Eurocode 3 for Dummies The Opportunities and Traps

a brief guide on element design to EC3

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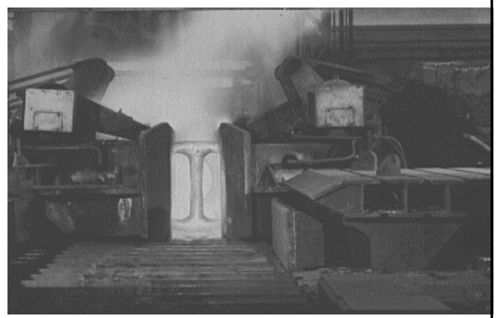
Slides available on the web

- http://www2.umist.ac.uk/construction/staff/mccarthy/index.htm
- Follow the link from my home page
- From 21 March 2003

Overview

- Eurocode 3
  - Current status
  - Coverage
- Pitfalls
  - Major and minor differences with BS5950
- Element Design
  - Beams, Struts
- Capacity comparisons



EC3 Current Status

PRÉNORME EUROPÉENNE
EUROPÄISCHE VORNORM 5 June 2002

UDC

Descriptors:

English version

Eurocode 3 : Design of steel structures

Part 1-1 : General ~~structural~~ rules and rules for buildings

Calcul des structures en acier

Partie 1-1 : Règles générales et règles pour ingènierie du bâtiment

Bemessung und Konstruktion von Stahlbauten

Teil 1-1 : Allgemeine Bemessungsregeln und Regeln für Hallen und Geschoßbauten

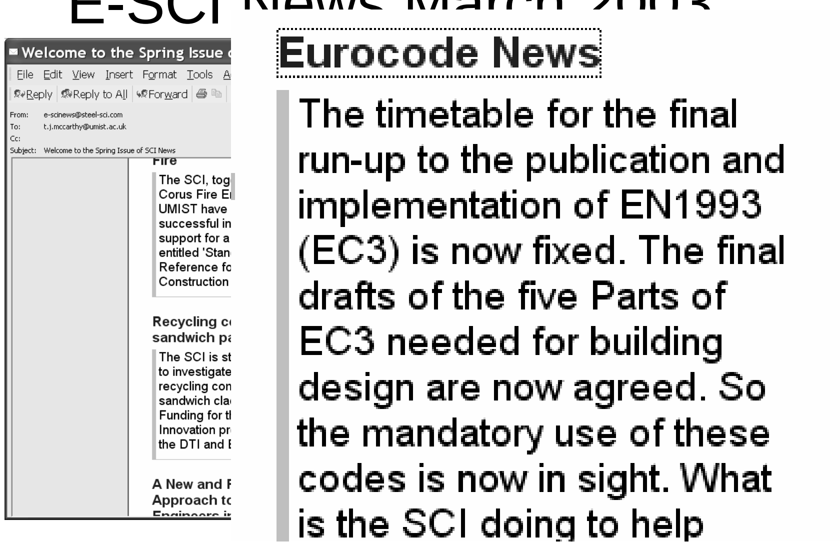
Stage 34 draft

Amendments sent prior to the CEN TC 250 / SC 3 meeting in Vienna are highlighted by yellow colour.

Amendments made during the CEN TC 250 / SC 3 meeting in Vienna are highlighted by light blue colour.

This document is a merger of the stage 34 drafts prEN 1993-1-1 and prEN 1993-3 both dated 1 May 2002

E-SCI News March 2003



Eurocode terminilogy

- EN – EuroNorm
  - mandatory standard
- ENV – EuroNorm Voluntaire
  - You can use it if you wish
- DD – Draft for development
- DC – Draft for public comment
- prEN
  - Pre-EuroNorm between DD and EN

EC3 Current Published Status

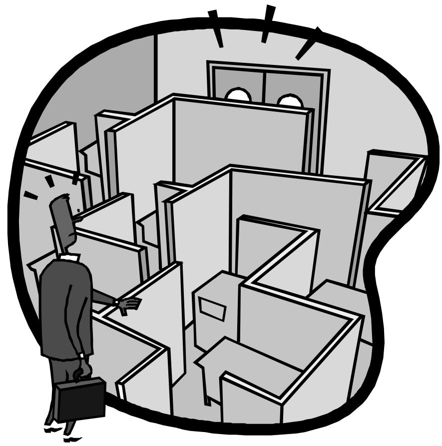
- **DD ENV 1993-1-1:1992** Eurocode 3. Design of steel structures. General rules and rules for buildings (together with United Kingdom National Application Document)
- **DD ENV 1993-1-2:2001** Eurocode 3. Design of steel structures. General rules. Structural fire design (together with United Kingdom National Application Document)
- **DD ENV 1993-1-3:2001** Eurocode 3. Design of steel structures. General rules. Supplementary rules for cold formed thin gauge members and sheeting

Other EC's Published Status

- **prEN 1994-1-1:2002** Design of composite steel and concrete structures. Part 1.1 General rules and rules for buildings. Stage 49 Examination Document
- **DD ENV 1998-3:1997** Eurocode 8: Design provisions for earthquake resistance of structures. Towers, masts and chimneys

Potential pitfalls

- Terminology
  - Restricted vocabulary
- Change in symbols
  - More logical symbol name conventions
  - Lots of subscripts
- Changes in values
  - Young’s Modulus etc
- Multiple documents
  - Need to consult more than one part



Terminology

BS5950	EC3
Force	Action
Capacity	Resistance
M_c	$M_{c,Rd}$
Design strength	Yield strength
p_y	f_y
Dead load	Permanent load
Live load	Variable load
Wind load	Another variable load

Terminal…ogy

BS5950 in wonderland

- Words evolved over time
- Inconsistent at times
- No link with concrete structural codes

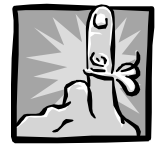
EC3

- Vocabulary consistent with meaning
- Consistent across all Eurocodes
- Easy to translate

Symbols

	BS5950	Eurocode
Elastic Modulus	Z	W_{el}
Plastic Modulus	S	W_{pl}
Radius of Gyration	r	i
Torsion constant	J	I_t
Warping constant	H	I_w

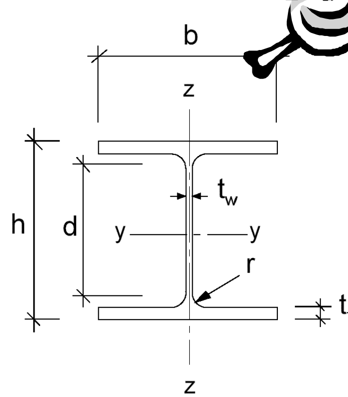
Changes in Values



- Young's Modulus
  - BS - 205000 N/mm²
  - EC - 210000 N/mm²
- Shear modulus
  - BS – 79000 N/mm²
  - EC - 81000N/mm²
- Changes in load factors
  - BS 1.4Gk + 1.6 Qk
  - EC 1.35Gk + 1.5 Qk
- Many extra load combinations in EC
  - Main variable action
  - Secondary variable action

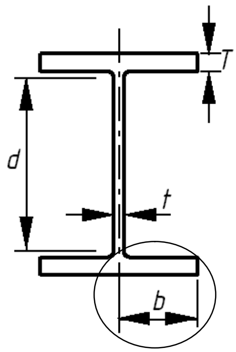
Axes redefined in Eurocod

- Major axis is y-y
- Vertical axis is z-z
- X direction is along the member
- This is consistent with most FE and Frame analysis software



EC3 Definitions

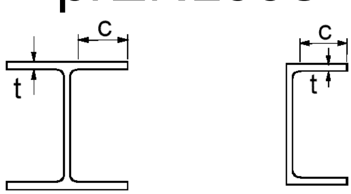
BS Section classification



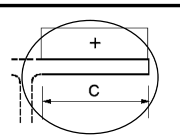
$\varepsilon = (275/p_y)^{0.5}$

		Class 1 plastic	Class 2 compact	Class 3 semi-compa
Rolled section	b/T	9ε	10ε	15ε
Welded section	b/T	8ε	9ε	13ε
Compression due to bending	b/T	28ε	32ε	40ε

prEN1993 Classification



Rolled sections

Class	Part subject to compression
Stress distribution in parts (compression positive)	
1	$c/t \le 9\varepsilon$
2	$c/t \le 10\varepsilon$

- Different outstand
- Different ε

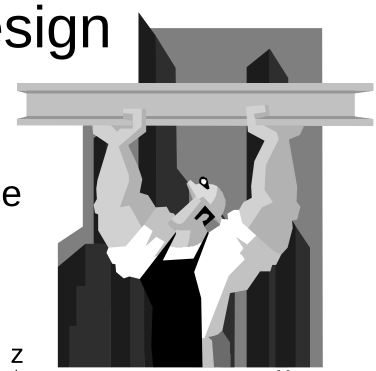
$\varepsilon = (235/f_y)^{0.5}$

Multiple documents

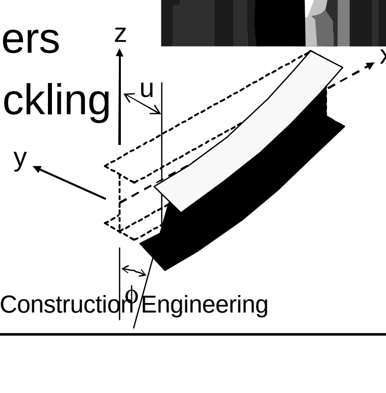
- The DD ENV 1993:1-1 contained all the information in one 300 page document.

  It also contained the National Application Document
- prEN1993-1-1 Contains member and frame design but omits fasteners
- prEN1993 must be read in conjunction with the UK National Annex

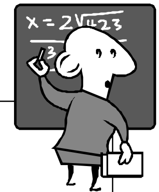
Element Design



- Beams
  - Moment capacity/resistance
  - Shear
  - Deflections
- Compression members
- Lateral Torsional Buckling



Moment Resistance



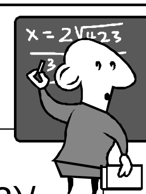
BS5950

- Class 1 and 2
  - $M_c = p_y S$
- Class 3 semi-compact
  - $M_c = p_y Z$ or $M_c = p_y S_{eff}$
- Class 4 slender
  - $M_c = p_y Z_{eff}$
- Low shear
  - $F_v < 60\ \%\ P_v$

EC3

- Class 1 and 2
  - $M_{c,Rd} = f_y W_{pl} / \gamma_{M1}$
  - $\gamma_{M1} = 1.05$ in UK
- Class 3
  - $M_{c,Rd} = f_y W_{el,min} / \gamma_{M1}$
- Class 4
  - $M_{c,Rd} = f_y W_{eff,min} / \gamma_{M1}$
- Low shear
  - $V_{Ed} < 50\% V_{plRd}$

Shear Resistance

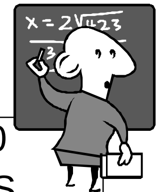


BS5950

- $P_v = 0.6\ p_y\ A_v$
- Shear area
  - $A_v = tD$
- Shear buckling if
  - $d/t > 70\varepsilon$

EC3

- $V_{pl,Rd} = A_v\ (f_y / \sqrt{3}) / \gamma_{M1}$
- Shear area
  - $A_v = A - 2bt_f + (t_w + 2r)t_f$
  - Approx = 1.04tD
- Shear buckling if
  - $h_w/t_w > 72\varepsilon$



Deflections

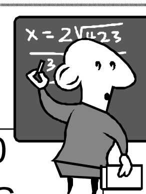
BS5950

- Serviceability LS
  - Imposed load only
  - Span/360 - brittle
  - Span/200 - generally

EC3 ? EN1990

- Serviceability LS
  - Permanent action, δ_1
  - Variable action, δ_2
  - Pre-camber, δ_0

  - $\delta_{max} < L/ 250$
  - $\delta_2 < L / 350$ brittle
  - $\delta_2 < L / 300$ generally



Deflections

BS5950

- Serviceability LS
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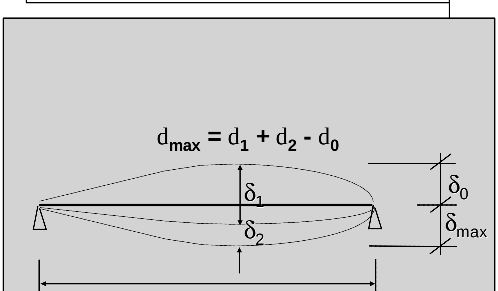
  - Span/200 - generally



EC3 ? EN1990

- Serviceability LS
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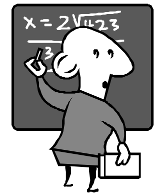
  - $\delta_{max} < L/ 250$
  - $\delta_2 < L / 350$ brittle
  - $\delta_2 < L / 300$ generally

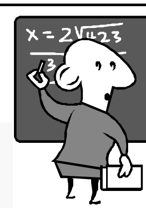
Compression Members



- P_c = Ag p_c from Tables 23 and 24
- p_c is a function of λ
- BS5950 requires a large number of tables

- $N_{b,Rd}=\chi\ A\ f_y/\gamma_{M1}$
- χ is a reduction factor
- χ depends on
  - $\bar{?}$ non-dimensional slenderness
  - Perry-Robertson approach

Compression members



$$N_{b,Rd} = cb_a A\, f_y / g_{M1}$$

$$? = \frac{1}{f + \left[f^2 - \bar{?}^2\right]^{0.5}} \quad \text{but} \quad ? \leq 1$$

$$f = 0,5\left[1 + a\left(\bar{?} - 0,2\right) + \bar{?}^2\right]$$

$$\bar{l} = \left[b_a A\, f_y / N_{cr}\right]^{0.5} = l / l_1, \quad l_1 = p\sqrt{E/ f_y}$$

Compression members

$$N_{b,Rd} = c b_a A f_y / g_{M1}$$

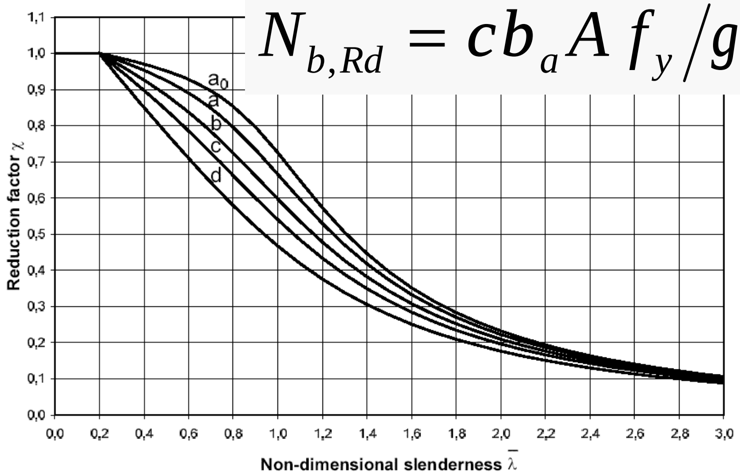


Figure 6.3: Buckling curves

Example

- UC 203x203x60 of grade S275 is axially loaded and pinned at each end of its 6m length.
- A = 76.4 cm², flange thickness, tf = 14.2mm, radius of gyration about minor axis, i_{zz} = 5.2 cm, depth, h = 209.6mm, width b = 205.8 h/b= 1.01 => H section
- **Table 3.1**: t_f = 14.2mm < 40mm therefore fy=275N/mm² for S275 grade
- E = 210000 N/mm²
- Slenderness - λzz= 600/5.2 = 115 <180 OK
- βa=1.0, implies $\lambda_1 = \pi (E/fy)^{0.5}$ = 86.8
- (λ_{zz}/ λ_1) $\beta a^{0.5}$= 115/86.8 = **1.324** ⟵ $\overline{?}$

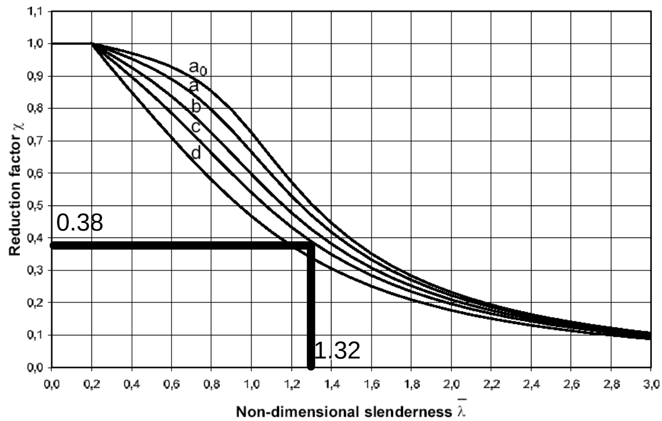


Figure 6.3: Buckling curves

Example

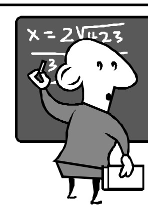
- UC 203x203x60 of grade S275 is axially loaded and pinned at each end of its 6m length.
- Figure 6.3 factor, $\chi = 0.38$
- $N_{bRd} = 0.38*1.0*76.4*10^2*275/1.05$
  $= $ **<u>760kN</u>**

BS5950 – 786kN

203x203x86	P_{cx}	2920	2920	2870	2810	2750	2690	2610	2450	2260	2050
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2030	1840	1460	1160	921
203x203x71	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2200	2140	2010	1850	1670
	P_{cy}	2380	2250	2110	1970	1820	1660	1500	1190	941	748
203x203x60	P_{cx}	2100	2100	2060	2020	1970	1920	1860	1740	1590	1420
	P_{cy}	2080	1960	1840	1710	1570	1430	1280	1010	786	622
203x203x52	P_{cx}	1820	1820	1790	1750	1710	1660	1620	1510	1370	1220
	P_{cy}	1800	1700	1590	1480	1360	1230	1110	868	678	536

But

- EC loads are typically 5% lower than BS
- Scaling the capacity by this figure gives:
- EC3 = 760/0.95 = 800 kN
- EC3 stronger than BS at 786 kN

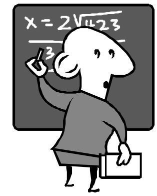


LTB BS5950:2000

- $M_x \leq M_b/m_{LT}$ and $M_x \leq M_{cx}$
- $M_b = p_b \times$ modulus
- p_b from λ_{LT}
- $\lambda_{LT} = uv\lambda\sqrt{\beta_W}$
- Class 1 & 2: $\beta_W = 1.0$

- Class 1 & 2: $Mb = p_b S_x$

LTB BS5950:2000

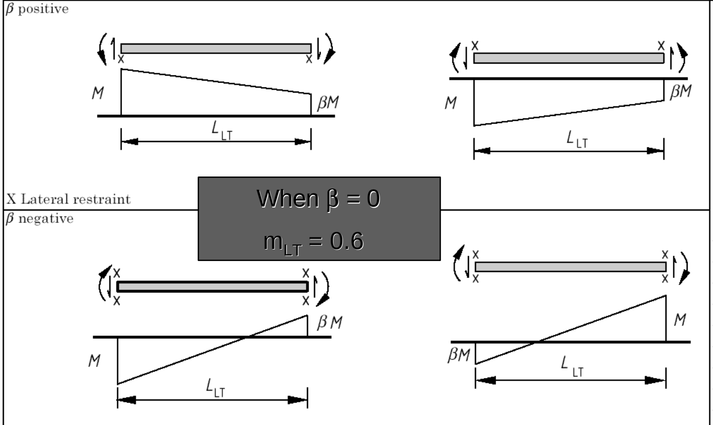


- $M_x \leq M_b/m_{LT}$ and $M_x \leq M_{cx}$
- $M_b = p_b \times$ modulus
- p_b from λ_{LT}
- $\lambda_{LT} = uv\lambda\sqrt{\beta_W}$
- $Mb = p_b S_x$

BS 5959 Table 18 m_{LT}

Segments with end moments only (values of m_{LT} from the formula for the general case)

β positive

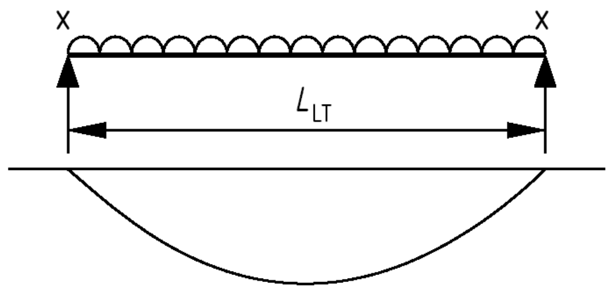


When β = 0

m_{LT} = 0.6

β	m_{LT}
1.0	1.00
0.9	0.96
0.8	0.92
0.7	0.88
0.6	0.84
0.5	0.80
0.4	0.76
0.3	0.72
0.2	0.68
0.1	0.64
0.0	0.60
− 0.1	0.56
− 0.2	0.52
− 0.3	0.48
− 0.4	0.46
− 0.5	0.44
− 0.6	0.44
− 0.7	0.44
− 0.8	0.44
− 0.9	0.44
− 1.0	0.44

BS5950 - m_{LT} for UDL

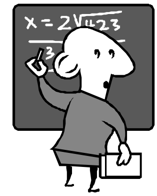


$m_{LT} = 0.925$

p_b from Table 16

λ_{LT}	**Steel grade and design strength p_y (N/mm²)**										
	S 275					**S 355**					
	235	245	255	265	275	315	325	335	345	355	400
25	235	245	255	265	275	315	325	335	345	355	400
30	235	245	255	265	275	315	325	335	345	355	395
35	235	245	255	265	273	307	316	324	332	341	378
40	229	238	246	254	262	294	302	309	317	325	359
45	219	227	235	242	250	280	287	294	302	309	340
50	210	217	224	231	238	265	272	279	285	292	320
55	199	206	213	219	226	251	257	263	268	274	299
60	189	195	201	207	213	236	241	246	251	257	278
65	179	185	190	196	201	221	225	230	234	239	257
70	169	174	179	184	188	206	210	214	218	222	237
75	159	164	168	172	176	192	195	199	202	205	219
80	150	154	158	161	165	178	181	184	187	190	201
85	140	144	147	151	154	165	168	170	173	175	185
90	132	135	138	141	144	153	156	158	160	162	170
95	124	126	129	131	134	143	144	146	148	150	157

EC3 LTB



1.0 For UB, UC

- Same approach as for Compression

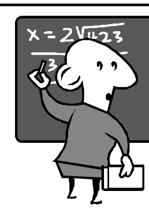
$$M_{b.Rd} = c_{LT}\, b_w W_{pl.y}\, f_y / g_{M1}$$

1.05

$$?_{LT} = \frac{1}{f_{LT} + \left[f_{LT}^{\ 2} - \overline{l}_{LT}^{\ 2}\right]^{0,5}}$$

$$f_{LT} = 0{,}5\left[1 + \propto_{LT} (\overline{l}_{LT} - 0.2) + \overline{l}_{LT}^{\ 2}\right]$$

EC3 LTB



$$f_{LT} = 0{,}5\left[1 + \propto_{LT} (\overline{l}_{LT} - 0.2) + \overline{l}_{LT}^{\ 2}\right]$$

$\alpha_{LT} = 0{,}34$ for rolled UCsections

$\alpha_{LT} = 0{,}49$ for rolled UB sections

$W_{ply}.f_y$

The non-dimensional slenderness

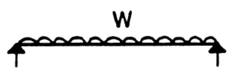
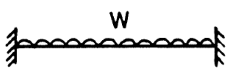
$$\overline{l}_{LT} = \sqrt{M_{pl.Rd} / M_{cr}}$$

$$M_{cr} = C_1 \frac{p^2 EI_z}{L^2} \sqrt{\frac{I_w}{I_z} + \frac{L^2 GI_t}{p^2 EI_z}}$$

Where C1 results from the bending moment diagram

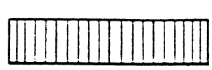
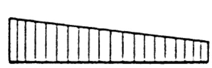
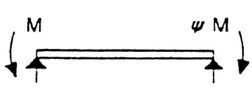
EC3 LTB

- Moment factor, C_1 loaded between restraints

Loading and support conditions	Bending moment diagram	Values of k	Val
			C_1
		1,0 0,5	1,132 0,972
		1,0 0,5	1,285 0,712

EC3 LTB

- Moment factor, $C_{1.}$ due to end moments

Loading and support conditions	Bending moment diagram	Value of k	Va
			C_1
	ψ = + 1 	1,0 0,7 0,5	1,000 1,000 1,000
	ψ = + ½ 	1,0 0,7 0,5	1,323 1,473 1,514
	ψ = 0 	1,0 0,7 0,5	1,879 2,092 2,150

Same curves as before!

$$M_{b.Rd} = c_{LT} b_w W_{pl.y} f_y / g_{M1}$$

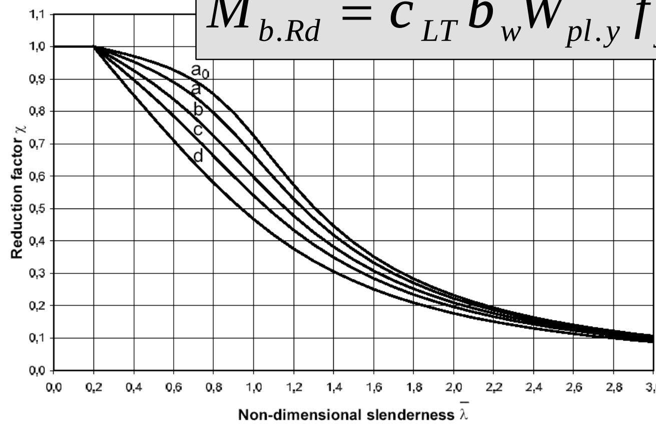


Figure 6.3: Buckling curves

Example

- Uniform moment – unbraced length 3m
- UB 610x229x140 S275
- BS M_b = 1100 kNm
- EC3 M_{bRd} = 960kNm
- For comparison scale by 1/0.95
  - M_{bRd} scaled = 1010 kNm < than BS

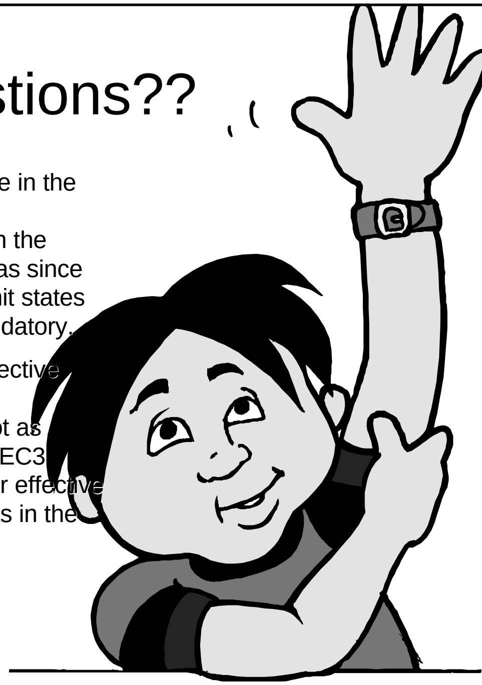
Summary of LTB

- BS5950 splits calculations between strength and equivalent moment
- EC3 combines equivalent moment and section properties to give a reduction factor
- EC3 uses EXACT same buckling curves for LTB and Strut buckling
- EC3 look awful but is easily programmed in a spreadsheet

Conclusions

- Eurocodes are not that difficult
- They are just a little different
- Rationalises terminology across materials and countries
- The EFTA region is 10 times bigger than UK
- Eurocodes are not going to go away this time

Questions??



1. How quickly will the take up be in the UK?
   Ans: It should be quicker than the switch from BS449 to 5950 was since both EC3 and BS5950 are limit states codes. EC3 will become mandatory.
2. What does EC3 say about effective lengths?
   Ans: The EC3 guidance is not as helpful as BS5950 Table 22. EC3 gives the general approach for effective lengths in frames which results in the same values as Table 22

Questions??

1. **How is Europe progressing with using EC3?**
   Ans: The German speaking countries have already adopted the DDENV as a DIN. Benelux countries are well advanced. The rest are planning the implementation.
2. **What's in EC3 about sway, lambda crit etc?**
   Ans: There is a lengthy section in the prEN on frame stability. On initial viewing, this looks very like the BS5950:2000 approach. See Section 5 of the prEN for the full details