_u / (b\, h\, f'_c)$ $p_u = 0.22$ $m_{uh} = M_{uh} / (b\, h^2\, f'_c)$ $m_{uh} = 0.081$ $m_{ub} = M_{ub} / (b^2\, h\, f'_c)$ $m_{ub} = 0.220$ $m_{ux} = \max(m_{uh}, m_{ub})$ $m_{ux} = 0.220$ $m_{uy} = \min(m_{uh}, m_{ub})$ $m_{uy} = 0.081$	Read ρ_g for $p_{u1} = 0.30$ $\rho_{g1} = 0.059$	Read ρ_g for $p_{u2} = 0.15$ $\rho_{g2} = 0.050$	$\rho_g = \rho_{g1} + (\rho_{g2} - \rho_{g1}) \times (p_u - p_{u1}) / (p_{u2} - p_{u1})$ $\rho_g = 0.054$	Compute $A_{st} = \rho_g\, b\, h$ = 18.97 in.^{2}
M_{uh} = 470 ft-kips M_{uh} = 5640 in-kips M_{ub} = 0 P_u= 420 kips (*)		$p_u = P_u / (b\, h\, f'_c)$ $p_u = 0.30$ $m_{uh} = M_{uh} / (b\, h^2\, f'_c)$ $m_{uh} = 0.161$ $m_{ub} = M_{ub} / (b^2\, h\, f'_c)$ $m_{ub} = 0$ $m_{ux} = \max(m_{uh}, m_{ub})$ $m_{ux} = 0.161$ $m_{uy} = \min(m_{uh}, m_{ub})$ $m_{uy} = 0$	Read ρ_g for $p_{u1} = 0.30$ $\rho_{g1} = 0.026$	Read ρ_g for $p_{u2} = 0.30$ $\rho_{g2} = 0.026$	$\rho_g = \rho_{g1} + (\rho_{g2} - \rho_{g1}) \times (p_u - p_{u1}) / (p_{u2} - p_{u1})$ $\rho_g = 0.026$	Compute $A_{st} = \rho_g\, b\, h$ A_{st} = 9.10 in.^{2}

(*) Data are the same as for First Example for Axial Load and Uniaxial Bending with Symmetrical Reinforcement. Results: A_s = 4.55 in.^{2} ; A'_s = 4.55 in.^{2} (A_{st} = 9.10 in.^{2})

2. VERIFICATION

These aids can be used to solve many problems ranging from dimensioning to checking safety. The variety is so wide that could not be fully exposed in this paper.

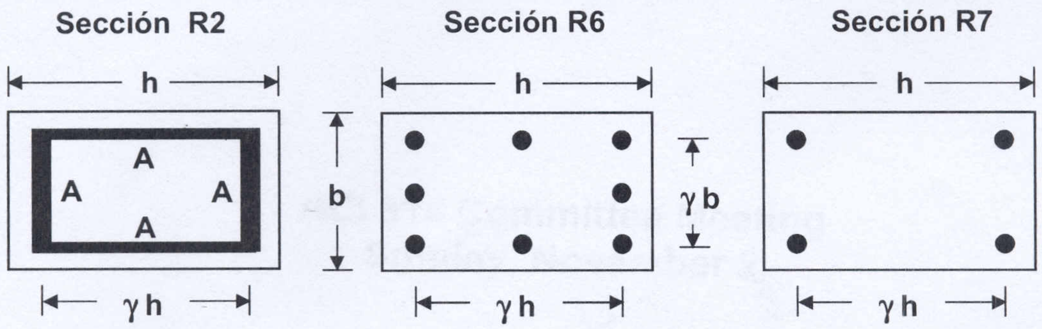
AXIAL LOAD AND BIAXIAL BENDING
DESIGN AIDS ABB - XX
PROPOSED SCHEME FOR THE WHOLE SET OF AIDS

Important: This basic scheme is open to discussion.

1.- General

Only tied sections are considered (not spirally reinforced sections are considered)

2.- Concrete Section and Reinforcement Arrangement to be Considered



3.- Other Parameters

3.1.- U.S. Customary Units Version

f'_c (psi): 2500, 3000, 4000, 5000, 6000, 7000, 8000, 9000
f_y (ksi): Grade 60 and 75
γ: 0.90, 0.80, 0.70

3.2.- Metric Version

f'_c (MPa): 17, 20, 25, 30, 35, 40, 45, 50, 55, 60
f_y (MPa): Grade 420 and 520
γ: 0.90, 0.80,0.70

4.- Estimated of Aids to be Developed

4.1.- U.S. Customary Units Version

3 Section Types × 2 Steel Grades × 8 Concrete Strengths × 3 Covers = 144 Aids

4.2.- Metric Version

3 Section Type3 × 2 Steel Grades × 10 Concrete Strengths × 3 Covers = 180 Aids