Zero Carbon Building, Construction Industry Council

7 March 2014

New opportunities and challenges in adopting Eurocodes in Hong Kong

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Hong Kong Constructional Metal Structures Association

Outline

1 Eurocodes

2 British Standards vs Eurocodes

3 Member buckling check for columns and beams

EN 1993: Steel beams susceptible to lateral buckling
EN 1993: Steel columns susceptible to axial buckling, as well as
EN 1994: Steel-concrete composite columns susceptible to axial buckling

4 Iron and Steel Industry in China

5 Hong Kong Constructional Metal Structures Association

6 International Engineering Design Centre for Infrastructures

Concluding Remarks

1 Eurocodes

There are 10 separate Structural Eurocodes, each Eurocode comprises a number of Parts, which are published as separate documents.

Each Part consists of:

- the main body of text
- Normative annexes
- Informative annexes

EN 1990 Eurocode 0: *Basis of structural design*
EN 1991 Eurocode 1: *Actions on structures*
EN 1992 Eurocode 2: *Design of concrete structures*
EN 1993 Eurocode 3: *Design of steel structures*
EN 1994 Eurocode 4: *Design of composite steel and concrete structures*
EN 1995 Eurocode 5: *Design of timber structures*
EN 1996 Eurocode 6: *Design of masonry structures*
EN 1997 Eurocode 7: *Geotechnical design*
EN 1998 Eurocode 8: *Design of structures for earthquake resistance*
EN 1999 Eurocode 9: *Design of aluminium structures*

2. British Standards vs Eurocodes

2.1 Axes

	BS5950	EC3
Along the member	X (?)	X
Major axis	X	Y
Minor axis	Y	Z

2. British Standards vs Eurocodes

2.2 Terminology

BS5950	EC3
Dead load W	Permanent action G
Imposed load W	Variable action Q
Wind load W	Variable action Q

	BS5950	EC3
Load factor	1.2 to 1.6	0.75 to 1.5
Material factor	1.0 to 1.2	1.0 to 1.1

2. British Standards vs Eurocodes

2.3 Symbols

BS5950	EC3	BS5950	EC3	BS5950	EC3
A	A	P	N	p_y	f_y
Z	W_{el}	M_x	M_y	p_b	$\chi_{LT} f_y$
S	W_{pl}	V	V	p_c	χf_y
I_x	I_y	H	I_w	r	i
I_y	I_z	J	I_t	λ	$\bar{\lambda}$

2. British Standards vs Eurocodes

2.4 Formulation

BS5950	EC3
$P = p_y A$	$N_{c,Rd} = A f_y / \gamma_{M0}$
$P = p_c A$	$N_{b,Rd} = \chi A f_y / \gamma_{M1}$
$M = p_y S$	$M_{c,Rd} = W_{pl} f_y / \gamma_{M0}$
$M = p_b S$	$M_{b,Rd} = \chi_{LT} W_{pl} f_y / \gamma_{M1}$

2. British Standards vs Eurocodes

2.5 Load combinations

If ψ_0 = 0.5 for W_k = 0.7 for Q_k	Dead	Imposed	Wind
EN 1990	1.35	1.5	0.75
	1.35	1.05	1.5
BS5950	1.4	1.6	
	1.2	1.2	1.2
	1.4		1.4

2. British Standards vs Eurocodes

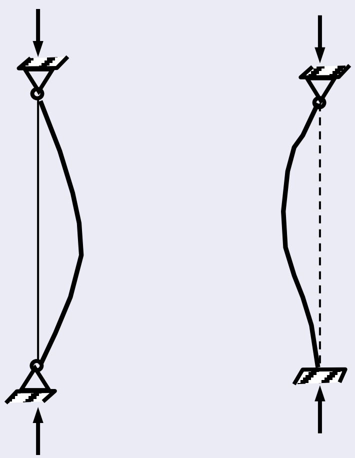
2.6 Slenderness

Slenderness	**BS5950**	**EC3**
	Geometric ratio	Force ratio
Column	$\lambda = \frac{L_E}{r}$	$\bar{\lambda} = \sqrt{\frac{Af_y}{N_{cr}}}$ where $N_{cr} = \frac{\pi^2 EI}{L^2}$
Beam	$\lambda_{LT} = uv\lambda$	$\bar{\lambda}_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}}$ where $M_{cr} = C_1 \frac{\pi^2 EI_z}{L^2} \sqrt{\frac{I_w}{I_z} + \frac{L^2 GI_t}{\pi^2 EI_z}}$

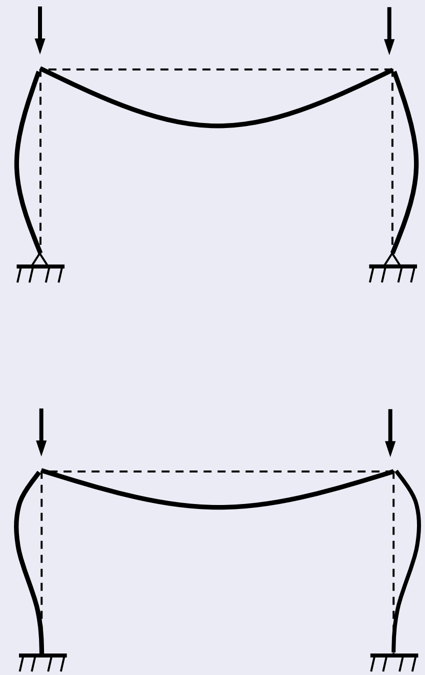
2. British Standards vs Eurocodes

2.7 Slenderness – Elastic critical force N_{cr} and elastic critical moment M_{cr}

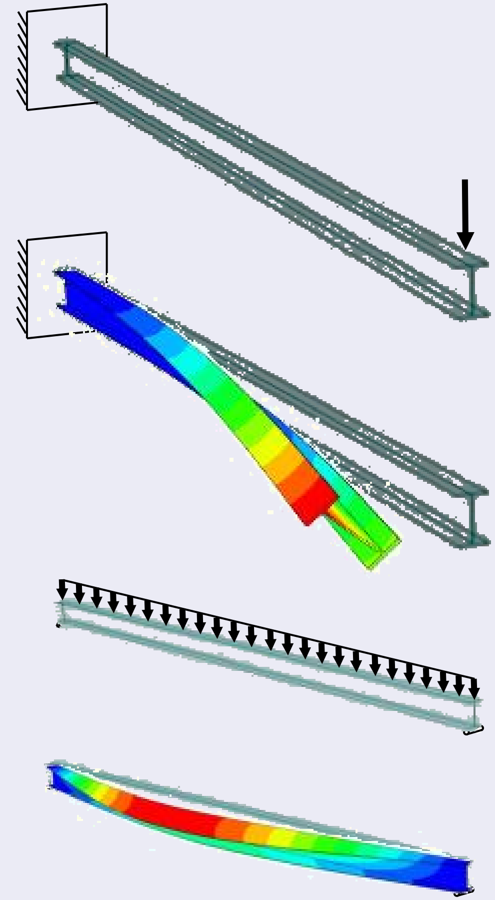
N_{cr} and M_{cr} are generic terms.



N_{cr}



F_{cr}



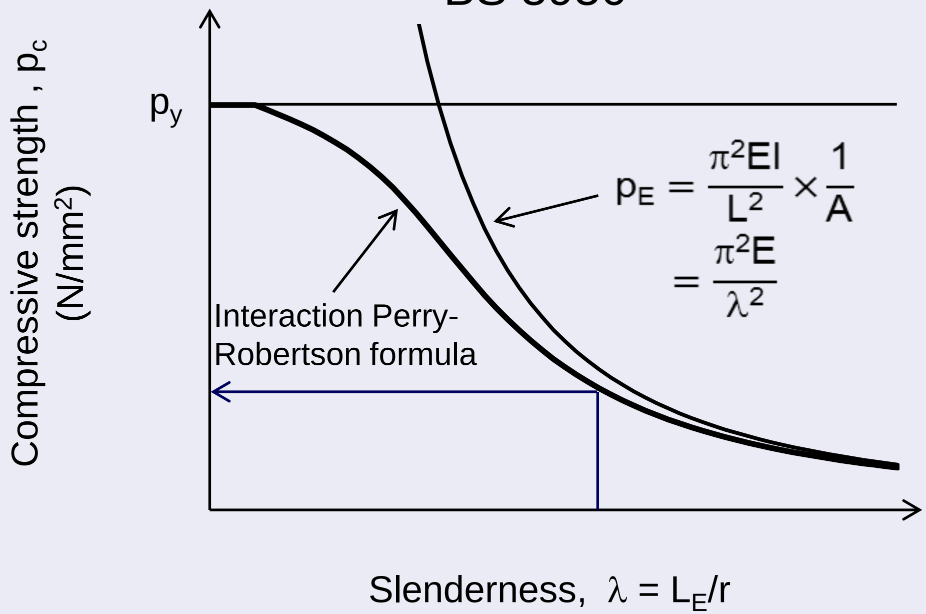
M_{cr}

N_{cr} and M_{cr} may be readily determined using eigenvalue analysis through finite element method.

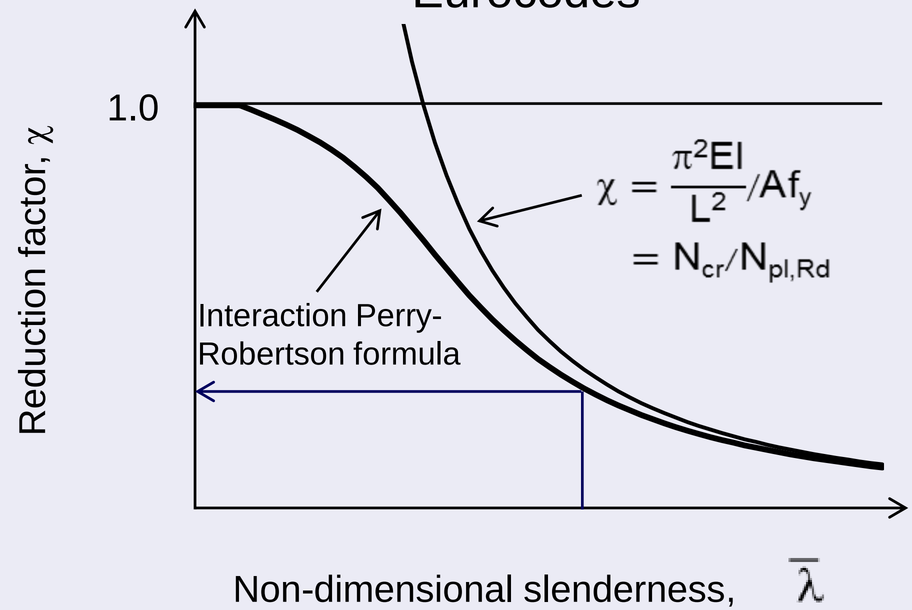
2. British Standards vs Eurocodes

2.8 Harmonization of column buckling curves in Eurocodes

BS 5950



Eurocodes



An interactive curve for each steel grade / design yield strength:

$$p_c = \frac{p_E p_y}{\phi + \sqrt{\phi^2 - p_E p_y}}$$

$$\phi = \frac{p_y + (\eta + 1) p_E}{2}$$

One interactive curve for all steel grades. The material parameter λ_1 is used:

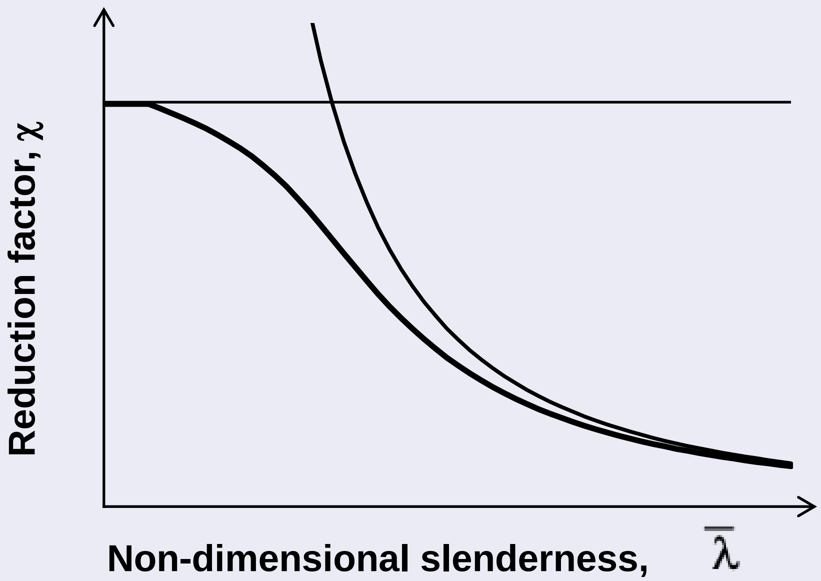
$$\bar{\lambda} = \frac{\lambda}{\lambda_1}$$

$$\lambda_1 = \pi \sqrt{\frac{E}{f_y}}$$

where E is the Young's modulus and f_y is the yield strength.

2. British Standards vs Eurocodes

2.8 Harmonization of column buckling curves in Eurocodes



Same format of design formulae is adopted for all structural members which may buckle:

- Steel
- Steel-concrete composite
- Timber
- Aluminium

More importantly, the design methods for structural members at room temperature and elevated temperatures have been developed into similar formats:

i.e. cold design and hot design are harmonized.

3. Member buckling check for columns and beams

With recent advances in design development of structural design codes, modern design codes allow rational design and analysis on the structural behaviour of a structure against well defined requirements at specific levels of acceptance.

It is very interesting to review the development of a number of national steel codes, and to examine some of the design methods and clauses which have evolved over the years. Illustrations on member buckling check are given below:

- Steel columns susceptible to axial buckling
- Steel beams susceptible to lateral buckling buckling
- Composite columns susceptible to axial buckling

3.1 Member Buckling Check for Steel Sections

Steel columns: British Steel Code BS 5950

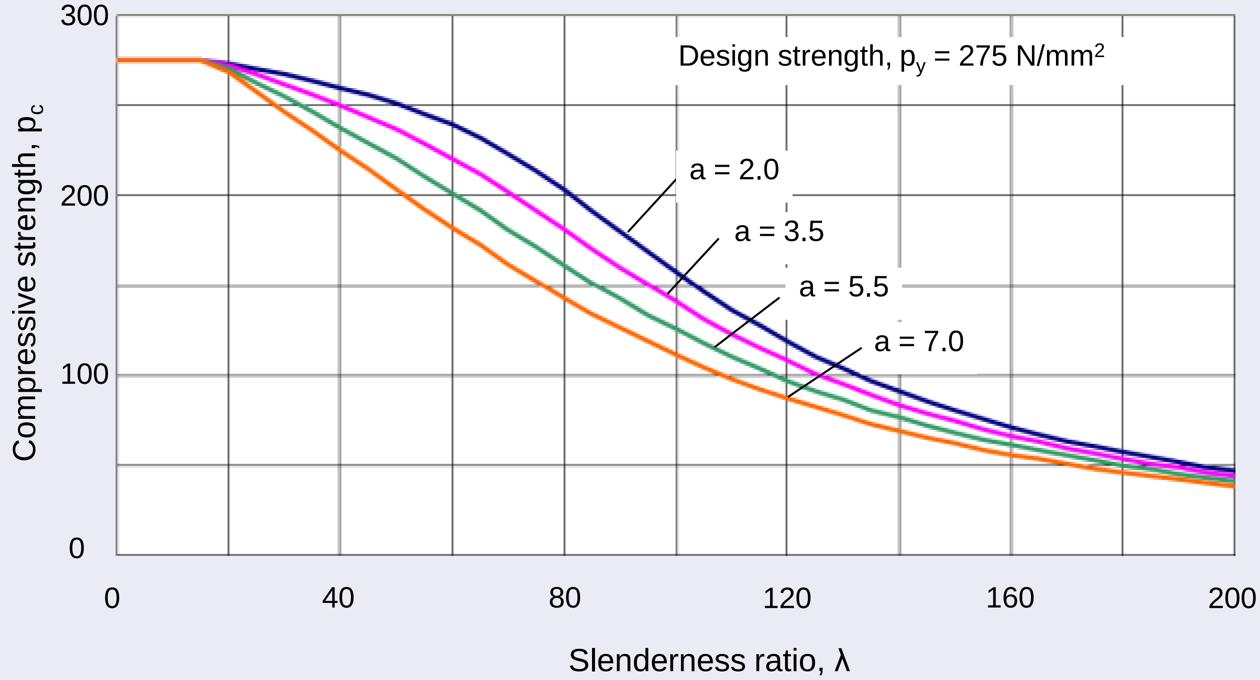
For a steel column susceptible to axial buckling, the slenderness of the column:

$\lambda = L_e / r_y$

where

L_e is the effective length of the column

r_y is the radius of gyration of the cross-section of the column



Column buckling curves to BS 5950

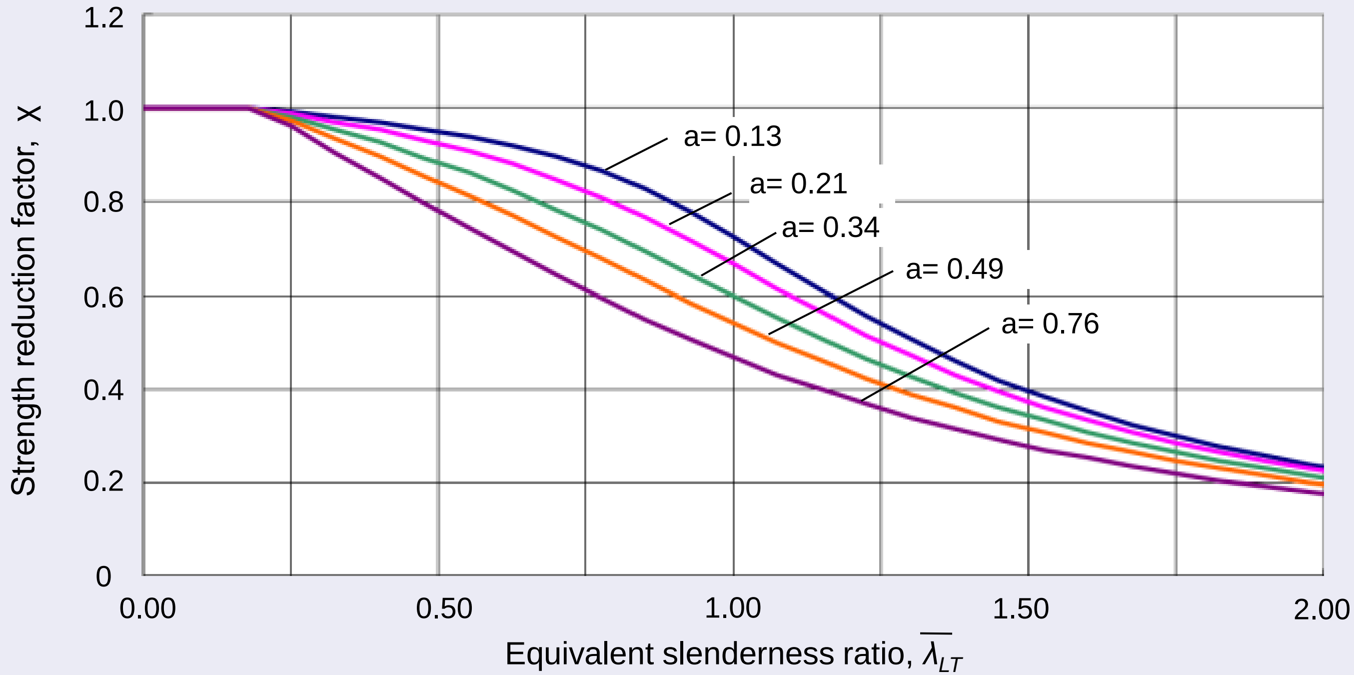
Through a non-linear interaction curve, which is commonly referred as the Perry-Robertson formula, the effect of axial buckling in a real column is expressed as *a reduction in its design strength from its yield value*, i.e. *a compressive strength*.

3.1 Member Buckling Check for Steel Sections

Steel columns: Eurocode 3

For a steel column susceptible to axial buckling, the slenderness of the column:

$$\bar{\lambda} = \frac{\lambda}{\lambda_Y} = \sqrt{\frac{N_c}{N_{cr}}}$$



Column buckling curves to EC3

The effect of axial buckling in a real column is expressed as *a reduction in resistance of the cross-sections*, i.e. a strength reduction factor, χ_c , multiplied to the axial compression resistance of the cross-section of the member.

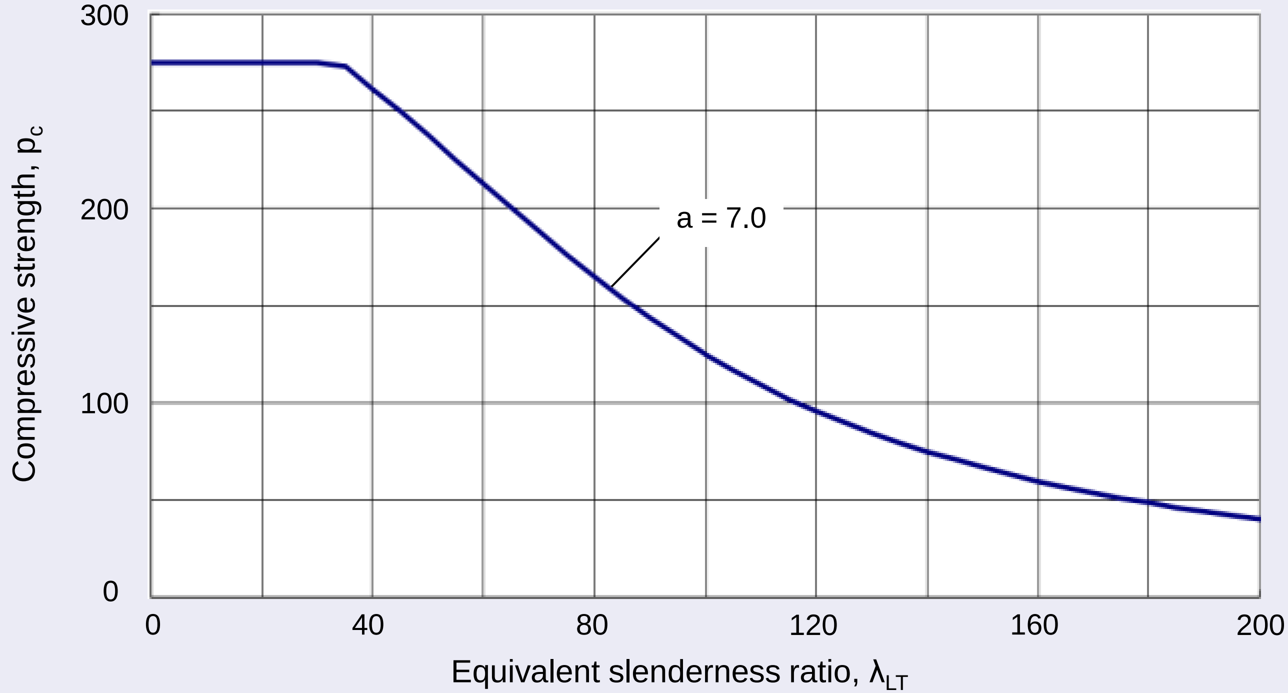
3.2 Member Buckling Check for Steel Sections

Steel beams: British Steel Code BS 5950

For a steel beam susceptible to lateral buckling, an equivalent slenderness of the beam:

$$\lambda_{LT} = u\,v\,\lambda$$

where u and v are secondary section properties of the beam related to lateral bending and torsion



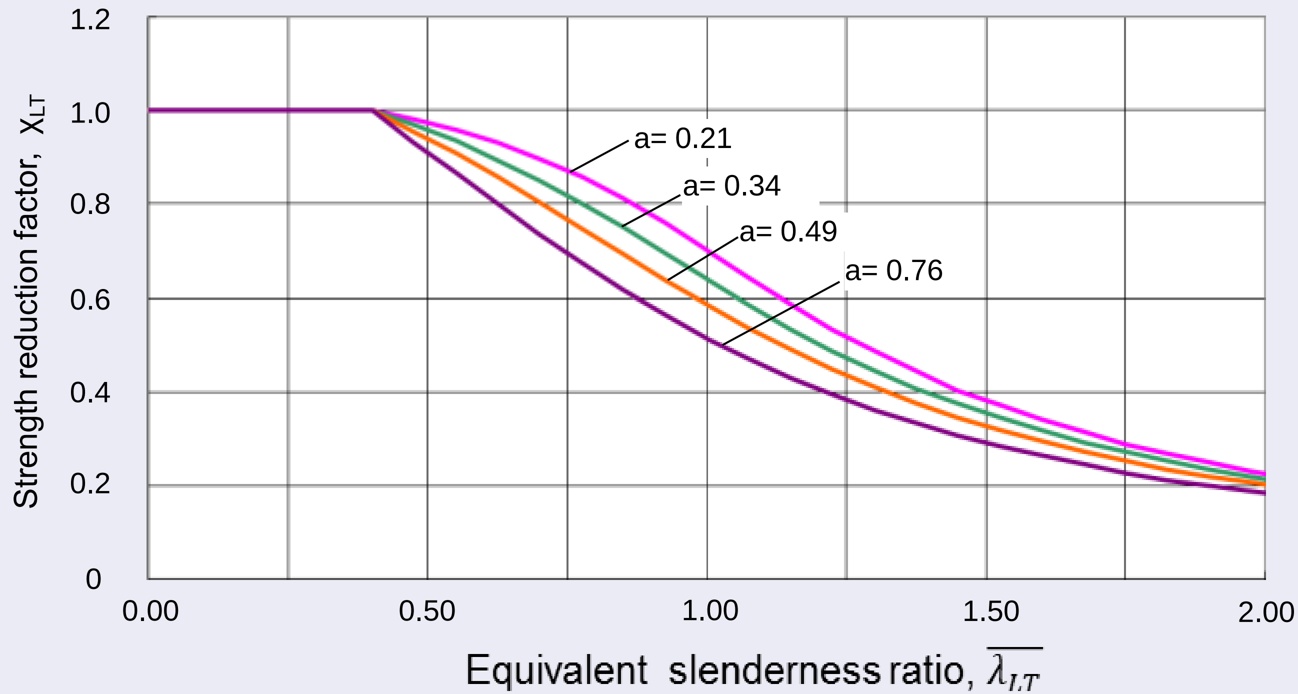
Beam buckling curves to BS 5950

The effect of lateral buckling in a real beam is expressed as *a reduction in its design strength from its yield value*, i.e. *a bending strength*.

3.2 Member Buckling Check for Steel Sections
Steel beams: Eurocode 3

For a steel beam susceptible to lateral buckling, an equivalent slenderness of the beam:

$$\overline{\lambda_{LT}} = \frac{\lambda}{\lambda_Y} = \sqrt{\frac{M_c}{M_{cr}}}$$



Beam buckling curves to EC3

The effect of lateral buckling in a real beam is expressed as *a reduction in resistance of the cross-sections*, i.e. a strength reduction factor, χ_b multiplied to the moment resistances of the cross-section of the member.

3.3 Member Buckling Check using Modified Slenderness

Composite columns: Eurocode 4

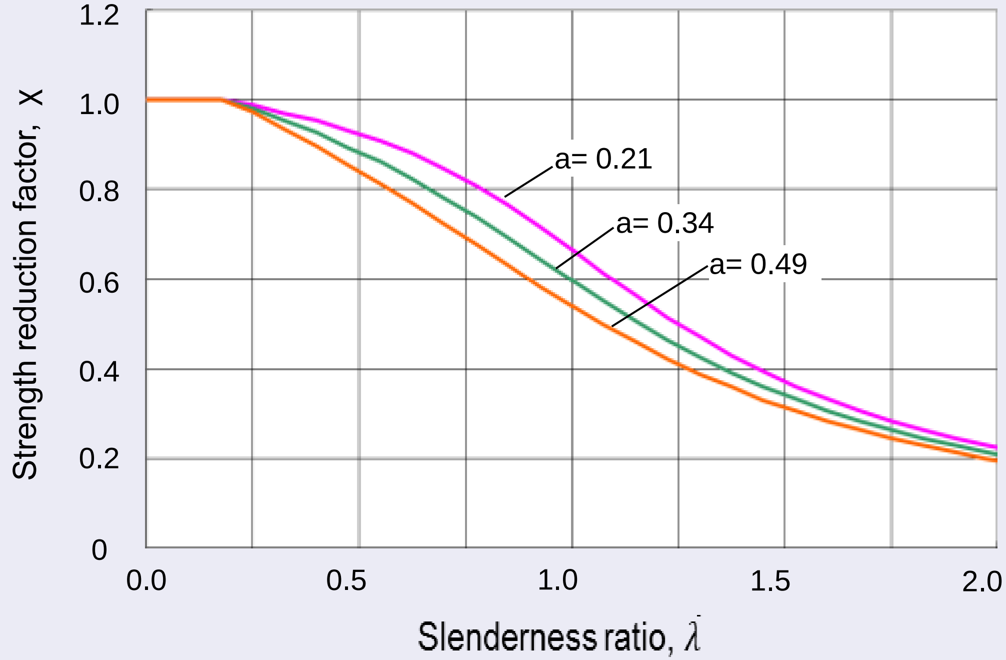
The axial buckling resistances of the composite columns are based on the modified slenderness:

$$\bar{\lambda} = \sqrt{\frac{N_{pl}}{N_{cr}}}$$

where

N_{pl} is the section capacity of the composite column

N_{cr} is the elastic axial buckling resistance of the composite column

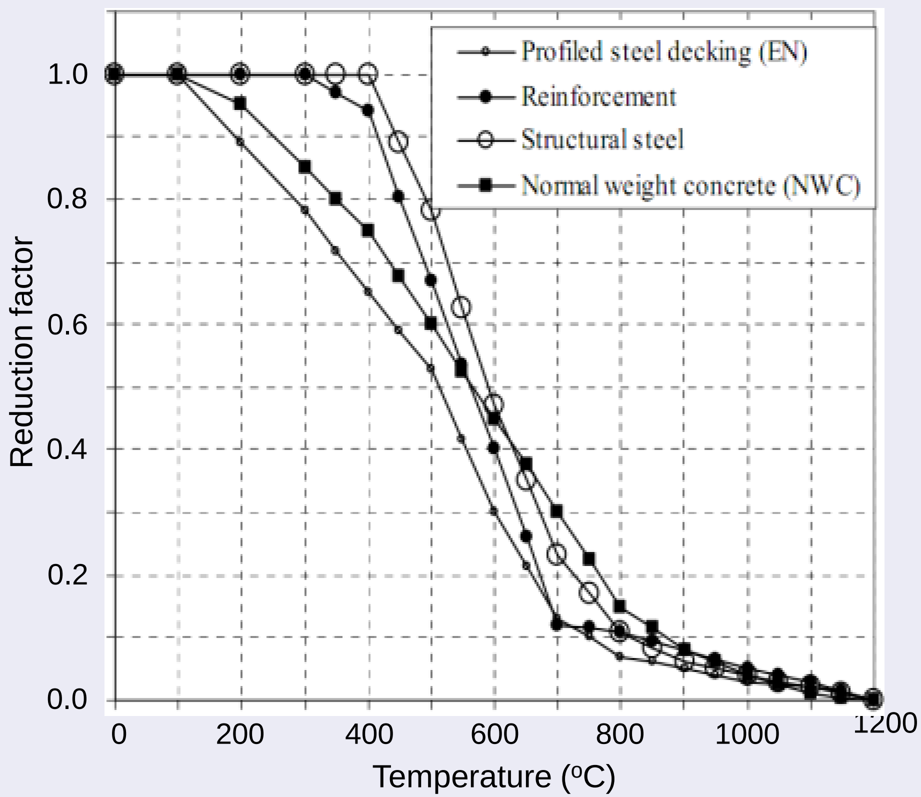


Member buckling curves to EC4

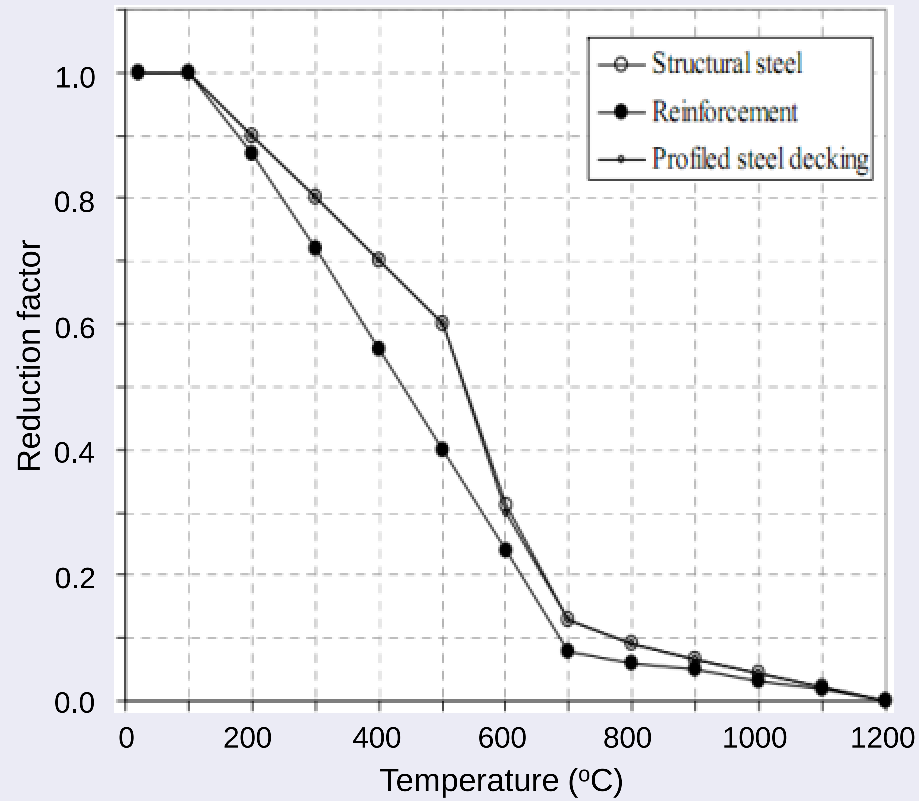
The effect of axial buckling in real composite columns is expressed as *a strength reduction to the resistances of the cross-sections of the members*, i.e. a strength reduction factor, χ_c ,multiplied to the compression resistances of the cross-sections of the composite columns.

3.4 Member Buckling Check at Elevated Temperatures

Steel and composite columns: Eurocodes 3 & 4



Strength reduction factors



Elastic modulus reduction factors

All of the materials retain only 50% of their original strengths when their temperatures reach 500 to 600 ºC.

3.4 Design procedure of a steel beam – cold & hot design

EN 1993: 1-1 & -2: 2005

Cold Design

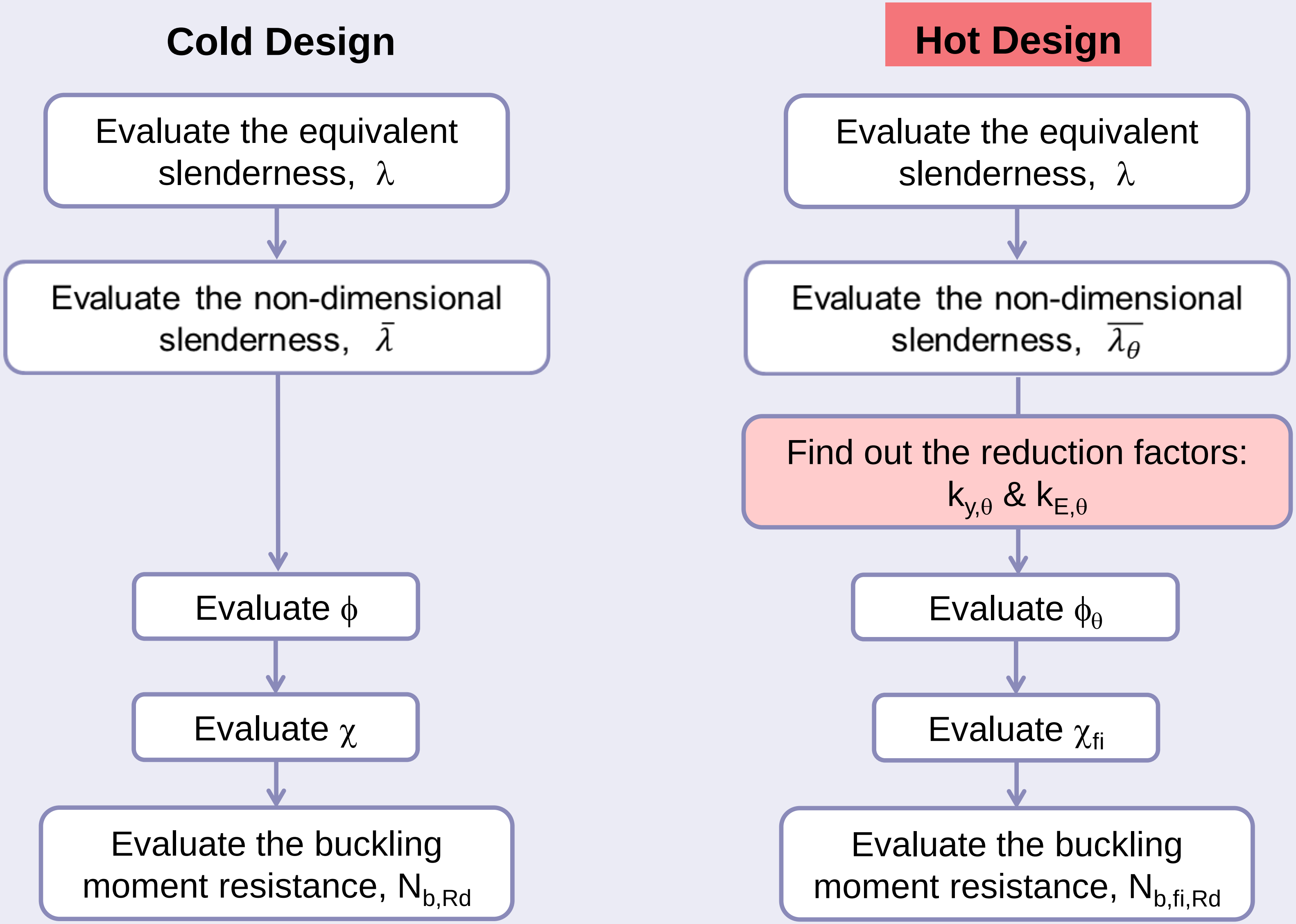
1. Evaluate the equivalent slenderness, λ_{LT}
2. Evaluate the non-dimensional slenderness, $\overline{\lambda}_{LT}$
3. Evaluate ϕ_{LT}
4. Evaluate χ_{LT}
5. Evaluate the buckling moment resistance, $M_{b,Rd}$

Hot Design

1. Evaluate the equivalent slenderness, λ_{LT}
2. Evaluate the non-dimensional slenderness, $\overline{\lambda}_{LT,\theta,com}$
3. Find out the reduction factors: $k_{y,\theta,com}$ & $k_{E,\theta,com}$
4. Evaluate $\phi_{LT,\theta,com}$
5. Evaluate $\chi_{LT,fi}$
6. Evaluate the buckling moment resistance, $M_{b,fi,Rd}$

3.4 Design procedure of a steel column - cold & hot design

EN 1993: 1-1 & -2: 2005



3.4 Design procedure of a composite column – cold & hot design

EN 1994: 1-2 & -2: 2005

Cold Design

1. Evaluate both the design and characteristic plastic resistance to compression, $N_{pl,Rd}$ & $N_{pl,R}$
2. Evaluate the effective flexural stiffness, $(EI)_{eff}$
3. Evaluate the non-dimensional slenderness, $\bar{\lambda}$
4. Evaluate ϕ
5. Evaluate χ
6. Evaluate the buckling resistance, $N_{b, Rd}$

Hot Design

1. Evaluate both the design and characteristic plastic resistance to compression, $N_{fi, pl, Rd}$ & $N_{fi, pl, R}$
2. Evaluate the effective flexural stiffness, $(EI)_{eff}$
3. Evaluate the non-dimensional slenderness, $\bar{\lambda}_\theta$
4. Evaluate ϕ_θ
5. Evaluate χ_θ
6. Evaluate the buckling resistance, $N_{b, fi, Rd}$

3.5 Harmonized Design

Owing to the successful design development on member buckling in the Structural Eurocodes, the **normalized slenderness ratios**:

$\bar{\lambda}$ for steel columns susceptible to axial buckling, and

$\bar{\lambda}_{LT}$ for steel beams susceptible to lateral buckling

are shown to be effective to determine corresponding strength reduction factors due to member buckling.

Hence, the **harmonized member buckling design** of steel beams and columns as well as steel-concrete composite columns at both room and elevated temperatures is presented, and this design method may be regarded as a generalized method readily applicable to various structural members.

Many other key design methods such as cross-section resistances have also been harmonized.

3.6 Construction projects to Eurocodes

It will take some time for the local construction industry to learn the new skills while adopting Eurocodes.

Similar to many successful stories in the past about working with British Standards since the 1980's, Hong Kong will be able to contribute to many overseas construction projects.

One of the fast growing sectors of overseas construction in the Region is steel construction, working with construction companies and structural steel fabricators to various codes of practice.

4 Iron and Steel Industry in China

Annual steel production (million metric tons)

Year	Australia	China	Japan	U.K.	U.S.A.	World
1980	7.6	37.1	111.4	11.3	101.5	568.5
1990	6.7	66.4	110.3	17.8	89.7	616.0
2000	7.1	128.5	106.4	15.2	101.8	848.9
2010	7.3	637.4	109.6	9.7	80.5	1428.7
2012	4.9	716.6	107.2	9.8	88.6	1510.2

Data from World Steel Association (www.worldsteel.org)

4 Iron and Steel Industry in China

Major steel-producing countries in 2012

Ranking	Country	Annual Production (mmt)	Proportion (%)	
1	China	716.5	47.4	84.5
2	Japan	107.2	7.1	
3	U.S.A.	88.7	5.9	
4	India	77.6	5.1	
5	Russia	70.4	4.7	
6	South Korea	69.1	4.6	
7	Germany	42.7	2.8	
8	Turkey	35.9	2.4	
9	Brazil	34.5	2.3	
10	Ukraine	33.0	2.2	
Total world production		**1510.2**		

Data from World Steel Association (www.worldsteel.org)

4 Iron and Steel Industry in China

- **China Constructional Metal Structures Association**
  中国建筑金属结构协会

- **China Iron and Steel Association**
  中国钢铁工业协会

- **China Steel Construction Society**
  中国钢结构协会

- **National Engineering Research Centre on Steel Construction**
  国家钢结构工程技术研究中心

The **Hong Kong Constructional Metal Structures Association** is established in July 2010 among engineers, managers, academics and other construction professionals.

It aims to promote the effective use of metal structures in construction in Hong Kong:

•To provide latest information on education, research, design and construction from overseas for continual professional training of engineers in Hong Kong, Macau, and the Mainland China.

•To promote exchange and collaboration on education, research and professional skills among engineers in Hong Kong, Macau, the Mainland China and overseas.

•To promote wide adoption of the Chinese steel materials and associated design standards, construction practice as well as technical and professional qualifications.

5 Hong Kong Constructional Metal Structures Association

Technological advancements

Professional Services Development Assistance Scheme: Schedule of Seminars

23 March 2012	Effective Design of Steel Structures to BS EN 1993-1-1	Dr T M Chan Prof K F Chung
16 & 17 August 2012	Effective Design of Steel-Concrete Composite Structures to BS EN 1994-1- EC4	Prof K F Chung Prof Dennis Lam Ir H Y Lee
2 & 9 November 2012	Effective Design of Steel Structures to BS EN 1993-1-1	Ir Dr Gary S K Chou Ir Prof K F Chung Dr Paul H F Lam Ir Dr Michael C H Yam Ir Alan H N Yau
7 & 14 December 2012	Effective Design of Steel-Concrete Composite Structures to BS EN 1994-1-1 EC 4	Ir Prof K F Chung Prof Dennis Lam Ir H Y Lee

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Technological advancements

Professional Services Development Assistance Scheme: Schedule of Seminars

12 & 19 April 2013	Effective Design of Steel Structures to BS EN 1993-1-1	Dr T M Chan Ir Dr Gary S K Chou Ir Prof K F Chung Dr Paul H F Lam Ir Alan H N Yau
27 Sept & 4 Oct 2013	Effective Design of Steel Structures to BS EN 1993-1-1	Dr T M Chan Ir Dr Gary S K Chou Ir Prof K F Chung Dr Paul H F Lam Ir Alan H N Yau

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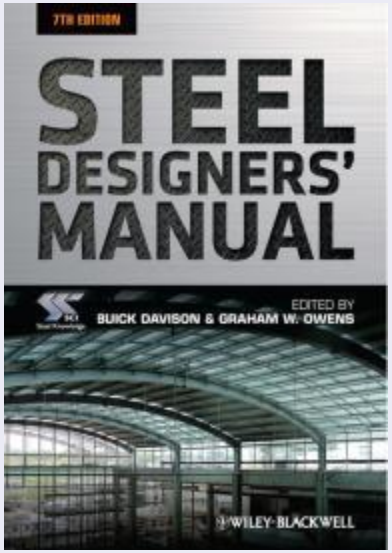
Technological advancements

Steel Designers' Manual, 7th Edition



- ***SDM7*** in accordance with Eurocodes
  The Steel Construction Institute, February 2012.

- ***SDM7*** - *Traditional Chinese Version*
  jointly published by **Macau Society of Metal Structures** and **HKCMSA**, August 2013.

- ***SDM7*** - *Simplified Chinese Version*
  jointly published by **China Steel Construction Society**, **National Engineering, Research Centre for Steel Construction**, **HKCMSA** and **MSMS**, tentatively 2014.

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Technological advancements

Effective use of high performance steel in construction

•***High strength steel: S460, S690, S890 …***

Design rules – cross-section resistances, member resistances, welding

Composite beams and columns, degree of shear connection, interfacial shear transfer

•***High resistances against corrosion and fire attack and high weldability***

Steel plates: 6.0 to 150 mm thick plates for fabricated sections

Steel strips: 1.0 to 5.0 mm thick strips for cold rolled sections and deckings

0.43 to 1 mm thick strips for sheetings and claddings

5 Hong Kong Constructional Metal Structures Association

Technological advancements

Equivalent steel materials to Modern Steel Design

- **Code of Practice for Structural Use of Steel**

Buildings Department, Hong Kong, 2007 & 2011

- **Design Guide on Use of Alternative Steel Materials**

Building and Construction Authority, Singapore, 2008 & 2012

First official documents in Hong Kong and Singapore formalize the use of non-British steel materials, in particular, Chinese steel materials (in comparison with approvals on individual projects.)

Different QA procedures to establish Class 1 steel materials with a material factor 1.0, when compared with Class 2 steel materials with a material factor 1.1.

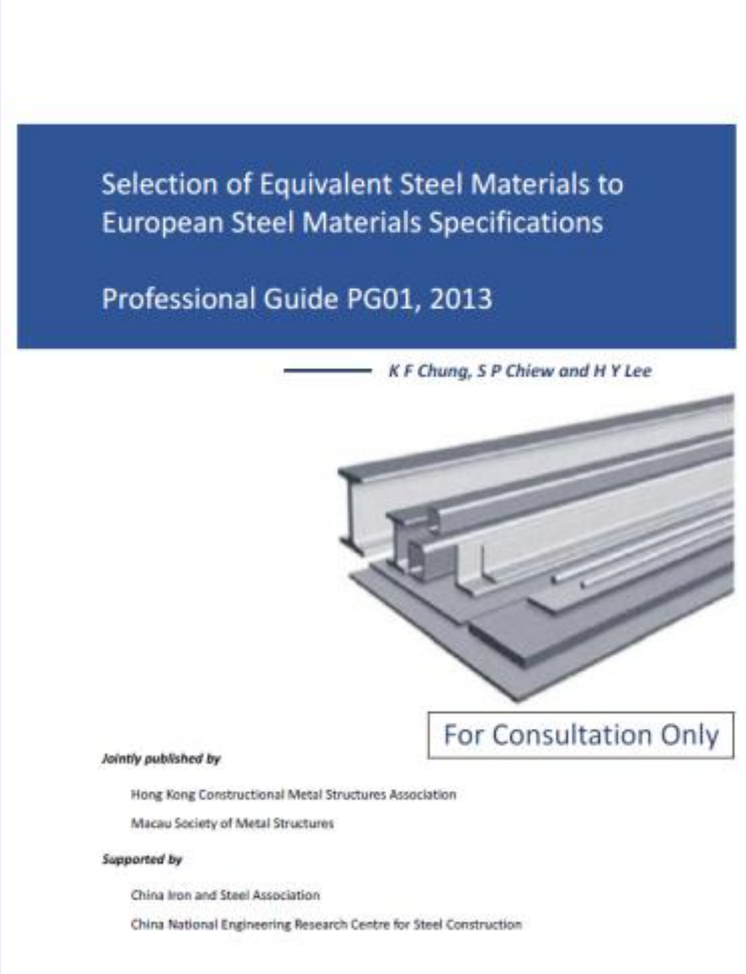
5 Hong Kong Constructional Metal Structures Association

Technological advancements

Equivalent steel materials to Modern Steel Design

- **Professional Guide on Selection of Equivalent Steel Materials to European Steel Materials Specifications**

Professional organizations and authorities of Hong Kong, Singapore, Malaysia and Macau



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Technological advancements

Equivalent steel materials to Modern Steel Design

•Professional Guide on Effective Use of Equivalent Steel Materials

Professional organizations and authorities of Hong Kong, Singapore, Malaysia and Macau

a)Modern Structural Steel Design Codes: EN1993-1 & EN1994-1

b)European Steel Materials Specifications against Australia / New Zealand, China, Japan, U.K., U.S.A.

c)Detailed materials requirements:

- Chemical compositions: Carbon, Phosphorus, Sulphur, Carbon Equivalent Value (CEV)
- Mechanical requirements: strengths, elongation limits, toughness and weldability according to CEV
- Technical guidelines for approving or disapproving specific batches of steel materials

5 Hong Kong Constructional Metal Structures Association

Technological advancements

Equivalent steel materials to Modern Steel Design

Further developments:

- Effective use of Chinese steel materials to modern structural steel design and construction in overseas projects
- Product conformity certification scheme / factory production control system for quality supply of steel materials
- Qualification and inspection schemes of fabricators for steel fabrication

6 International Engineering Design Centre for Infrastructures

Hong Kong Construction Industry

Develops / Architects / Engineers / Surveyors / Project Managers / Legal and Financial Professionals

Professional skills

International exposure and network

Flexibility towards different conditions and constraints

Working experiences in many countries in the Region

6 International Engineering Design Centre for Infrastructures

Some evidence…

A Senior Engineer worked on the following projects in the past 8 years:

- Wave Mega City Centre at Noida, ***India***
- IREO City, Gurgaon, ***India***
- Resorts World at Sentosa, ***Singapore***
- Etihad Towers, Abu Dhabi, ***United Arab Emirates***
- Grand Lisboa Hotel, ***Macau***
- Shanghai Wheelock Square, China, and
- Many commercial and residential buildings in Hong Kong.

New opportunities and challenges in adopting Eurocodes in Hong Kong

1 Adopting Eurocodes provides the Hong Kong Construction Industry a challenge as well as an opportunity to learn, to grow and to go overseas.

2 Steel construction is fast-growing, and it travels to many parts of the world.

3 Hong Kong is well placed to collaborate with the China Steel and Iron Industry, to lead, to advise and to control quality.

It is happening now ! Are you ready to ride on ?

Zero Carbon Building, Construction Industry Council

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