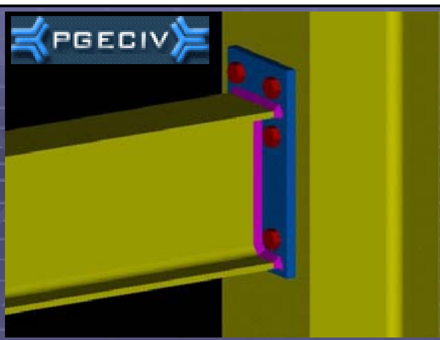
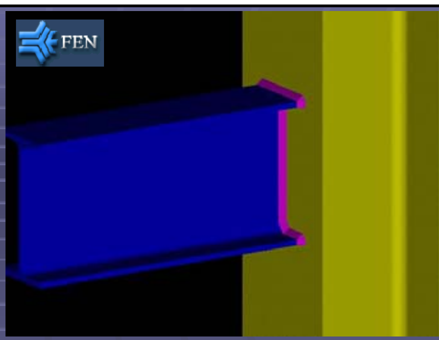
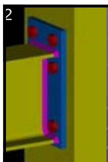




Ligações Aparafusadas

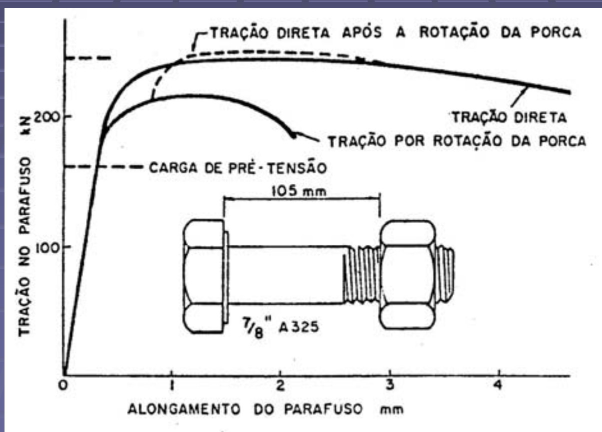
Quarta Parte

Programa de Pós-Graduação em Engenharia Civil
PGECIV - Mestrado Acadêmico
Faculdade de Engenharia – FEN/UERJ
Disciplina: Tópicos Especiais em Projeto (Ligações em Aço e Mistas)
Professor: Luciano Rodrigues Ornelas de Lima



11. Dimensionamento

- Tração no parafuso
  - ✓ Influência da Protensão



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11. Dimensionamento

- $T = A_r F_u$ $\quad A_r = P/4\ d^2\ (1 - KP/D)^2$
  - ✓ K = 0,9743 para roscas UNC
  - ✓ K = 0,9382 para roscas métricas grossas
  - ✓ P é o Passo D é o diametro do parafuso
- $A_r = 75\%\ A_b$ muito conservador para diâmetros maiores que 25mm

ISO	UNC	P (passo em mm)	A_b (mm²)	A_r (mm²)	A_p / A_b
M12	-	1.75	113	84.3	0.75
-	1/2"	1.95	126	91.6	0.72
-	5/8"	2.31	198	146	0.74
M16	-	2.00	201	157	0.78
-	3/4"	2.54	285	215	0.76
M20	-	2.50	314	245	0.78
M22	-	2.50	380	303	0.80
-	7/8"	2.82	388	298	0.77
M24	-	3.00	452	353	0.78
-	1"	3.18	506	391	0.77
M27	-	3.00	573	459	0.80

ISO	UNC	P (passo em mm)	A_b (mm²)	A_r (mm²)	A_p / A_b
-	1 1/8"	3.63	641	492	0.77
M30	-	3.50	707	591	0.82
-	1 1/4"	3.63	792	625	0.79
M33	-	3.50	855	694	0.81
-	1 3/8"	4.21	958	745	0.78
M36	-	4.00	1018	817	0.80
-	1 1/2"	4.23	1140	907	0.80
M42	-	4.50	1385	1120	0.81
-	1 3/4"	5.08	1552	1226	0.79
M49	-	5.00	1810	1470	0.81
-	2"	5.64	2027	1613	0.80

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11. Dimensionamento

- Resistência a tração

$$\boxed{T_r = 0{,}75\ \phi_b A_b F_u}$$

$\phi_b = 0{,}80$

ϕA_b = área da seção transversal do parafuso (bruta)

F_u = tensão última do parafuso

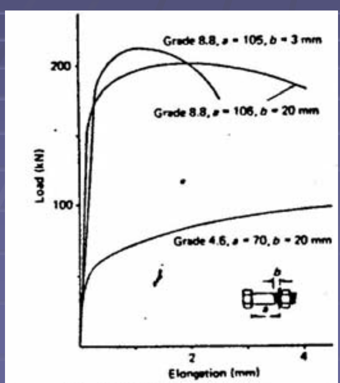

Figure 5.9 Tensile behaviour of dowel bolts

- Parafusos sem protensão
  - ✓ Comprimento de rosca, b
  - ✓ Material
  - ✓ A_r/A_b
  - ✓ 3 roscas inteiras + final da rosca
  - ✓ 4.6 → ductil
  - ✓ $F_{u,rosca} = F_{u,parafuso}$
  - ✓ Espanar a rosca não ocorre → tolerâncias e especificações
  - ✓ Não é válido para $F_{u,rosca} < F_{u,parafuso}$

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11. Dimensionamento

- Tração no parafuso

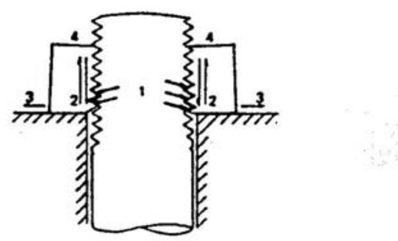

Figure 5.10 Thread-stripping mode of failure (nut weaker than bolt)

  - 1- Plastificação das Roscas → $\sigma_{contacto}$
  - 2- Parte inferior escoa
  - 3- Reduz área de contacto
  - 4- deformação cilíndrica no topo visível

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11. Dimensionamento

- Tração no parafuso – Eurocode 3 pt. 1.8
- A) Category D: non-preloaded
  - ✓ Bolts from class 4.6 up to class 10.9 should be used.
  - ✓ No preloading is required
  - ✓ Should not be used where the connections are frequently subjected to variations of tensile loading
  - ✓ May be used in connections designed to resist normal wind loads.
- B) Category E: preloaded
  - ✓ Preloaded 8.8 and 10.9 bolts with controlled tightening in conformity with 2.8 Ref. Stand. Group 7 should be used.

11. Dimensionamento

- Tração no parafuso – Eurocode 3 pt. 1.8

Table 3.2: Categories of bolted connections

Category	Criteria	Remarks
Tension connections		
D non-preloaded	$F_{t,Ed} \leq F_{t,Rd}$ $F_{t,Ed} \leq B_{p,Rd}$	No preloading required. Bolt classes from 4.6 to 10.9 may be used. $B_{p,Rd}$ see Table 3.4.
E preloaded	$F_{t,Ed} \leq F_{t,Rd}$ $F_{t,Ed} \leq B_{p,Rd}$	Preloaded 8.8 or 10.9 bolts should be used. $B_{p,Rd}$ see Table 3.4.
The design tensile force $F_{t,Ed}$ should include any force due to prying action, see 3.11. Bolts subjected to both shear force and tensile force should also satisfy the criteria given in Table 3.4.		

11. Dimensionamento

- Tração no parafuso – Eurocode 3 pt. 1.8

Failure mode	Bolts	Rivets
Tension resistance [2)]	$F_{t,Rd} = \dfrac{k_2\ f_{ub}\ A_s}{\gamma_{M2}}$ where $k_2 = 0{,}63$ for countersunk bolt, otherwise $k_2 = 0{,}9$.	$F_{t,Rd} = \dfrac{0{,}6\ f_{ur}\ A_0}{\gamma_{M2}}$
Punching shear resistance	$B_{p,Rd} = 0{,}6\,\pi\, d_m\, t_p\, f_u / \gamma_{M2}$	No check needed

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12. Tração x Cisalhamento

- Tração + cisalhamento combinados

(sem atrito)

$$\left(\frac{V_f}{V_r}\right)^2 + \left(\frac{T_f}{T_r}\right)^2 \leq 1{,}0$$

V_r = resistência ao corte

T_r = resistência à tração

V_f e T_f = esforços atuantes

(com atrito)

$$\frac{V}{V_s} + 1{,}9\frac{T}{n.A_b.F_u} \leq 1{,}0$$

V_s = resistência ao atrito

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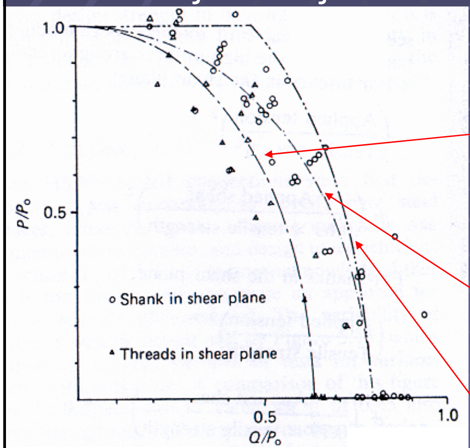
12. Tração x Cisalhamento

- Interação: Tração x Cisalhamento (Owens)



P – tração no parafuso na ruptura

Q –cisalhamento no parafuso na ruptura

P_0 – resistência à tração do parafuso

Com rosca no plano de corte (eq. elipse)

($\tau_y / \sigma_y \rightarrow 0{,}63 – 0{,}68$)

$$\left(\frac{P}{\sigma_y}\right)^2 + \left(\frac{Q}{0{,}63\sigma_y}\right)^2 < 1{,}0$$

Sem rosca no plano de corte

($\tau_y / \sigma_y \rightarrow 0{,}75 – 0{,}89$)

$$\left(\frac{P}{\sigma_y}\right)^2 + \left(\frac{Q}{0{,}79\sigma_y}\right)^2 \leq 1{,}0$$

$$0{,}63/0{,}80 = 0{,}79$$

$$\downarrow$$

$$\frac{A_r}{A_b}$$

Com rosca no plano de corte

$$\left(\frac{0{,}8.P}{\sigma_y}\right)^2 + \left(\frac{Q}{0{,}79\sigma_y}\right)^2 = 1{,}0$$

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12. Tração x Cisalhamento

- Interação: Tração x Cisalhamento (Owens)
  - ✓ Modo de ruína (incertezas na posição do plano de ruptura)
    - Tração na área rosqueada
    - Cisalhamento e tração combinados no plano de corte
    - Se a parte rosqueada está distante do plano de corte, o cisalhamento pode ser desprezado
    - "Grip"
      - Quanto maior, mais flexão pode ser provocada → seção transversal elíptica, não-ortogonal ao plano de cisalhamento → aumentando a resistência ao cisalhamento

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12. Tração x Cisalhamento

- Interação: Tração x Cisalhamento – Canadense

Table 3-8 **For A325M and A325**

$$\left(\frac{V_f}{V_r}\right)^2 + \left(\frac{T_f}{T_r}\right)^2 \leq 1{,}0$$

Shear Tension Ratio $X = V_f/T_f$		Bolt Size 3/4		M20		M22		7/8		M24		1	
X	$1/X$	V_f	T_f	V_f	T_f	V_f	T_f	V_f	T_f	V_f	T_f	V_f	T_f
0	T_r	0	118	0	131	0	158	0	161	0	188	0	210
0.10		11.7	117	13.0	130	15.7	157	16.0	160	18.7	187	20.8	208
0.20		23.0	115	25.4	127	30.8	154	31.4	157	36.6	183	40.8	204
0.30		33.3	111	36.9	123	44.7	149	45.3	151	53.1	177	59.4	198
0.40		42.4	106	47.2	118	56.8	142	58.0	145	67.6	169	75.6	189
0.50		50.5	101	56.0	112	67.5	135	69.0	138	80.5	161	90.0	180
0.60		57.4	95.7	63.6	106	76.8	128	78.6	131	91.2	152	102	170
0.70		63.1	90.2	70.0	100	84.7	121	86.1	123	101	144	113	161
0.80		68.0	85.0	75.5	94.4	91.2	114	92.8	116	108	135	121	151
0.90		72.0	80.0	79.9	88.8	96.3	107	98.1	109	115	128	128	142
1.00	1.00	75.4	75.4	83.7	83.7	101	101	103	103	120	120	134	134
1.11	0.90	78.6	70.7	87.1	78.4	105	94.6	107	96.4	126	113	140	126
1.25	0.80	81.6	65.3	90.6	72.5	109	87.4	111	89.1	130	104	145	116
1.43	0.70	84.7	59.3	94.0	65.8	113	79.4	116	80.9	135	94.5	151	106
1.67	0.60	87.7	52.6	97.3	58.4	118	70.5	120	71.8	140	83.9	156	93.7
2.00	0.50	90.6	45.3	100	50.2	121	60.6	124	61.8	144	72.1	161	80.5
2.50	0.40	93.0	37.2	103	41.3	125	49.8	127	50.8	148	59.3	166	66.2
3.33	0.30	94.6	28.5	105	31.7	127	38.2	129	38.9	151	45.5	168	50.8
5.00	0.20	94.6	19.3	105	21.5	127	25.9	129	26.4	151	30.8	168	34.4
10.0	0.10	94.6	9.8	105	10.8	127	13.3	129	13.3	151	15.6	168	17.4
V_r	0	94.6	0	105	0	127	0	129	0	151	0	168	0

$V_f = XT_f$, $T_f = \sqrt{\beta T_r^2/(X^2+\beta)}$ where $\beta = 0.69$ for threads excluded.

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12. Tração x Cisalhamento

- Interação: Tração x Cisalhamento – Canadense

Table 3-9 **For A490M and A490 Bolts**

Shear Tension Ratio $X = V_f/T_f$		Bolt Size											
		3/4		M20		M22		7/8		M24		1	
x	$1/x$	V_f	T_f	V_f	T_f	V_f	T_f	V_f	T_f	V_f	T_f	V_f	T_f
0	T_r	0	148	0	164	0	199	0	202	0	238	0	264
0.10		14.7	147	16.3	163	19.7	197	20.0	100	23.6	236	26.2	262
0.20		28.6	143	31.6	158	38.4	192	39.0	195	46.0	230	51.0	255
0.30		41.1	137	45.6	152	55.5	185	56.1	187	66.3	221	73.5	245
0.40		52.4	131	58.0	145	70.4	176	71.2	178	84.0	210	93.2	233
0.50		61.5	123	68.0	136	82.5	165	84.0	168	99.0	198	110	220
0.60		69.0	115	76.8	128	93.0	155	94.8	158	112	186	124	206
0.70		75.6	108	84.0	120	102	145	104	148	122	174	135	193
0.80		80.8	101	89.6	112	109	136	110	138	130	163	144	180
0.90		85.1	94.6	94.5	105	114	127	116	129	137	152	152	169
1.00	1.00	88.7	88.7	98.3	98.3	119	119	121	121	143	143	158	158
1.11	0.90	91.9	82.7	102	91.6	123	111	126	113	148	133	163	147
1.25	0.80	95.0	76.0	105	84.2	128	102	130	104	153	122	170	136
1.43	0.70	98.1	68.7	109	76.1	132	92.3	134	93.7	157	110	176	123
1.67	0.60	101	60.6	112	67.2	136	81.5	138	82.7	163	97.5	180	108
2.00	0.50	104	51.9	115	57.5	139	69.7	142	70.8	167	83.4	185	92.5
2.50	0.40	106	42.4	118	47.0	143	57.1	145	57.9	171	68.2	189	75.7
3.33	0.30	108	32.4	120	35.9	145	43.6	147	44.2	174	52.1	193	57.8
5.00	0.20	110	21.9	122	24.3	148	29.5	150	29.9	176	35.2	196	39.1
10.00	0.10	110	11.0	122	12.2	149	14.9	151	15.1	178	17.8	197	19.7
V_f	0	119	0	131	0	159	0	161	0	189	0	211	0

$V_f = XT_f$, $T_f = \sqrt{\beta T_r^2/(X^2+\beta)}$ where $\beta = 0.56$ for thread excluded.

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12. Tração x Cisalhamento

- Corte + Tração no parafuso – Eurocode 3 pt. 1.8

Failure mode	Bolts	Rivets
Combined shear and tension	$\dfrac{F_{v,Ed}}{F_{v,Rd}} + \dfrac{F_{t,Ed}}{1{,}4\,F_{t,Rd}} \le 1{,}0$	

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12. Tração x Cisalhamento

- Tração + Atrito – Eurocode 3 pt. 1.8
- If a slip-resistant connection is subjected to an tensile force, $F_{t,Ed}$ or $F_{t,Ed,serv}$, + shear force, $F_{v,Ed}$ or $F_{v,Ed,serv}$, tending to produce slip, the slip resistance is:
- Cat. B joint:

$$F_{s,Rd,serv} = \frac{k_s \; n \; \mu \; (F_{p,C} \; - \; 0{,}8\,F_{t,Ed,serv})}{\gamma_{M3}} \qquad (3.8a)$$

- Cat. C joint:

$$F_{s,Rd} = \frac{k_s \; n \; \mu \; (F_{p,C} \; - \; 0{,}8\,F_{t,Ed})}{\gamma_{M3}} \qquad (3.8b)$$

- If, in a moment connection, a contact force on the compression side counterbalances the applied tensile force no reduction in slip resistance is required

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12. Tração x Cisalhamento

- Ligações com Soldas e Parafusos – Eurocode 3 pt. 1.8
- Preloaded class 8.8 and 10.9 bolts in connections designed as slip-resistant at the ultimate limit state (Cat. C) may be assumed to share load with welds, provided that the final tightening of the bolts is carried out after the welding is complete.

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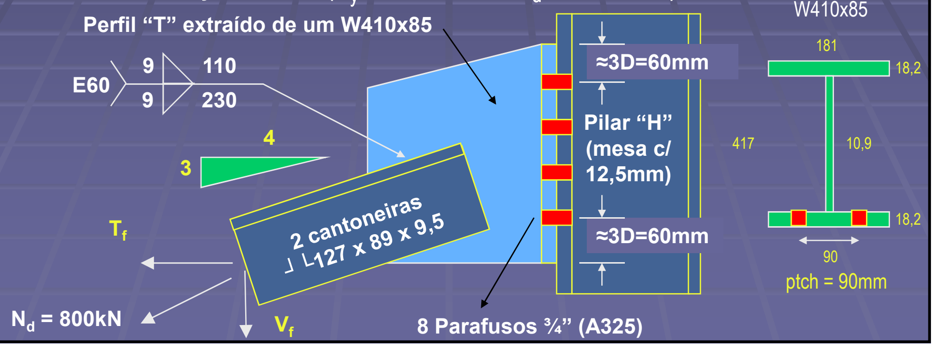
13. Tração x Cisalhamento - Exemplos

3. Verificar a resistência da parte aparafusada da ligação apresentada a seguir considerando-se que as roscas estão fora do plano de corte sem considerar o atrito.

Dados: parafusos A325 c/ d = 7/8" (F_y = 635MPa e F_u = 825MPa)

Aço MR250 (F_y = 250MPa e F_u = 400MPa)



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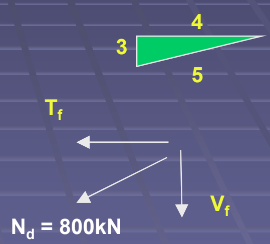
13. Tração x Cisalhamento - Exemplos

Cisalhamento em cada parafuso:

$$V_f = \frac{3}{\sqrt{3^2+4^2}}\left(\frac{N_d}{8}\right) = \frac{3}{5}\left(\frac{800}{8}\right) = 60\text{kN}$$

Tração em cada parafuso:

$$T_f = \frac{4}{\sqrt{3^2+4^2}}\left(\frac{N_d}{8}\right) = \frac{4}{5}\left(\frac{800}{8}\right) = 80\text{kN}$$



Área do parafuso:

$$\frac{V_f}{T_f} = \frac{60}{80} = 0{,}75$$

d = 3/4" * 25,4mm = 19,05mm

$A_b = \pi d2 / 4 = \pi (19{,}05)^2 / 4 = 285\text{mm}^2$

Tabela 3-8

$$V_r = 72{,}7\text{kN e } T_r = 97{,}2\text{kN}$$

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13. Tração x Cisalhamento - Exemplos

a) Resistência de 1 parafuso ao corte

$V_r = 0{,}60\ \phi_b\ n\ m\ A_b\ F_u = 0{,}60 \,.\, 0{,}80 \,.\, 1 \,.\, 1 \,.\, 285 \,.\, 0{,}825 = 112{,}9\text{kN}$

b) Verificação do esmagamento da chapa

$$B_r \begin{cases} 3\ \phi_{br}\ t\ n\ d\ F_u = 3 \,.\, 0{,}67 \,.\, 12{,}5 \,.\, 1 \,.\, 19{,}05 \,.\, 0{,}400 = 191{,}5\text{kN} \\ \text{esmagamento} \\ \phi_{br}\ t\ n\ e\ F_u = 0{,}67 \,.\, 12{,}5 \,.\, 1 \,.\, 60 \,.\, 0{,}400 = 201{,}0\text{kN} \\ \text{rasgamento} \end{cases}$$

$V_r = 112{,}9\text{kN}$

c) Resistência à tração

- $T_r = 0{,}75 \,.\, \phi_b \,.\, A_g \,.\, F_y = 0{,}75 \,.\, 0{,}80 \,.\, 285 \,.\, 0{,}825 = 141{,}1\text{kN}$

d) Resistência combinada

$$\left(\frac{V_f}{V_r}\right)^2 + \left(\frac{T_f}{T_r}\right)^2 = \left(\frac{60}{112{,}9}\right)^2 + \left(\frac{80}{141{,}1}\right)^2 = 0{,}61 \le 1{,}0$$

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14. Tabelas Manual Canadense

BOLT DATA
Metric and Imperial Series **Table 3-1**

Bolt Size		Nominal Diameter of Bolt (mm)	Nominal Area (A_b) (mm^2)	$A_b F_u$** (kN)				
Metric*	Imperial			A325M	A490M	A325	A490	A307
	1/2	12.70	127			104	131	
	5/8	15.88	198			163	206	81.9
M16		16.00	201	167	209			
	3/4	19.05	285			235	295	118
M20		20.00	314	261	327			
M22		22.00	380	316	396			
	7/8	22.23	388			320	402	161
M24		24.00	452	375	470			
	1	25.40	507			418	524	
M27		27.00	573	475	595			
	1–1/8	28.58	641			465	664	
M30		30.00	707	587	735			
	1–1/4	31.75	792			574	819	
M36		36.00	1018	845	1060			
	1–1/2	38.10	1140			827	1180	

*The number following the letter M is the nominal bolt diameter in millimetres.
**See Table 3–3 page 3–8 for specified minimum tensile strengths, F_u.

Cálculo de $A_b\ F_u$

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14. Tabelas Manual Canadense

Table 3–2 — **CAN/CSA-S16.1-M89 SUMMARY Bearing-Type Connections**

Bolt Situation in Joint	Factored Resistance	Unit Factored Resistance ($n = m = A_b = 1$)	Clause Reference
BOLTS IN SHEAR			13.11.2
Shear on bolts with threads excluded from shear plane	$V_r = 0.60\,\phi_b\, n\, m\, A_b\, F_u$	$V_r = 0.40\,F_u$	13.11.2(b)
Shear on bolts with threads intercepted by shear plane	$V_r = 0.42\,\phi_b\, n\, m\, A_b\, F_u$	$V_r = 0.28\,F_u$	
For joints longer than 1300 mm	Shear = $0.8\,V_r$		
Bearing on main material (the lesser of)	$B_r = 3\,\phi\, t\, d\, n\, F_u$ $B_r = \phi\, t\, n\, e\, F_u$	$B_r = 2.0\, t\, d\, F_u$ $B_r = 0.67\, t\, e\, F_u$	13.10.1(c)
BOLTS IN TENSION	$T_r = 0.75\,\phi_b\, n\, A_b\, F_u$	$T_r = 0.50\,F_u$	13.11.3

Notes: 1. Oversize holes are not permitted in bearing-type connections (see Clause 23.3.2(a) of CAN/CSA-S16.1-M89.
2. See Clause 23.3.2(b), (c) of CAN/CSA-S16.1-M89 re use of slotted holes in bearing-type connections.
3. See Clause 23.3.2(e) of CAN/CSA-S16.1-M89 for hole diameters permitted with M20 or 3/4-inch diameter, M22 or 7/8-inch diameter, and M24 or 1-inch diameter bolts.

Resumo das equações da Norma Canadense

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14. Tabelas Manual Canadense

Resistência ao cisalhamento e tração para

$A_b = m = n = 1$

UNIT FACTORED SHEAR AND TENSILE RESISTANCES** — **Table 3–3**

$\phi b = 0.67$

Bolt Grade	Specified Minimum Tensile Strength, F_u (MPa)	Unit Factored Shear Resistance: Threads Excluded $0.40\,F_u$ (MPa)	Unit Factored Shear Resistance: Threads Intercepted $0.28\,F_u$ (MPa)	Unit Factored Tensile Resistance $0.50\,F_u$ (MPa)
A325M	830	334	234	417
A490M	1040	418	293	523
A325 (d < 1")	825	332	232	415
A325 (d > 1–1/8")	725	291	204	364
A490	1035	416	291	520
A307*	414	168	117	208

* Use of A307 bolts in connections is covered in Clauses 22.2 and 22.4 of CAN/CSA-S16.1-M89.
**Values for imperial series bolts are based on ASTM specifications A325 and A490 soft converted to SI units.

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14. Tabelas Manual Canadense

Resistência a tração e corte m = 1 por parafuso

FACTORED SHEAR AND TENSILE RESISTANCES (kN PER BOLT)

Table 3–4

Bolt Size		Nominal Area A_b (mm^2)	Factored Shear Resistance† – Single Shear** (kN/bolt)						Factored Tensile Resistance, T_r (kN/bolt)		
			Threads Excluded			Threads Intercepted ††					
Metric*	Imperial		A325 A325M	A490 A490M	A307	A325 A325M	A490 A490M	A307	A325 A325M	A490 A490M	A307
	1/2	127	42.2	52.8		29.5	37.0		52.7	66.0	
	5/8	198	65.7	82.4	32.9	45.9	57.6	23.2	82.2	103	41.2
M16		201	67.1	84.0		47.3	58.9		83.8	105	
	3/4	285	94.6	119	47.3	66.1	82.9	33.4	118	148	59.3
M20		314	105	131		73.5	92.0		131	164	
M22		380	127	159		88.9	111		158	199	
	7/8	388	129	161	64.4	90.0	113	45.4	161	202	80.7
M24		452	151	189		106	132		188	236	
	1	507	168	211		118	148		210	264	
M27		573	191	240		134	168		239	300	
	1–1/8	641	187	267		131	187		233	333	
M30		707	236	296		165	207		295	370	
	1–1/4	792	230	329		162	230		288	412	
M36		1018	340	426		238	298		425	532	
	1–1/2	1140	332	474		233	322		415	593	

* The number following the letter M is the nominal bolt diameter in millimetres.
† For joints longer than 1 300 mm, use 80% of the factored shear resistance.
** For double shear, multiply tabulated values by 2.0.
†† Treads are intercepted if thin material next to the nut is combined with detailing for minimum bolt stick-through (the nut).

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14. Tabelas Manual Canadense

Resistência ao esmagamento 0,67 F_u

Table 3-5 — UNIT FACTORED BEARING RESISTANCE

	Material Standard and Grade	Specified Minimum Tensile Strength, F_u (MPa)	0,67 F_u (MPa)	Maximum 2.0 F_u (MPa)
CAN/CSA G40.21-M	230G	380	255	760
	260W, 260WT	410	275	820
	300W for HSS only	410	275	820
	300W, 350W, 300WT	450	302	900
	350G, 350WT, 350R, 350A, 350AT	480	322	960
	380W and 380WT for HSS only	480	322	960
	400W, 400WT, 400A, 400AT	520	348	1040
	480W, 480WT, 480A, 480AT	590	395	1180
ASTM	A36 — MR250	400	268	800
	A572 Grade 42	415	278	830
	A572 Grade 50	450	302	900
	A441 $F_y = 42$	435	291	870
	A441 $F_y = 46$	460	308	920
	A441 $F_y = 50$	485	325	970

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Table 3-6 — **FACTORED BEARING RESISTANCE, B_r* (kN/bolt)**

CSA G40.21-M 300W, 350W, 300WT (F_u = 450 MPa)

Material Thickness t (mm)	End Distance**, e (mm): 20	25	30	35	40	45	50	60	70	80	90	100
4	24.1	30.1	36.2	42.2	48.2	54.3	60.3	72.4	84.4	96.5	109	121
4.5	27.1	33.9	40.7	47.5	54.3	61.1	67.8	81.4	95.0	109	122	136
5	30.1	37.7	45.2	52.8	60.3	67.8	75.4	90.4	106	121	136	151
6	36.2	45.2	54.3	63.3	72.4	81.4	90.4	109	127	145	163	181
7	42.2	52.8	63.3	73.9	84.4	95.0	106	127	148	169	190	211
8	48.2	60.3	72.4	84.4	96.5	109	121	145	169	193	217	241
9	54.3	67.8	81.4	95.0	109	122	136	163	190	217	244	271
10	60.3	75.4	90.4	106	121	136	151	181	211	241	271	301
11	66.3	82.9	99.5	116	133	149	166	199	232	265	298	332
12	72.4	90.4	109	127	145	163	181	217	253	289	326	362
13	78.4	98.0	118	137	157	176	196	235	274	314	353	392
14	84.4	106	127	148	169	190	211	253	295	338	380	422
15	90.4	113	136	158	181	204	226	271	317	362	407	452
16	96.5	121	145	169	193	217	241	289	338	386	434	482
17	103	128	154	179	205	231	256	308	359	410	461	513
18	109	136	163	190	217	244	271	326	380	434	488	543
19	115	143	172	200	229	258	286	344	401	458	516	573
20	121	151	181	211	241	271	301	362	422	482	543	603
21	127	158	190	222	253	285	317	380	443	507	570	633
22	133	166	199	232	265	298	332	398	464	531	597	663
23	139	173	208	243	277	312	347	416	485	555	624	693
24	145	181	217	253	289	326	362	434	507	579	651	724
25	151	188	226	264	301	339	377	452	528	603	678	754
28		211	253	295	338	380	422	507	591	675	760	844
30		226	271	317	362	407	452	543	633	724	814	904
32		241	289	338	386	434	482	579	675	772	868	965
35		264	317	369	422	475	628	633	739	844		

Approximate Range of B_r for bolt diameters: 5/8, M16; 3/4, M20; M22, 7/8; M24, 1; M27; 1-1/8, M30; 1-1/4; M36, 1-1/2

Approximate minimum end distance line.

Approximate 3d line

* $B_r = 0.67\ t\ e\ F_u$ — ** For e > 3d use B_r value for e = 3d.

Notes: 1. Bolt shear governs if less than bearing. See Table 3–4.
2. Bearing values below dashed horizontal lines exceed single shear bolt values.

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F_u = 450MPa

Com espessura e distancia a borda → resistência ao esmagamento

Distancias mínimas e 3D

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FACTORED BEARING RESISTANCE, B_r* (kN/bolt) — **Table 3-7**

ASTM A36 (F_u = 400 MPa)

Material Thickness t (mm)	End Distance**, e (mm): 20	25	30	35	40	45	50	60	70	80	90	100
4	21.4	26.8	32.2	37.5	42.9	48.2	53.6	64.3	75.0	85.8	96.5	107
4.5	24.1	30.1	36.2	42.2	48.2	54.3	60.3	72.4	84.4	96.5	109	121
5	26.8	33.5	40.2	46.9	53.6	60.3	67.0	80.4	93.8	107	121	134
6	32.2	40.2	48.2	56.3	64.3	72.4	80.4	96.5	113	129	145	161
7	37.5	46.9	56.3	65.7	75.0	84.4	93.8	113	131	150	169	188
8	42.9	53.6	64.3	75.0	85.8	96.5	107	129	150	172	193	214
9	48.2	60.3	72.4	84.4	96.5	109	121	145	169	193	217	241
10	53.6	67.0	80.4	93.8	107	121	134	161	188	214	241	268
11	59.0	73.7	88.4	103	118	133	147	177	206	236	265	295
12	64.3	80.4	96.5	113	129	145	161	193	225	257	289	322
13	69.7	87.1	105	122	139	157	174	209	244	279	314	348
14	75.0	93.8	113	131	150	169	188	225	263	300	338	375
15	80.4	100	121	141	161	181	201	241	281	322	362	402
16	85.8	107	129	150	172	193	214	257	300	343	386	429
17	91.1	114	137	159	182	205	228	273	319	364	410	456
18	96.5	121	145	169	193	217	241	289	338	386	434	482
19	102	127	153	178	204	229	255	306	356	407	458	509
20	107	134	161	188	214	241	268	322	375	429	482	536
21	113	141	169	197	225	253	281	338	394	450	507	563
22	118	147	177	206	236	266	295	354	413	472	531	590
23	123	154	185	216	247	277	308	370	431	493	555	616
24	129	161	193	225	257	289	322	386	450	515	579	643
25	134	167	201	234	268	301	335	402	469	536	603	670
28	150	188	225	263	300	338	375	450	525	600	675	750
30	161	201	241	281	322	362	402	482	563	643	724	804
32		214	257	300	343	386	429	515	600	686	772	858
35		234	281	328	375	422	469	563	657	750	844	938

Approximate Range of B_r for bolt diameters: 5/8, M16; 3/4, M20; M22, 7/8; M24, 1; M27; 1-1/8, M30; 1-1/4; M36, 1-1/2

Approximate minimum end distance line

Approximate 3d Line.

MR250

F_u chapa

F_u = 450MPa

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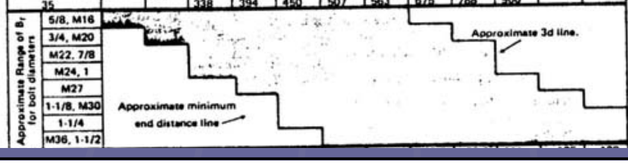
Table 3-7 FACTORED BEARING RESISTANCE, B_r* (kN/bolt)

CSA G40.21-M 350G, 350WT, 350R, 350A, 380W, 380WT (F_u = 480 MPa)

Material Thickness t (mm)	End Distance **, e (mm): 20	25	30	35	40	45	50	60	70	80	90	100
4	25.7	32.2	38.6	45.0	51.5	57.9	64.3	77.2	90.0	103	116	129
4.5	28.9	36.2	43.4	50.7	57.9	65.1	72.4	86.8	101	116	130	145
5	32.2	40.2	48.2	56.3	64.3	72.4	80.4	96.5	113	129	145	161
6	38.6	48.2	57.9	67.5	77.2	86.8	96.5	116	135	154	174	193
7	45.0	56.3	67.5	78.8	90.0	101	113	135	158	180	203	225
8	51.5	64.3	77.2	90.0	103	116	129	154	180	206	232	257
9	57.9	72.4	86.8	101	116	130	145	174	203	232	260	289
10	64.3	80.4	96.5	113	129	145	161	193	225	257	289	322
11	70.8	88.4	106	124	142	159	177	212	248	283	318	354
12	77.2	96.5	116	135	154	174	193	232	270	309	347	386
13	83.6	105	125	146	167	188	209	251	293	334	376	418
14	90.0	113	135	158	180	203	225	270	315	360	405	450
15	96.5	121	145	169	193	217	241	289	338	386	434	482
16	103	129	154	180	206	232	257	309	360	412	463	515
17	109	137	164	191	219	246	273	328	383	437	492	547
18	116	145	174	203	232	260	289	347	405	463	521	579
19	122	153	183	214	244	275	306	367	428	489	550	611
20	129	161	193	225	257	289	322	386	450	515	579	643
21	135	169	203	236	270	304	338	405	473	540	608	675
22	142	177	212	248	283	318	354	425	495	566	637	708
23	148	185	222	259	296	333	370	444	518	592	666	740
24	154	193	232	270	309	347	386	463	540	617	695	772
25	161	201	241	281	322	362	402	482	563	643	724	804
28		225	270	315	360	405	450	540	630	720	810	900
30		241	289	338	386	434	482	579	675	772	868	
32		257	309	360	412	463	515	617	720	823	926	
35			338	394	450	507	563	675	788	900		



F_u chapa

Fu = 480MPa

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Material Thickness t (mm)	End Distance**, e (mm): 20	25	30	35	40	45	50	60	70	80	90	100
4	27.9	34.8	41.8	48.8	55.7	62.7	69.7	83.6	97.6	111	125	139
4.5	31.4	39.2	47.0	54.9	62.7	70.6	78.4	94.1	110	125	141	157
5	34.8	43.5	52.3	61.0	69.7	78.4	87.1	105	122	139	157	174
6	41.8	52.3	62.7	73.2	83.6	94.1	105	125	146	167	188	209
7	48.8	61.0	73.2	85.4	97.6	110	122	146	171	195	219	244
8	55.7	69.7	83.6	97.6	111	125	139	167	195	223	251	279
9	62.7	78.4	94.1	110	125	141	157	188	219	251	282	314
10	69.7	87.1	105	122	139	157	174	209	244	279	314	348
11	76.6	95.8	115	134	153	172	192	230	268	307	345	383
12	83.6	105	125	146	167	188	209	251	293	334	376	418
13	90.6	113	136	159	181	204	226	272	317	362	408	453
14	97.6	122	146	171	195	219	244	293	341	390	439	488
15	106	131	157	183	209	235	261	314	366	418	470	523
16	111	139	167	195	223	251	279	334	390	446	502	557
17	118	148	178	207	237	267	296	355	415	474	533	592
18	125	157	188	219	251	282	314	376	439	502	564	627
19	132	165	199	232	265	298	331	397	463	530	596	662
20	139	174	209	244	279	314	348	418	488	557	627	697
21	146	183	219	256	293	329	366	439	512	585	658	732
22	153	192	230	268	307	345	383	460	537	613	690	766
23	160	200	240	280	321	361	401	481	561	641	721	801
24		209	251	293	334	376	418	502	585	669	753	836
25		218	261	305	348	392	435	523	610	697	784	871
28		244	293	341	390	439	488	585	683	780	878	
30		261	314	366	418	470	523	627	732	836	941	
32			334	390	446	502	557	669	780	892		
35			366	427	488	549	610	732	854			

CSA G40.21-M 400W, 400WT, 400A, 400AT (F_u = 520 MPa)

* B_r = 0.67 t e F_u ** For e > 3d use B_r value for e = 3d.

Notes: 1. Bolt shear governs if less than bearing. See Table 3–4.
2. Bearing values below dashed horizontal lines exceed single shear bolt values.

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F_u chapa

F_u = 520MPa

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Table 3–10 UNIT SLIP RESISTANCE, $0.53\, c_1\, k_s\, F_u$* (MPa)
For 5% Probability of Slip

Contact Surface of Bolted Parts	Class	A	B	C
	Description	Clean mill scale, or blast-cleaned with Class A coatings $k_s = 0.33$	Blast-cleaned, or blast-cleaned with Class B coatings $k_s = 0.50$	Hot-dip galvanized with wire brushed surfaces $k_s = 0.40$
A325M	c_1	0.82	0.89	0.90
$F_u = 830$ MPa	$0.53\, c_1\, k_s\, F_u$ (MPa)	119	196	158
A490M	c_1	0.78	0.85	0.85
$F_u = 1040$ MPa	$0.53\, c_1\, k_s\, F_u$ (MPa)	142	234	187
A325 ($d \le 1$ inch)	c_1	0.82	0.89	0.90
$F_u = 825$ MPa	$0.53\, c_1\, k_s\, F_u$ (MPa)	118	195	157
A325 ($d \ge 1$-1/8 inch)	c_1	0.82	0.89	0.90
$F_u = 725$ MPa	$0.53\, c_1\, k_s\, F_u$ (MPa)	104	171	138
A490	c_1	0.78	0.85	0.85
$F_u = 1035$ MPa	$0.53\, c_1\, k_s\, F_u$ (MPa)	141	233	187

* See CAN/CSA-S16.1-M89, Clause 13.12.2 for values of c_1 and k_s.

Resistência ao atrito por unidade de área em função da classe, D, tipo de parafuso

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Table 3–11 SLIP RESISTANCE, V_s,* (kN/BOLT)
For Single Shear ** (m = 1)

Bolt Size		Nominal Area	Class A Surfaces		Class B Surfaces	
Metric'	Imperial	A_b (mm^2)	A325M, A325	A490M, A490	A325M, A325	A490M, A490
	1/2	127	15.0	17.9	24.7	29.6
	5/8	198	23.4	28.0	38.5	46.2
M16		201	23.9	28.5	39.3	47.1
	3/4	285	33.7	40.2	55.5	66.4
M20		314	37.4	44.6	61.5	73.6
M22		380	45.2	53.9	74.4	89.0
	7/8	388	45.9	54.8	75.5	90.5
M24		452	53.8	64.1	88.5	106
	1	507	60.0	71.6	98.7	118
M27		573	68.2	81.3	112	134
	1-1/8	641	66.6	90.5	110	149
M30		707	84.2	100	138	166
	1-1/4	792	82.4	112	135	185
M36		1018	121	144	199	238
	1-1/2	1140	119	161	195	266

* These resistances are for use with specified loads in accordance with Clause 13.12 of CAN/CSA-S16.1-M89.
** For double shear (m = 2) multiply tabulated values by 2.0.
' The number following the letter M is the nominal bolt diameter in millimetres.

Resistência ao atrito para m =1

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Example

Given:

A single shear connection is subject to 370 kN at specified load level and 550 kN at factored load level. Select the number of M20 A325M bolts required for a slip-critical connection. Steel is G40.21-M 300W 6mm thick, and the surface is clean mill scale (Class A).

Solution:

(a) For specified loads

From Table 3–11, V_s = 37.4 kN (M20 A325M bolt for clean mill scale).

Number of bolts required = 370/37.4 = 9.9 —use 10

(b) Check connection at factored loads

From Table 3–4 (page 3–8), V_r = 73.5 kN (M20 A325M, threads intercepted)

Factored shear resistance of joint is $10 \times 73.5 = 735$ kN > 550 —OK

The factored bearing resistance of the joint for factored loads also needs to be checked, based upon thicknesses and end distances of the connected material:

For 6 mm thick material and an end distance of 30 mm, Table 3–6 (page 3–9) lists a bearing value of 54.3 kN per bolt which is less than 55.0 kN required for the 550 kN load.

Increase the edge distance, possibly to 35mm (B_r = 63.3 kN).

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Table 3–12
$C_1 = 0.82$
$k_s = 0.33$

SPECIFIED SHEAR AND TENSION (kN/BOLT)
Slip-Critical Connections, Class A Surfaces
A325M and A325 Bolts

Shear-Tension Ratio X = V/T		3/4		M20		M22		7/8		M24		1	
X	1/X	V	T	V	T	V	T	V	T	V	T	V	T
0.5		21.9	43.8	24.5	49.0	29.9	59.7	30.0	60.1	35.3	70.6	39.3	78.5
0.6		23.3	38.8	26.0	43.3	31.7	52.8	31.9	53.1	37.4	62.4	41.7	69.4
0.7		24.3	34.8	27.2	38.8	33.1	47.2	33.3	47.6	39.1	55.9	43.6	62.2
0.8		25.2	31.5	28.1	35.2	34.2	42.8	34.5	43.1	40.5	50.6	45.1	56.4
0.9		25.9	28.8	28.9	32.1	35.2	39.1	35.5	39.4	41.7	46.3	46.4	51.5
1.0	1.0	26.5	26.5	29.6	29.6	36.0	36.0	36.3	36.3	42.6	42.6	47.5	47.5
1.11	0.9	27.1	24.4	30.2	27.2	36.7	33.0	37.1	33.4	43.5	39.2	48.5	43.6
1.25	0.8	27.7	22.2	30.9	24.7	37.5	30.0	37.9	30.3	44.5	35.6	49.5	39.6
1.43	0.7	28.3	19.8	31.6	22.1	38.3	26.8	38.7	27.1	45.5	31.8	50.6	35.4
1.67	0.6	29.0	17.4	32.3	19.4	39.2	23.5	39.6	23.8	46.5	27.9	51.8	31.1
2.00	0.5	29.7	14.8	33.0	16.5	40.1	20.0	40.6	20.3	47.6	23.8	53.0	26.5
2.50	0.4	30.4	12.2	33.8	13.5	41.0	16.4	41.5	16.6	48.7	19.5	54.3	21.7
3.33	0.3	31.2	9.4	34.7	10.4	42.0	12.6	42.5	12.8	49.9	15.0	55.6	16.7
5.00	0.2	32.0	6.4	35.5	7.1	43.0	8.6	43.6	8.7	51.1	10.2	57.0	11.4
10.00	0.1	32.8	3.3	36.4	3.6	44.1	4.4	44.7	4.5	52.4	5.2	58.5	5.8
Vs	0	33.7	0	37.4	0	45.2	0	45.9	0	53.8	0	60.0	0

$V = XT, \quad T = \frac{V_s}{X + V_s / T_i}$

Atrito + Tração Aproximada pela equação

$$\frac{V}{V_s} + \frac{T}{T_s} \leq 1{,}0$$

Ao invés de:

$$\frac{V}{V_s} + \frac{T}{1{,}9T_s} \leq 1{,}0$$

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14. Tabelas Manual Canadense

Example

Given:

Find the number of M20 A325M bolts required in a slip-critical connection to resist a specified tension force of 320 kN and a specified shear force of 400 kN. The single faying surface consists of clean mill scale.

Solution:

Prying is not a factor when making the specified shear vs. specified tension interaction check. Within permitted loadings, prying is only a redistribution of the contact forces between the material surfaces, having no significant affect upon resistance to slipping.

However, the connection also has to be confirmed for strength as a bearing-type connection at factored loads.

Shear-tension ratio is 400 / 320 = 1.25

From Table 3–12, for M20 bolts and V/ T = 1.25,

permitted V = 30.9 kN and T = 24.7 kN per bolt

Therefore, number of bolts required is 400 / 30.9 or 320 / 24.7 = 12.9

Try 14 bolts

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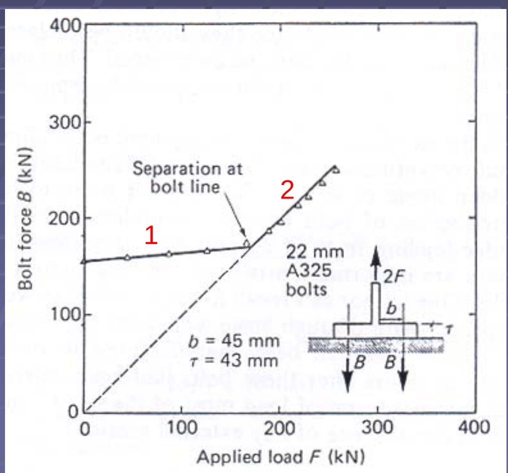
15. Efeito de Alavanca

- Efeito de Alavanca ("Prying Action")



Placas grossas

1. Carga menor do que o somatório das cargas de protensão mínimas aplicadas nos parafusos
2. Após este limite não ocorre mais deformação na placa devido sua rigidez elevada

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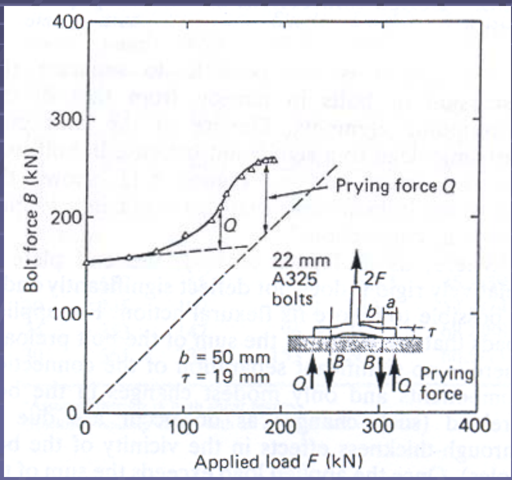
15. Efeito de Alavanca

- Efeito de Alavanca ("Prying Action")



Placas finas (flexíveis)

1. **2B = 2F + 2Q**
2. **Q → efeito de alavanca que amplifica a carga nos parafusos (B)**
   a) **A separação das placas é antecipada**
   b) **Redução na rigidez da ligação**
   c) **Redução na capacidade última 260kN → 190kN**

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15. Efeito de Alavanca

- Efeito de Alavanca ("Prying Action")
- 1- Análise Elasto-Plástica
- 2- Efeito das imperfeições/tolerancias na distribuição final das forças
- 3- Avaliação da rigidez real dos parafusos
- 4- Incerteza na distribuição de pressões de contacto (cabeça do parafuso x porca)
- 5- Incerteza da curvatura inicial na linha de ação das forças de alavanca
- 6- Efeitos locais ao longo da espessura da placa na região próxima aos furos

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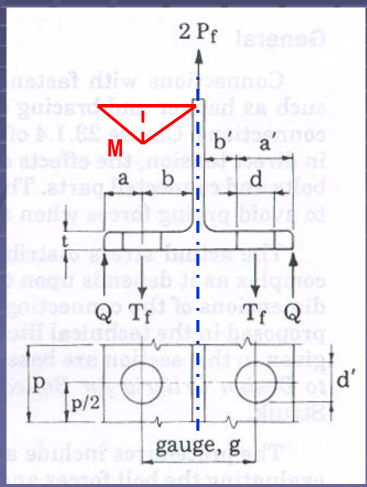
15. Efeito de Alavanca

- Efeito de Alavanca (“Prying Action”) – Canadense



- $P_f \cdot b = Q \cdot a \longrightarrow Q / P_f = b / a$

$$K = 4\,b'\,10^3 / (\phi\, p\, F_y) \quad (1)$$

$$\delta = 1 - d'/p \quad (2)$$

$$\text{Range of } t = \left(\frac{K\,P_f}{(1+\delta\,\alpha)}\right)^{1/2} \qquad t_{min} \text{ when } \alpha = 1.0, \quad t_{max} \text{ when } \alpha = 0.0 \quad (3)$$

$$\alpha = \left(\frac{K\,T_r}{t^2} - 1\right) \times \frac{a'}{\delta\,(a'+b')}, \quad 0 \le \alpha \le 1.0 \quad (4)$$

$$\text{Connection capacity} = (t^2/K)\,(1+\delta\,\alpha)\,n \quad (5)$$

$$\alpha = \left(\frac{K\,P_f}{t^2} - 1\right) \times \frac{1}{\delta} \quad (6)$$

$$T_f \approx P_f \left[1 + \left(\frac{b'}{a'} \times \frac{\delta\,\alpha}{1+\delta\,\alpha}\right)\right] \le T_r \quad (7)$$

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15. Efeito de Alavanca

- Efeito de Alavanca (“Prying Action”) – Canadense
  - $K \longrightarrow$ parâmetro conforme apresentado anteriormente
  - $P_f \longrightarrow$ carga fatorada aplicada em cada parafuso
  - $Q \longrightarrow$ força de alavanca por parafuso em função da carga fatorada ($Q = T_f - P_f$)
  - $T_f \longrightarrow$ carga fatorada por parafuso incluindo as forças de alavanca
  - $T_r \longrightarrow$ resistência à tração fatorada dos parafusos ($\phi_b \cdot 0{,}75 \cdot A_b \cdot F_u$)
  - $F_y \longrightarrow$ tensão de escoamento da mesa do T-stub (MPa)
  - $a \longrightarrow$ distância da linha de parafusos até a extremidade livre da mesa do T-stub não maior que 1,25b (mm)
  - $a' \longrightarrow a + d/2$ (mm)
  - $b \longrightarrow$ distância da linha de parafusos até a face da alma do T-stub (mm)
  - $b' \longrightarrow b - d/2$ (mm)

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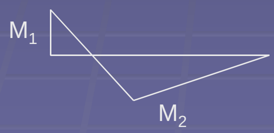
15. Efeito de Alavanca

- Efeito de Alavanca (“Prying Action”) – Canadense

- d ⟶ diâmetro do parafuso (mm)
- d’ ⟶ diâmetro nominal do furo (mm)
- n ⟶ número de parafusos em tração
- p ⟶ comprimento da mesa a ser considerado para cada parafuso
- t ⟶ espessura da mesa do T-stub
- α ⟶ Razão entre momento positivo e momento negativo



$\alpha = M_1 / M_2$

- δ ⟶ razão entre a área líquida e a área bruta da face do T-stub
- ϕ ⟶ fator de resistência do material do T-stub (0,9)

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15. Efeito de Alavanca

- Efeito de Alavanca (“Prying Action”) – Canadense

Design Procedure

Trial Section

1) Select an intended bolt size as a function of the applied factored tensile load per bolt P_f and the anticipated prying ratio. (D ⟶ P_f e Q)
2) With P_f, the bolt size, and trial values of *b* and *p*, use Eqns. 1, 2 and 3 (with α =0.0 and α = 1.0) to identify a range of acceptable flange thicknesses. (Alternatively, use Table 3–13 on page 3–24.) ($t_{máx}$ e $t_{mín}$ para a mesa)
3) Identify an intended flange thickness. (t escolhido)

Figure 3–2 (page 3–25) may also be used to identify an intended bolt size and flange geometry, based on the amplified bolt force being less than the bolt tensile resistance.

Design Check

1) Calculate α by using Eqn. 4, for use in Eqn. 5.
2) Calculate the connection capacity with Eqn. 5. If α from Eqn. 4 < 0.0, use α = 0.0, and if α > 1.0, use α = 1.0.
3) Equations 6 and 7 can be used, if desired, to determine the total bolt tension including prying (amplified bolt force), that results from the applied load.

15. Efeito de Alavanca

- Efeito de Alavanca ("Prying Action") – Canadense

RANGE OF t — **Table 3-13**

$$t = \left[\frac{K P_f}{(1 + \delta\alpha)} \right]^{1/2}$$

t_{min} when α = 1.0 and t_{max} when α = 0.0

b (mm)	Bolt Size	P_f = 60 kN pitch p (mm)			P_f = 80 kN pitch p (mm)			P_f = 100 kN pitch p (mm)			P_f = 120 kN pitch p (mm)		
		80	90	100	80	90	100	80	90	100	80	90	100
35	3/4	12.8 16.8	11.9 15.9	11.2 15.0	14.7 19.4	13.8 18.3	13.0 17.4	16.5 21.7	15.4 20.5	14.5 19.4			
	M20	12.7 16.7	11.9 15.7	11.2 14.9	14.7 19.2	13.7 18.1	12.9 17.2	16.4 21.5	15.3 20.3	14.4 19.2	17.9 23.6	16.8 22.2	15.8 21.1
40	3/4	14.0 18.4	13.1 17.3	12.3 16.5	16.1 21.2	15.1 20.0	14.2 19.0	18.0 23.8	16.9 22.4	15.9 21.2			
	M20	13.9 18.3	13.0 17.2	12.2 16.3	16.1 21.1	15.0 19.9	14.1 18.9	17.9 23.6	16.8 22.2	15.8 21.1	19.7 25.8	18.4 24.3	17.3 23.1
45	3/4	15.1 19.9	14.1 18.7	13.3 17.8	17.4 22.9	16.3 21.6	15.3 20.5	19.4 25.6	18.2 24.2	17.1 22.9			
	M20	15.0 19.7	14.0 18.6	13.2 17.6	17.3 22.8	16.2 21.5	15.3 20.4	19.4 25.5	18.1 24.0	17.1 22.8	21.2 27.9	19.8 26.3	18.7 24.9
50	3/4	16.1 21.2	15.0 20.0	14.2 19.0	18.6 24.5	17.4 23.1	16.4 21.9	20.8 27.4	19.4 25.8	18.3 24.5			
	M20	16.1 21.1	15.0 19.9	14.1 18.9	18.5 24.3	17.3 23.0	16.3 21.8	20.7 27.2	19.4 25.7	18.2 24.3	22.7 29.8	21.2 28.1	20.0 26.7
55	3/4	17.1 22.5	15.9 21.2	15.0 20.1	19.7 26.0	18.4 24.5	17.4 23.2	22.0 29.0	20.6 27.4	19.4 26.0			
	M20	17.0 22.4	15.9 21.1	15.0 20.0	19.7 25.8	18.4 24.3	17.3 23.1	22.0 28.9	20.5 27.2	19.4 25.8	24.1 31.6	22.5 29.8	21.2 28.3

15. Efeito de Alavanca

- Efeito de Alavanca ("Prying Action") – Canadense

b (mm)	Bolt Size	P_f = 100 kN pitch p (mm)			P_f = 120 kN pitch p (mm)			P_f = 140 kN pitch p (mm)			P_f = 160 kN pitch p (mm)		
		90	100	110	90	100	110	90	100	110	90	100	110
40	M22	16.6 21.8	15.6 20.7	14.8 19.8	18.2 23.9	17.1 22.7	16.2 21.6	19.6 25.9	18.5 24.5	17.5 23.4			
	7/8	16.6 21.8	15.6 20.7	14.8 19.7	18.2 23.9	17.1 22.7	16.2 21.6	19.6 25.8	18.5 24.5	17.5 23.3	21.0 27.6	19.7 26.2	18.7 24.9
45	M22	18.0 23.7	16.9 22.4	16.0 21.4	19.7 25.9	18.5 24.6	17.6 23.4	21.3 28.0	20.0 26.6	19.0 25.3			
	7/8	18.0 23.6	16.9 22.4	16.0 21.4	19.7 25.9	18.5 24.5	17.5 23.4	21.2 27.9	20.0 26.5	18.9 25.3	22.7 29.9	21.4 28.3	20.3 27.0
50	M22	19.2 25.3	18.1 24.0	17.2 22.9	21.1 27.8	19.8 26.3	18.8 25.1	22.8 30.0	21.4 28.4	20.3 27.1			
	7/8	19.2 25.3	18.1 24.0	17.2 22.9	21.1 27.7	19.8 26.3	18.8 25.1	22.8 29.9	21.4 28.4	20.3 27.1	24.3 32.0	22.9 30.4	21.7 28.9
55	M22	20.4 26.9	19.2 25.5	18.2 24.3	22.4 29.5	21.1 28.0	20.0 26.7	24.2 31.8	22.8 30.2	21.6 28.8			
	7/8	20.4 26.9	19.2 25.5	18.2 24.3	22.4 29.4	21.1 27.9	20.0 26.6	24.2 31.8	22.8 30.2	21.6 28.8	25.8 34.0	24.3 32.3	23.1 30.8

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15. Efeito de Alavanca

- Efeito de Alavanca (“Prying Action”) – Canadense

b (mm)	Bolt Size	P_f = 140 kN pitch p (mm)			P_f = 160 kN pitch p (mm)			P_f = 180 kN pitch p (mm)			P_f = 200 kN pitch p (mm)		
		100	110	120	100	110	120	100	110	120	100	110	120
40	M24	**18.3** **24.1**	**17.3** **23.0**	**16.5** **22.0**	**19.5** **25.8**	**18.5** **24.6**	**17.6** **23.5**	**20.7** **27.3**	**19.6** **26.1**	**18.7** **24.9**			
	1	18.1 23.8	17.1 22.7	16.3 21.7	19.4 25.4	18.3 24.3	17.4 23.2	20.5 27.0	19.4 25.7	18.5 24.6	21.6 28.4	20.5 27.1	19.5 26.0
45	M24	**19.8** **26.2**	**18.8** **24.9**	**17.9** **23.9**	**21.2** **28.0**	**20.1** **26.7**	**19.1** **25.5**	**22.5** **29.7**	**21.3** **28.3**	**20.3** **27.1**			
	1	19.7 25.9	18.7 24.7	17.8 23.6	21.1 27.7	19.9 26.4	19.0 25.3	22.3 29.3	21.1 28.0	20.1 26.8	23.5 30.9	22.3 29.5	21.2 28.2
50	M24	**21.3** **28.1**	**20.2** **26.8**	**19.2** **25.6**	**22.8** **30.0**	**21.5** **28.6**	**20.5** **27.4**	**24.1** **31.8**	**22.9** **30.4**	**21.8** **29.1**			
	1	21.2 27.8	20.0 26.5	19.1 25.4	22.6 29.7	21.4 28.4	20.4 27.1	24.0 31.5	22.7 30.1	21.6 28.8	25.3 33.2	24.0 31.7	22.8 30.3
55	M24	**22.6** **29.9**	**21.4** **28.5**	**20.4** **27.3**	**24.2** **31.9**	**22.9** **30.4**	**21.8** **29.1**	**25.7** **33.9**	**24.3** **32.3**	**23.1** **30.9**			
	1	22.5 29.6	21.3 28.2	20.3 27.0	24.1 31.7	22.8 30.2	21.7 28.9	25.6 33.6	24.2 32.0	23.0 30.7	26.9 35.4	25.5 33.8	24.3 32.3

$K = 4b' 10^3 / (\phi p F_y)$ where $\phi = 0.90$ and $F_y = 300$ MPa

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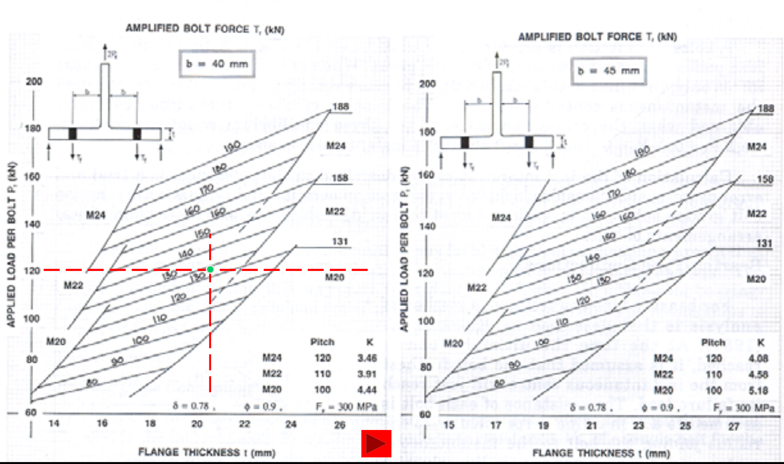
15. Efeito de Alavanca

- Efeito de Alavanca (“Prying Action”) – Canadense

Figure 3.2 **AMPLIFIED BOLT FORCE, T_f (kN)**



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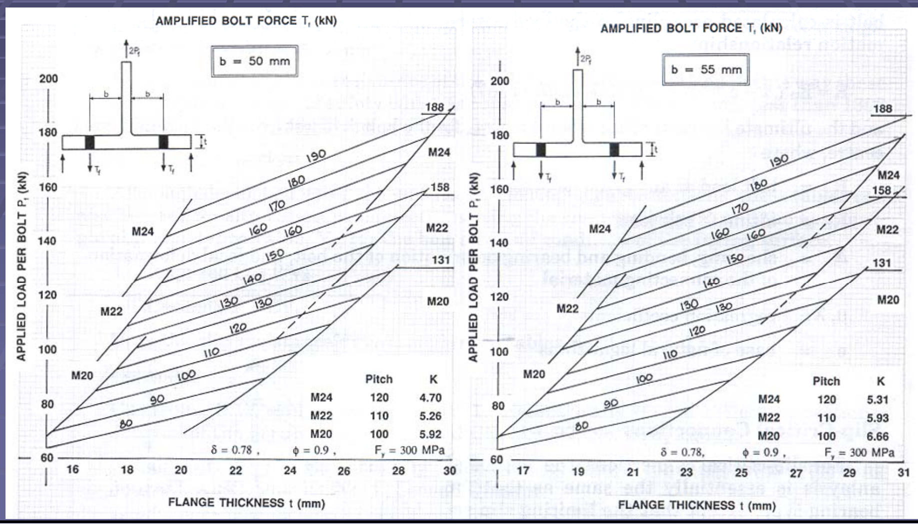
15. Efeito de Alavanca

- Efeito de Alavanca ("Prying Action") – Canadense



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15. Efeito de Alavanca

- Efeito de alavanca – Eurocode 3 pt. 1.8
- Where fasteners are required to carry an applied tensile force, they should be designed to resist the additional force due to prying action
- Rules given in 6.2.4 implicitly account for prying forces

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15. Efeito de Alavanca

- Efeito de alavanca – Eurocode 3 pt. 1.8

6.2.4 Equivalent T-stub in tension

6.2.4.1 General

(1) In bolted connections an equivalent T-stub in tension may be used to model the design resistance of the following basic components:

- column flange in bending;
- end-plate in bending;
- flange cleat in bending;
- base plate in bending under tension.

(2) Methods for modelling these basic components as equivalent T-stub flanges, including the values to be used for e_{min}, ℓ_{eff} and m, are given in 6.2.6.

(3) The possible modes of failure of the flange of an equivalent T-stub may be assumed to be similar to those expected to occur in the basic component that it represents.

(4) The total effective length $\sum \ell_{eff}$ of an equivalent T-stub, see Figure 6.2, should be such that the design resistance of its flange is equivalent to that of the basic joint component that it represents.

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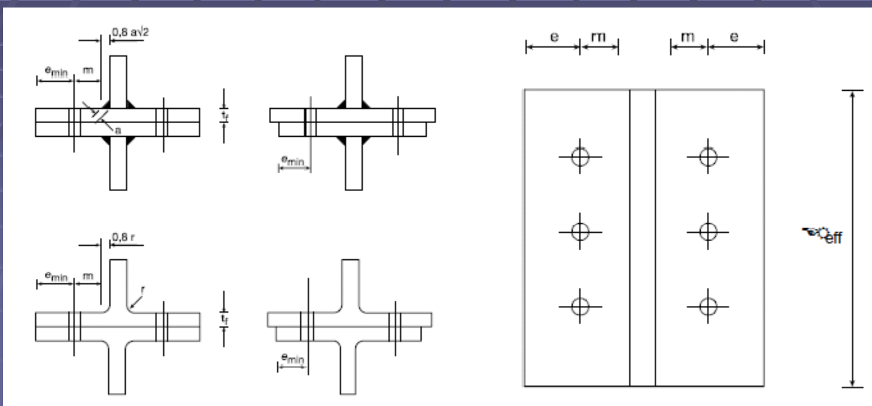
15. Efeito de Alavanca

- Efeito de alavanca – Eurocode 3 pt. 1.8



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15. Efeito de Alavanca

- Efeito de alavanca – Eurocode 3 pt. 1.8

Table 6.2: Design Resistance $F_{T,Rd}$ of a T-stub flange

	Prying forces may develop, i.e. $L_b \leq L_b^*$		No prying forces
Mode 1	Method 1	Method 2 (alternative method)	
without backing plates	$F_{T,1,Rd} = \dfrac{4M_{pl,1,Rd}}{m}$	$F_{T,1,Rd} = \dfrac{(8n-2e_w)M_{pl,1,Rd}}{2mn-e_w(m+n)}$	$F_{T,1\text{-}2,Rd} = \dfrac{2M_{pl,1,Rd}}{m}$
with backing plates	$F_{T,1,Rd} = \dfrac{4M_{pl,1,Rd}+2M_{bp,Rd}}{m}$	$F_{T,1,Rd} = \dfrac{(8n-2e_w)M_{pl,1,Rd}+4nM_{bp,Rd}}{2mn-e_w(m+n)}$	
Mode 2	$F_{T,2,Rd} = \dfrac{2M_{pl,2,Rd}+n\Sigma F_{t,Rd}}{m+n}$		
Mode 3	$F_{T,3,Rd} = \Sigma F_{t,Rd}$		

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15. Efeito de Alavanca

Mode 1: Complete yielding of the flange
Mode 2: Bolt failure with yielding of the flange
Mode 3: Bolt failure

L_b is - the bolt elongation length, taken equal to the grip length (total thickness of material and washers), plus half the sum of the height of the bolt head and the height of the nut or
- the anchor bolt elongation length, taken equal to the sum of 8 times the nominal bolt diameter, the grout layer, the plate thickness, the washer and half the height of the nut

$L_b^* = \dfrac{8{,}8m^3 A_s}{\Sigma \ell_{eff,1} t_f^{\,3}}$

$F_{T,Rd}$ is the design tension resistance of a T-stub flange
Q is the prying force

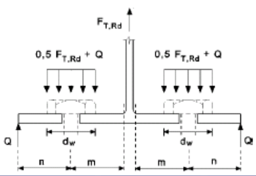
$M_{p\ell,1,Rd} = 0{,}25 \Sigma \ell_{eff,1} t_f^{\,2} f_y / \gamma_{M0}$

$M_{p\ell,2,Rd} = 0{,}25 \Sigma \ell_{eff,2} t_f^{\,2} f_y / \gamma_{M0}$

$M_{bp,Rd} = 0{,}25 \Sigma \ell_{eff,1} t_{bp}^{\,2} f_{y,bp} / \gamma_{M0}$

$n = e_{min}$ but $n \leq 1{,}25m$

$F_{t,Rd}$ is the design tension resistance of a bolt, see Table 3.4;
$\sum F_{t,Rd}$ is the total value of $F_{t,Rd}$ for all the bolts in the T-stub;
$\sum \ell_{eff,1}$ is the value of $\sum \ell_{eff}$ for mode 1;
$\sum \ell_{eff,2}$ is the value of $\sum \ell_{eff}$ for mode 2;
e_{min}, m and t_f are as indicated in Figure 6.2.
$f_{y,bp}$ is the yield strength of the backing plates;
t_{bp} is the thickness of the backing plates;
$e_w = d_w / 4$;
d_w is the diameter of the washer, or the width across points of the bolt head or nut, as relevant.



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15. Efeito de Alavanca

NOTE 1: In bolted beam-to-column joints or beam splices it may be assumed that prying forces will develop.
NOTE 2: In method 2, the force applied to the T-stub flange by a bolt is assumed to be uniformly distributed under the washer, the bolt head or the nut, as appropriate, see figure, instead of concentrated at the centre-line of the bolt. This assumption leads to a higher value for mode 1, but leaves the values for $F_{T,1\text{-}2,Rd}$ and modes 2 and 3 unchanged.

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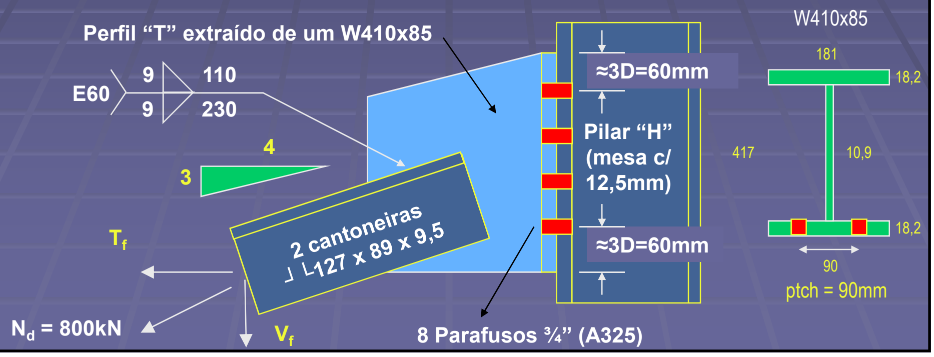
16. Efeito de Alavanca - Exemplos

4- Verificar o efeito de alavanca na ligação abaixo.

Dados: parafusos A325 c/ d = 7/8” (F_y = 635MPa e F_u = 825MPa)

Aço MR250 (F_y = 250MPa e F_u = 400MPa)



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16. Efeito de Alavanca - Exemplos

Avaliação da força de alavanca

- P_f = 60kN
- W410x85 $\longrightarrow$ t=18,2mm, w=10,9mm e b_f=181mm
- b = (90 - 10,9)/2 = 39,6mm; b' = 39,6 - 19,05 / 2 = 30,1mm e 1,25b = 49,5
- a = (181 - 90) / 2 = 45,5 < 1,25 b; a' = 45,5 + 19,05 / 2 = 55mm
- K = (4 . 30,1 . 10^3) / (0,9 . 90 . 250) = 5,95
- δ = 1 – 19,05 / 90 = 0,788

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16. Efeito de Alavanca - Exemplos

Força de alavanca (continuação)

- Usando o máximo T_f permitido na equação (4), ou seja, T_f=97,2kN

$$\alpha = \left(\frac{5{,}95 \text{ x } 97{,}2}{18{,}2^2} - 1 \right) \text{x} \frac{55}{0{,}788(55 + 30{,}1)} = 0{,}612$$ **(por parafuso)**

- Capacidade da ligação (alma do T) =

$$\left(\frac{18{,}2^2}{5{,}95} \right) \text{x} (1 + 0{,}788 \text{x} 0{,}612) \text{x} 8 = 660\text{kN} > 480\text{kN}$$

- Força amplificada no parafuso

$$\alpha = \left(\frac{5{,}95 \text{ x } 60}{18{,}2^2} - 1 \right) \text{x} \frac{1}{0{,}788} = 0{,}100$$

(para a carga aplicada)

$\delta . \alpha$ = 0,078

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16. Efeito de Alavanca - Exemplos

Força de alavanca (continuação)

$$T_f = 80x\left[1+\left(\frac{30{,}1}{55}x\frac{0{,}078}{1{,}078}\right)\right] = 83{,}2kN < 97{,}2kN$$

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16. Efeito de Alavanca - Exemplos

- Efeito de Alavanca ("Prying Action") – Exemplo 5

Example 1

Given:

Design a tension tee connection with 4 ASTM A325M bolts in tension for a factored static load of 500 kN assuming the bolts on a 100 mm gauge, at a pitch of 110 mm, with the tee connected to rigid supports. Use G40.21-M 300W steel. Fy

Solution: t_f?

Trial Section

Applied load per bolt = 500/4 = 125 kN = P_f

Assume M22 bolts, 24 mm hole diameter, 15 mm web. T_r = 158 kN (tabela de parafusos 3-4)

Available prying ratio T_r / P_f is 158/125 = 1.26 ∴ OK for near minimum flange

1,00 < Tf / Pf < 1,33

$b = (100 - 15) / 2 = 42.5$ mm; $b' = 42.5 - 11 = 31.5$

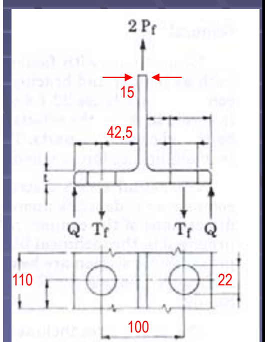
$K = 4 \times 31.5 \times 10^3 / (0.9 \times 110 \times 300) = 4.25$ (Eqn. 1)

$\delta = 1 - (24 / 110) = 0.782$ (Eqn. 2)

$$t_{min} = \left(\frac{4.25 \times 125}{1.782}\right)^{1/2} = 17.3\text{ mm}; \quad t_{max} = \left(\frac{4.25 \times 125}{1.0}\right)^{1/2} = 23.0\text{ mm} \quad \text{(Eqn. 3)}$$

(Alternatively, the range of *t*, by rough interpolation from Table 3–13 on page 3–24, could be seen to be about 17 to 23 mm.)

Two possible solutions are W460x97, *t* = 19.0 mm, and W530x138, *t* = 23.6 mm, the choice being determined by the maximum available prying ratio T_r / P_f for the bolt size finally selected.



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16. Efeito de Alavanca - Exemplos

- Efeito de Alavanca ("Prying Action") – Exemplo 5

Design Check

Try W460x97 with M22 bolts, d = 22 mm, d′ = 24 mm

t = 19.0, w = 11.4, flange width = 193

$b = (100 - 11.4) / 2 = 44.3$ mm; $b' = 44.3 - 11 = 33.3$; $1.25\,b = 55.4$

$K = 4 \times 33.3 \times 10^3 / (0.9 \times 110 \times 300) = 4.48$ (Eqn. 1)

$\delta = 0.782$ (as above, by Eqn. 2)

$a = (193 - 100) / 2 = 46.5$ mm $< 1.25\,b$; $a' = 46.5 + 11 = 57.5$; $a' + b' = 90.8$

$$\alpha = \left(\frac{4.48 \times 158}{19.0^2} - 1\right) \times \frac{57.5}{0.782 \times 90.8} = 0.778 \quad \text{(Eqn. 4)}$$

$\delta\alpha = 0.608$

Connection capacity = $(19.0^2 / 4.48)(1.608)\,4 = 518$ kN > 500 (Eqn. 5)

To find actual bolt tension, if desired:

$$\alpha = \left(\frac{4.48 \times 125}{19.0^2} - 1\right) \times \frac{1}{0.782} = 0.705 \quad \text{(Eqn. 6)}$$

$\delta\alpha = 0.551$

$$T_f \approx 125\left[1 + \left(\frac{33.3}{57.5} \times \frac{0.551}{1 + 0.551}\right)\right] = 151\ \text{kN}, \quad < 158 \quad \text{(Eqn. 7)}$$

Tee stem capacity is $0.9\,(2 \times 110)\,11.4 \times 300 / 1\,000 = 677$ kN > 500 $\therefore$ OK

(With M20 bolts, $T_r / P_f = 131 / 125 = 1.05$, and the heavier W530x138 is required.)

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16. Efeito de Alavanca - Exemplos

- Efeito de Alavanca ("Prying Action") – Exemplo 6

Example 2

Given:

Use Table 3–13 to select bolt sizes and trial dimensions for a factored tensile load of 480 kN, assuming tees cut from a W460x106 section (G40.21-M 300W), and a gauge dimension of 90 mm.

Solution:

Since Table 3–13 is intended only for the selection of a trial section which must be checked with Eqns. 1, 2, 4 and 5 on page 3–20 (illustrated in the previous example), precise interpolation is not necessary. A comparison of the available ratio T_r / P_f for the bolts chosen, to the ratio of t_{max} to flange thickness, for the value of t_{max} selected from Table 3–13, will indicate whether a combination of bolt size, flange thickness and geometry may be a suitable choice.

For W460x106, t = 20.6 mm and w = 12.6 mm

For g = 90 mm, $b = (90 - 12.6) / 2 = 38.7$ (Use b = 40 for Table 3–13)

With 4 bolts, $P_f = 480/4 = 120$ kN, and $T_r / P_f = 131/120 = 1.09$ for M20 bolts, and $159/120 = 1.32$ for M22 bolts.

Tabela 3-4

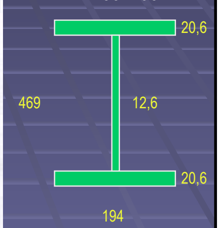
Table 3–13, with $b = 40$, M20 bolts and $P_f = 120$, $p = 100$ gives $t_{max} = 23.1$ mm

$t_{max} / t = 23.1 / 20.6 = 1.12$ $> T_r / P_f = 1.09$ Likely not OK

Table 3–13, with $b = 40$, M22 bolts and $P_f = 120$, $p = 90$ gives $t_{max} = 23.9$ mm

$t_{max} / t = 23.9 / 20.6 = 1.16$ $< T_r / P_f = 1.32$ $\therefore$ OK, check the design

W460x106



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16. Efeito de Alavanca - Exemplos

- Efeito de Alavanca ("Prying Action") – Exemplo 6

Alternatively, Fig. 3–2 can be used to select the bolt size based on the flange thickness and the amplified bolt force.

Use graph for b = 40 mm (b = 38.7, see above)

Enter graph at applied load per bolt of 120 kN and flange thickness t = 20.6 mm

With M20 bolts, amplified bolt force ≈ 138 kN $> T_r = 131$ kN No good

With M 22 bolts, amplified bolt force ≈ 125 kN $< T_r = 158$ kN ∴ OK

Proceed with design check using M22 bolts; p = 5d = 110 mm.

$b = 38.7$; $b' = 38.7 - 11 = 27.7$; $1.25\,b = 48.4$

$K = 4 \times 27.7 \times 10^3 / (0.9 \times 110 \times 300) = 3.73$ (Eqn. 1)

$\delta = 1 - (24/110) = 0.782$ (Eqn. 2)

$a = (194 - 90)/2 = 52.0\text{ mm} > 1.25\,b$

Use $a = 1.25\,b = 48.4$; $a' = 48.4 + 11 = 59.5$; $a' + b' = 87.2$

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16. Efeito de Alavanca - Exemplos

- Efeito de Alavanca ("Prying Action") – Exemplo 6

$$\alpha = \left(\frac{3.73 \times 158}{20.6^2} - 1\right) \times \frac{59.5}{0.782 \times 87.2} = 0.339 \quad \text{(Eqn. 4)} \qquad \delta\,\alpha = 0.265$$

Connection capacity = $(20.6^2/3.73)(1.265)\,4 = 576$ kN > 480 (Eqn. 5)

Check bolt tension (amplified bolt force)

$$\alpha = \left(\frac{3.73 \times 120}{20.6^2} - 1\right) \times \frac{1}{0.782} = 0.070 \quad \text{(Eqn. 6)} \qquad \delta\,\alpha = 0.055$$

$$T_f \approx 120\left[1 + \left(\frac{27.7}{59.5} \times \frac{0.055}{1 + 0.055}\right)\right] = 123\text{ kN}, \quad < 158 \quad \text{(Eqn. 7)}$$