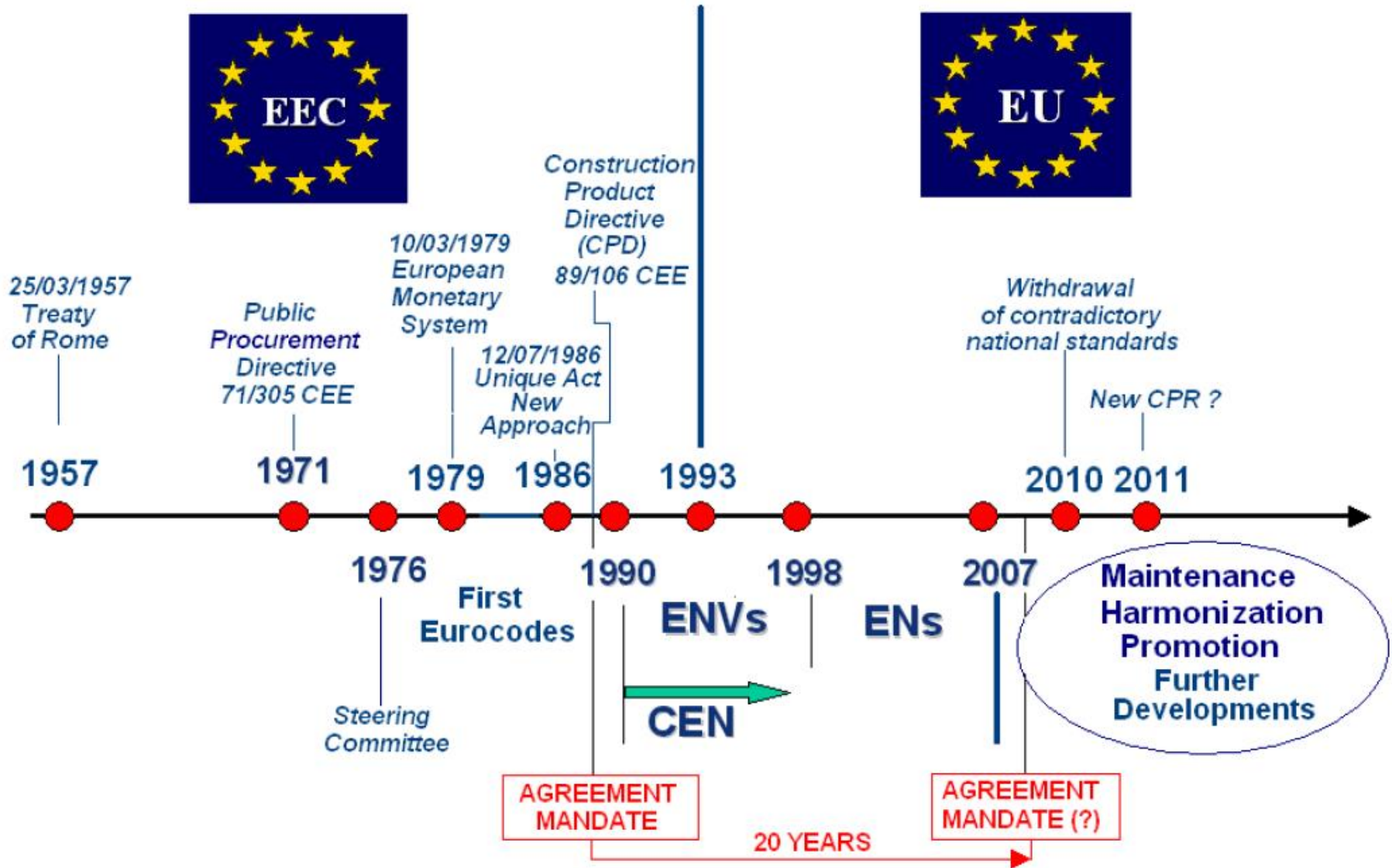


Aktuálny stav navrhovania tenkostenných konštrukcií

Ivan BALÁŽ

**Katedra kovových a drevených
konštrukcií, SvF STU v Bratislave**

A BRIEF HISTORY OF EUROCODES



EU + EFTA (EZVA): 31 štátov Európskej ekonomickej oblasti je členom CEN



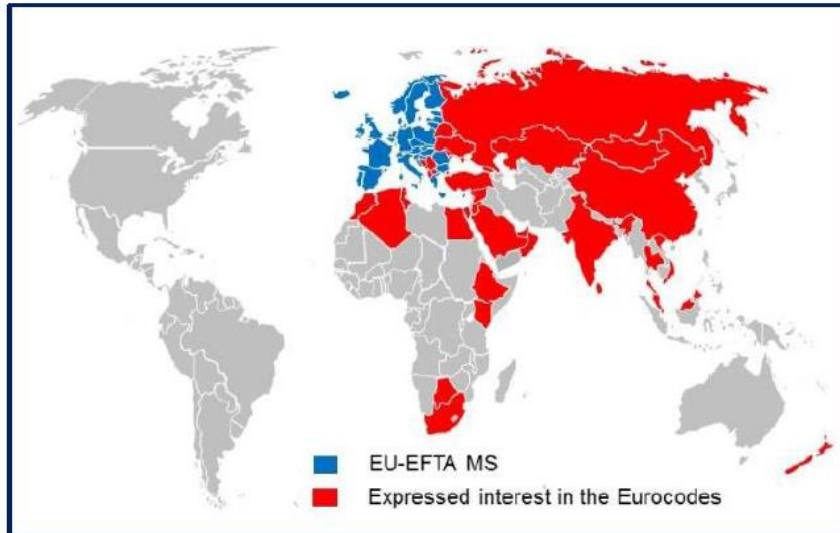
31 členských štátov CEN

Členmi CEN sú národné normalizačné organizácie Belgicka, Bulharska, Cypru, Česka, Dánska, Estónska, Fínska, Francúzska, Grécka, Holandska, Chorvátska, Írska, Islandu, Litvy, Lotyšska, Luxemburska, Maďarska, Malty, Nemecka, Nórska, Poľska, Portugalska, Rakúska, Rumunska, Slovenska, Slovinska, Spojeného kráľovstva, Španielska, Švajčiarska, Švédska a Talianska.

PROMOTION

Eurocodes all-over the world

Malajzia
Singapur
Vietnam

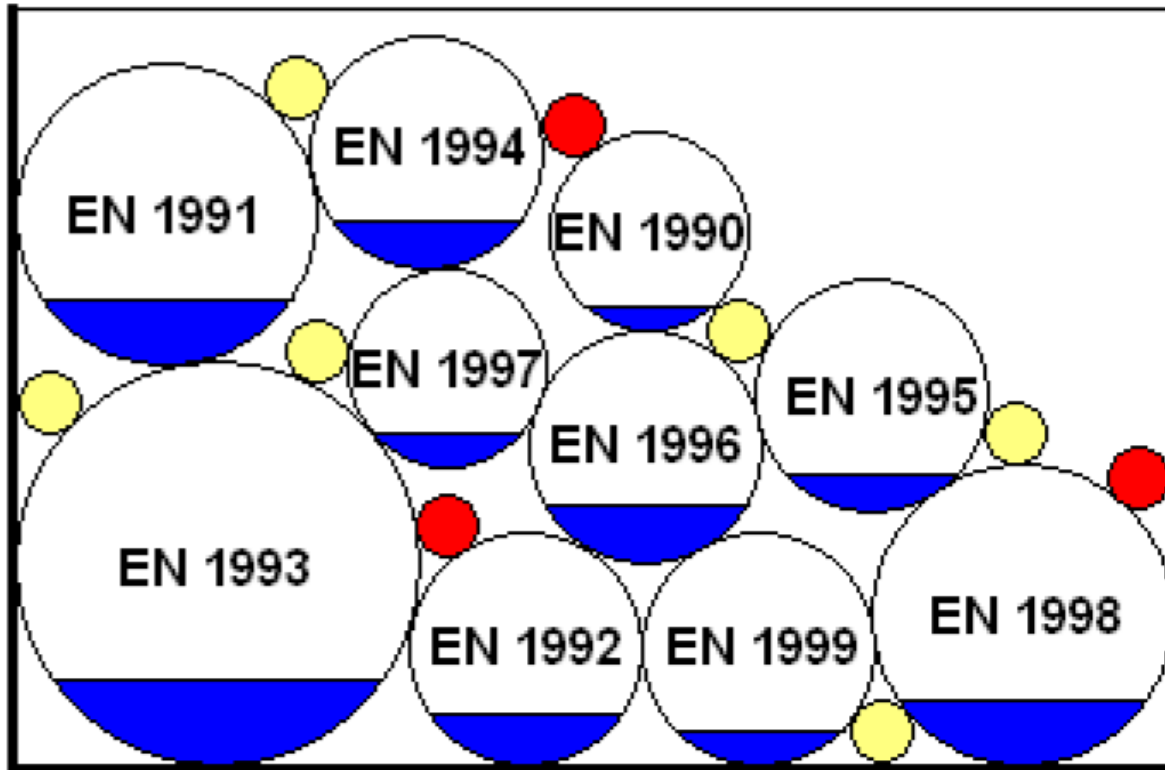


- **Russia** requested CEN for the Eurocodes for their review.
- **Mongolian Standards** requested to participate in the activities of CEN/TC250.

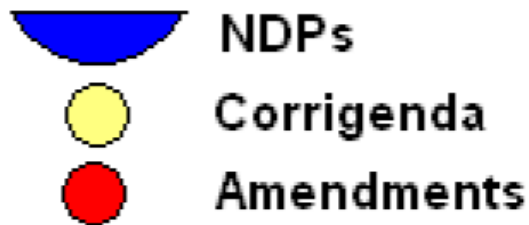
- **South Africa** requested CEN to adopt EN 1993-1-1 and EN 1992-1-1.
- **The United Arab Emirates** requested CEN to adopt EN 1993-1-1 and EN 1992-1-1.
- **New Zealand** requested CEN for EN 1992-1-1 and EN 1998-1 for their review.

Joint
Research
Centre

THE EUROCODES FAMILY TODAY



EN 1990	-	109 pages
EN 1991	-	783
EN 1992	-	469
EN 1993	-	1470
EN 1994	-	331
EN 1995	-	289
EN 1996	-	
EN 1997	-	371
EN 1998	-	686
EN 1999	-	553
Complete		5320 pages



RADA č. 1

- Napíš do GOOGLE označenie eurokódu, napr. EN 1993-1-1
- Objaví sa

[PDF] [EN 1993-1-1: Eurocode 3: Design of steel structures - Part 1-1 ...](https://law.resource.org/pub/eu/eurocode/en.1993.1.1.2005.pdf)

<https://law.resource.org/pub/eu/eurocode/en.1993.1.1.2005.pdf> ▼ Preložiť túto stránku

EN 1993-1-1 (2005) (English): Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings. [Authority: The European Union Per ...

- Otvor a stiahni si KONSOLIDOVANÝ eurokód EN 1993-1-1 v pdf v angličtine.
- Vyzerá to takto



The European Union

EDICT OF GOVERNMENT

In order to promote public education and public safety, equal justice for all, a better informed citizenry, the rule of law, world trade and world peace, this legal document is hereby made available on a noncommercial basis, as it is the right of all humans to know and speak the laws that govern them.

EN 1993-1-1 (2005) (English): Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings
[Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC]

Čo znamená KONSOLIDOVANÝ:

BS EN 1993-1-1:2005
EN 1993-1-1:2005 (E)

(4) The effects of uneven settlements or imposed deformations or other forms of prestressing imposed during erection should be taken into account by their nominal value P_k as permanent actions and grouped with other permanent actions $\boxed{\text{AC}_2}$ G_k to form a single action $\boxed{\text{AC}_2}$ $(G_k + P_k)$.

(5) Fatigue actions not defined in EN 1991 should be determined according to Annex A of EN 1993-1-9.

2.3.2 Material and product properties

(1) Material properties for steels and other construction products and the geometrical data to be used for design should be those specified in the relevant ENs, ETAGs or ETAs unless otherwise indicated in this standard.

2.4 Verification by the partial factor method

2.4.1 Design values of material properties

$\boxed{\text{AC}_1}$ (1)P For the design of steel structures characteristic values $\boxed{\text{AC}_2}$ X_k $\boxed{\text{AC}_2}$ or nominal values X_n of material properties shall be used as indicated in this Eurocode. $\boxed{\text{AC}_1}$

RADA č. 2

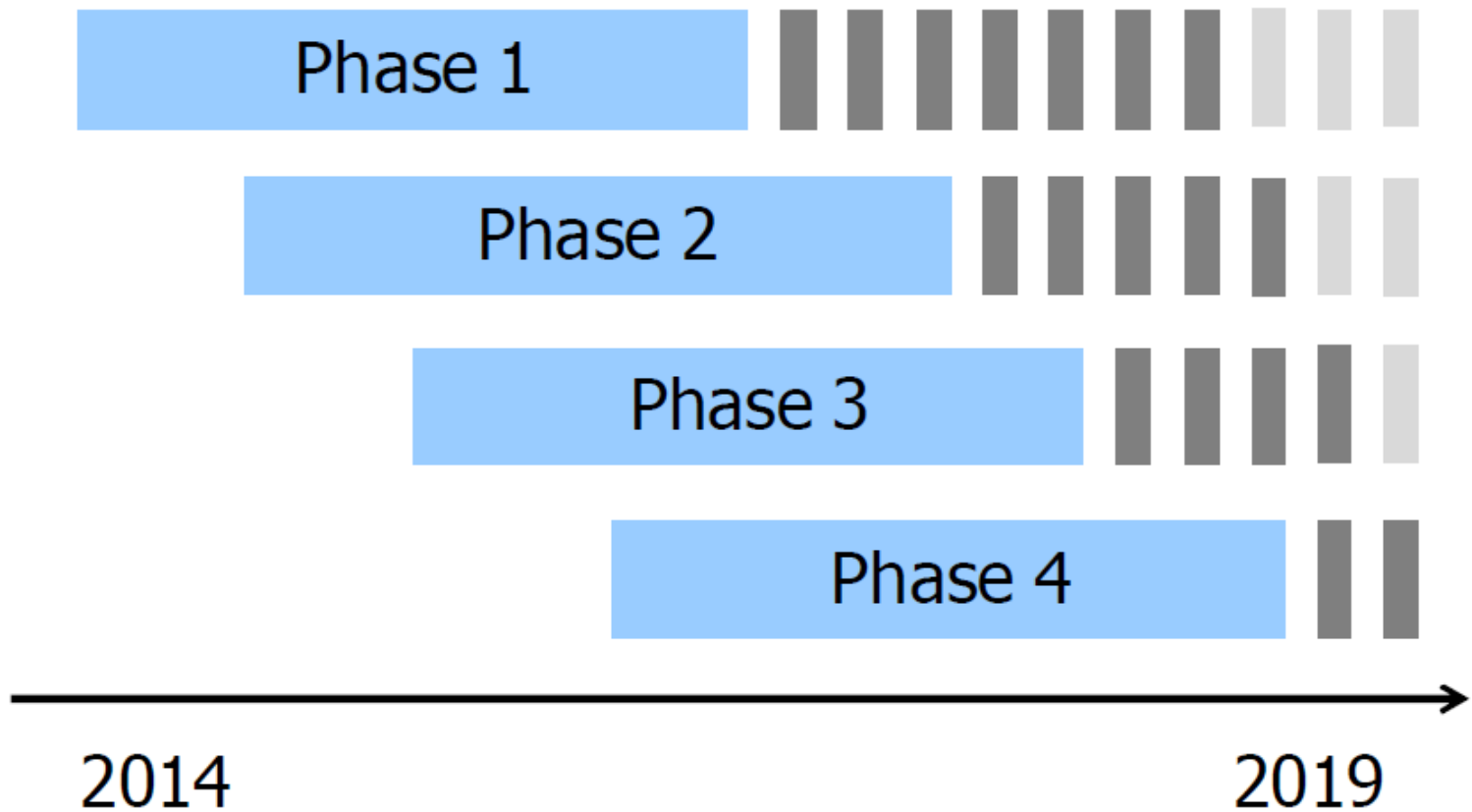
- Stiahni si zadarmo užitočné publikácie k súčasným eurokódom zo stránky
- <http://eurocodes.jrc.ec.europa.eu/listpublications.php?en=8&lg&gen=0>
- Hlavne z časti

JRC: Scientific and Technical Report,

kde sú nielen názvy ale celé publikácie, napr.

Commentary and worked examples to EN 1993-1-5
"Plated structural elements" [4.28 MB]

Tvorba novej generácie eurokódov



Štruktúra CEN/TC 250

CEN/TC 250 Structural Eurocodes

Chairman: S Denton
Vice Chair: M Fardis
Secretary: T Wilkins [BSI]
CEN PM: G Ascensao
NEN M/515 lead: M Lurvink

Predým prof. Calgario

CEN/TC 250 Subcommittees

SC 10 - EN 1990

Chairman: P Formichi
Secretary: V Meløysund [SN]

SC 1 - EN 1991

Chairman: N Malakatas
Secretary: J Brunner [DIN]

SC 2 - EN 1992

Chairman: H Ganz
Secretary: A Schleifer [DIN]

SC 3 - EN 1993

Chairman: U Kuhlmann
Secretary: S Kempa [DIN]

SC 4 - EN 1994

Chairman: G Couchman
Secretary: J Duncan [BSI]

SC 5 - EN 1995

Chairman: S Winter
Secretary: A Stenmark [SIS]

SC 6 - EN 1996

Chairman: R Van der Pluijm
Secretary: P Rauh [DIN]

SC 7 - EN 1997

Chairman: A Bond
Secretary: M Lurvink [NEN]

SC 8 - EN 1998

Chairman: P Bisch
Secretary: E Coelho [IPQ]

SC 9 - EN 1999

Chairman: F Mazzolani
Secretary: R Sægrov [SN]

SC 11 - EN 'Structural Glass'

Chairman: M Feldmann
Secretary: S Tiedtke [DIN]

**CEN/TC 250
Coordination Group**

Chairman: S Denton
Secretary: T Wilkins [BSI]

Horizontal Group Bridges
Convenor: P Croce

Horizontal Group Fire
Convenor: B Zhao

WG 1 Policy and guidelines
Convenor: J Moore [UK]

Other Tier 1 WG's

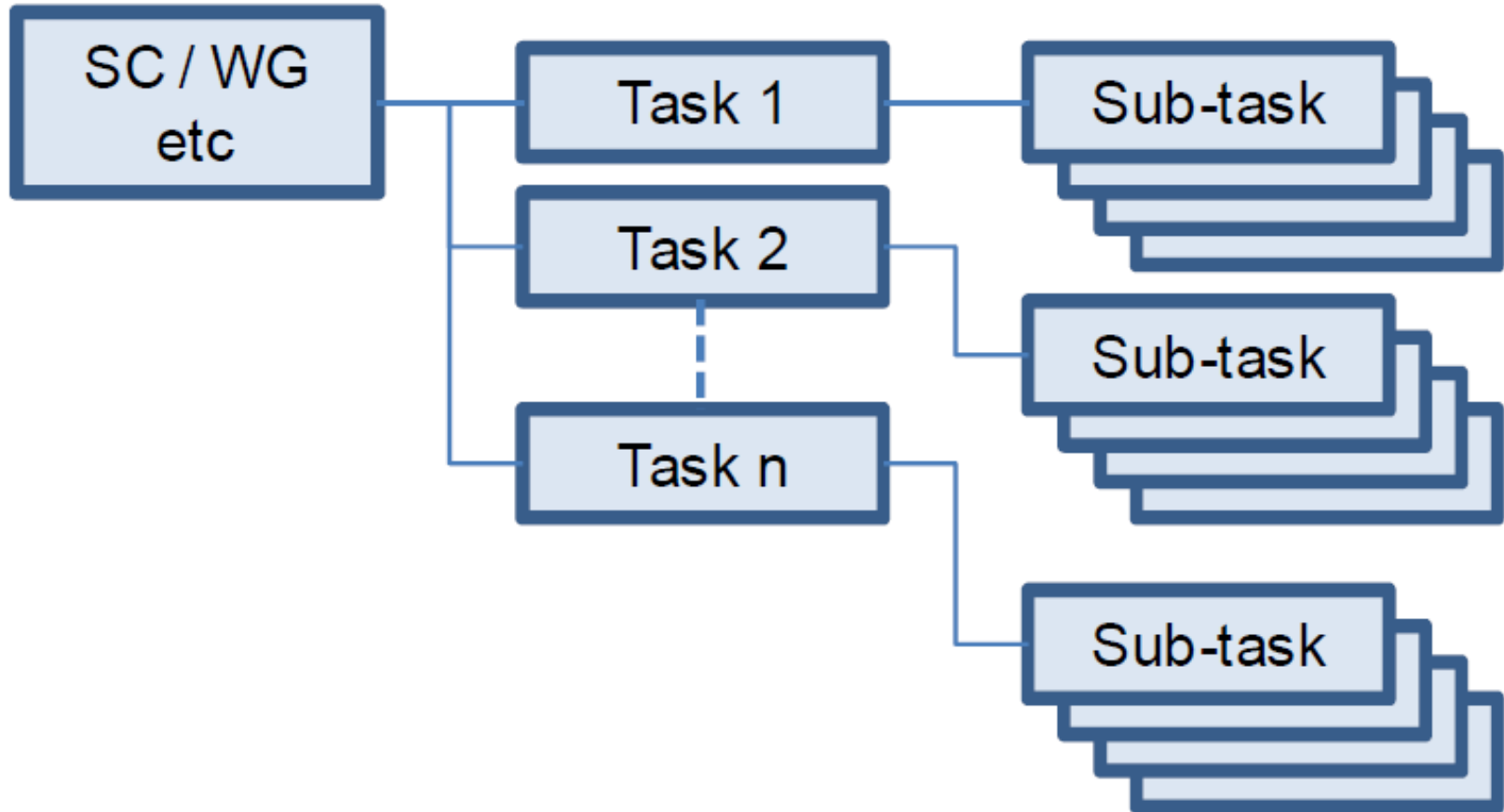
WG 2 Existing Structures
Convenor: P Lüchinger [SNV]

WG 4 Fibre reinforced polymer
Convenor: L Ascione [UNI]

WG 5 Membrane Structures
Convenor: M Mollaert [NBN]

WG 6 Robustness
Convenor: R Van der Pluijm [NEN]

Štruktúra prác v rámci SC / WG



Požiadavky na novú generáciu eurokódov

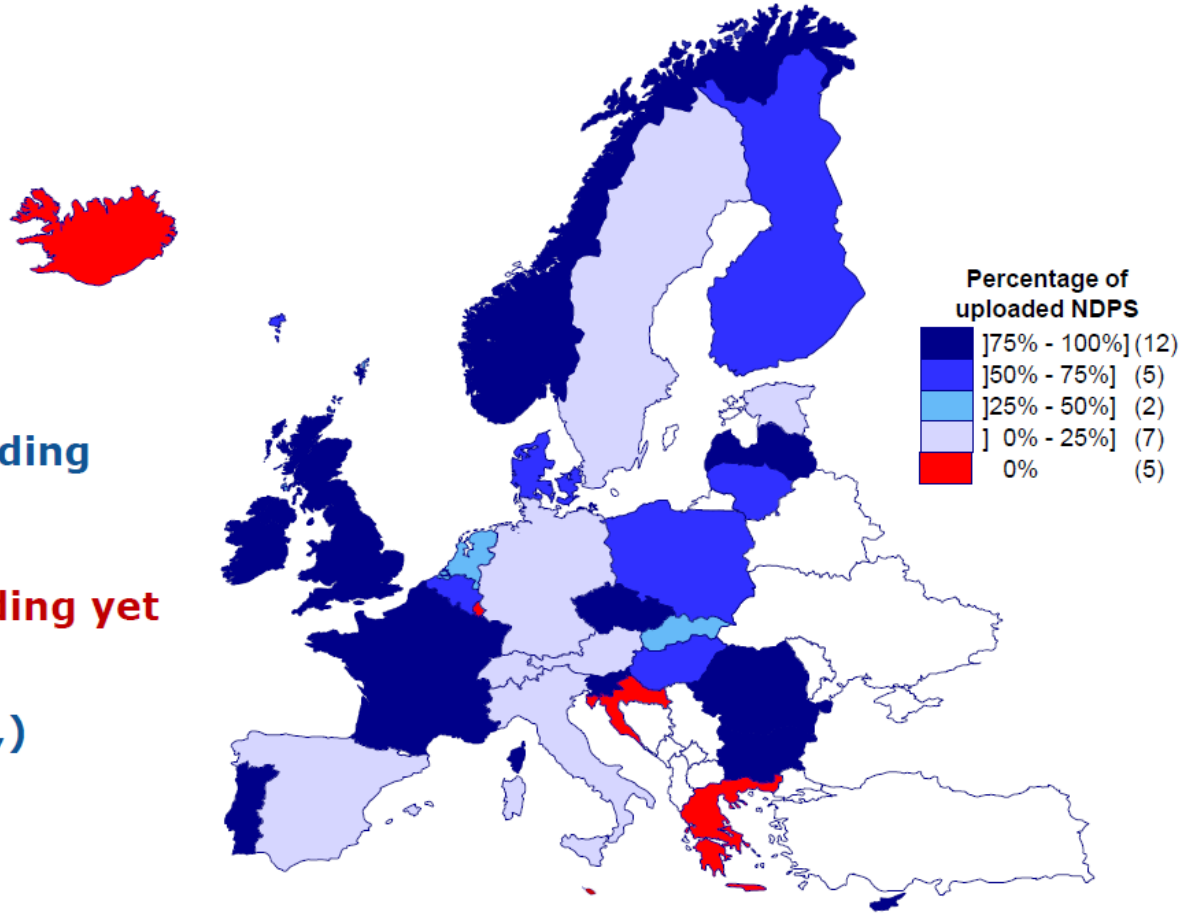
- Zredukovať rozsah
- Zredukovať alternatívne návrhové pravidlá
- Zmenšiť počty národne definovaných parametrov
- Zjednodušiť text, aby bol zrozumiteľnejší pre projektantov v praxi
- Harmonizovať časti eurokódov alebo eurokódy navzájom
- Zapracovať najnovšie výsledky a inovácie

HARMONIZATION

NDPs database – progress of uploading by Country (by 12 November 2014, % calculated on published NAs)

Out of **31 countries**
(28 EU MS + 3 EFTA MS):

- **26** Registered and **uploading**
(all MS registered)
- **4** Registered, **not uploading yet**
(4 MS - Croatia, **Greece**,
Luxembourg and **Malta**,)
- **1 Not registered**
(Iceland)



Nové časti eurokódov

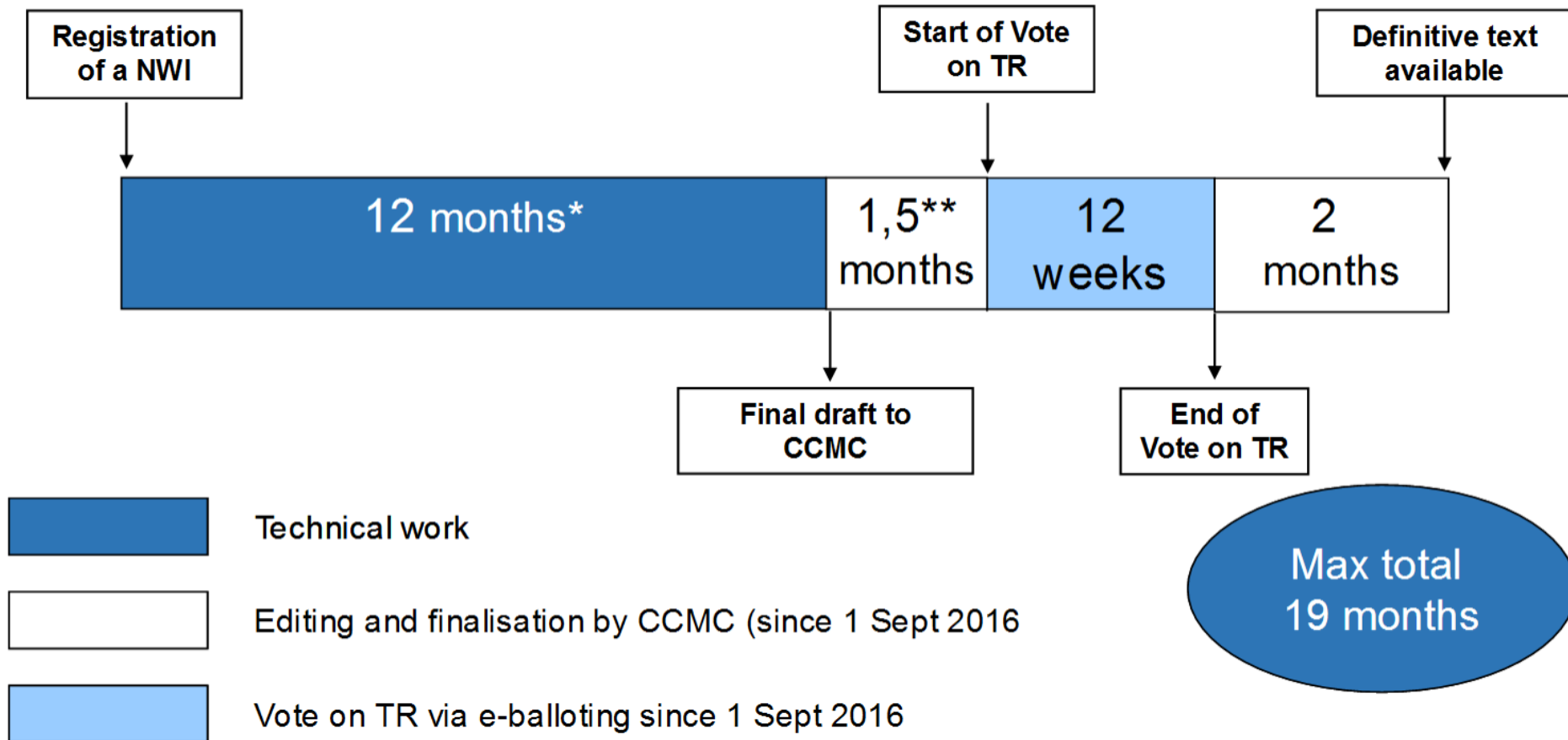
- Konverzia ISO 12494 na EN ISO 12494
Atmoferická námraza (EN 1991-1-8)
- Konverzia ISO 21650 na EN ISO 21650
Zaťaženie vlnami a prúdmi na pobrežné
konštrukcie (EN 1991-1-9)

SC 11 - EN 'Structural Glass'
Chairman: M Feldmann
Secretary: S Tiedtke [DIN]

- **Vedecká a technická správa sa konvertuje na:**
- **Technickú špecifikáciu TS, ktorá sa konvertuje na:**
- **EN nový eurokód pre navrhovanie nosných sklenených konštrukcií**

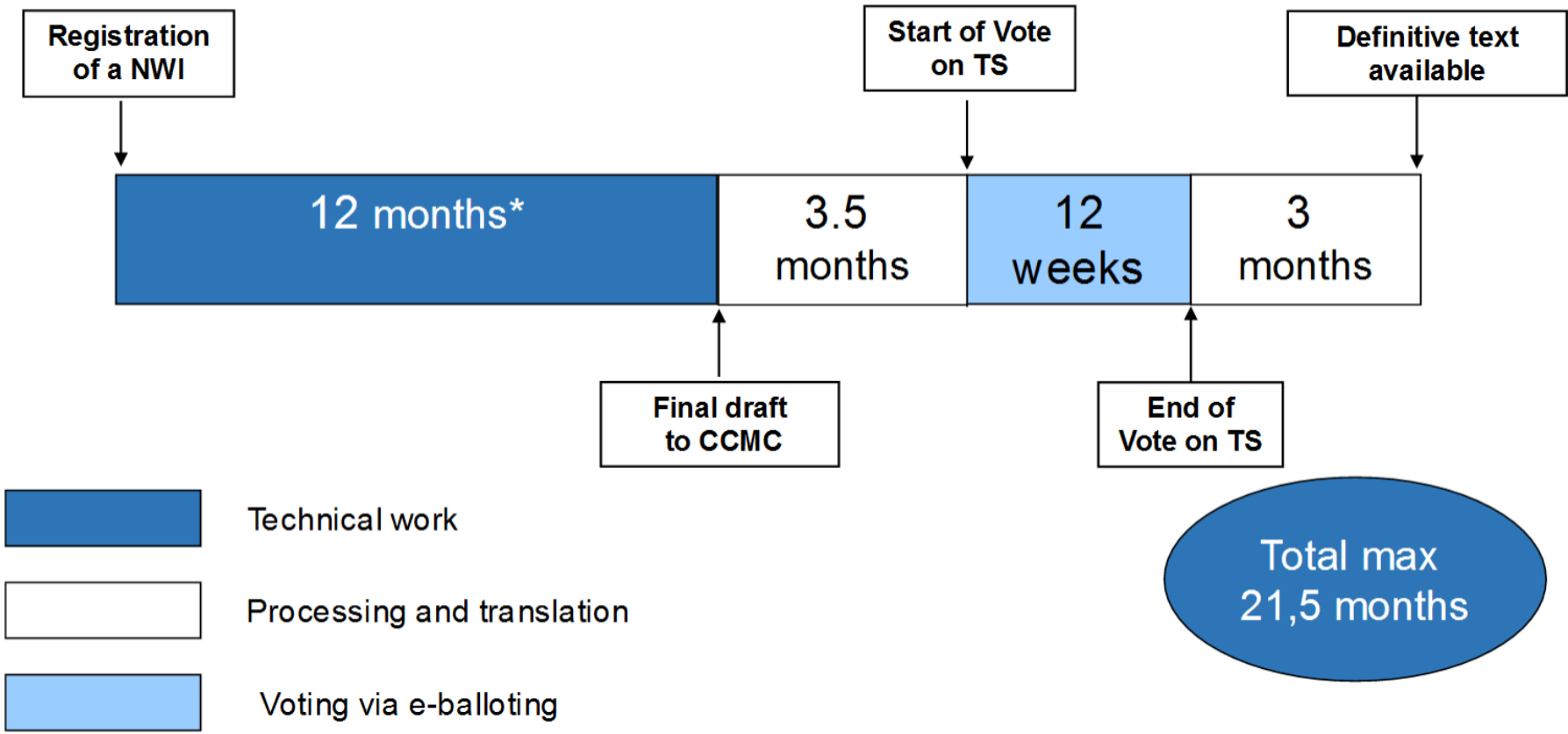
- Rozšírenie návrhových pravidiel na:
Ohodnotenie existujúcich konštrukcií a ich zosilenie
- **Vedecká a technická správa sa konvertuje na:**
- **Technickú špecifikáciu TS pre:**
 - všeobecné pravidlá,
 - pravidlá pre zaťaženie.

Detailed Timeframe - Technical Reports (TR)



*An extension of 9 months may be requested

Detailed Timeframe - Technical Specifications (TS)



*An extension of 9 months may be requested

WG 4 Fibre reinforced polymer
Convenor: L Ascione [UNI]

- **Vedecká a technická správa sa konvertuje na:**
- **Technickú špecifikáciu TS**

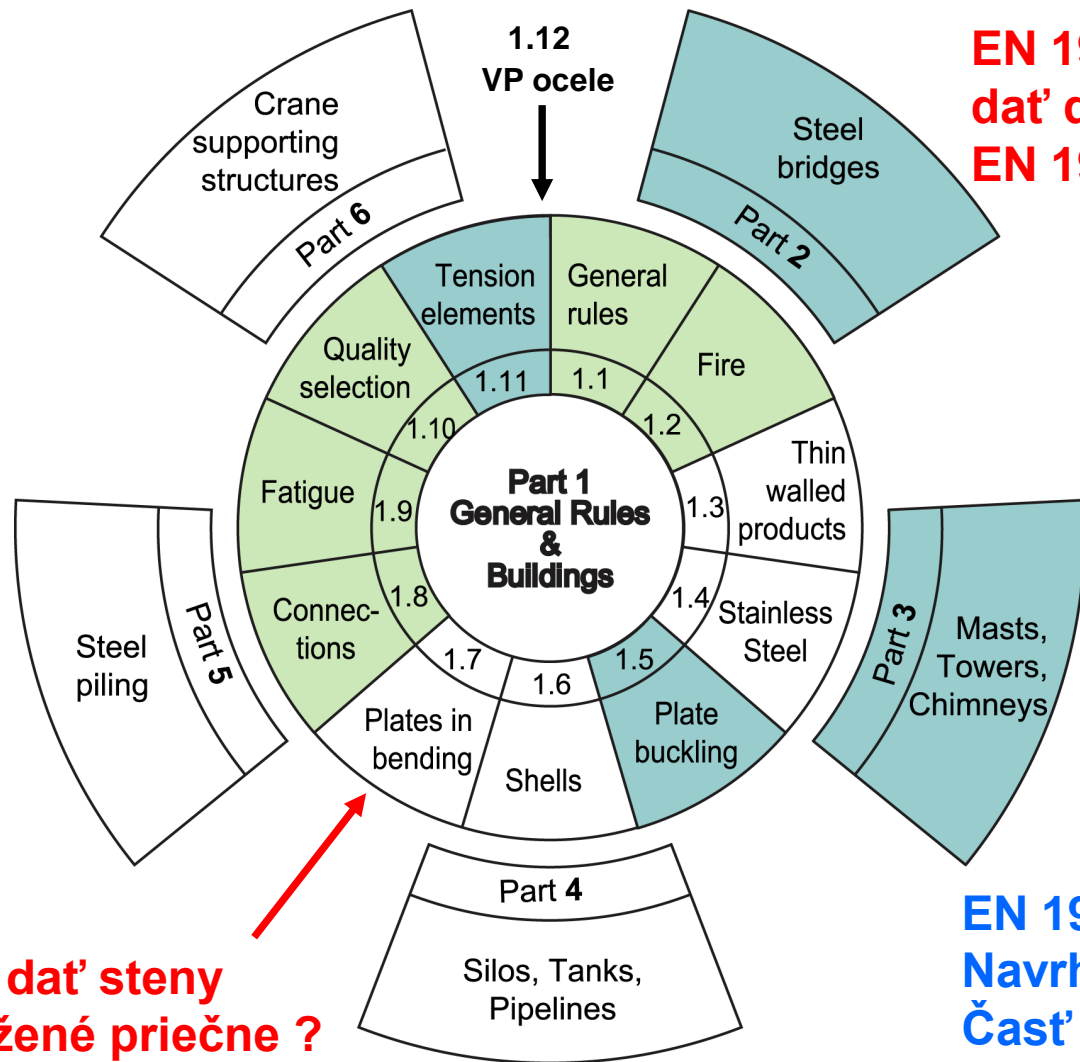
- **Vedecká a technická správa sa konvertuje na:**
- **Technickú špecifikáciu TS**

WG 6 Robustness

Convenor: R Van der Pluijm [NEN]

- Rozšírenie existujúcich horizontálnych pravidiel o robustness
- Adaptovanie do EN 1990 a EN 1991
- Nové alebo modifikované pravidlá v materiálových eurokódoch:
(SC2, SC3, SC4, SC5, SC6, SC9)

EN 1993 Servants & Masters



EN 1993-1-12 Pravidlá pre VP ocele dať do ostatných častí, hlavne do EN 1993-1-1

γ_M

Kam dať steny zaťažené priečne ?

EN 1993-1-13 Eurokód 3. Navrhovanie ocelových konštrukcií. Časť 1-13: Pravidlá pre nosníky s veľkými otvormi v stene.

EN 1999 Navrhovanie hliníkových konštrukcií

- EN 1999-1-1 Všeobecné pravidlá pre konštrukcie
- EN 1999-1-2 Navrhovanie konštrukcií na účinky požiaru
- EN 1999-1-3 Konštrukcie náchylné na únavu
- EN 1999-1-4 Nosné plošné profily tvarované za studena
- EN 1999-1-5 Škrupinové konštrukcie

Členstvo v TK v rámci ÚNMS SR

- TK 4 Kovové, spriahnuté ocel'obetónové, drevené a sklenené konštrukcie
- TK 15 Zaťaženia stavebných konštrukcií
- TK 111 Uplatňovanie a používanie eurokódov

Členstvo v SC a WG v rámci CEN v TC v rámci ECCS

- SC3 Ocelové konštrukcie
- WG EN 1993-1-1 Všeobecné pravidlá a pravidlá pre budovy
- WG EN 1993-1-3 Profily tvarované za studena
- WG EN 1993-1-5 Nosné stenové prvky
- WG EN 1993-2 Ocelové mosty
- SC9 Hliníkové konštrukcie
- WG EN 1999-1-1 Všeobecné pravidlá

ENC a členstvo v TC v rámci ECCS

- Eurocode National Correspondent
- TC 7, TWG 7.5, ECCS (European Convention for Constructional Steelwork), Technical Committee 7: Tenkostenné profily tvarované za studena

Podmienky v pracovných komisiách

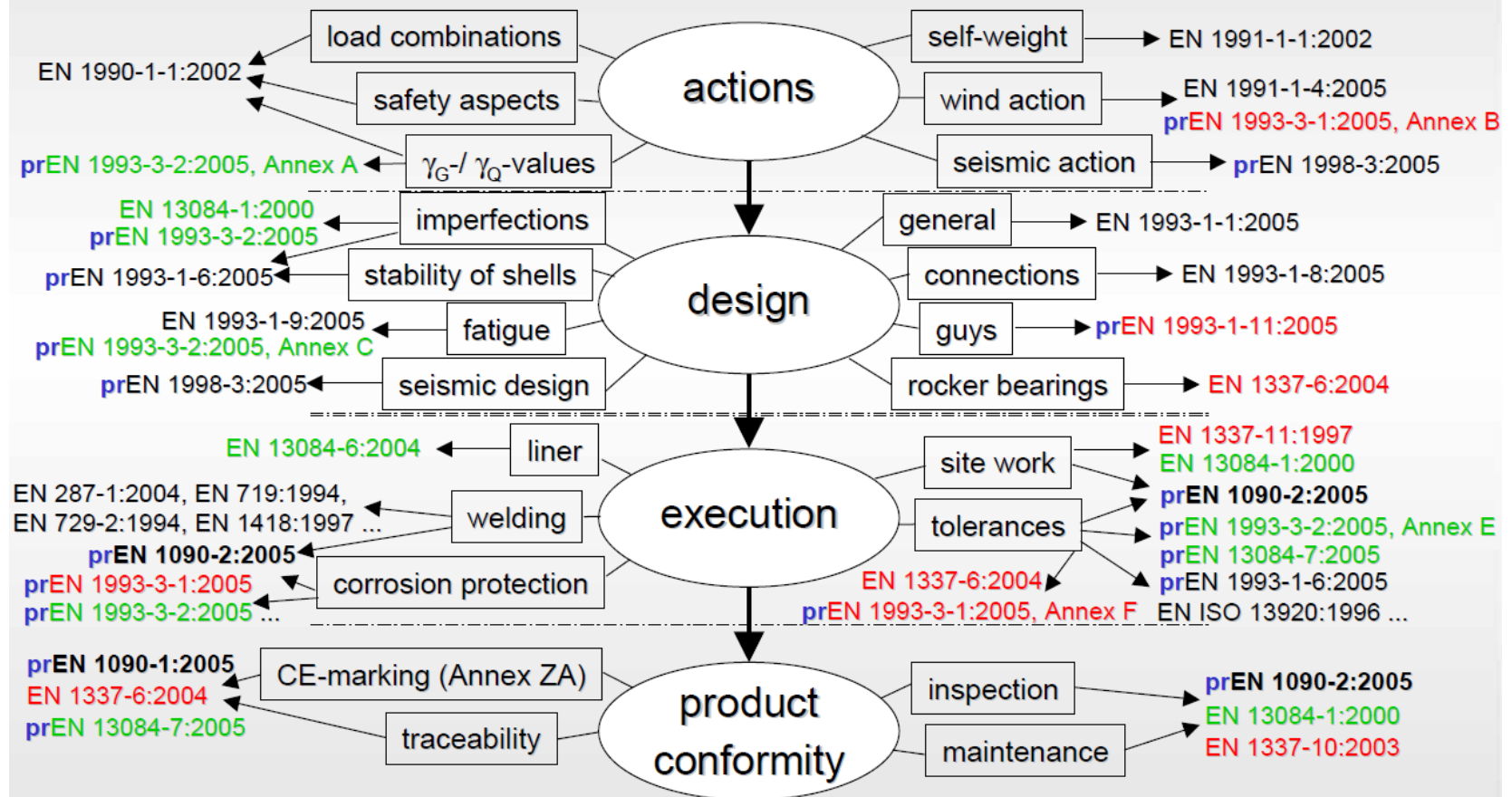
- Práca V SC a WG je na dobrovoľnej báze a nie je honorovaná
- V SR tieto aktivity nepodporuje vôbec nikto
- Práca v PT je honorovaná takto:
 - predseda PT cca 25 000 EUR
 - člen PT cca 5000 EUR

EN 1090 Zhotovovanie oceľových a hliníkových konštrukcií

- EN 1090-1 Časť 1: Požiadavky na posudzovanie zhody konštrukčných dielcov
- EN 1090-2 Časť 2: Technické požiadavky na oceľové konštrukcie
- EN 1090-3 Časť 3: Technické požiadavky na hliníkové konštrukcie
- EN 1090-4 Časť 4: Technické požiadavky na tenkostenné, za studena tvarované prvky a konštrukcie pre použitie na strechy, stropy, podlahy a steny
- EN 1090-5 Časť 5: Technické požiadavky na tenké, za studena tvarované hliníkové prvky a konštrukcie striech, stropov, podláh a stenových aplikácií

Príklad súboru noriem potrebných na navrhovanie veží a stožiarov

Guidance - Series of standards for steel towers and masts



Eurokód 3

Navrhovanie ocelových konštrukcií

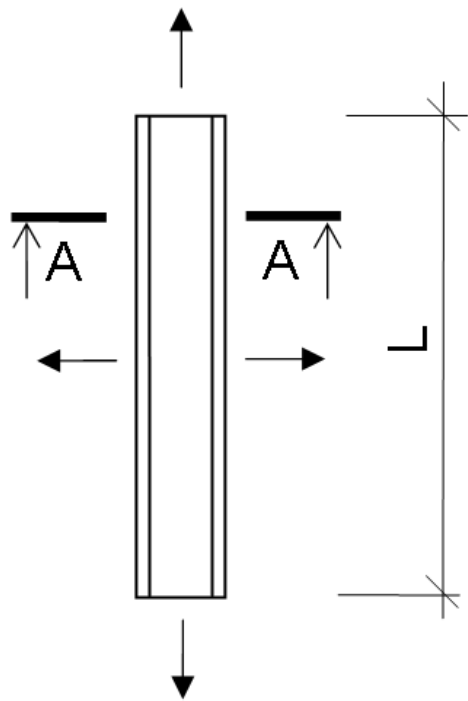
Časť 1-3: Všeobecné pravidlá – Doplnkové pravidlá pre prútové a plošné profily tvarované za studena

Charakteristické vlastnosti v dôsledku malej hrúbky:

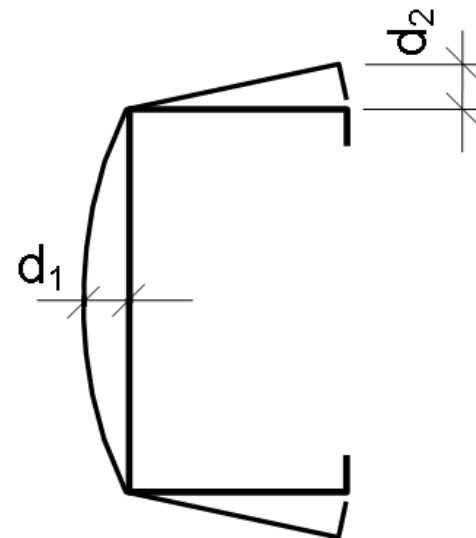
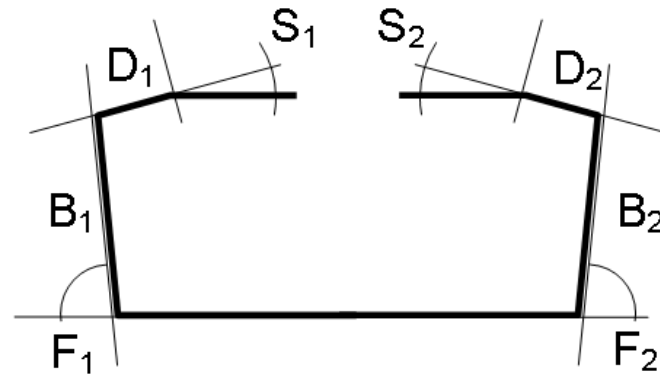
- malá krutová tuhosť
- malá odolnosť proti skrúteniu
- jednoduchý výpočet vnútorných síl krútenia na základe analógie s ohybom
- malá odolnosť proti strate:
 - globálnej stability (ohybom, skrútením, ich kombináciou),
 - distorznej stability (zmena tvaru prierezu),
 - lokálnej stability (vydúvanie tlačенých štíhlych stien),
 - ich kombinácii (coupled instability).

Local, Distortional, Global Buckling

Ďuricová, S. - Ondík, S.
TSUS, Košice



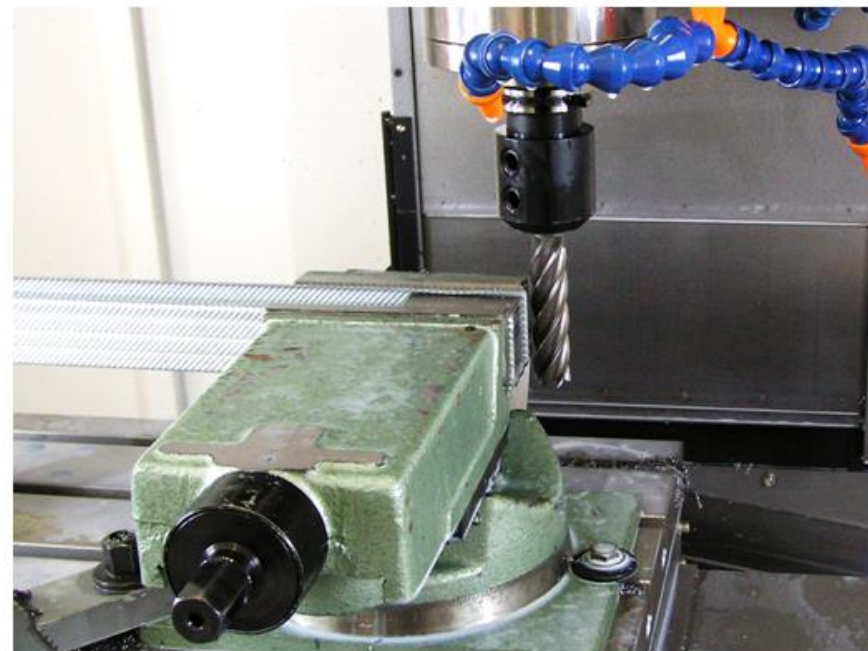
A – A



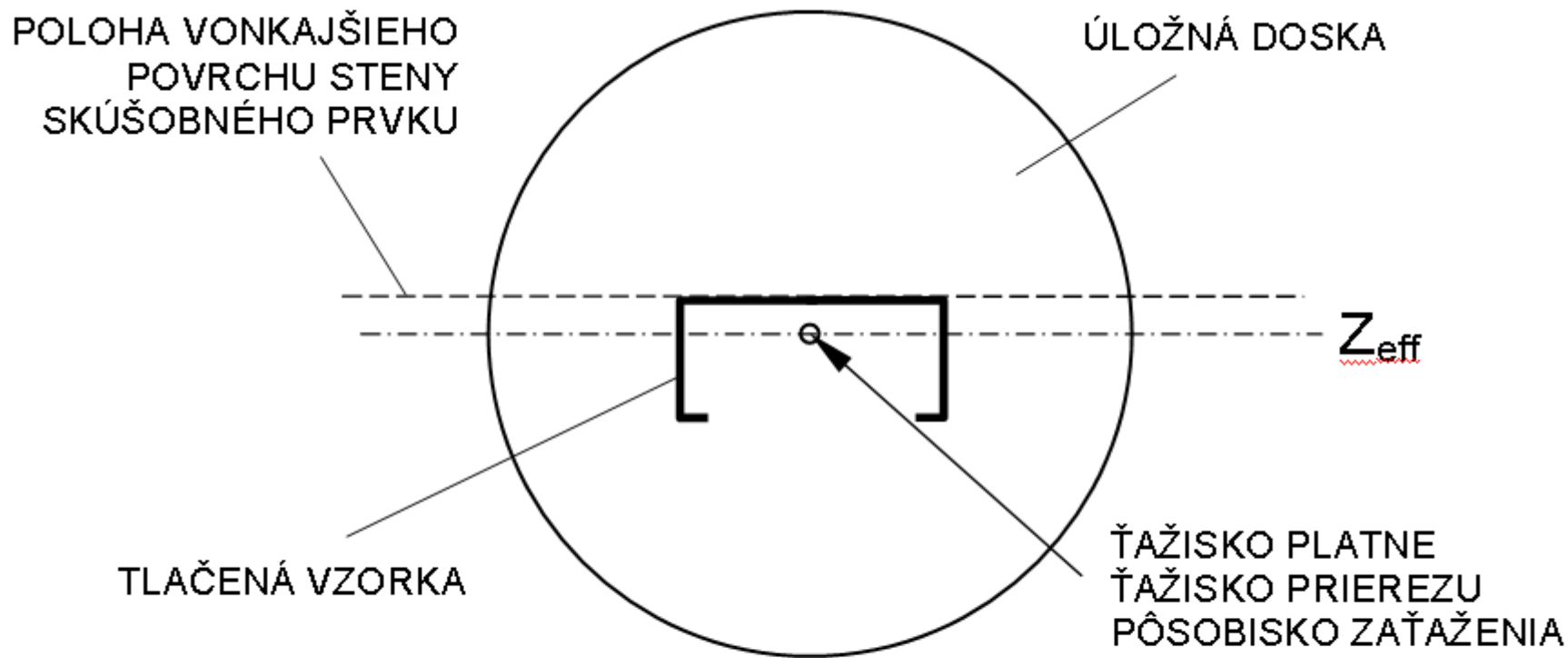
Obr. 3 Merané rozmery a imperfekcie

Tab. 1 Dĺžky skúšobných vzoriek

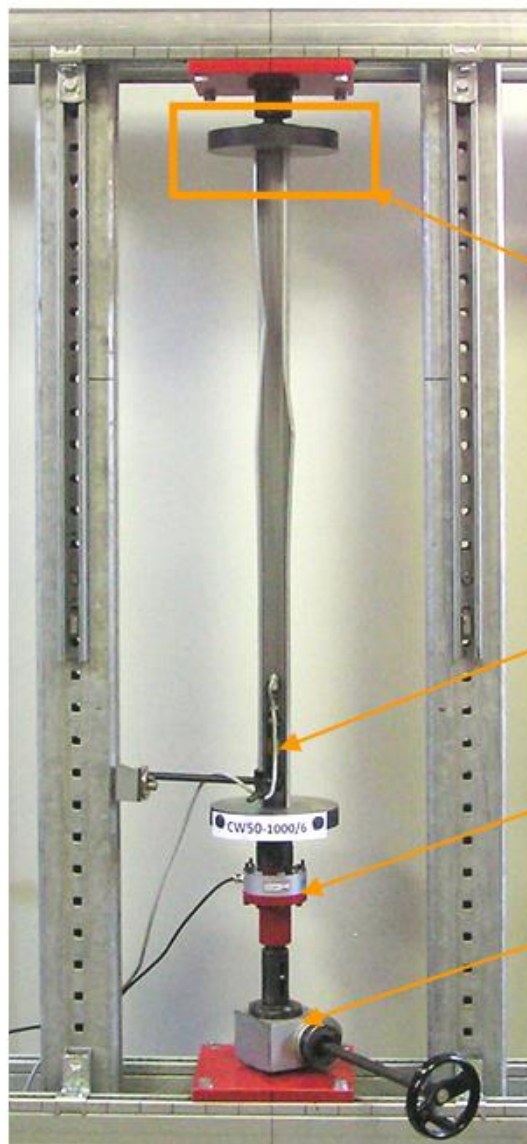
Profil	Dĺžka „krátkych“ vzoriek (mm)	Pomerná štíhlosť dlhých vzoriek $\bar{\lambda}$	Dĺžka „dlhých“ vzoriek (mm)	Teoretická dĺžka ohýbaných prútov (mm)	Oblasť namáhaná čistým ohybom (mm)
CW50	200	0,67	1000	900	300
CW75	300	0,91	1350	1000	300
CW100	400	0,92	1350	1500	500



Obr. 1 Frézovanie koncov dlhých tlačných vzoriek



Obr. 6 Poloha vzoriek v skúšobnom zariadení



SNÍMAČ POSUNOV

SILOMER

ZARIADENIE NA VYVOLANIE
POSUNU

Obr. 5 Zaťažovací rám, okrajové podmienky s trením

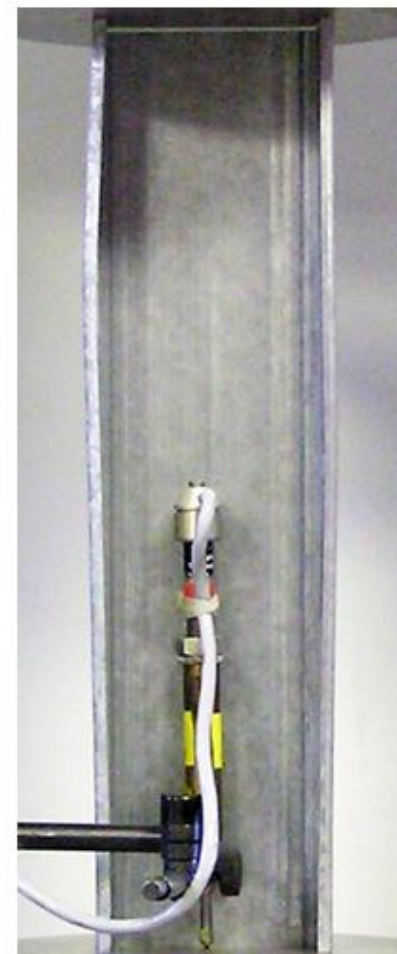
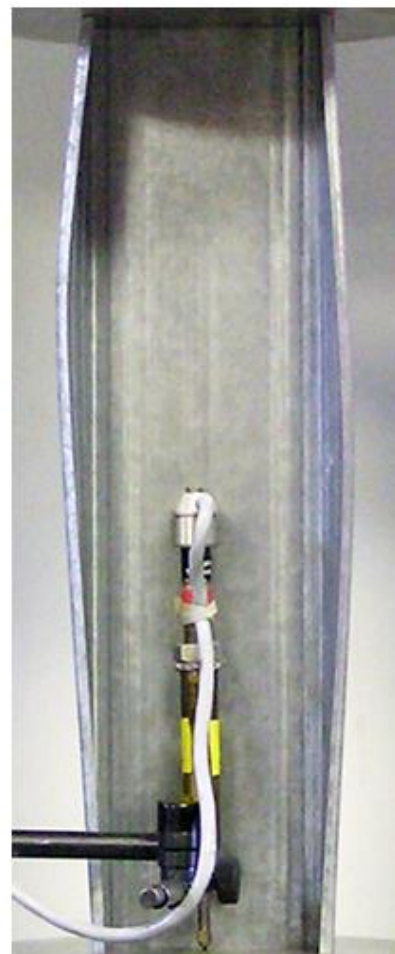
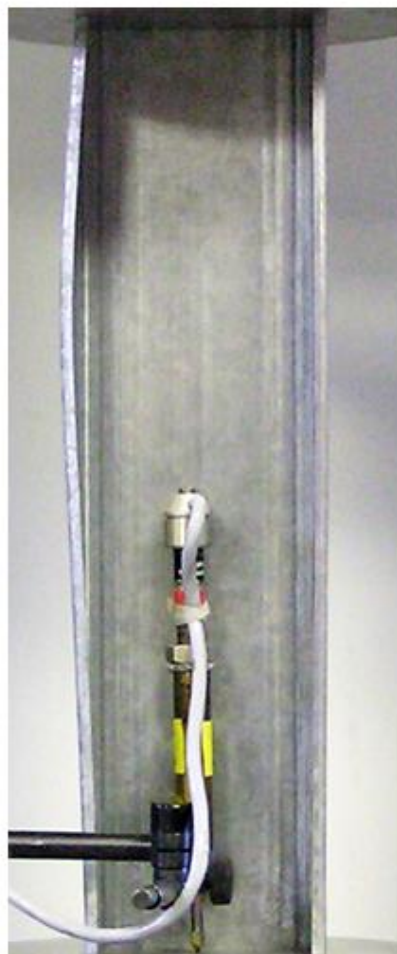
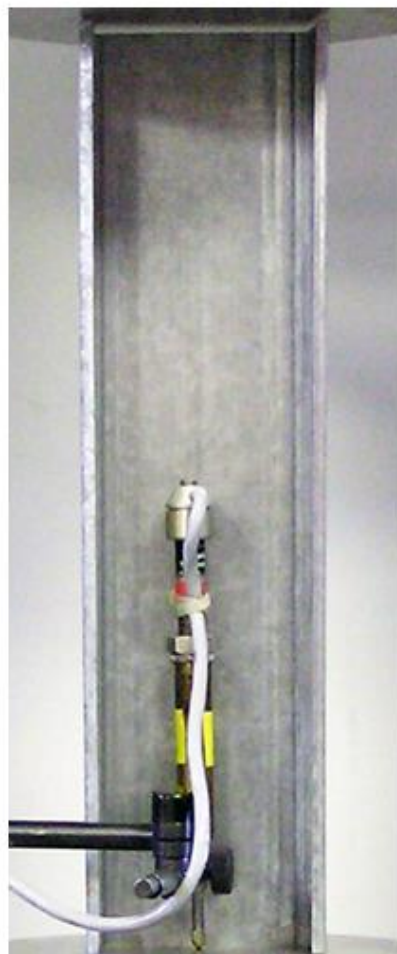
Tab. 2 Porušovanie krátkych vzoriek CW100

CW100
0 (N)

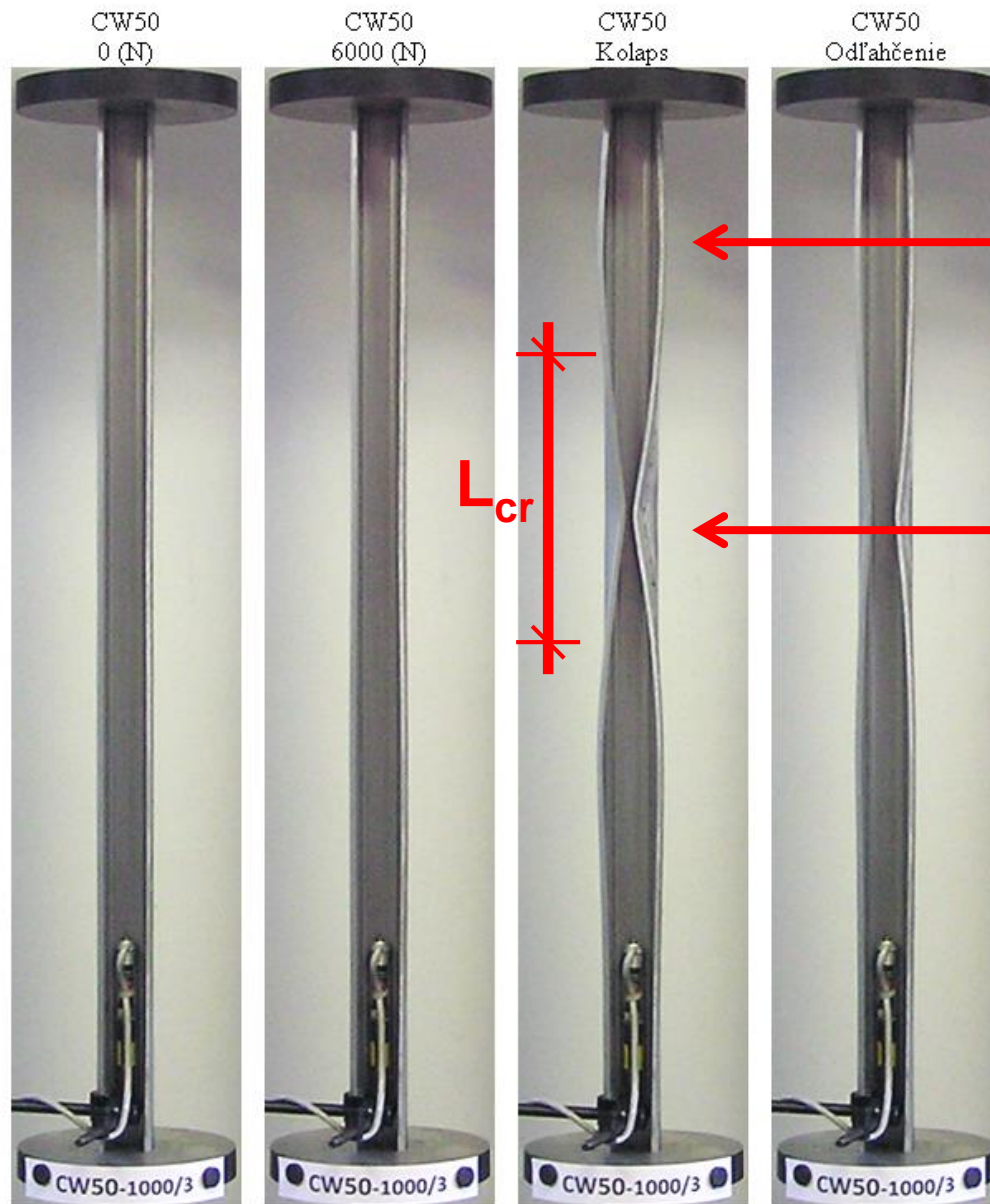
CW100
9000 (N)

CW100
Kolaps

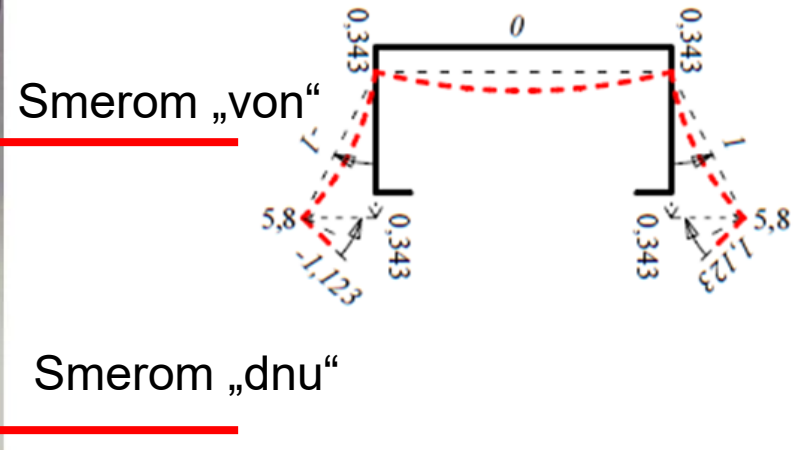
CW100
Odľahčenie



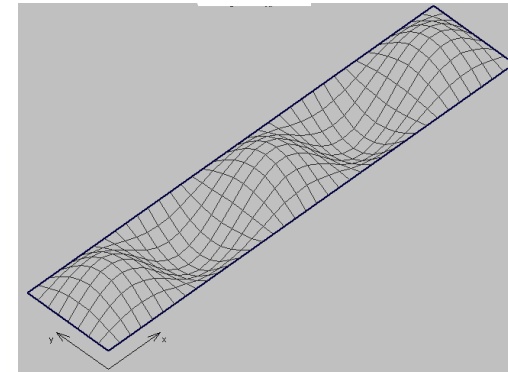
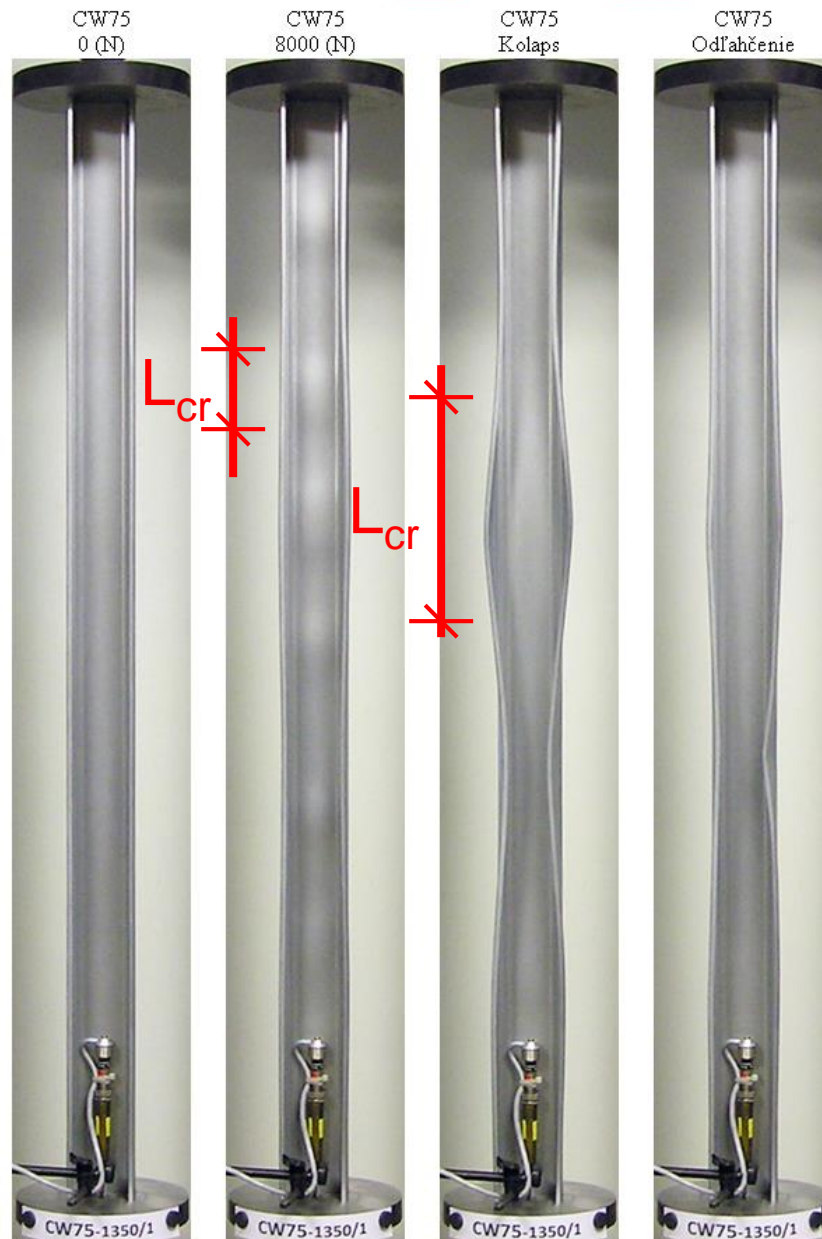
Tab. 3 Porušovanie dlhých vzoriek CW50 (distorzia)



Distorzia = zmena tvaru prierezu

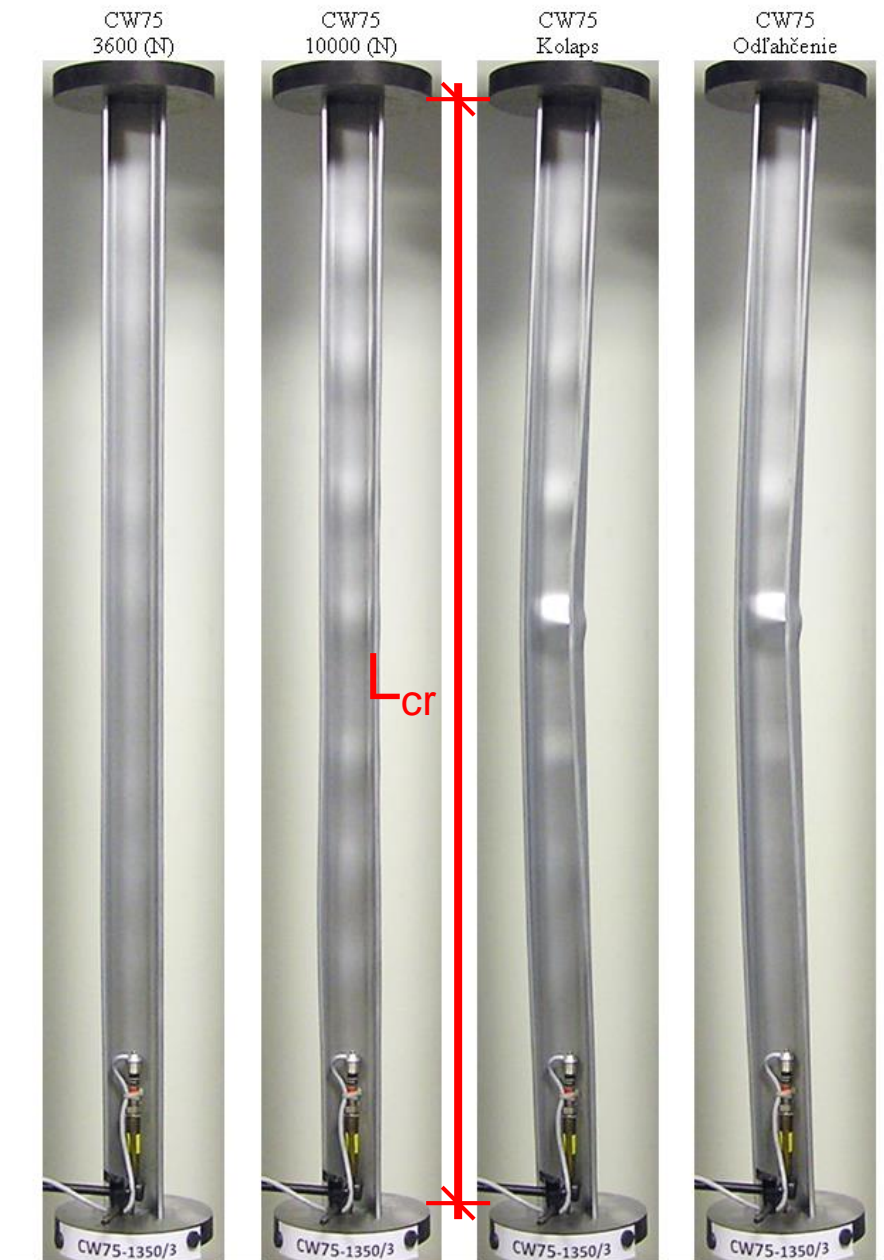


Tab. 4 Porušovanie dlhých vzoriek CW75 (lokálna strata stability a distorzia)



Lokálna strata stability.
Vydúvanie tlačenej
štíhlej steny

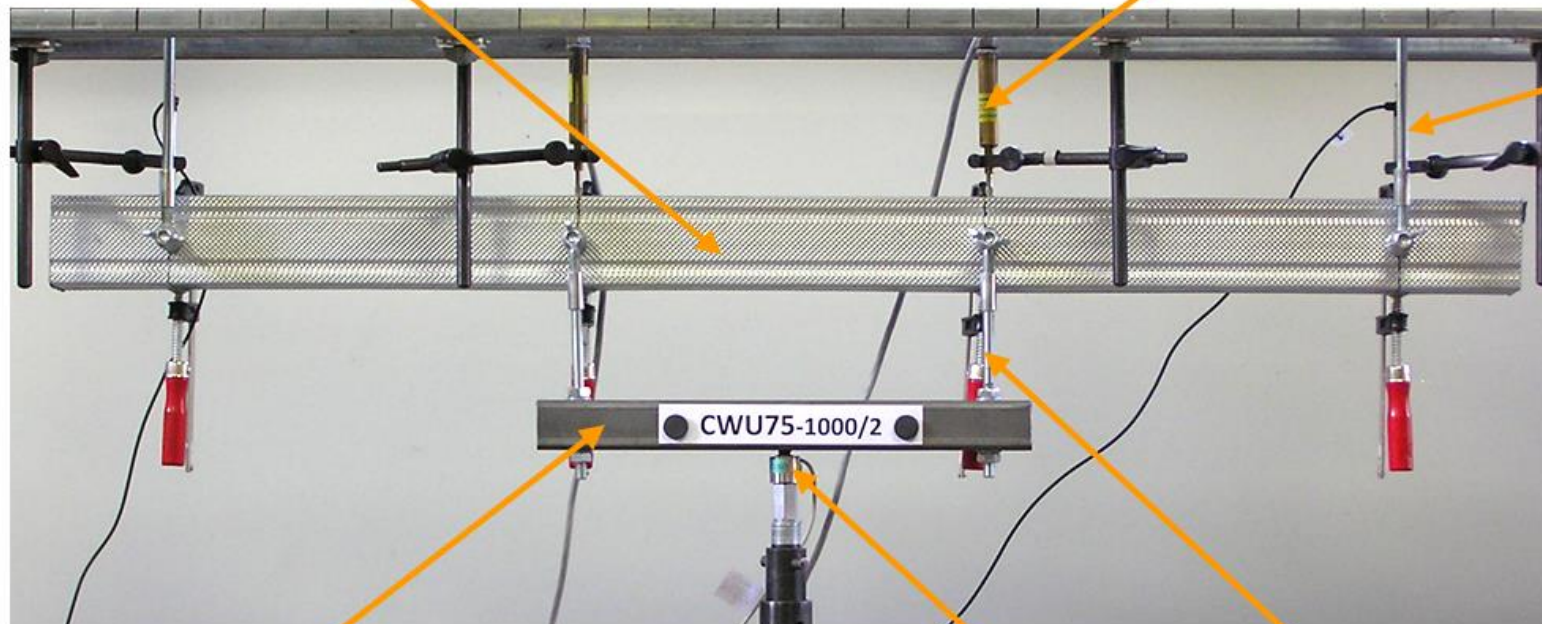
Tab. 5 Porušovanie dlhých vzoriek CW75 (lokálna a globálna strata stability)



SKÚŠOBNÁ VZORKA

SNÍMAČ PRIEHYBU

ZÁVES



ROZNÁŠACÍ PRVOK

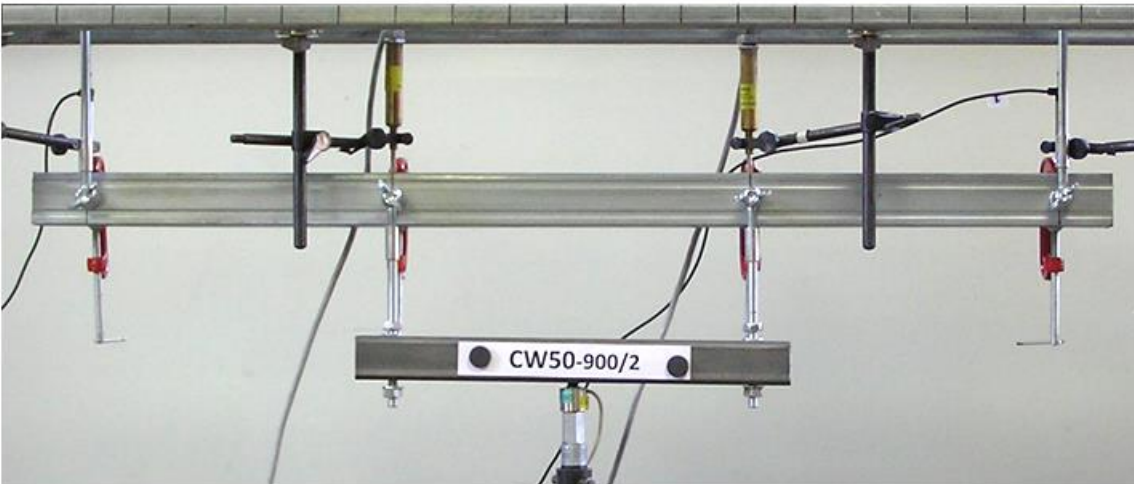
SILOMER

ZÁVES

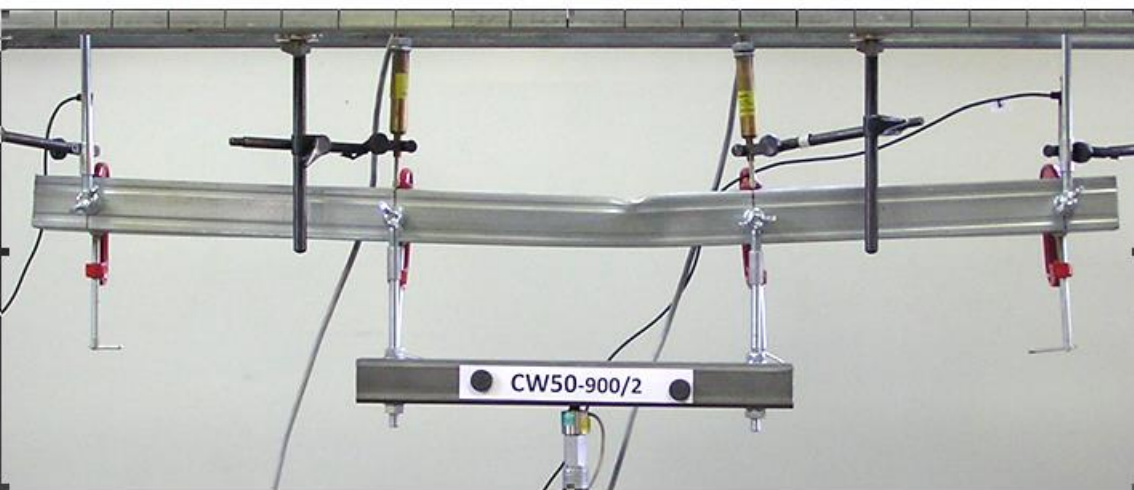
Obr. 9 Skúšobná zostava skúšky ohybom

Tab. 6 Porušovanie ohýbaných vzoriek CW50

CW50
0 (N)



CW50
Kolaps

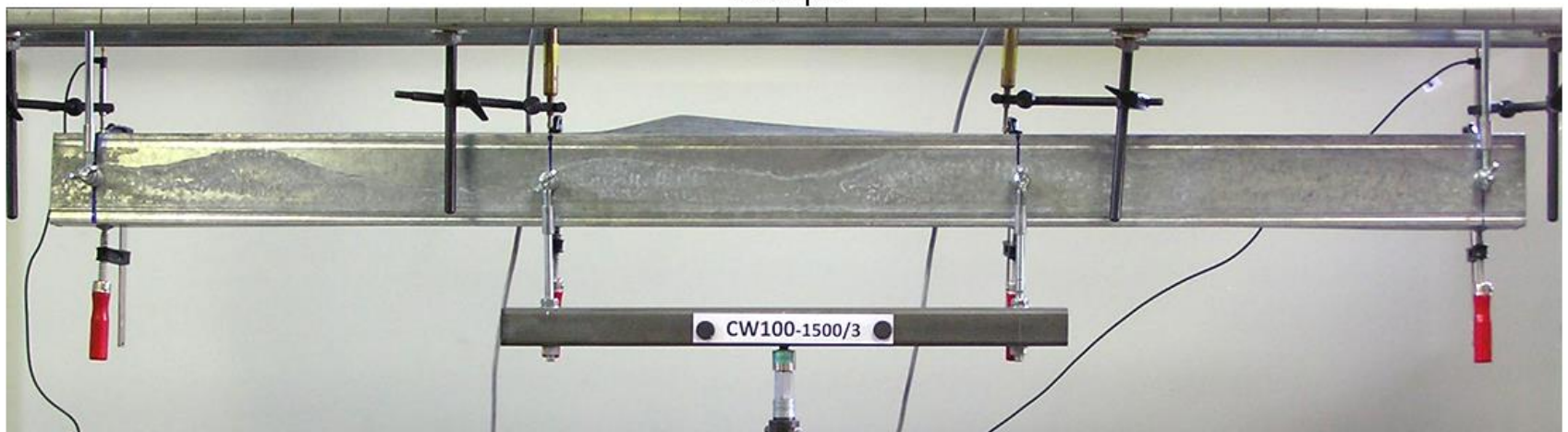


Tab. 7 Porušovanie ohýbaných vzoriek CW100

CW100
0 (N)



CW100
Kolaps



RADA č. 3

- Stiahnite si zadarmo program CUFSM

<http://www.ce.jhu.edu/bschafer/cufsm/>

DSM - Direct Strength Method,

Prof. Ben Schafer, Johns Hopkins University, Baltimore, Maryland, USA

- Stiahnite si zadarmo program GBTUL

<http://www.civil.ist.utl.pt/gbt/>

GBT - Generalised Beam Theory

Prof. Dinar Camotim, Instituto Superior Técnico, University of Lisbon, Portugal

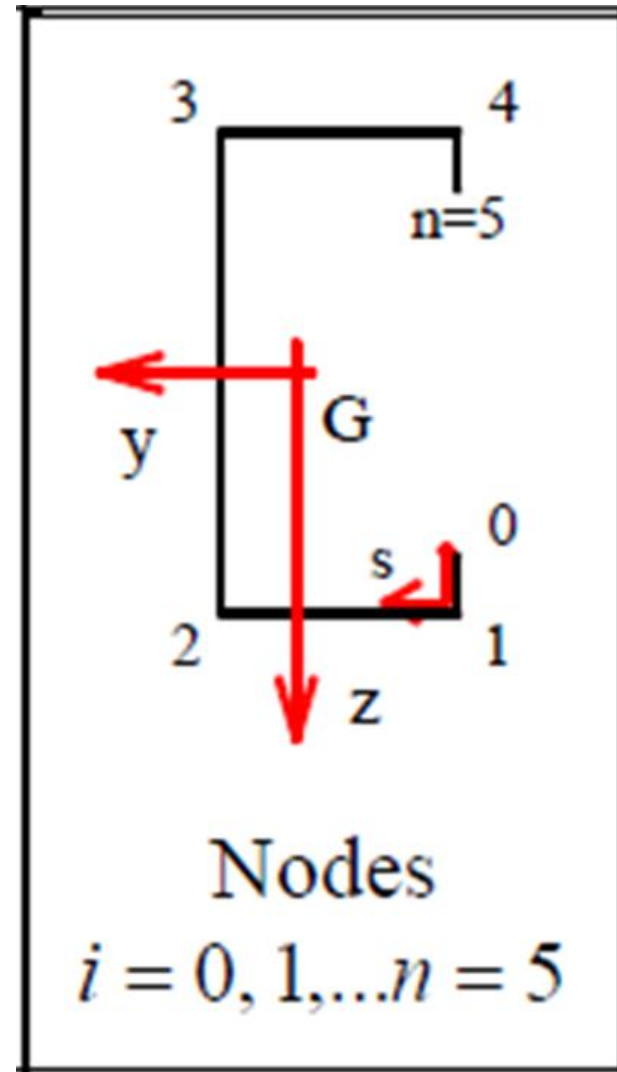
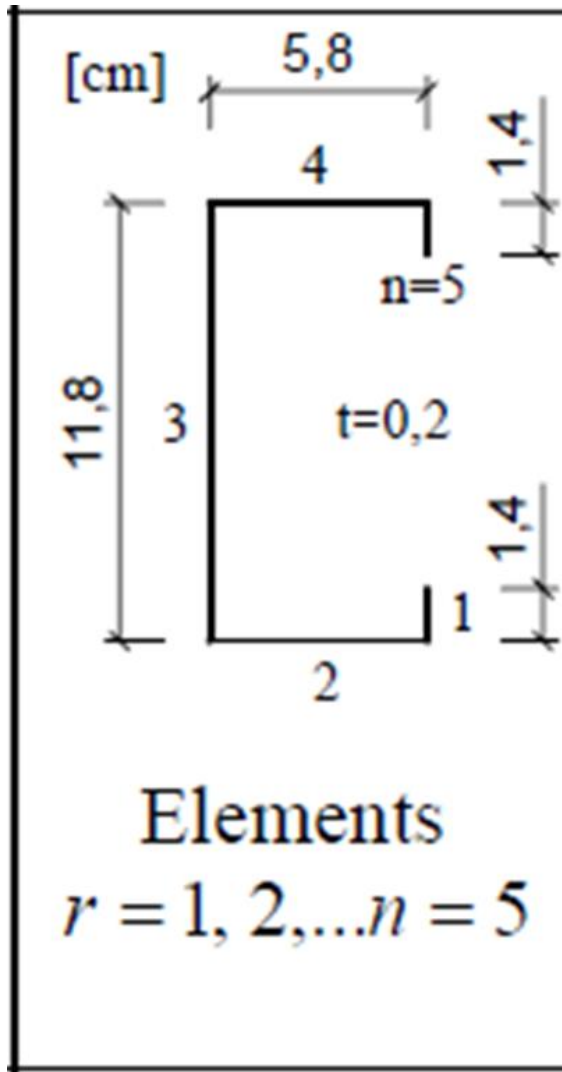
RADA č. 4

- Stiahnite si zadarmo program EBPlate
<https://www.cesdb.com/ebplate.html>
CTICM Paris, France

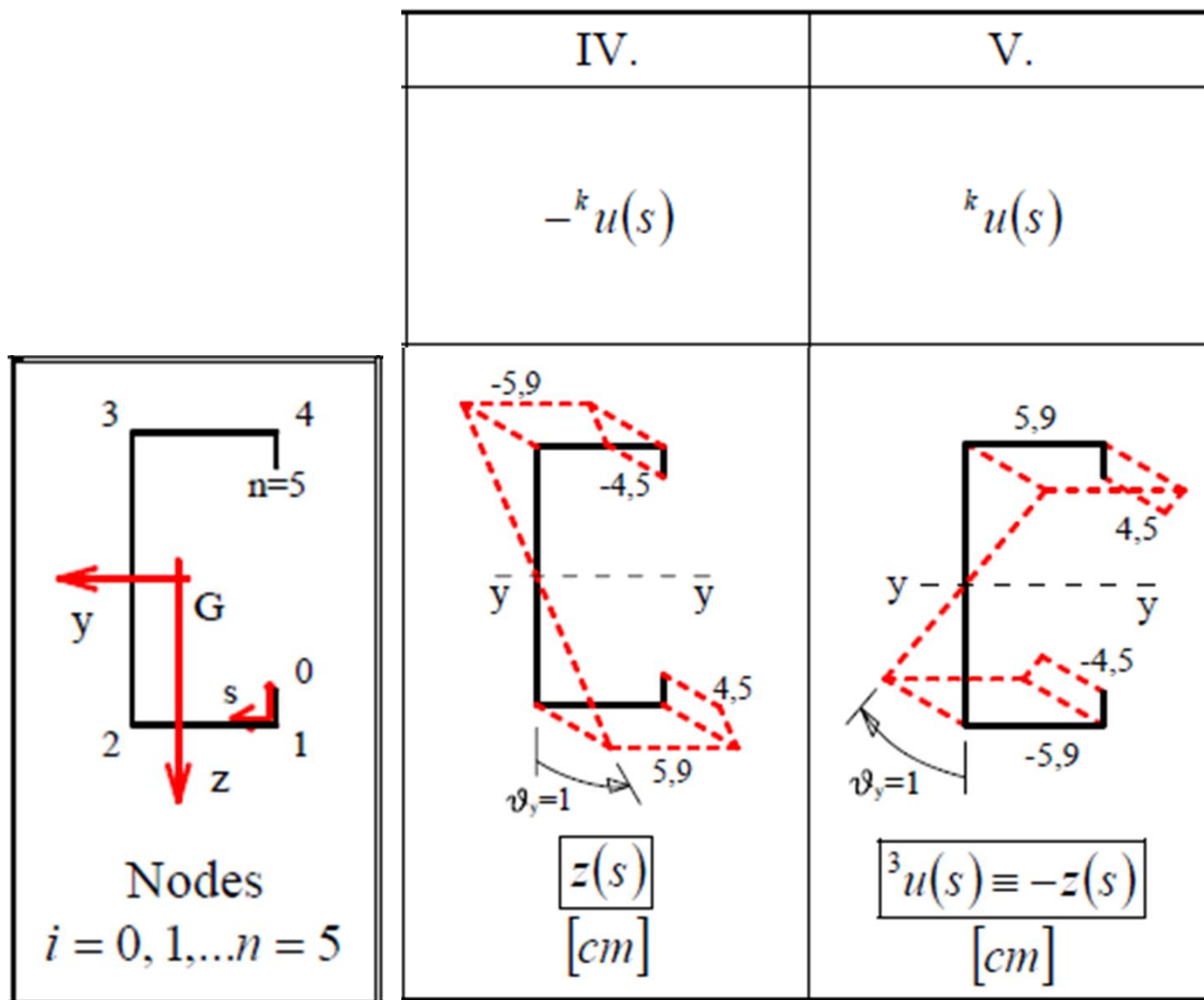
VTB – Verallgemeinerte Biegetheorie (ZOT - Zovšeobecnená ohybová teória)

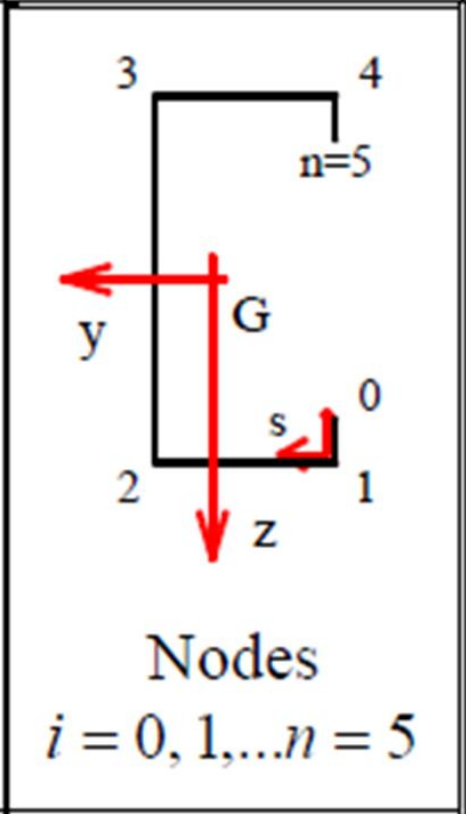
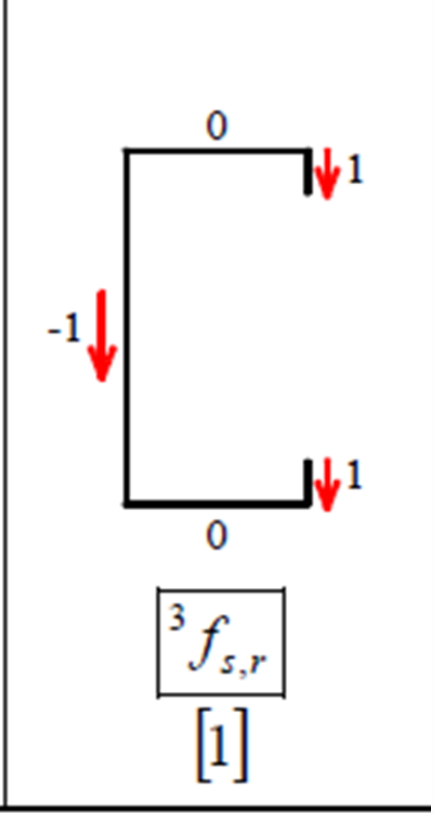
Autor: Prof. Richard Schardt, TU Darmstadt


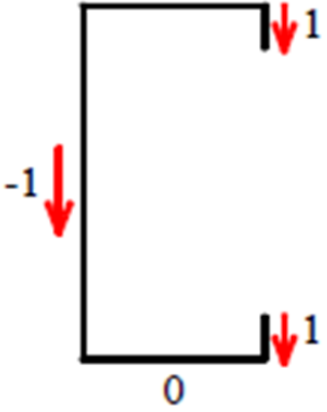
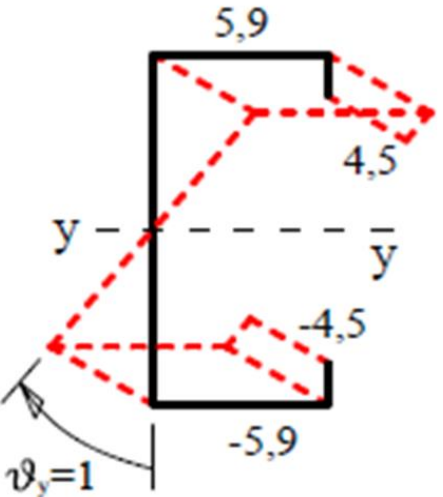
ZÁKLADY GBT

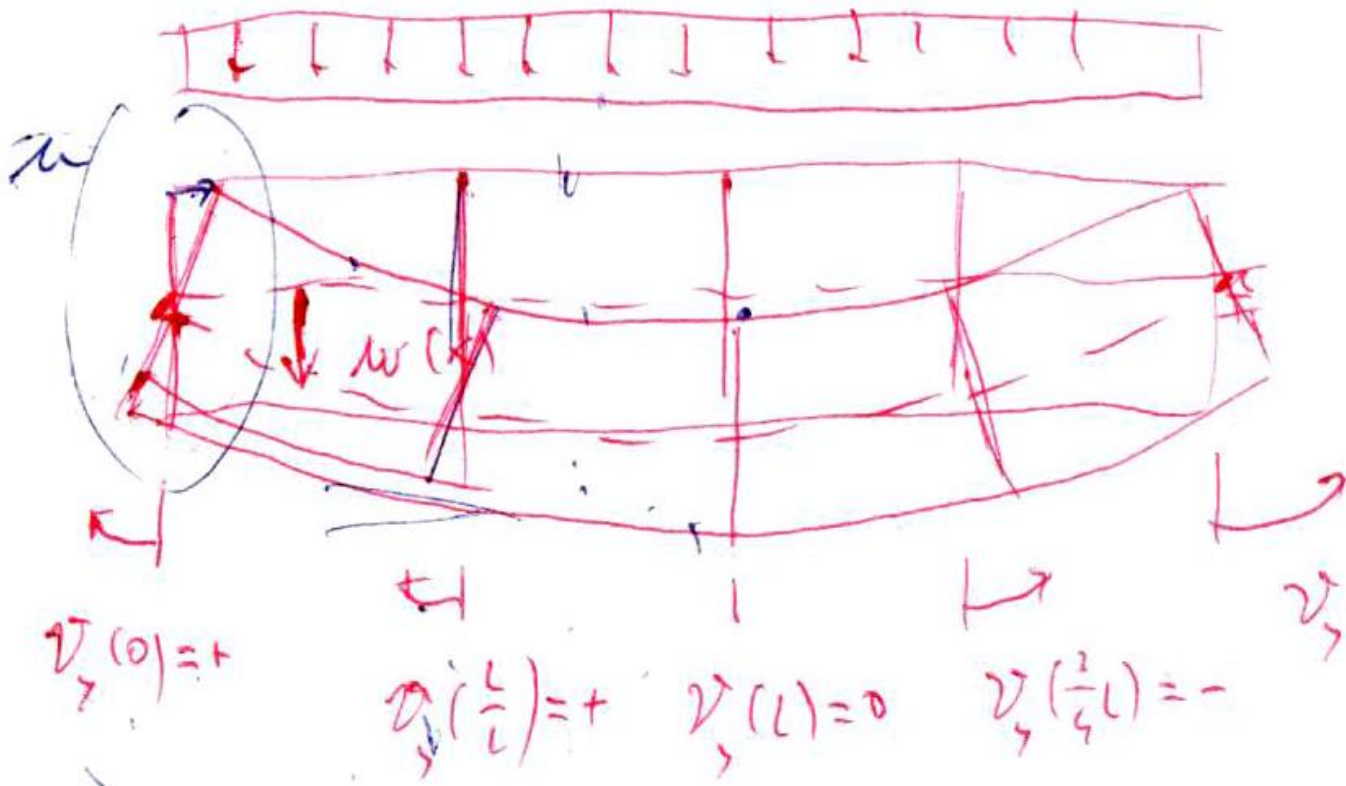


3 OHYB VO ZVISLEJ ROVINE, OKOLO OSI y



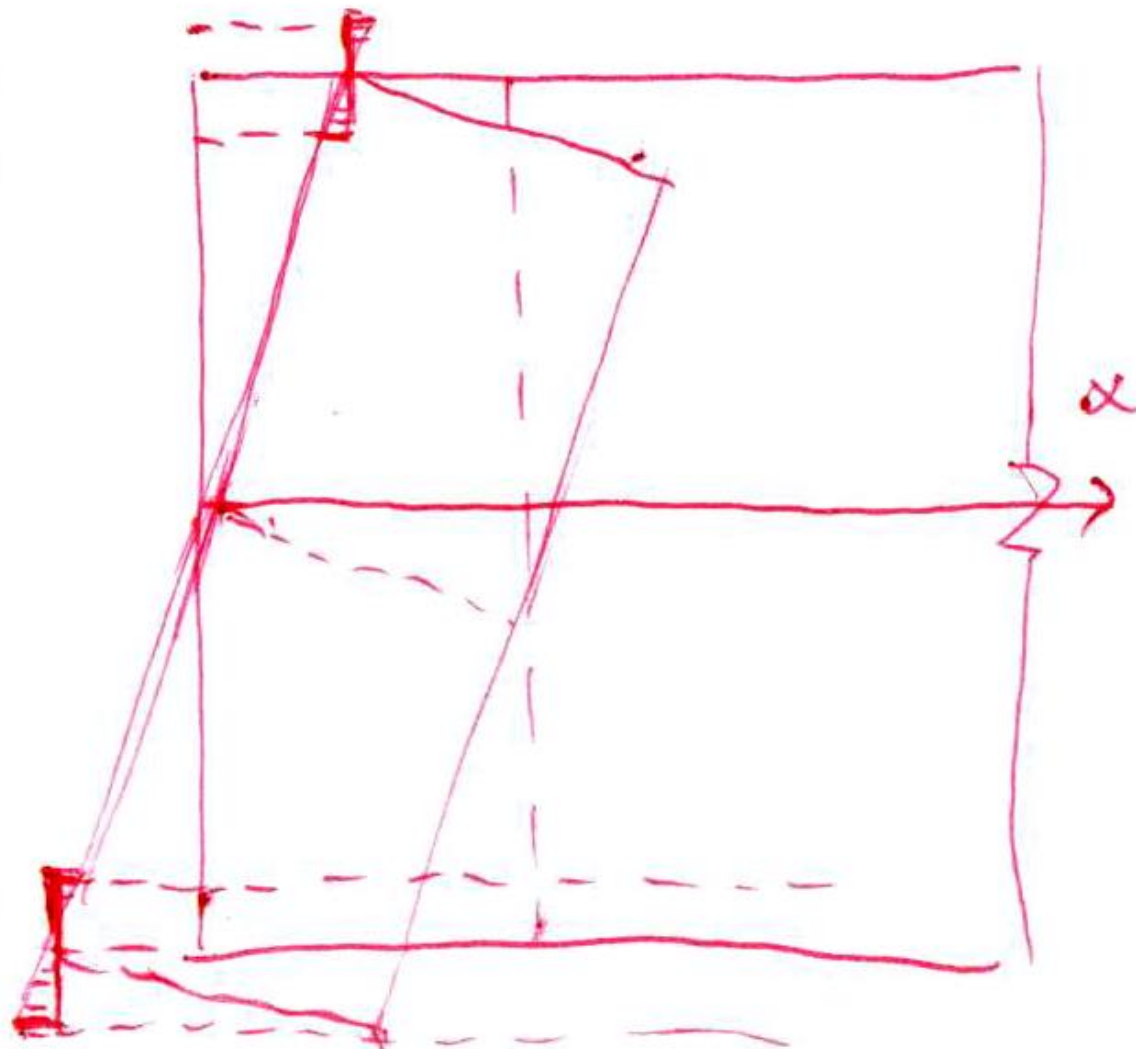
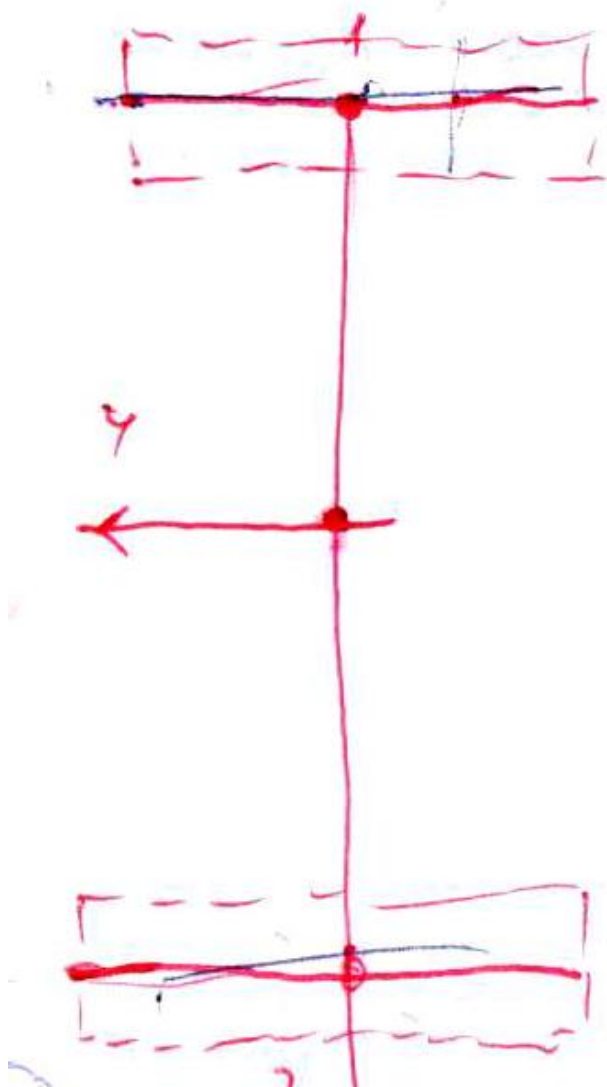
III.	V.
${}^k f_{s,r} =$ $= -\frac{d[{}^k u(s)]}{ds}$	${}^k u(s)$
 <p data-bbox="285 1082 467 1139">Nodes</p> <p data-bbox="185 1162 568 1219">$i = 0, 1, \dots, n = 5$</p>	 <p data-bbox="819 1048 950 1153">${}^3 f_{s,r}$</p> <p data-bbox="853 1162 915 1239">[1]</p> <p data-bbox="1186 1076 1530 1173">${}^3 u(s) \equiv -z(s)$</p> <p data-bbox="1302 1182 1414 1259">[cm]</p>

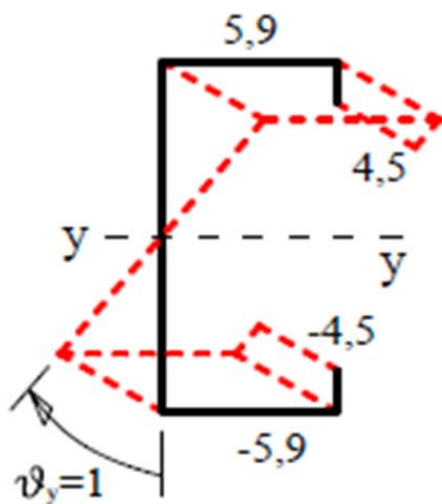
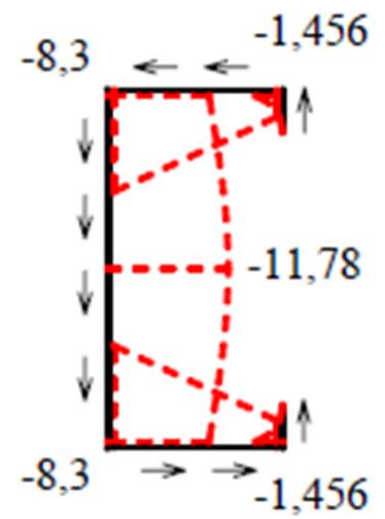
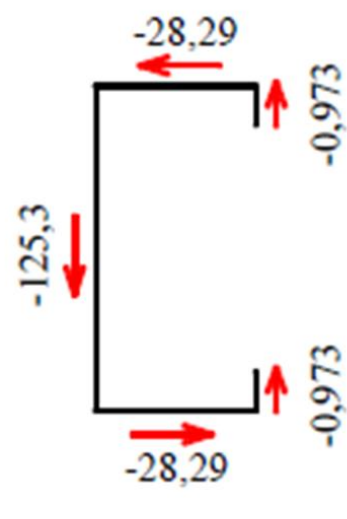
II.	III.	V.
${}^k V^k f_{s,r}; \quad {}^k f_{\vartheta,r}$ $[cm] \quad [rad]$	${}^k f_{s,r} =$ $= -\frac{d[{}^k u(s)]}{ds}$	${}^k u(s)$
${}^3 V \equiv w_z = 1 \quad [cm]$  ${}^3 V^3 f_{s,r}; \quad {}^3 f_{\vartheta,r} = 0$	 <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 0 auto;"> ${}^3 f_{s,r}$ $[1]$ </div>	 <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 0 auto;"> ${}^3 u(s) \equiv -z(s)$ $[cm]$ </div>

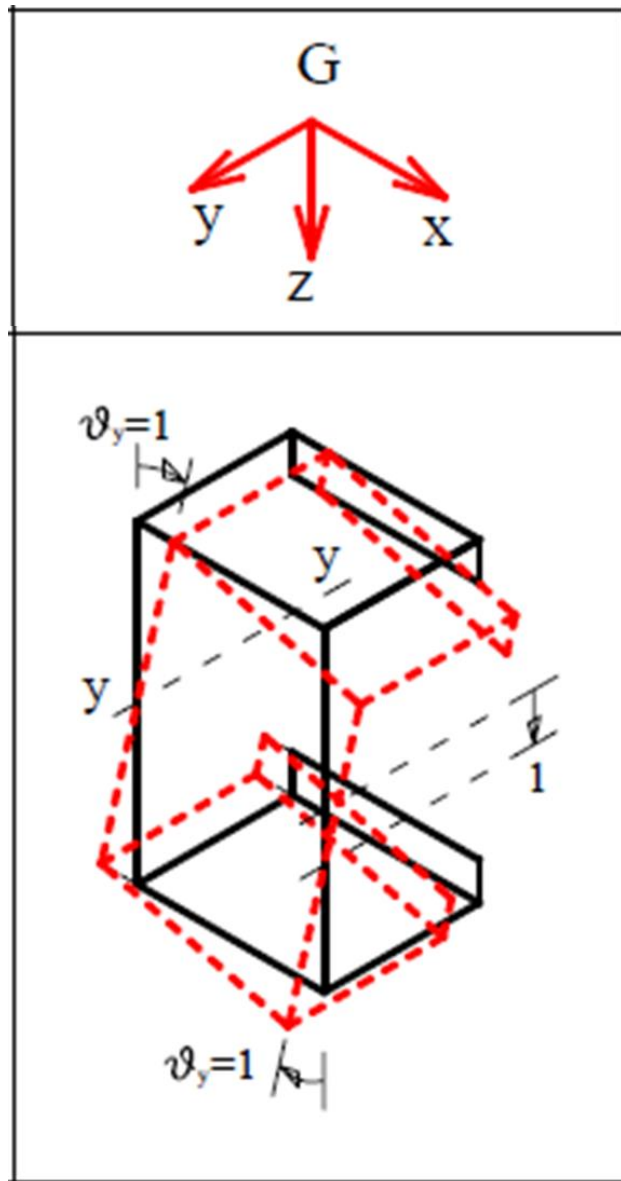


$$v_y'' = w'$$

$$v_y'' = -z$$



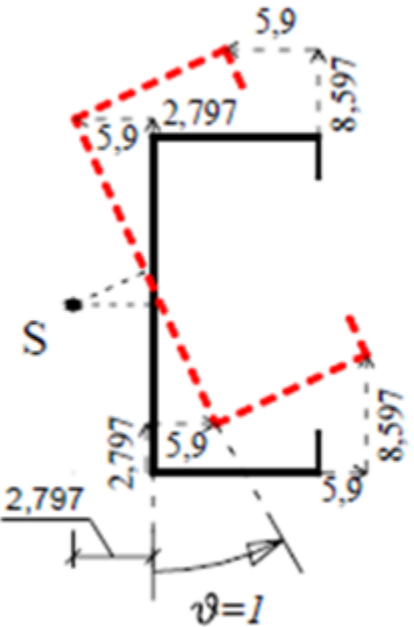
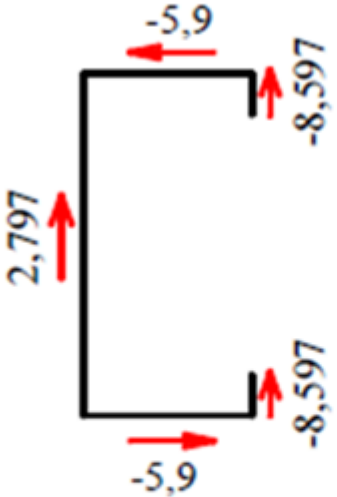
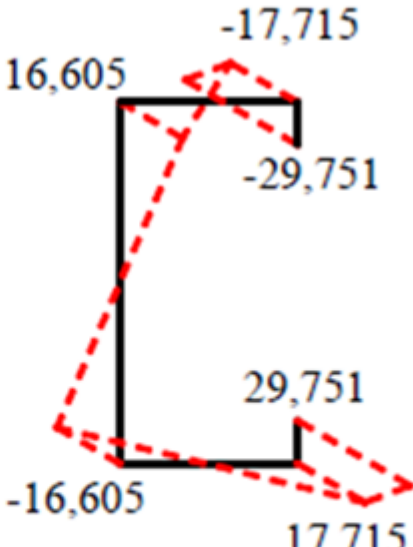
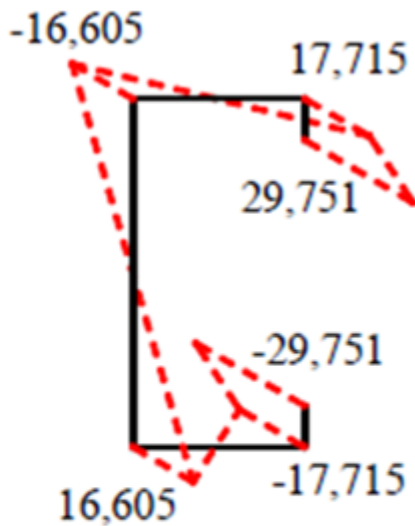
V.	VI.	VII.
${}^k u(s)$	${}^k S(s) = \int_0^n {}^k u(s) t(s) ds$	${}^k Q_r = \int_i^{i+1} {}^k S(s) ds$
 <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> ${}^3 u(s) \equiv -z(s)$ <p style="text-align: center;">[cm]</p> </div>	 <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> ${}^3 S_y(s) \equiv -S_y(s)$ <p style="text-align: center;">[cm³]</p> </div>	 <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> ${}^3 Q_r \equiv -Q_{y,r}$ <p style="text-align: center;">[cm⁴]</p> </div>

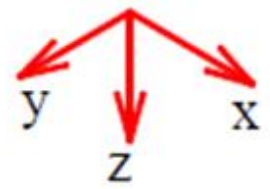
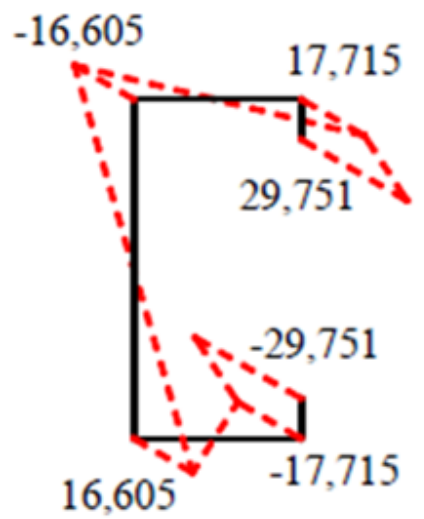
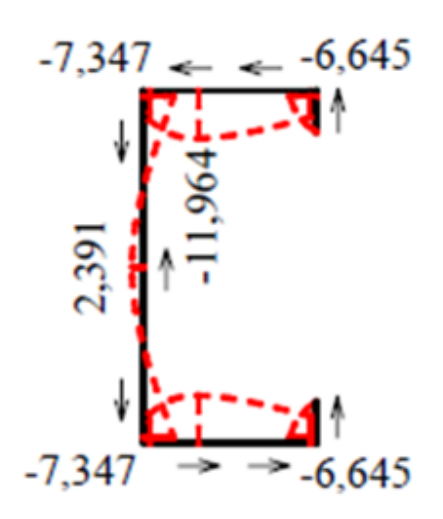
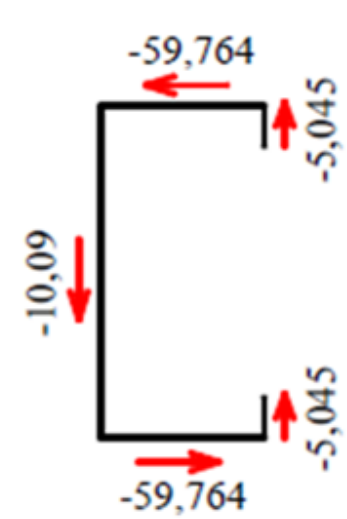
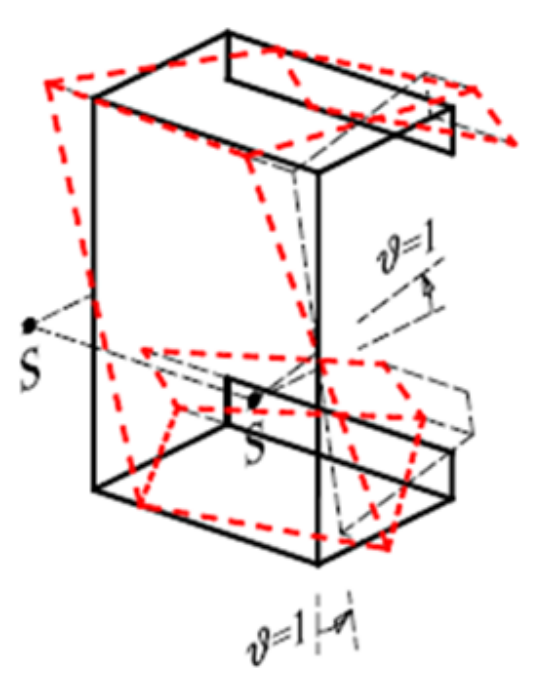


1 OSOVÉ NAMÁHANIE, 2 OHYB VO VODOROVNEJ ROVINE, OKOLO OSI z

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
k	${}^k m_s(s)$ $\left[\frac{kNcm}{cm} \right]$	${}^k V f_{s,r}; {}^k f_{\vartheta,r}$ $[cm] \quad [rad]$	${}^k f_{s,r} =$ $= -\frac{d[{}^k u(s)]}{ds}$	$-{}^k u(s)$	${}^k u(s)$	${}^k S(s) =$ $= \int_0^n {}^k u(s) r(s) ds$	${}^k Q_r =$ $= \int_i^{i+1} {}^k S(s) ds$	
1	<p>Nodes $i = 0, 1, \dots, n = 5$</p>	${}^1 V = 0$ <p>${}^1 V f_{s,r} = 0; {}^1 f_{\vartheta,r} = 0$</p>	<p>${}^1 f_{s,r} = 0$ $[cm^{-1}]$</p>	<p>$[1]$ $[1]$</p>	<p>${}^1 u(s) \equiv -1$ $[1]$</p>	<p>${}^1 S(s)$ $[cm^2]$</p>	<p>${}^1 Q_r$ $[cm^3]$</p>	
2	<p>Elements $r = 1, 2, \dots, n = 5$</p>	${}^2 V \equiv v_y = 1 [cm]$ <p>${}^2 V f_{s,r}; {}^2 f_{\vartheta,r} = 0$</p>	<p>${}^2 f_{s,r}$ $[1]$</p>	<p>${}^2 y(s)$ $[cm]$</p>	<p>${}^2 u(s) \equiv -y(s)$ $[cm]$</p>	<p>${}^2 S_z(s) \equiv -S_z(s)$ $[cm^3]$</p>	<p>${}^2 Q_r \equiv -Q_{z,r}$ $[cm^4]$</p>	

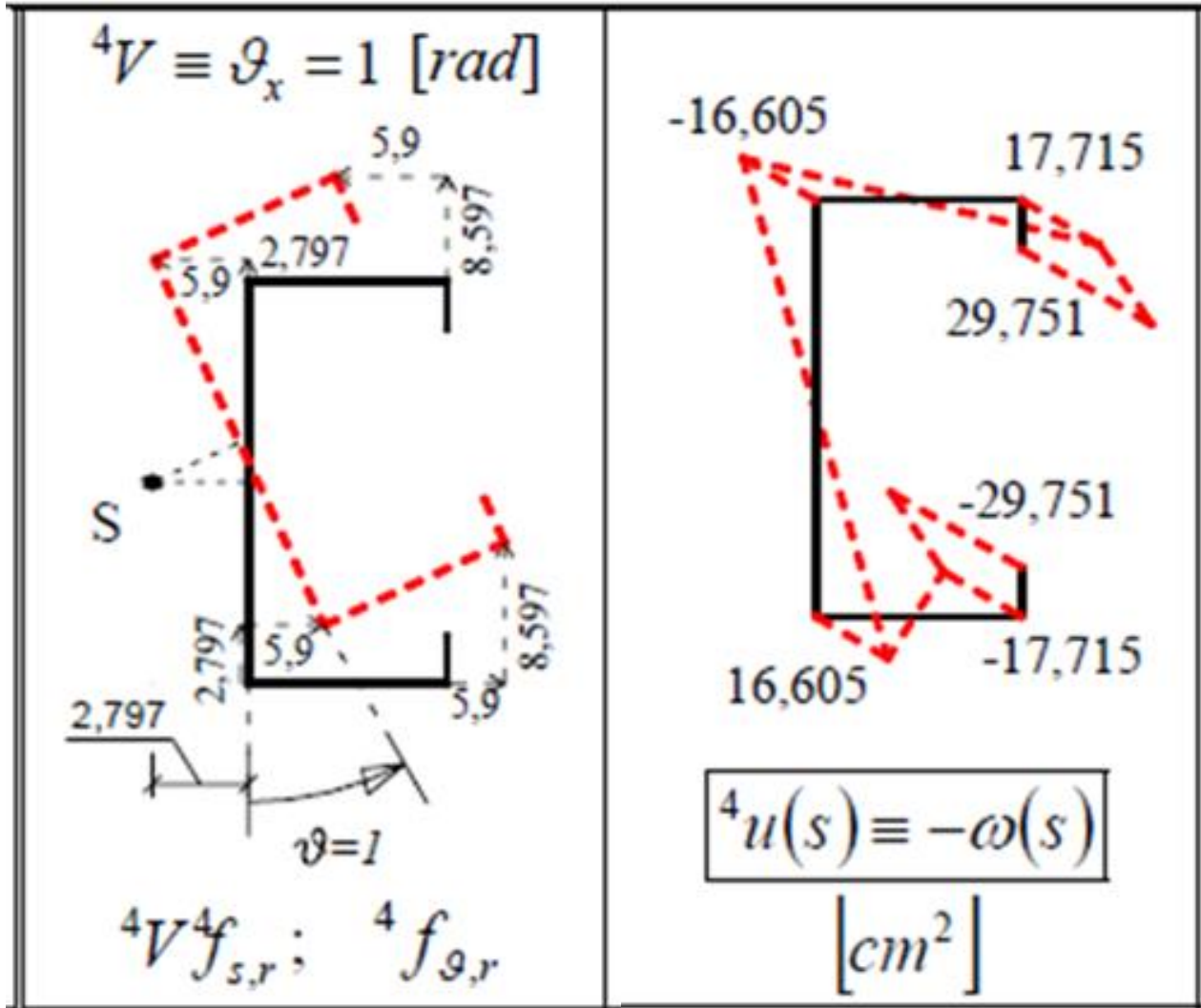
4 KRÚTENIE OKOLO OSI x_+

II.	III.	IV.	V.
${}^k V f_{s,r}; \quad {}^k f_{\vartheta,r}$ $[cm] \quad [rad]$	${}^k f_{s,r} =$ $= -\frac{d[{}^k u(s)]}{ds}$	$-{}^k u(s)$	${}^k u(s)$
${}^* V \equiv \vartheta_x = 1 [rad]$  ${}^4 V f_{s,r}; \quad {}^4 f_{\vartheta,r}$	 ${}^4 f_{s,r}$ $[cm]$	 $\omega(s)$ $[cm^2]$	 ${}^4 u(s) \equiv -\omega(s)$ $[cm^2]$

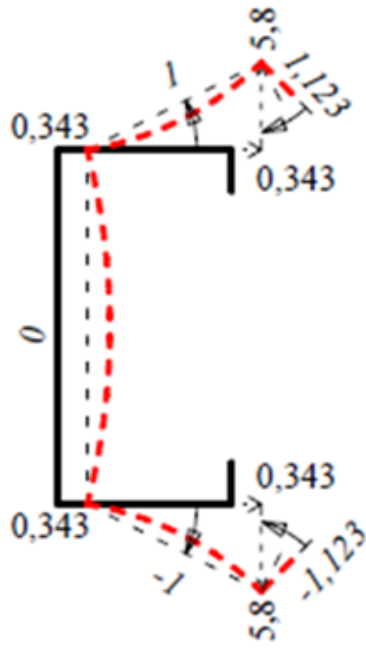
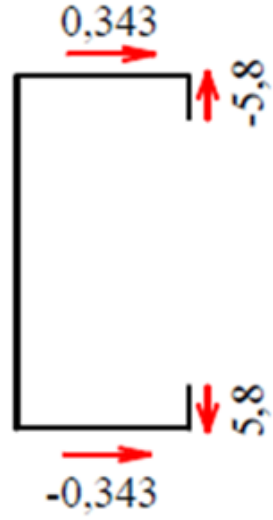
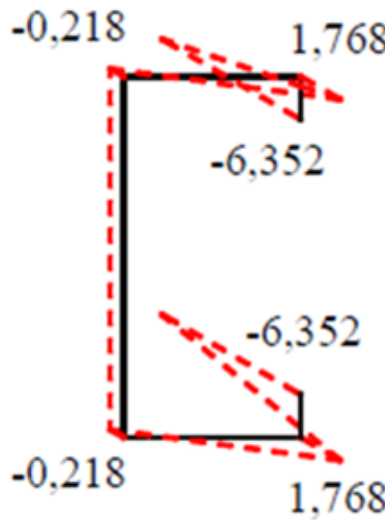
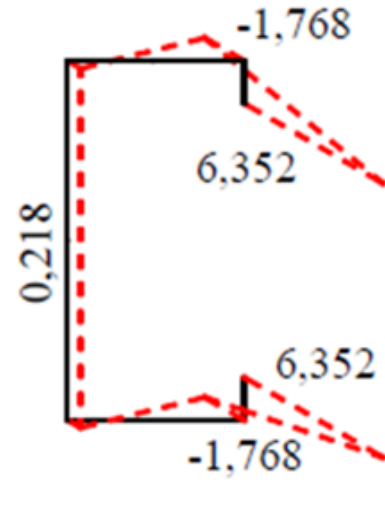
V.	VI.	VII.	VIII.
${}^k u(s)$	${}^k S(s) = \int_0^n {}^k u(s) t(s) ds$	${}^k Q_r = \int_i^{i+1} {}^k S(s) ds$	<p style="text-align: center;">G</p> 
 <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> ${}^4 u(s) \equiv -\omega(s)$ </div> <p style="text-align: center;">$[cm^2]$</p>	 <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> ${}^4 S(s) \equiv -S_\omega(s)$ </div> <p style="text-align: center;">$[cm^4]$</p>	 <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> ${}^4 Q_r \equiv -Q_{\omega,r}$ </div> <p style="text-align: center;">$[cm^5]$</p>	

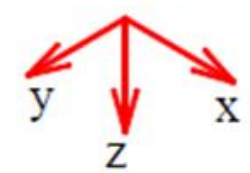
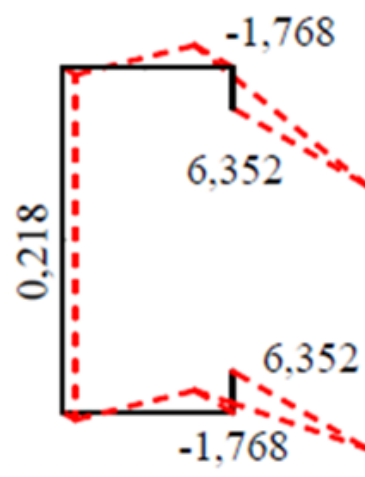
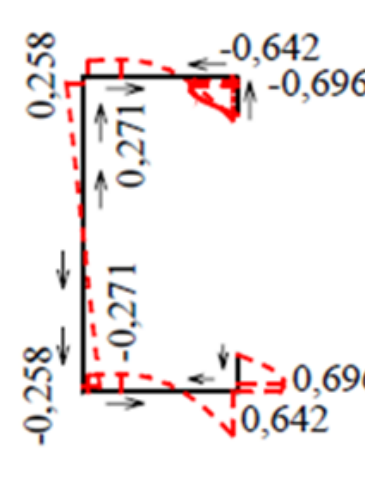
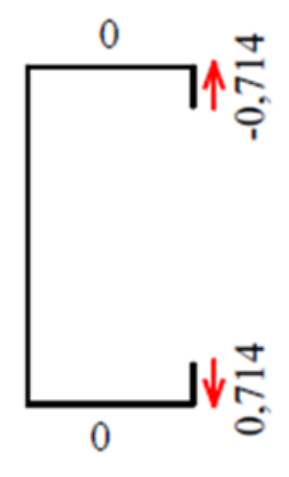
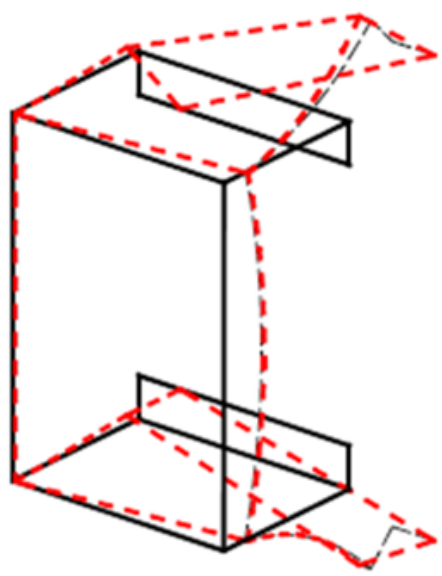
JEDNOTKOVÉ DEFORMÁCIE V: a) V ROVINE, b) Z ROVINY PRIEREZU

Čo je jednotková deplanácia ?

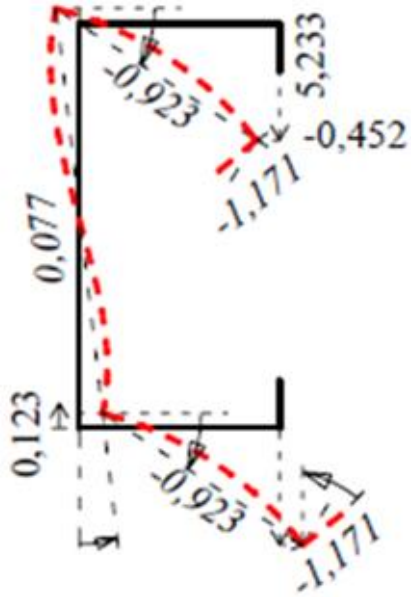
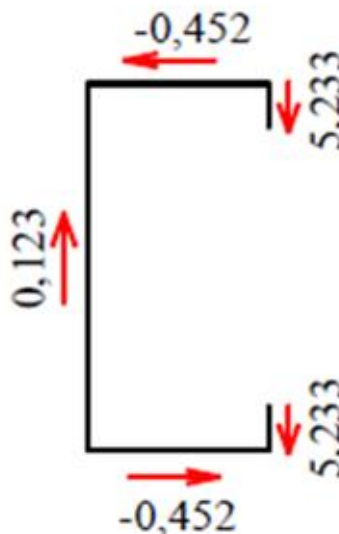
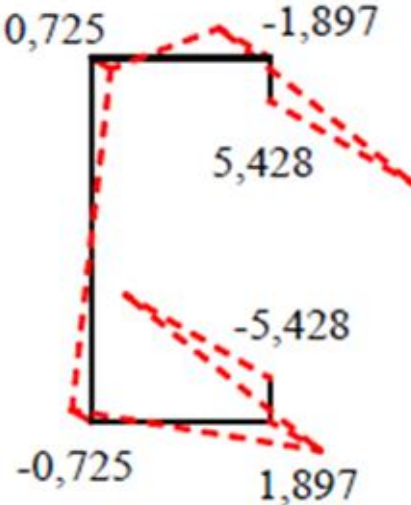
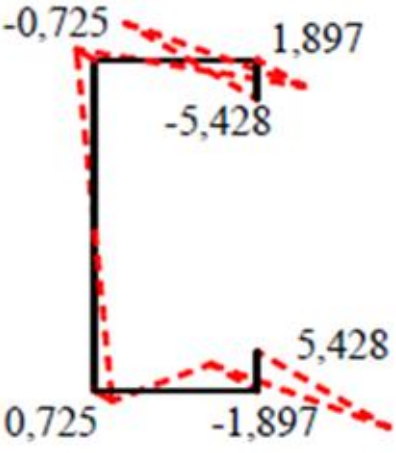


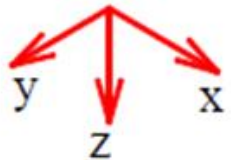
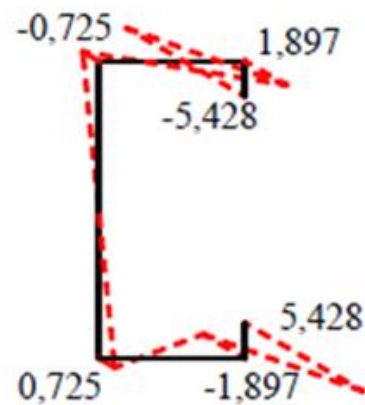
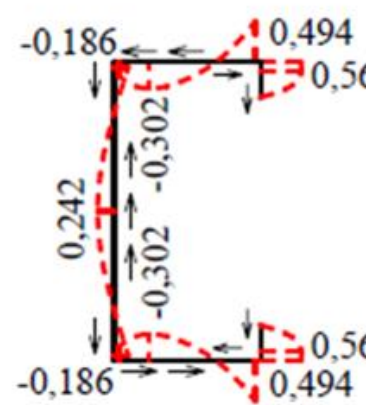
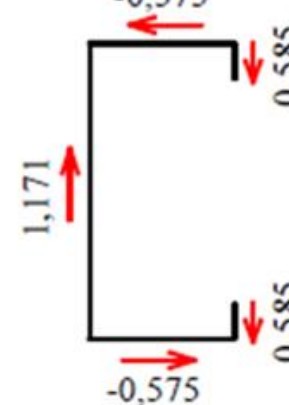
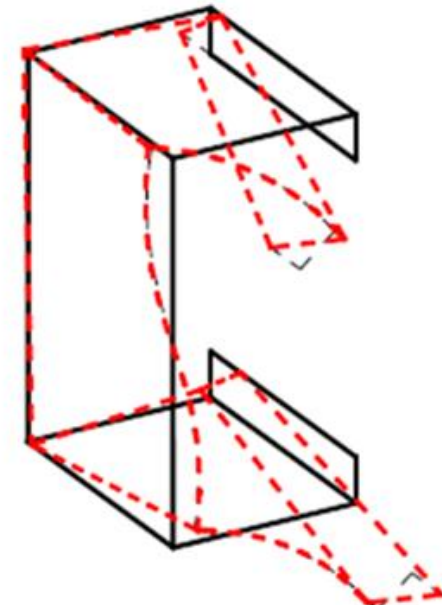
5 DISTORZIA – SYMETRICKÁ ZMENA TVARU

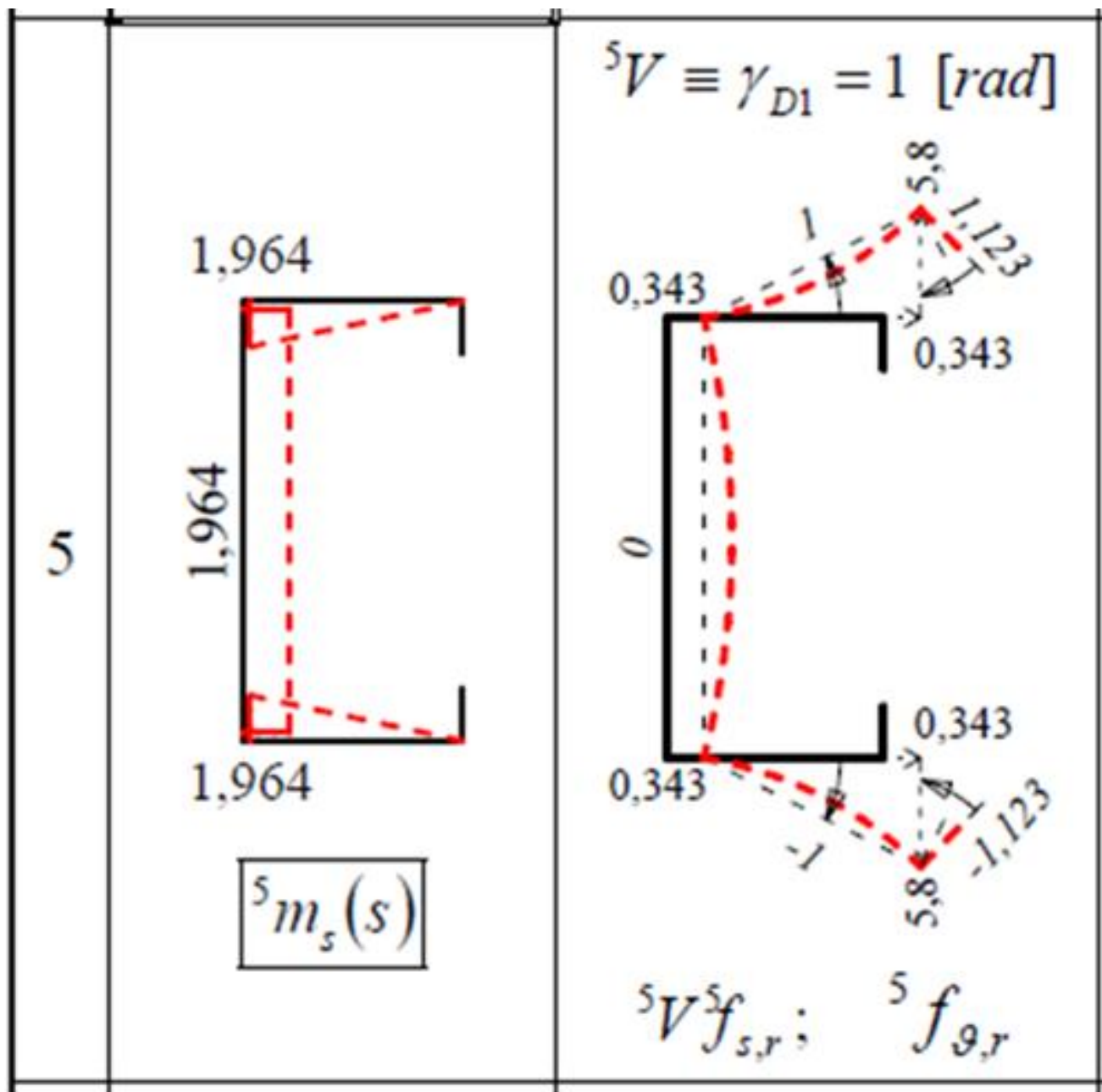
II.	III.	IV.	V.
${}^k V f_{s,r}^k; \quad {}^k f_{\theta,r}$ $[cm] \quad [rad]$	${}^k f_{s,r} =$ $= -\frac{d[{}^k u(s)]}{ds}$	$-{}^k u(s)$	${}^k u(s)$
${}^5 V \equiv \gamma_{D1} = 1 [rad]$  ${}^5 V f_{s,r}^5; \quad {}^5 f_{\theta,r}$	 ${}^5 f_{s,r}$ $[cm]$	 $\omega_{D1}(s)$ $[cm^2]$	 ${}^5 u(s) \equiv -\omega_{D1}(s)$ $[cm^2]$

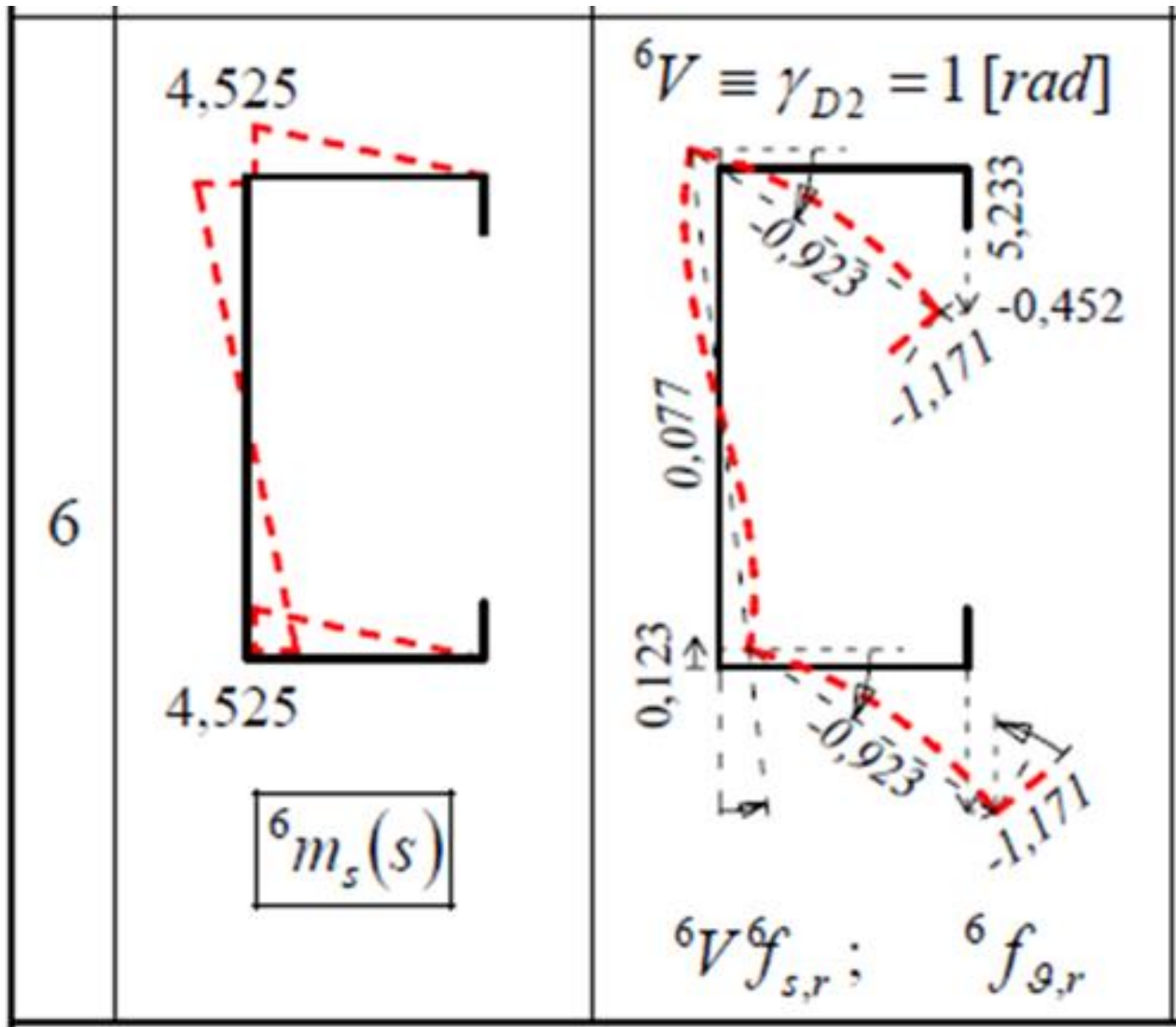
V.	VI.	VII.	VIII.
${}^k u(s)$	${}^k S(s) = \int_0^n {}^k u(s) t(s) ds$	${}^k Q_r = \int_i^{i+1} {}^k S(s) ds$	<p style="text-align: center;">G</p> 
 <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> ${}^5 u(s) \equiv -\omega_{D1}(s)$ $[cm^2]$ </div>	 <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> ${}^5 S(s) \equiv -S_{D1}(s)$ $[cm^4]$ </div>	 <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> ${}^5 Q_r \equiv -Q_{D1,r}$ $[cm^5]$ </div>	

6 DISTORZIA – ANTISYMETRICKÁ ZM. TVARU

II.	III.	IV.	V.
${}^k V f_{s,r} ; \quad {}^k f_{\theta,r}$ $[cm] \quad [rad]$	${}^k f_{s,r} =$ $= -\frac{d[{}^k u(s)]}{ds}$	$-{}^k u(s)$	${}^k u(s)$
${}^6 V \equiv \gamma_{D2} = 1 [rad]$  ${}^6 V f_{s,r} ; \quad {}^6 f_{\theta,r}$	 ${}^6 f_{s,r}$ $[cm]$	 $\omega_{D2}(s)$ $[cm^2]$	 ${}^6 u(s) \equiv -\omega_{D2}(s)$ $[cm^2]$

V.	VI.	VII.	VIII.
${}^k u(s)$	${}^k S(s) = \int_0^n {}^k u(s) t(s) ds$	${}^k Q_r = \int_i^{i+1} {}^k S(s) ds$	<p style="text-align: center;">G</p> 
 <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> ${}^6 u(s) \equiv -\omega_{D2}(s)$ </div> <p style="text-align: center;">$[cm^2]$</p>	 <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> ${}^6 S(s) \equiv -S_{D2}(s)$ </div> <p style="text-align: center;">$[cm^4]$</p>	 <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> ${}^6 Q_r \equiv -Q_{D2,r}$ </div> <p style="text-align: center;">$[cm^5]$</p>	





Prierezové charakteristiky

$${}^k C^M = \int_0^n [{}^k u(s)]^2 ds = = \int_0^n \frac{d[{}^k u(s)]}{ds} {}^k S(s) ds = = \sum_{r=1}^{n=5} \frac{d[{}^k u(s)]}{ds} {}^k Q_r = \sum_{r=1}^{n=5} {}^k f_{s,r} {}^k Q_r$$

Table 2: Cross-sectional properties and stiffnesses of C-profile

k	Mode k	${}^k C$ warping constants	${}^k D$ “torsion” constants	${}^k B$ transverse bending “cross-section frame” stiffnesses
1	Axial (extension in x direction)	$A = 5,24 \text{ cm}^2$	-	-
2	Bending about z	$I_z = 25,861 \text{ cm}^4$	-	-
3	Bending about y	$I_y = 123,377 \text{ cm}^4$	-	-
4	Torsion about x	$I_w = 763.764 \text{ cm}^6$	$I_t = 0,069867 \text{ cm}^4$	-
5	Distortion $D1$ (symmetrical)	$I_{w,D1} = 8.287 \text{ cm}^6$	$I_{t,D1} = 0,04 \text{ cm}^4$	$EI_{R,D1} = 3,928 \frac{\text{kN.cm}}{\text{cm}}$
6	Distortion $D2$ (antisymmetrical)	$I_{w,D2} = 6.79 \text{ cm}^6$	$I_{t,D2} = 0,03 \text{ cm}^4$	$EI_{R,D2} = 7,89 \frac{\text{kN.cm}}{\text{cm}}$

RADA č. 5

- Kúpte si Dlubalov program:

DUENQ – nemecký názov,

SHAPE – anglický názov.

Vypočíta Vám súradnicové funkcie:

1 , $y(s)$, $z(s)$, $\omega(s)$, (nie distorziu !) a ich integrály – statické momenty.

Mám vlastný program SEKTOR, ktorý spočíta aj distorziu uzavretých prierezov a ďalší program aj distorziu otvorených prierezov.

2.2 Z-profile

$$h = 11.8\text{cm}; \quad b = 5.8\text{cm}; \quad c = 1.4\text{cm}; \quad t = 0.2\text{cm};$$

$$\alpha = \frac{c}{h} = 0.119; \quad \beta = \frac{b}{h} = 0.492; \quad \delta = \frac{t}{h} = 0.016949;$$

$$D_5 = 4\alpha^4 + 8\alpha^3 + 12\alpha^2 + 6\alpha + 16\alpha^3\beta + 12\alpha^2\beta + 4\alpha\beta + \beta^2 + 2\beta = 14.326;$$

$$D_6 = 12\alpha^4 + 6\alpha + 16\alpha^3\beta + 12\alpha^2\beta + 12\alpha\beta + 3\beta^2 + 2 \cdot \beta = 25.749;$$

$${}^5u(0) = {}^5u(5) = \frac{\alpha\beta(-2\alpha^2 - 3\alpha - 2\alpha^2\beta - 2\alpha\beta - \beta^2 - 2\beta)}{D_5} h^2 = 11.840\text{cm}^2;$$

$${}^5u(1) = {}^5u(4) = \frac{\alpha^2\beta(-4\alpha - 4\alpha\beta - 2\beta - 3)}{D_5} h^2 = 2.783\text{cm}^2;$$

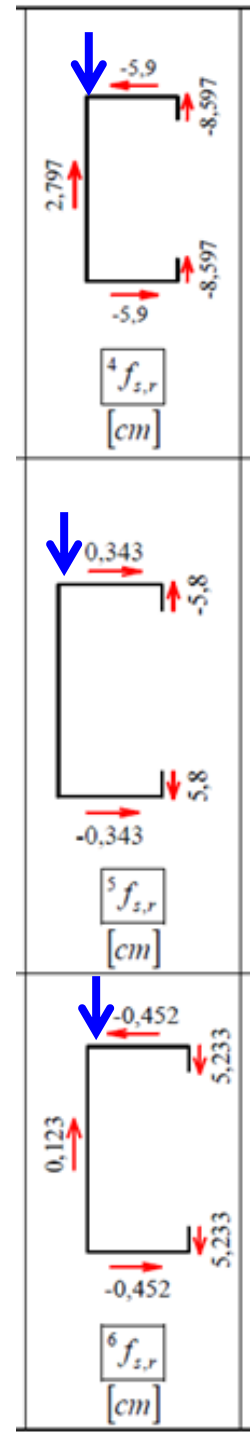
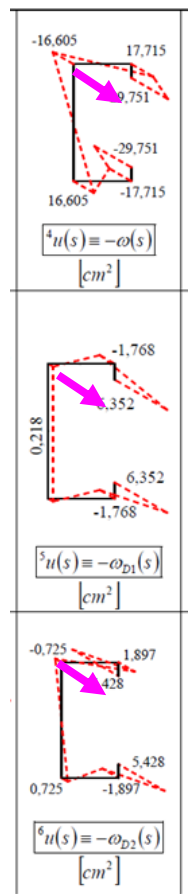
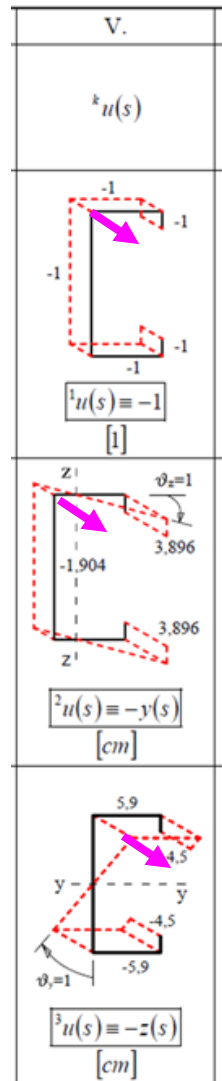
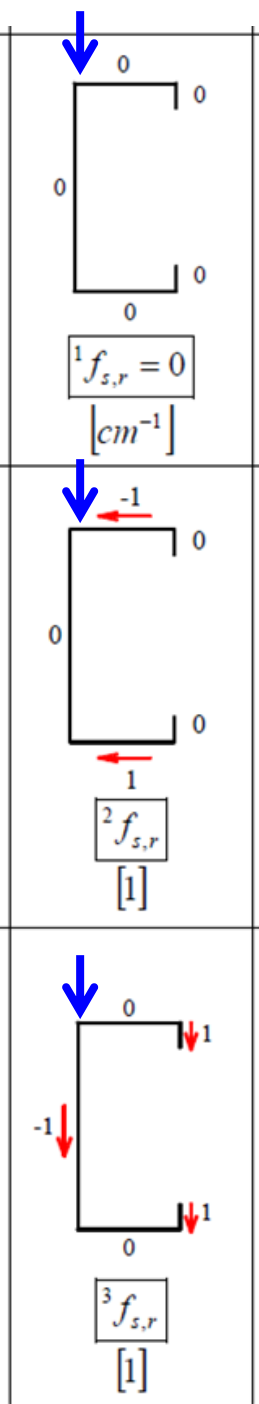
$${}^5u(2) = {}^5u(3) = \frac{\alpha^2\beta(-2\alpha^2 - 4\alpha\beta - \beta)}{D_5} h^2 = 1.145\text{cm}^2;$$

$${}^6u(0) = - {}^6u(5) = \frac{\alpha\beta(-3\alpha - 2\alpha^2\beta - 6\alpha\beta - 2\beta - 3\beta^2)}{D_6} h^2 = 13.085\text{cm}^2;$$

$${}^6u(1) = - {}^6u(4) = \frac{\alpha^2\beta(-4\alpha\beta - 6\beta - 3)}{D_6} \cdot h^2 = -2.659\text{cm}^2;$$

$${}^6u(2) = - {}^6u(3) = \frac{\alpha^2\beta(-6\alpha^2 - 8\alpha\beta - 3\beta)}{D_6} \cdot h^2 = 1.608\text{cm}^2$$

ZLOŽKY ZAŤAŽENIA



van Baláž PhD
| v Blave

SKSI, B. Bystrica, 9:05-11:15,
25.4.2017

VÝPOČET VNÚTORNÝCH SÍL

- Veľmi ľahko hocijakým programom, ktorý dokáže spočítať vnútorné sily ohýbaných nosníkov.
- Na základe analógie dokážete vypočítať všetky vnútorné sily:
 - krútenia (viazaného, voľného)
 - symetrickej a antisymetrickej distorzie – zmeny tvaru prierezu

Ja používam program IQ 100.

Mixed Torsion

$$EI_{\omega} \vartheta^{IV}(x) - GI_t \vartheta^{II}(x) = t_t(x)$$

Warping Torsion

$$EI_{\omega} \vartheta^{IV}(x) = t_t(x)$$

$$kL = \frac{L}{L_{\omega t}} = \sqrt{\frac{GI_t}{EI_{\omega}}} L = 0$$

Bending-Torsion Parameter

$$GI_t = 0 \text{ [kNm]}$$

$$L_{\omega t} = \sqrt{\frac{EI_{\omega}}{GI_t}} = \infty$$

Warping Torsion

$$EI_{\omega} \vartheta^{IV}(x) = t_t(x)$$

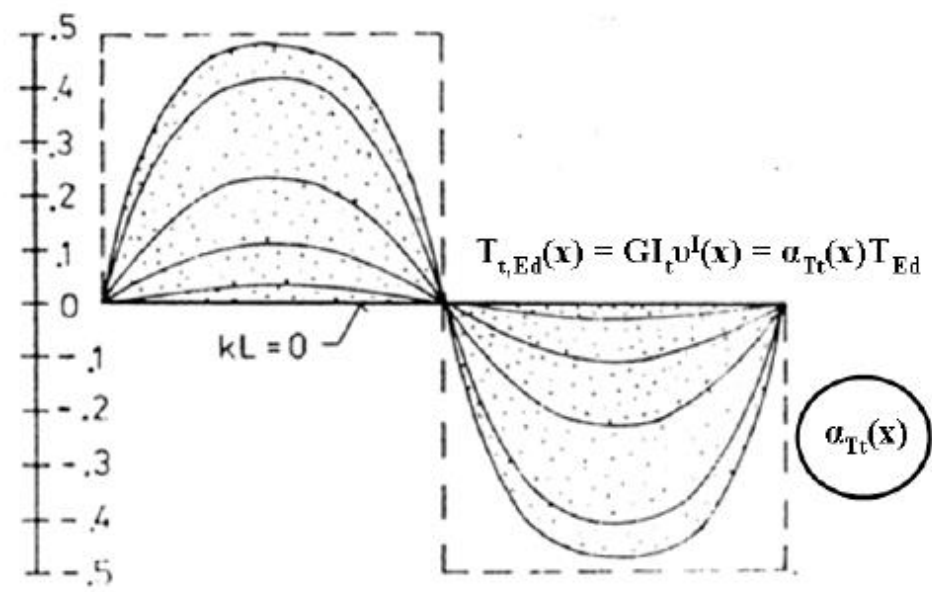
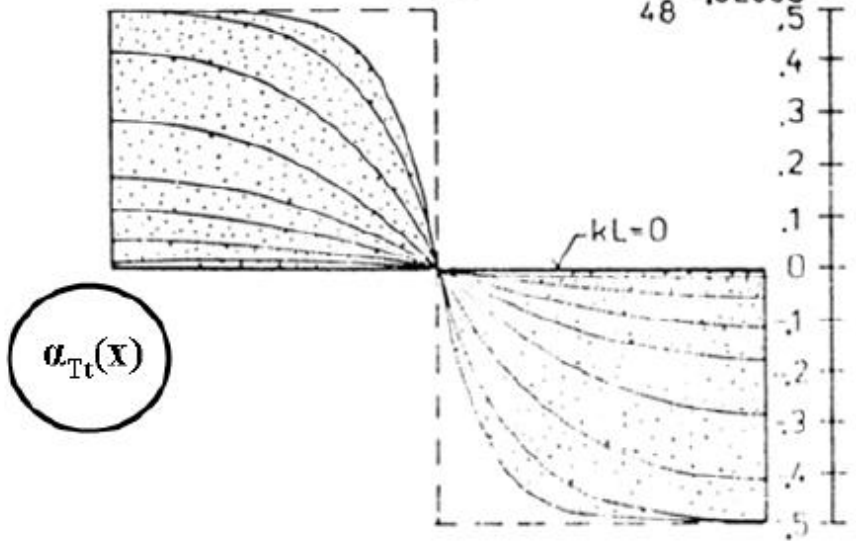
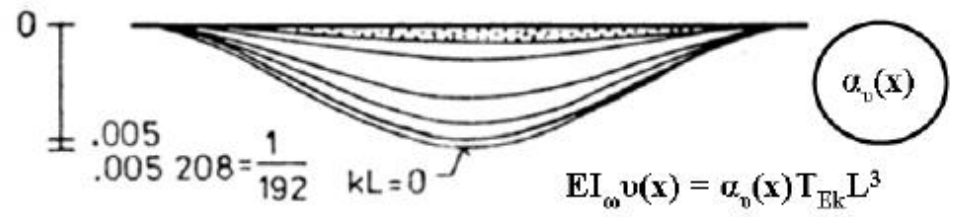
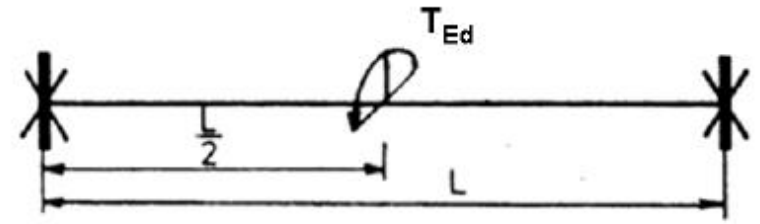
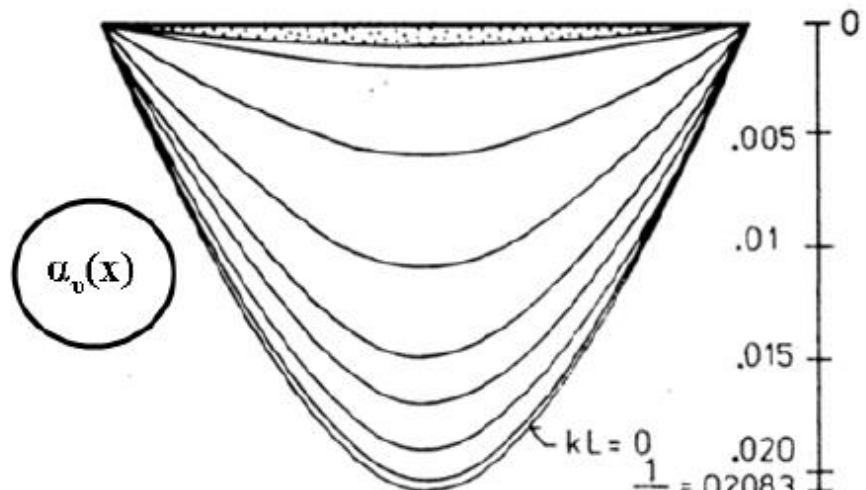
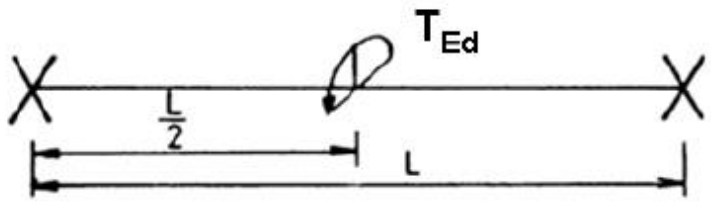
$$kL = \frac{L}{L_{\omega t}} = \sqrt{\frac{GI_t}{EI_{\omega}}} L = 0 \quad GI_t = 0 \quad [\text{kNm}] \quad L_{\omega t} = \sqrt{\frac{EI_{\omega}}{GI_t}} = \infty$$

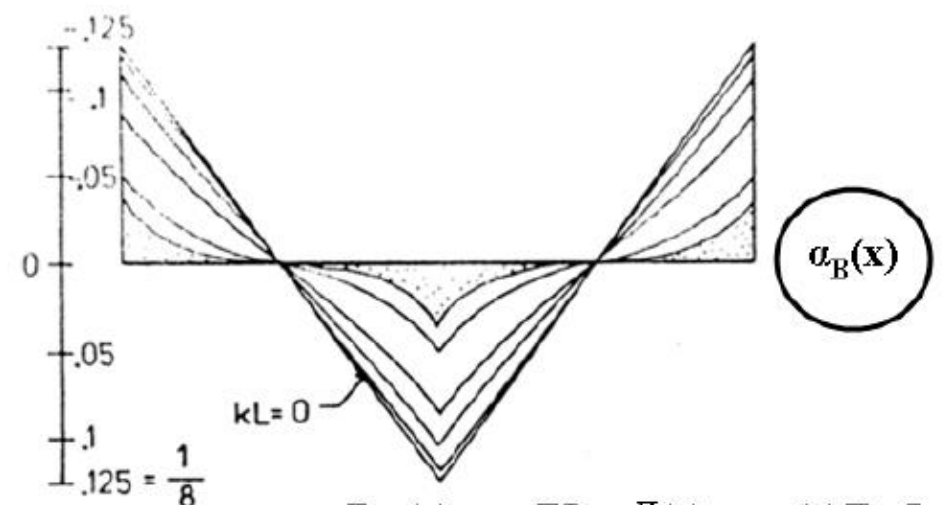
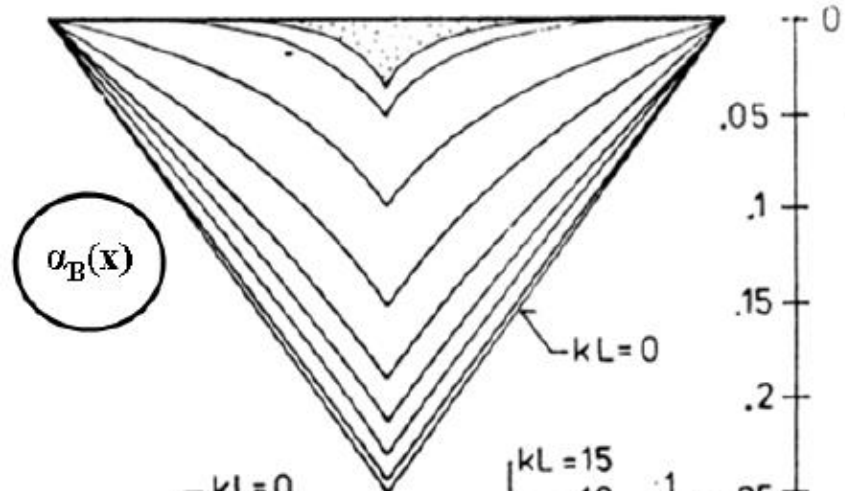
$$kL \leq 0.5 \quad \text{or} \quad L_{\omega t} \geq 2L$$

$$kL \leq 0.75 \quad \text{or} \quad L_{\omega t} \geq 1.33L$$

$$kL \leq 1.25 \quad \text{or} \quad L_{\omega t} \geq 0.8L$$

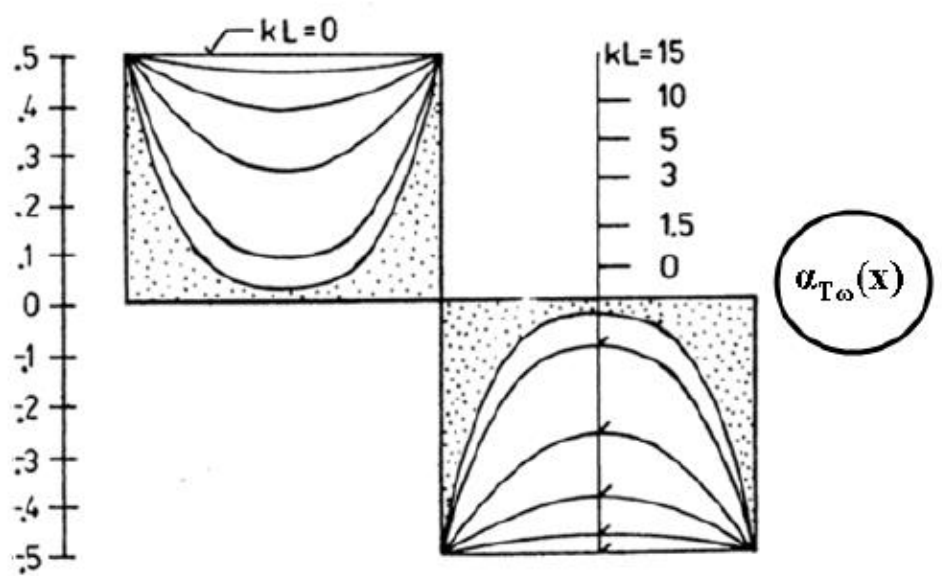
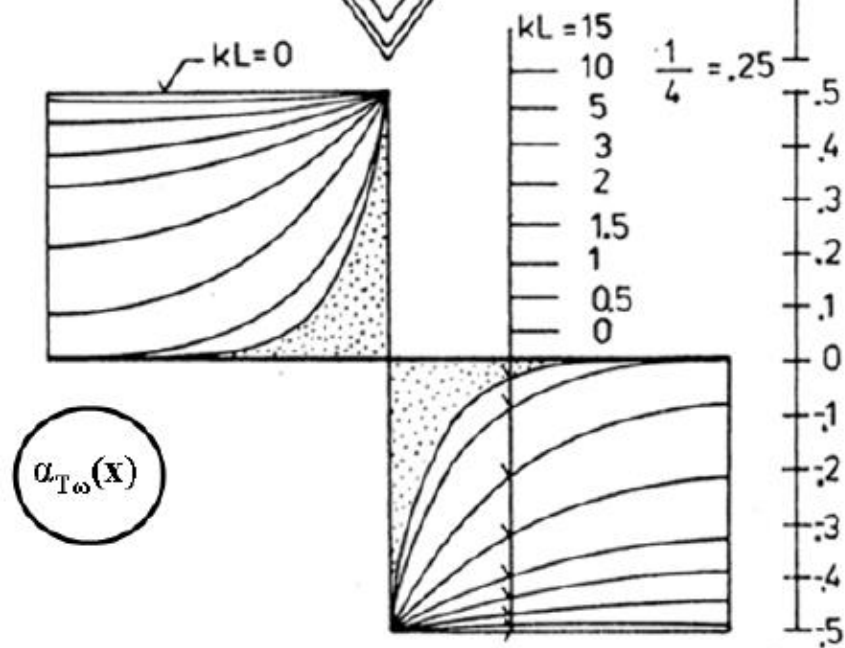
$$kL \leq 1.5 \quad \text{or} \quad L_{\omega t} \geq 0.67L$$



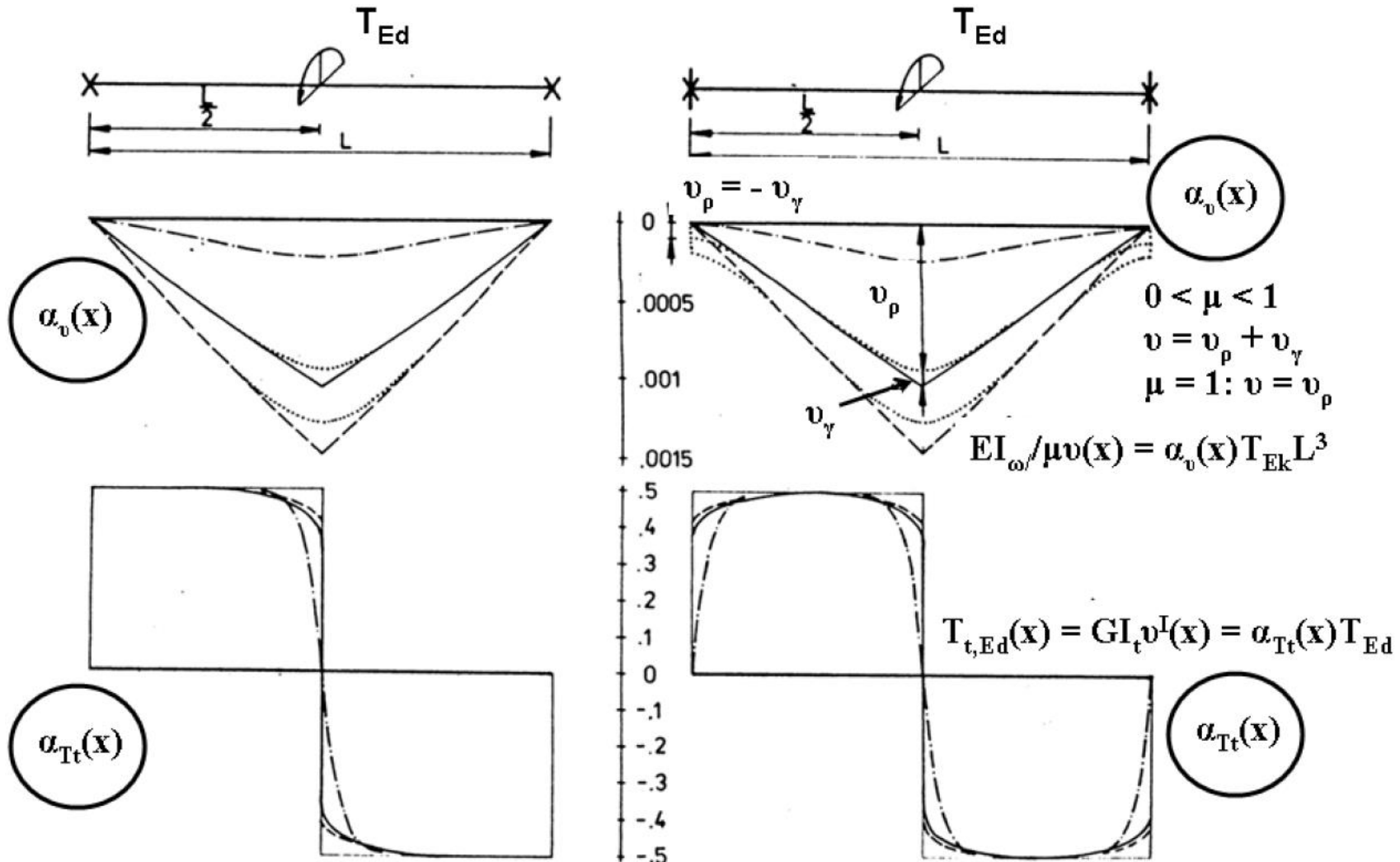


$$B_{Ed}(x) = -EI_{\omega} v_p^{II}(x) = \alpha_B(x) T_{Ed} L$$

$$T_{\omega, Ed}(x) = -EI_{\omega} v_p^{III}(x) = \alpha_{T\omega}(x) T_{Ed} L$$

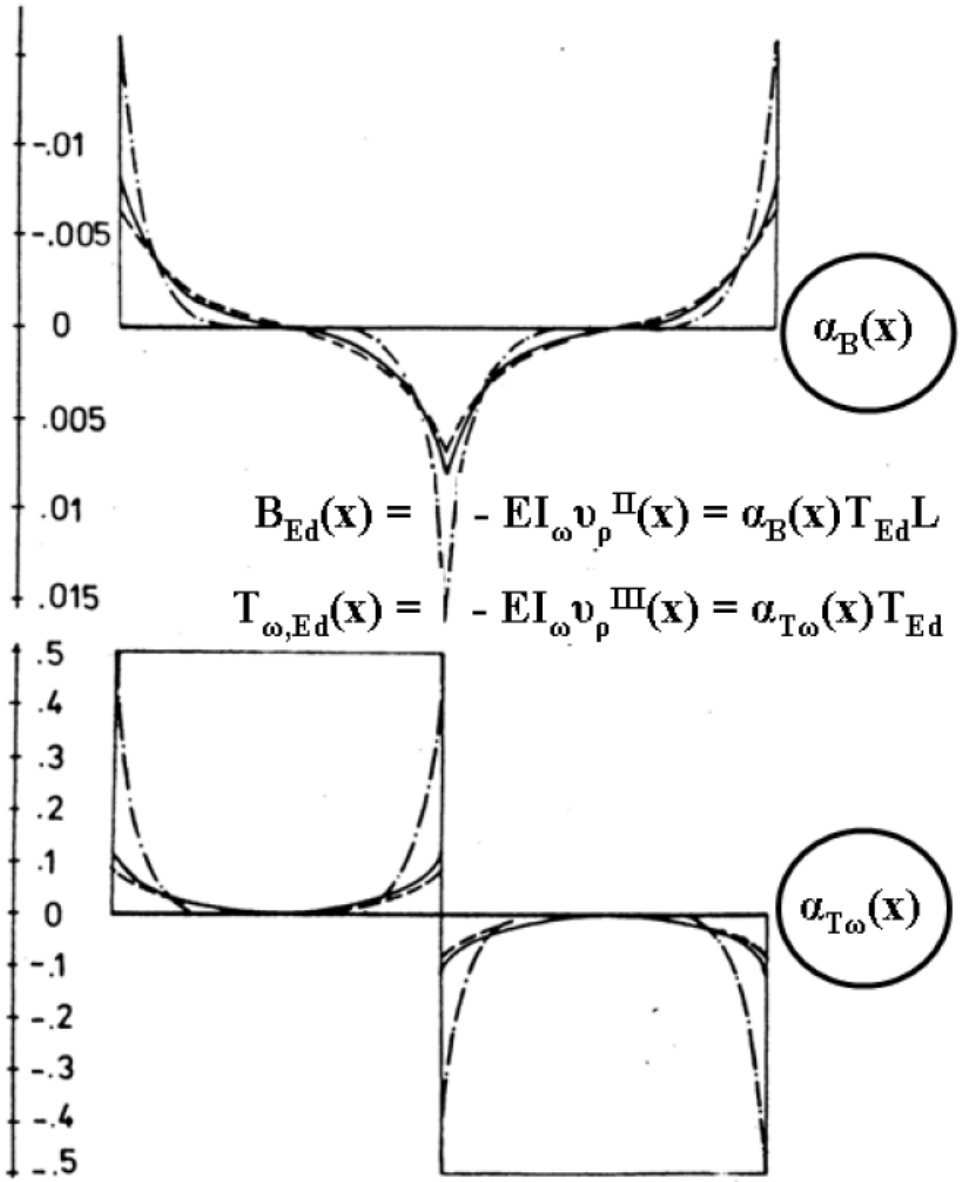
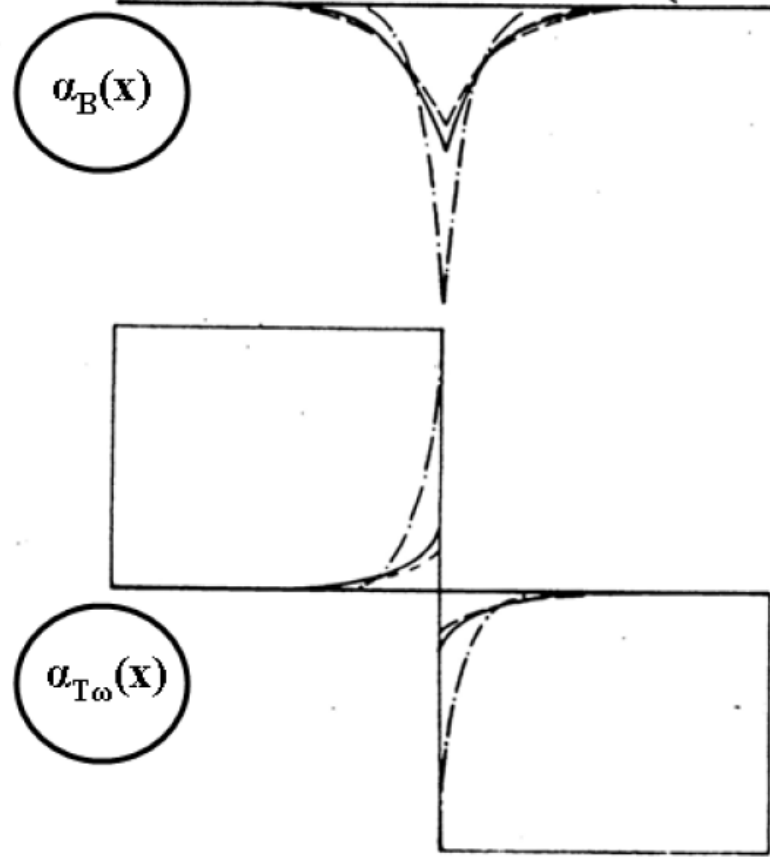


Mixed Torsion



Influence of shear taken into account:

No	-----	$\mu=1$	$kL_v = 30.605$	According to: UMANSKIJ BENSCOTER HEILIG DŽANELIDZE PANOVKO
Yes	—————	$\mu=0.2418$	$kL_v = 15.05$	
Yes	- - - - -	$\mu=0.173$	$kL_v = 12.73$	



$$\sigma_i = \sum_{r=1}^{n=5} {}^k \sigma_i = \sum_{r=1}^{n=5} -\frac{{}^k W}{{}^k C} {}^k u_i$$

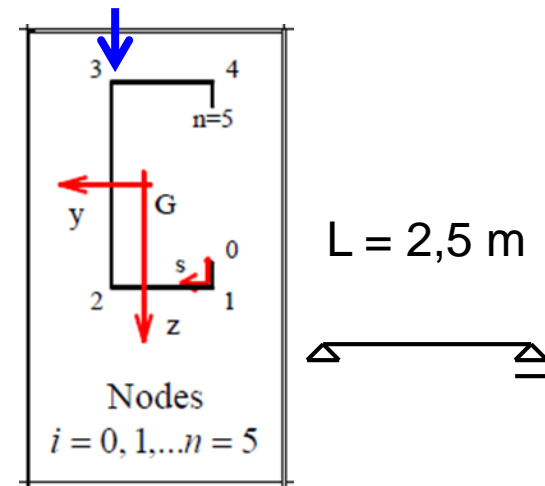
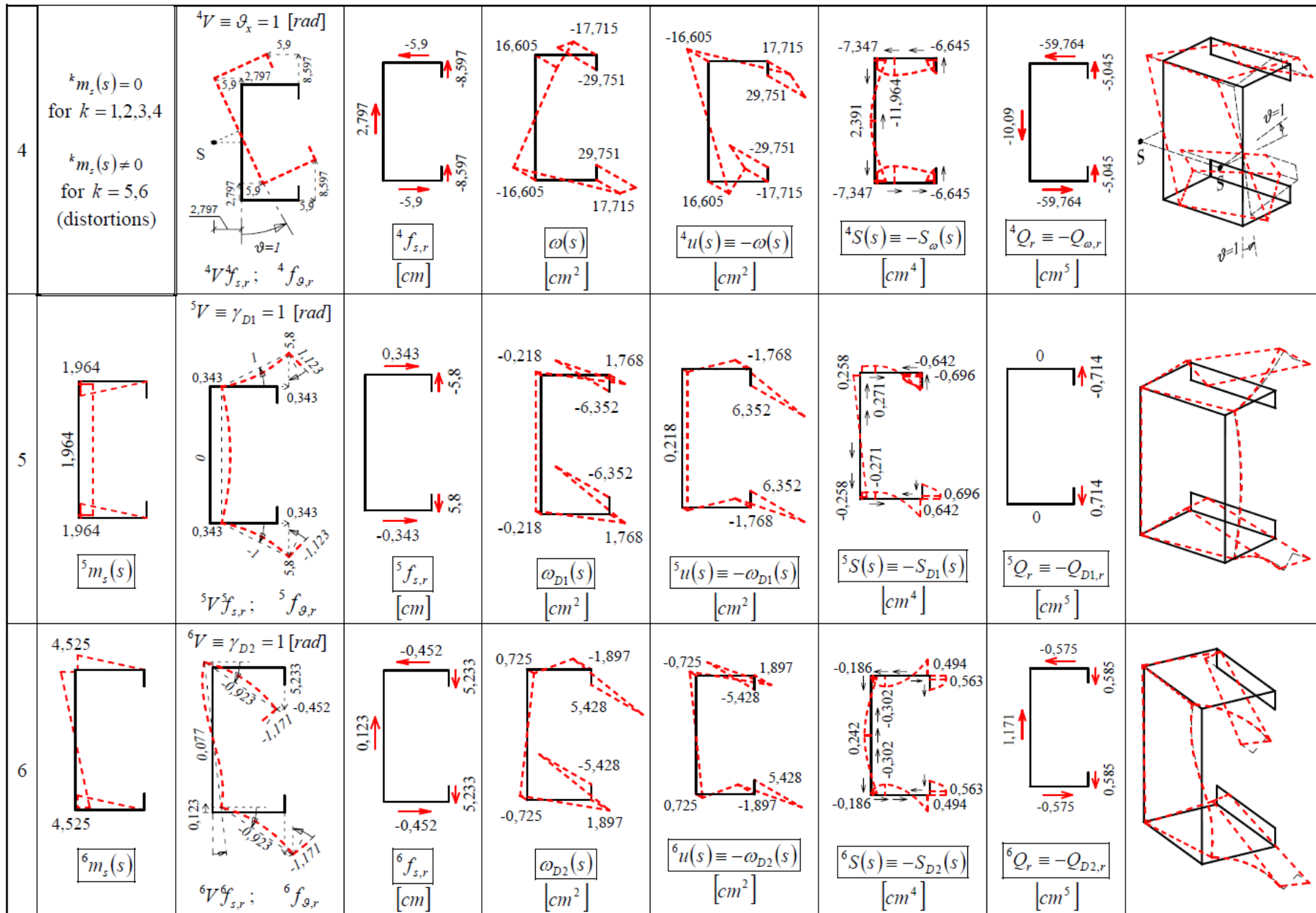


Table 3: Longitudinal stresses σ_i [MPa] in midspan

Modes k	Nodes i					
	0	1	2	3	4	5
${}^1 \sigma_i$	0	0	0	0	0	0
${}^2 \sigma_i$	0	0	0	0	0	0
${}^3 \sigma_i$	56,99	74,72	74,72	-74,72	-74,72	-56,99
${}^4 \sigma_i$	-138,327	-82,364	76,739	-76,739	82,364	138,327
${}^5 \sigma_i$	0	0	0	0	0	0
${}^6 \sigma_i$	0,000549	-0,000192	0,000073	-0,000073	0,000192	0,000549
$\sum_{r=1}^{n=5} {}^k \sigma_i$	-81,336	-7,644	151,459	-151,459	7,644	81,336

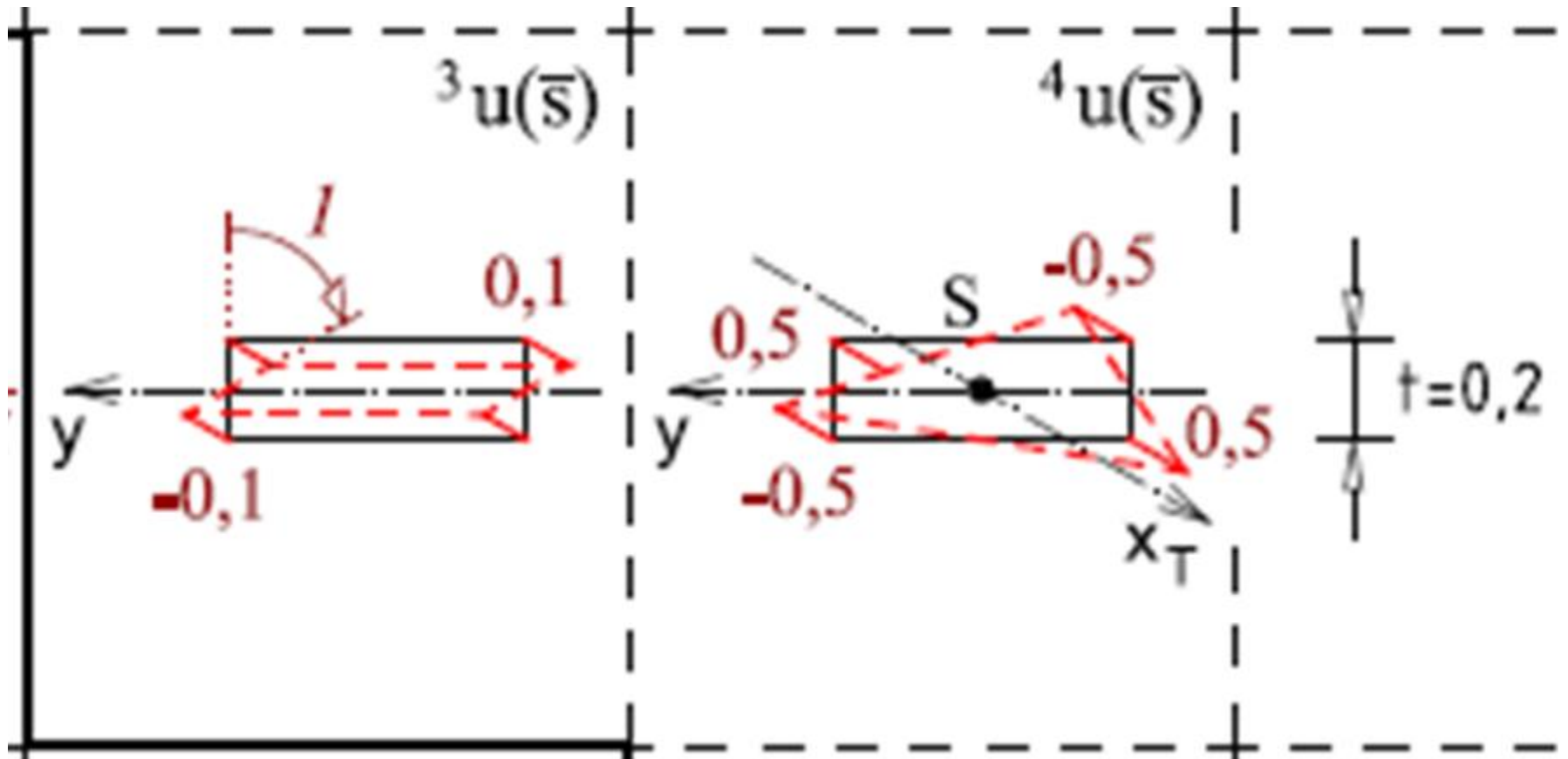
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
k	${}^k m_z(s)$ $\left[\frac{kNcm}{cm} \right]$	${}^k V f_{s,r}; {}^k f_{\vartheta,r}$ $[cm] \quad [rad]$	${}^k f_{s,r} =$ $= -\frac{d[{}^k u(s)]}{ds}$	$-{}^k u(s)$	${}^k u(s)$	${}^k S(s) =$ $= \int_0^n {}^k u(s) t(s) ds$	${}^k Q_r =$ $= \int_i^{i+1} {}^k S(s) ds$	G y z x
1	 Nodes $i = 0, 1, \dots, n = 5$	${}^1 V = 0$ ${}^1 V f_{s,r} = 0; {}^1 f_{\vartheta,r} = 0$	 ${}^1 f_{s,r} = 0$ $[cm^{-1}]$	 ${}^1 u(s) \equiv -1$ $[1]$	 ${}^1 u(s) \equiv -1$ $[1]$	 ${}^1 S(s)$ $[cm^2]$	 ${}^1 Q_r$ $[cm^3]$	
2	 Elements $r = 1, 2, \dots, n = 5$	${}^2 V \equiv v_y = 1 [cm]$ ${}^2 V f_{s,r}; {}^2 f_{\vartheta,r} = 0$	 ${}^2 f_{s,r}$ $[1]$	 ${}^2 u(s)$ $[cm]$	 ${}^2 u(s) \equiv -y(s)$ $[cm]$	 ${}^2 S_z(s) \equiv -S_z(s)$ $[cm^3]$	 ${}^2 Q_r \equiv -Q_{z,r}$ $[cm^4]$	
3	 ${}^3 V \equiv w_z = 1 [cm]$ ${}^3 V f_{s,r}; {}^3 f_{\vartheta,r} = 0$	 ${}^3 f_{s,r}$ $[1]$	 ${}^3 u(s)$ $[cm]$	 ${}^3 u(s) \equiv -z(s)$ $[cm]$	 ${}^3 S_y(s) \equiv -S_y(s)$ $[cm^3]$	 ${}^3 Q_r \equiv -Q_{y,r}$ $[cm^4]$		


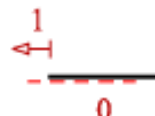
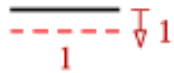
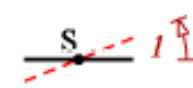


$^1u(s)$ [1]	$^2u(s)$ [cm]	$^3u(s)$ [cm]	$^4u(s)$ [cm ²]	$^5u(s)$ [cm ²]	$^6u(s)$ [cm ²]
<p>n=0</p>					
<p>n=1 t=0,2</p>		<p>$^3u(\bar{s})$</p>	<p>$^4u(\bar{s})$</p>		
<p>n=2 t=0,2</p>		<p>$^3u(\bar{s})$</p>	<p>$^4u(\bar{s})$</p>		
<p>n=3 t=0,2</p>		<p>$^3u(\bar{s})$</p>	<p>$^4u(\bar{s})$</p>		
<p>n=4 t=0,2</p>		<p>$^3u(\bar{s})$</p>	<p>$^4u(\bar{s})$</p>		
<p>n=5 t=0,2</p>		<p>$^3u(\bar{s})$</p>	<p>$^4u(\bar{s})$</p>		

6v [rad]	5v [rad]	4v [rad]	3v [cm]	2v [cm]	$^1u(s)$ [l]	$^2u(s)$ [cm]	$^3u(s)$ [cm]	$^4u(s)$ [cm ²]	$^5u(s)$ [cm ²]	$^6u(s)$ [cm ²]
<div style="border: 1px solid black; padding: 5px; width: fit-content;"> dimensions [cm] displacements [cm] rotations [rad] points numbering </div>					n=0					
					n=1 t=0,2					
					n=2 t=0,2					
					n=3 t=0,2					
					n=4 t=0,2					
					n=5 t=0,2					

DEPLANÁCIA PO HRÚBKE



cross-section		k_{f_s}	k_{f_v}	$k_{C^B} = \frac{1}{E} \sum_{r=1}^n K_r \cdot b_r \left(k_{f_s}^2 + k_{f_v}^2 \frac{b_r^2}{12} \right); \quad K_r = \frac{E \cdot t_r^3}{12(1-\nu^2)}$
shape	k			
	n=1			
	2		0	$\frac{E \cdot t^3}{E \cdot 12(1-\nu^2)} \cdot b \cdot \left(0^2 + 0^2 \frac{b^2}{12} \right) = 0$
	3		0	$\frac{E \cdot t^3}{E \cdot 12(1-\nu^2)} \cdot b \cdot \left(1^2 + 0^2 \frac{b^2}{12} \right) = \frac{1}{12} \cdot \frac{b \cdot t^3}{1-\nu^2}$
	4	0		$\frac{E \cdot t^3}{E \cdot 12(1-\nu^2)} \cdot b \cdot \left(0^2 + 1^2 \frac{b^2}{12} \right) = \frac{1}{144} \cdot \frac{b^3 t^3}{1-\nu^2}$

cross-section		k_{f_s}	k_{f_v}	$k_{CB} = \frac{1}{E} \sum_{r=1}^n K_r \cdot b_r \left(k_{f_s}^2 + k_{f_v}^2 \frac{b_r^2}{12} \right) ; \quad K_r = \frac{E \cdot t_r^3}{12(1-\nu^2)}$
shape	k			
	2		0	$\frac{1}{12} \cdot \frac{t_w^3}{1-\nu^2} \cdot h$
	3		0	$2 \frac{1}{12} \cdot \frac{t_f^3}{1-\nu^2} \cdot b$
	4			$\frac{t_w^3}{12(1-\nu^2)} \cdot h \cdot \frac{h^2}{12} + 2 \frac{t_f^3}{12(1-\nu^2)} \cdot b \cdot \frac{b^2}{12} = \frac{1}{144} \cdot \frac{(h^3 t_w^3 + b^3 t_f^3)}{1-\nu^2}$

$$I_z := I_2 + C_{2.B} = 25.871 \cdot \text{cm}^4$$

$$\frac{I_2}{I_z} = 0.9996$$

$$I_y := I_3 + C_{3.B} = 123.362 \cdot \text{cm}^4$$

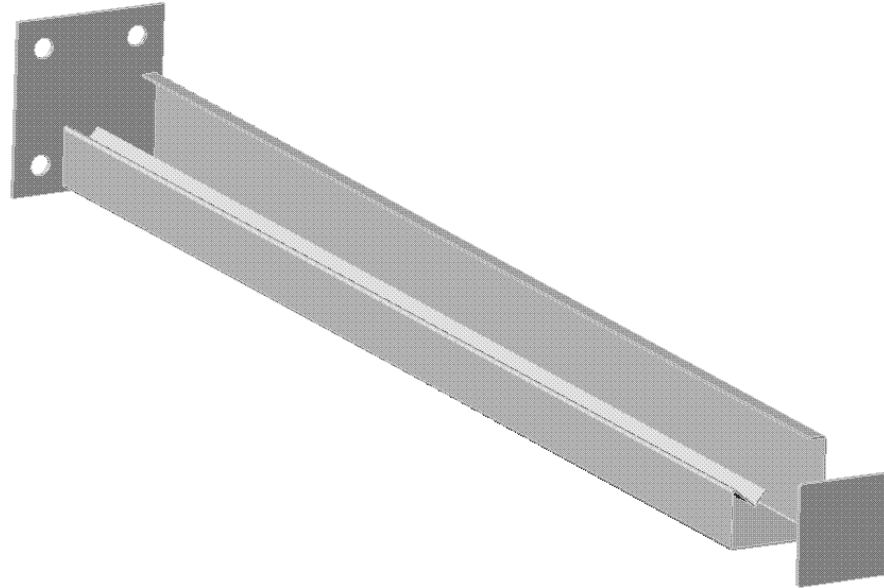
$$\frac{I_3}{I_y} = 0.9999$$

$$I_w := I_4 + C_{4.B} = 764.193 \cdot \text{cm}^6$$

$$\frac{I_4}{I_w} = 0.9994$$

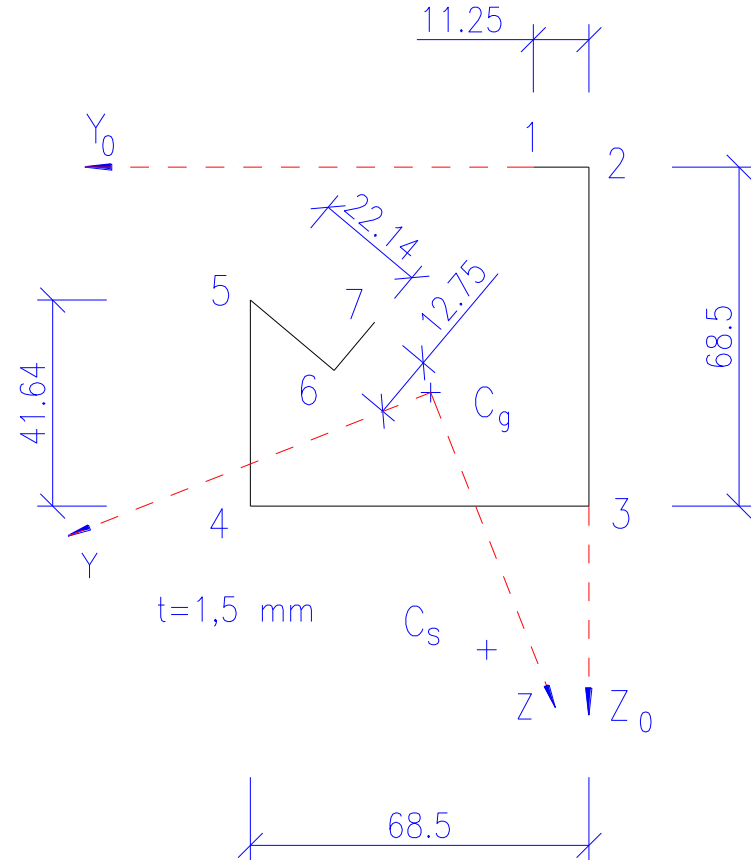
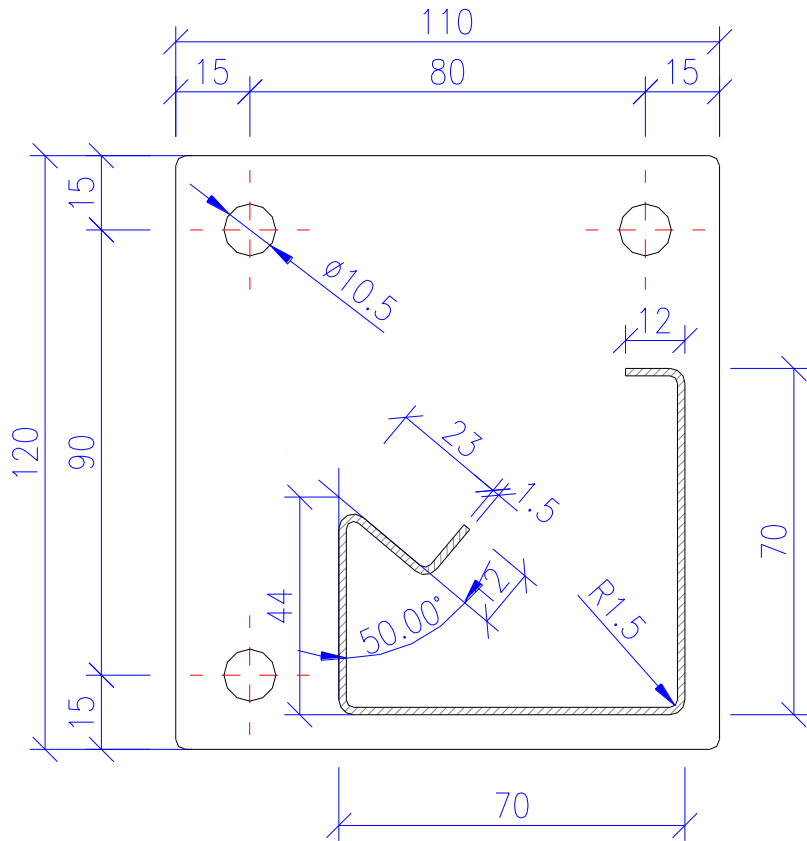
Steel Cantilever with Thin Walled Cross-Section

Authors: Ing. S.Rendek, prof. Ing. I.Baláž,
CSc.,



- Theoretical Calculation of the Beam with Thin Walled Deformable Cross-Section by Generalized Beam Theory
- Experiment
- Numerical Results vs. Experiment
- Influence of Distortion on Cross-Sectional Stresses

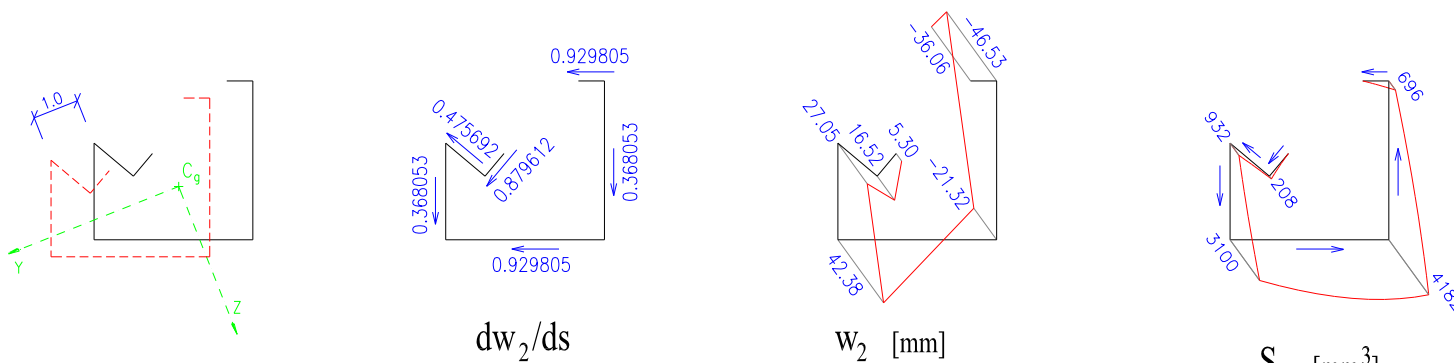
Geometrical Shape of Investigated Cross-Section



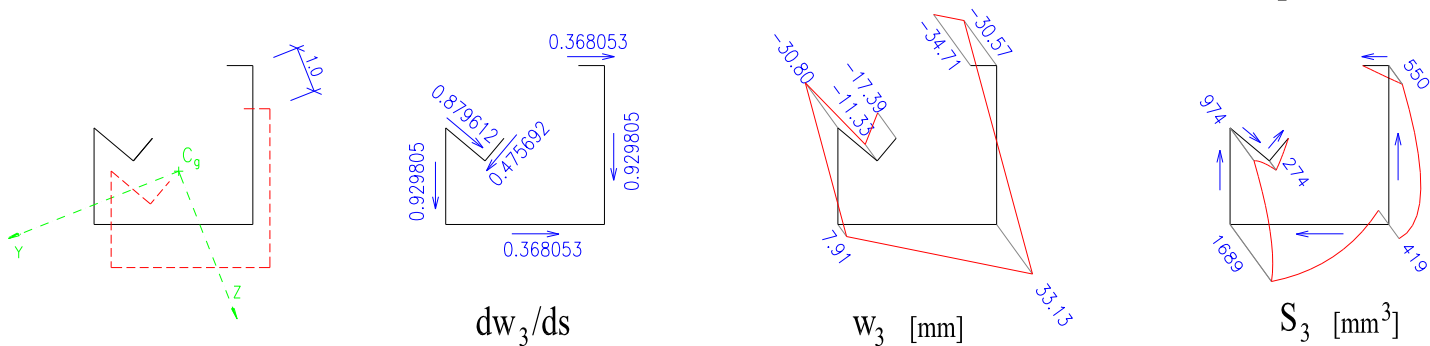
All Units are in millimeters

Unit Deformations

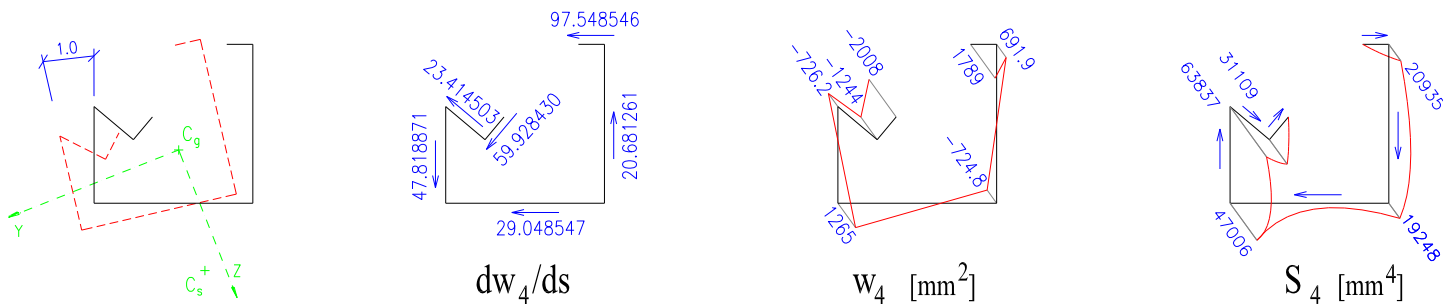
Bending (z axis)



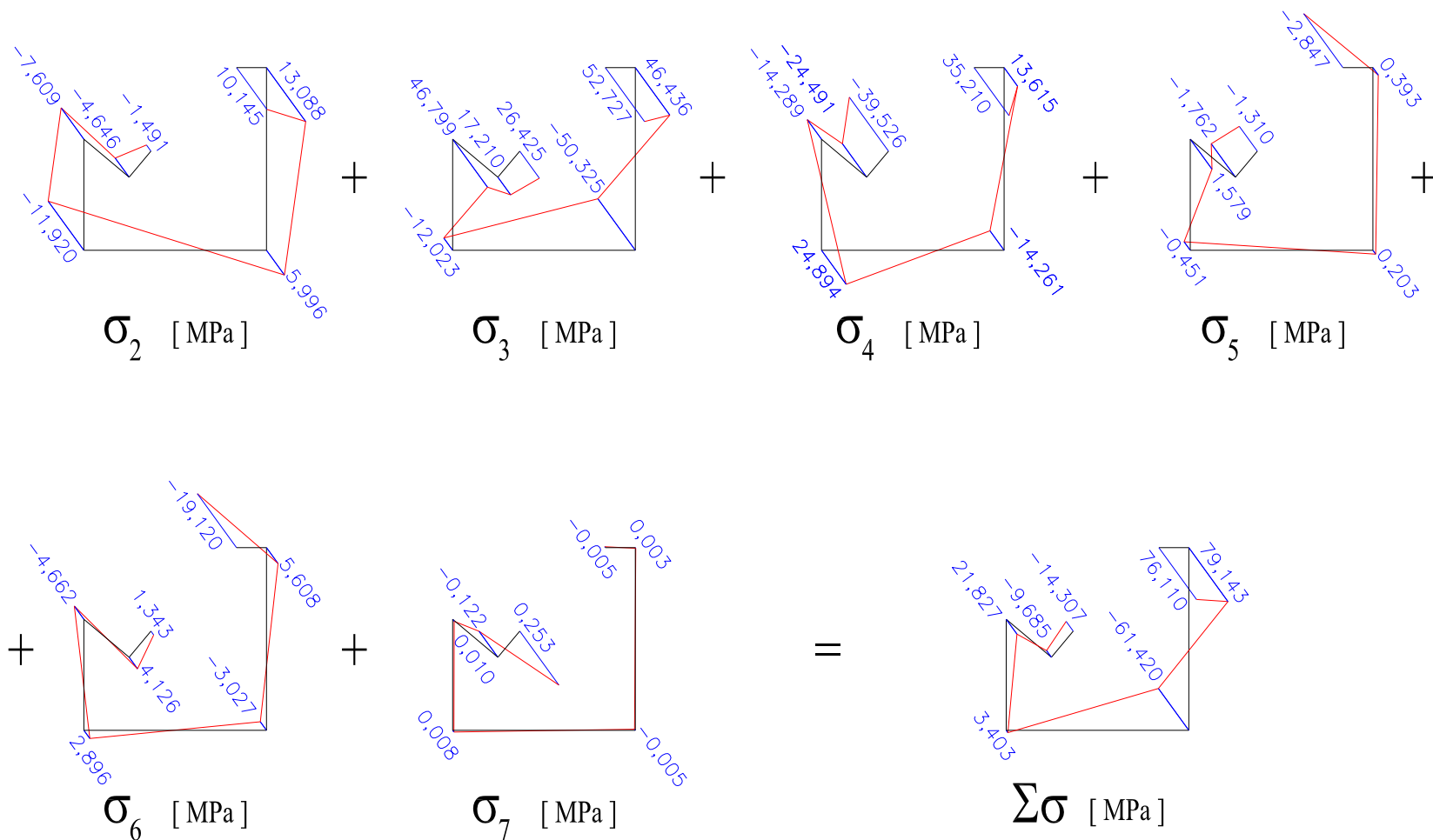
Bending (y axis)



Torsion

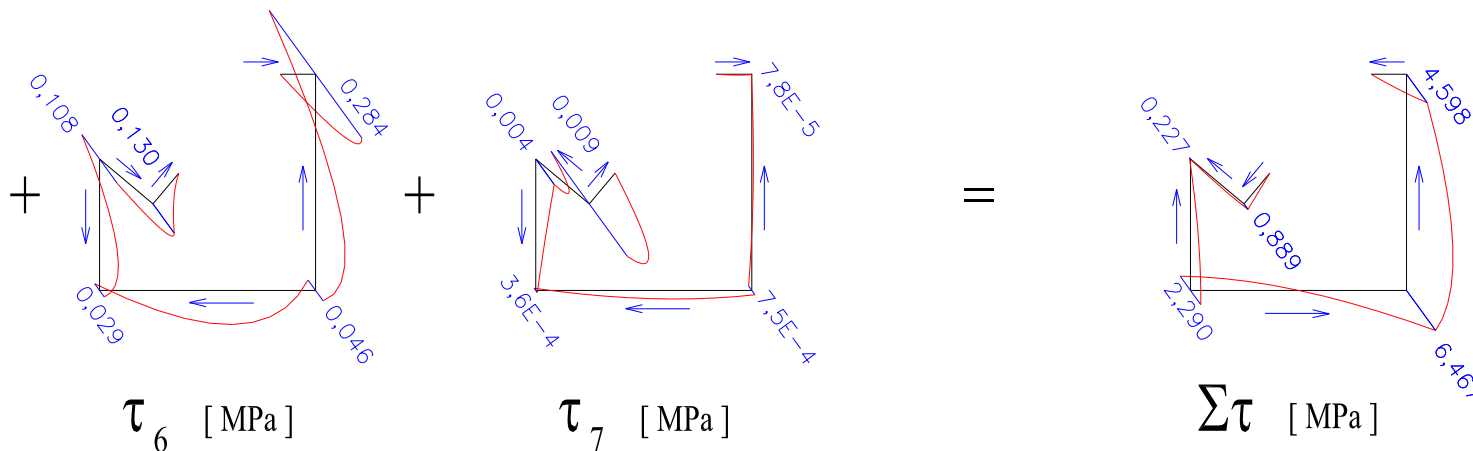
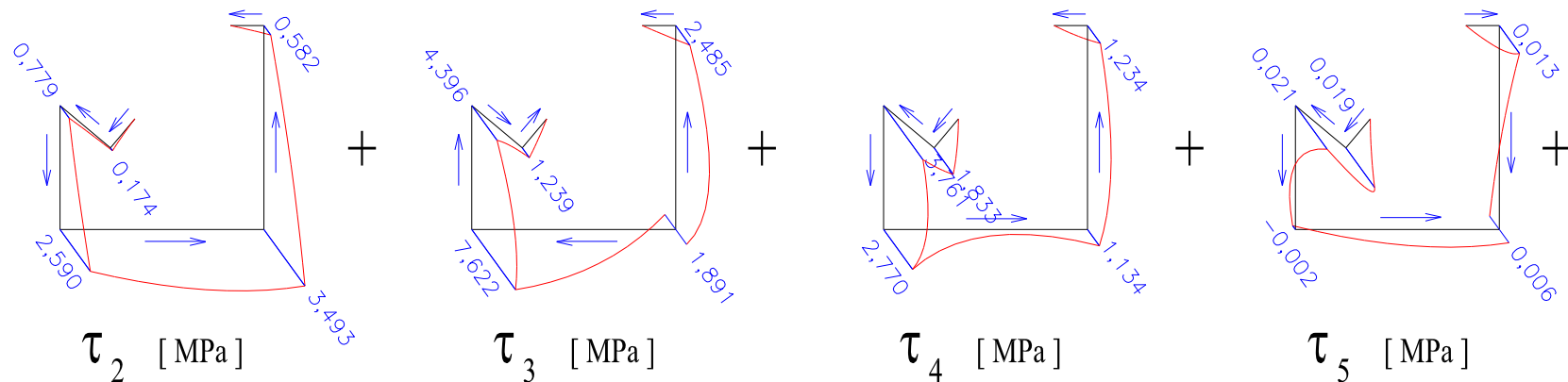


Normal Stresses

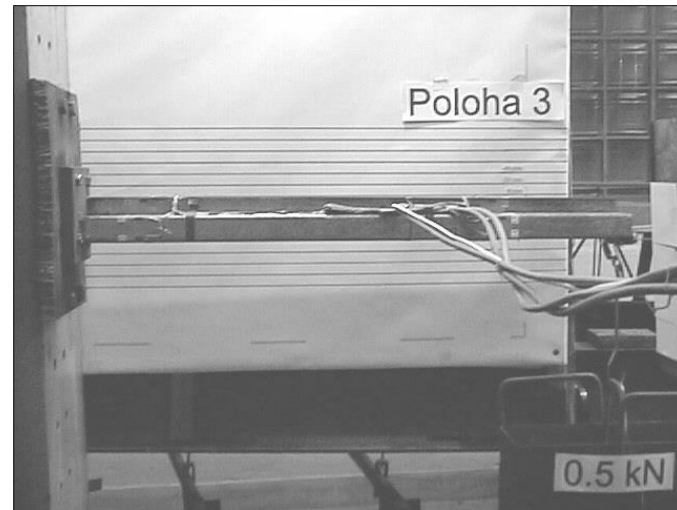
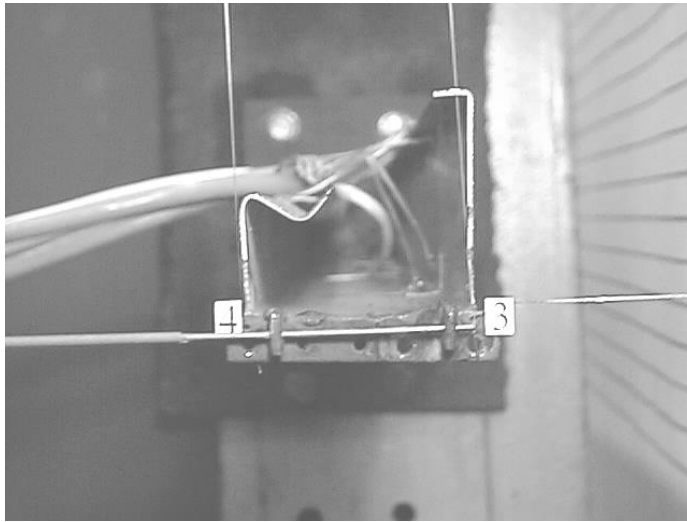


Force position number 3, Cross-section $x = 674$ mm.

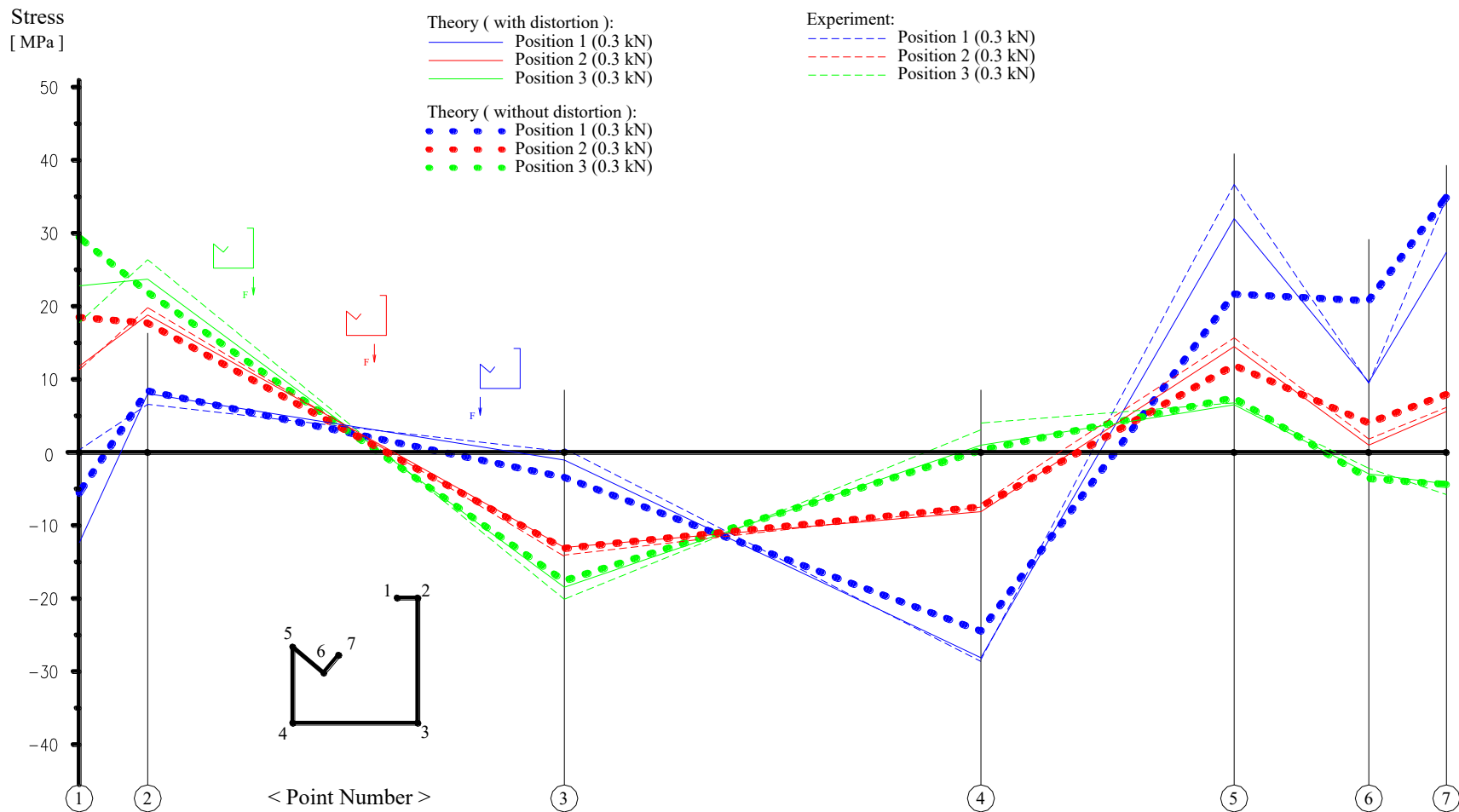
Shear Stresses



Force position number 3, Cross-section $x = 674$ mm.



Influence of Distortion on Cross-Sectional Stresses



Force positions number 1 - 3, Cross-section x = 674 mm.

STABILITA – TEÓRIA II. RÁDU

- Globálna strata stability, kritické sily

$$N_{cr,y} = \frac{\pi^2 EI_y}{k_y^2 L^2} \quad N_{cr,z} = \frac{\pi^2 EI_z}{k_z^2 L^2} \quad N_{cr,T} = \frac{1}{i_s^2} \left[GI_t + \frac{\pi^2 EI_w}{k_w^2 L^2} \right]$$

- Distorzná strata stability, kritické zaťaženie

$${}^{0,k}W_{cr} = \frac{1}{{}^{0kk}K_\sigma} \cdot \left(2 \cdot \sqrt{E^k \tilde{C}^k \tilde{B}} + G^k \tilde{D} \right)$$

- Lokálna strata stability, kritické napätia

$$\sigma_{cr,p} = k_{\sigma,p} \sigma_E \quad \sigma_E = \frac{\pi^2 E t^2}{12(1-\nu^2)b^2}$$

Strata stability ohybom

klasický:

$$E I_y w'''' - N w'' = 0$$

GBT:

$$E {}^1\tilde{C}^1 V'''' + {}^0W^{011} {}_{\mathcal{K}_\sigma}^1 V'' = 0$$

Zaťaženie: $i = 0$, Tvar vybočenia: $j, k = 1$

Strata stability skrútením

klasický:

$$E I_\omega \vartheta'''' - G I_t \vartheta'' - N i_S^2 \vartheta'' = 0$$

GBT:

$$E {}^3\tilde{C}^3 V'''' - G {}^3\tilde{D}^3 V'' + {}^0W^{033} {}_{\mathcal{K}_\sigma}^3 V'' = 0$$

Zaťaženie: $i = 0$, Tvar vybočenia: $j, k = 3$

Priestorový vzper

klasický:

$$E I_z v'''' - N v'' - N z_s \vartheta'' = 0$$

$$E I_\omega \vartheta'''' - G I_t \vartheta'' - N z_s v'' - N i_s^2 \vartheta'' = 0$$

GBT:

$$E \widetilde{C}^k V'''' - G \widetilde{D}^k V'' + {}^0W \sum_{j=2,3} {}^{0jk} K_\sigma^j V'' = 0$$

Zaťaženie: $i = 0$, Tvar vybočenia: $j, k = 2, 3$

Priestorový vzper excentricky zťaženého prúta

klasický:

$$E I_y w'''' - N (v'' - z_M \vartheta'') + M_z \vartheta'' = 0$$

$$E I_z v'''' - N (w'' - y_M \vartheta'') + M_y \vartheta'' = 0$$

$$E I_\omega \vartheta'''' - G I_t \vartheta'' - N (z_s v'' - y_s w'' + i_s^2 \vartheta'') + M_y (v'' - r_s \vartheta'') + M_z (w'' - r_s \vartheta'') = 0$$

GBT:

$$E \widetilde{C}^k V'''' - G \widetilde{D}^k V'' + \sum_{i=0,1,2} {}^iW \sum_{j=1,2,3} {}^{ijk} K_\sigma^j V'' = 0$$

Zaťaženie: $i = 0,1,2$ Tvar vybočenia: $j, k = 1, 2, 3$

Klopenie nosníka zaťaženého koncovým momentom M_y

klasický:

$$E I_z v'''' + M_y \vartheta'''' = 0$$

$$E I_\omega \vartheta'''' - G I_t \vartheta'' + M_y (v'' - r_s \vartheta'') = 0$$

GBT:

$$E \widetilde{C}^k V'''' - G \widetilde{D}^k V'' + {}^1W \sum_{j=2,3} {}^{1j}k_{\mathcal{K}_\sigma} V'' = 0$$

Zaťaženie: $i = 1$, Tvar vybočenia: $j, k = 2, 3$

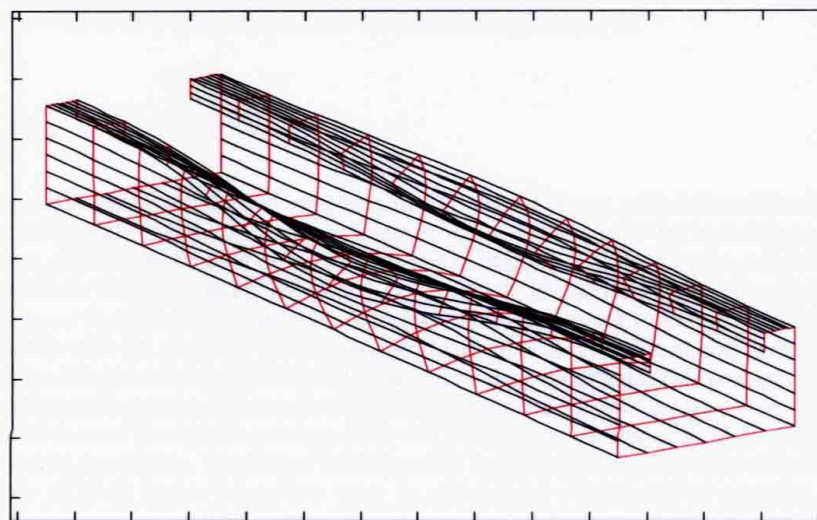
RADA č. 6

- Stiahnite si zadarmo program LTBeam
<http://ltbeam.software.informer.com/1.0/>
CTICM Paris, France
- Stiahnite si zadarmo program ALPHA cr
z TU Innsbruck, Prof. G. Lener
<http://www.uibk.ac.at/stahlbau>

Ing. Peter Buček

STABILITNÉ PROBLÉMY TENKOSTENNÝCH KONŠTRUKCIÍ RIEŠENÉ POMOCOU GBT

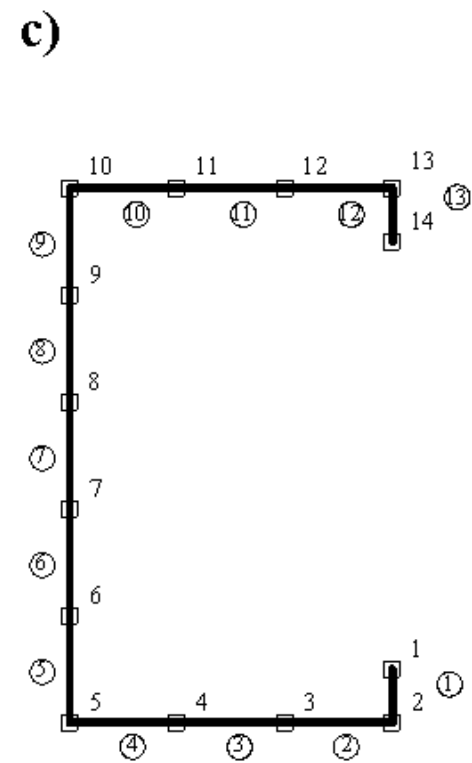
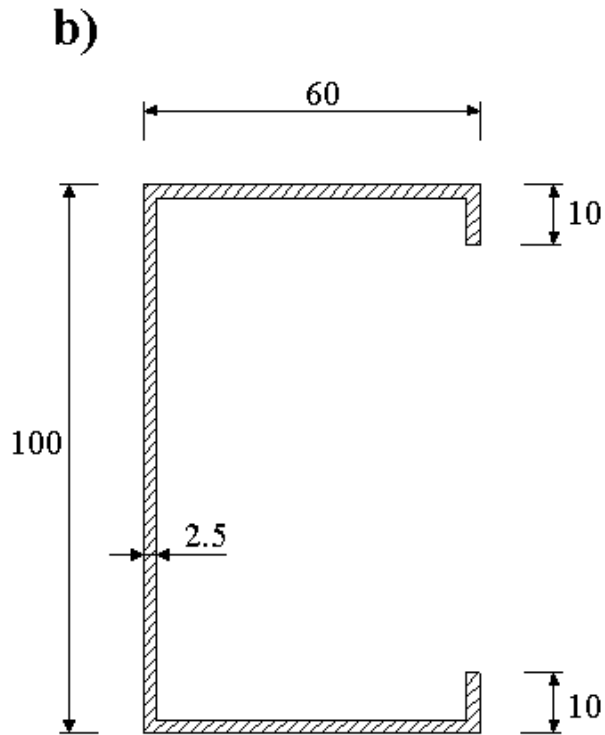
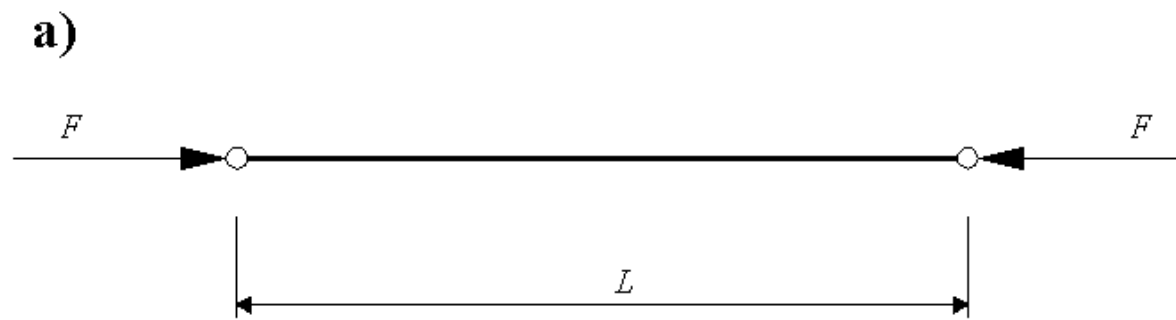
Dizertačná práca



Školiteľ

Prof. Ing. Ivan Baláž, PhD.

2008



Obr. 4.1 Výpočtový model: (a) statická schéma; (b) rozmery priečného rezu; (c) označenie elementov a uzlových bodov

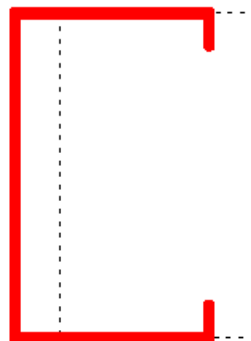
Mode 0



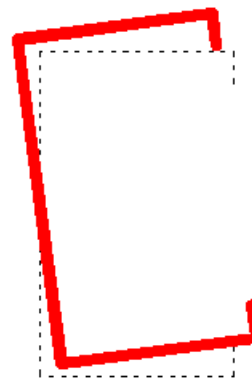
Mode 1



Mode 2



Mode 3



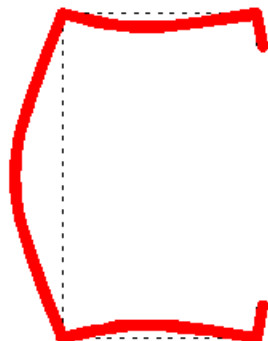
Mode 4



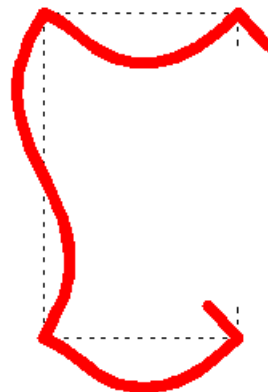
Mode 5



Mode 6



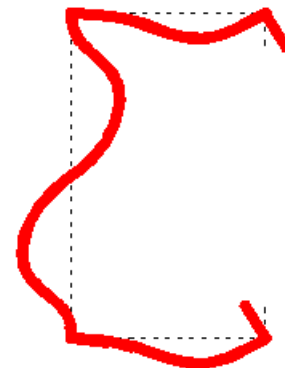
Mode 7



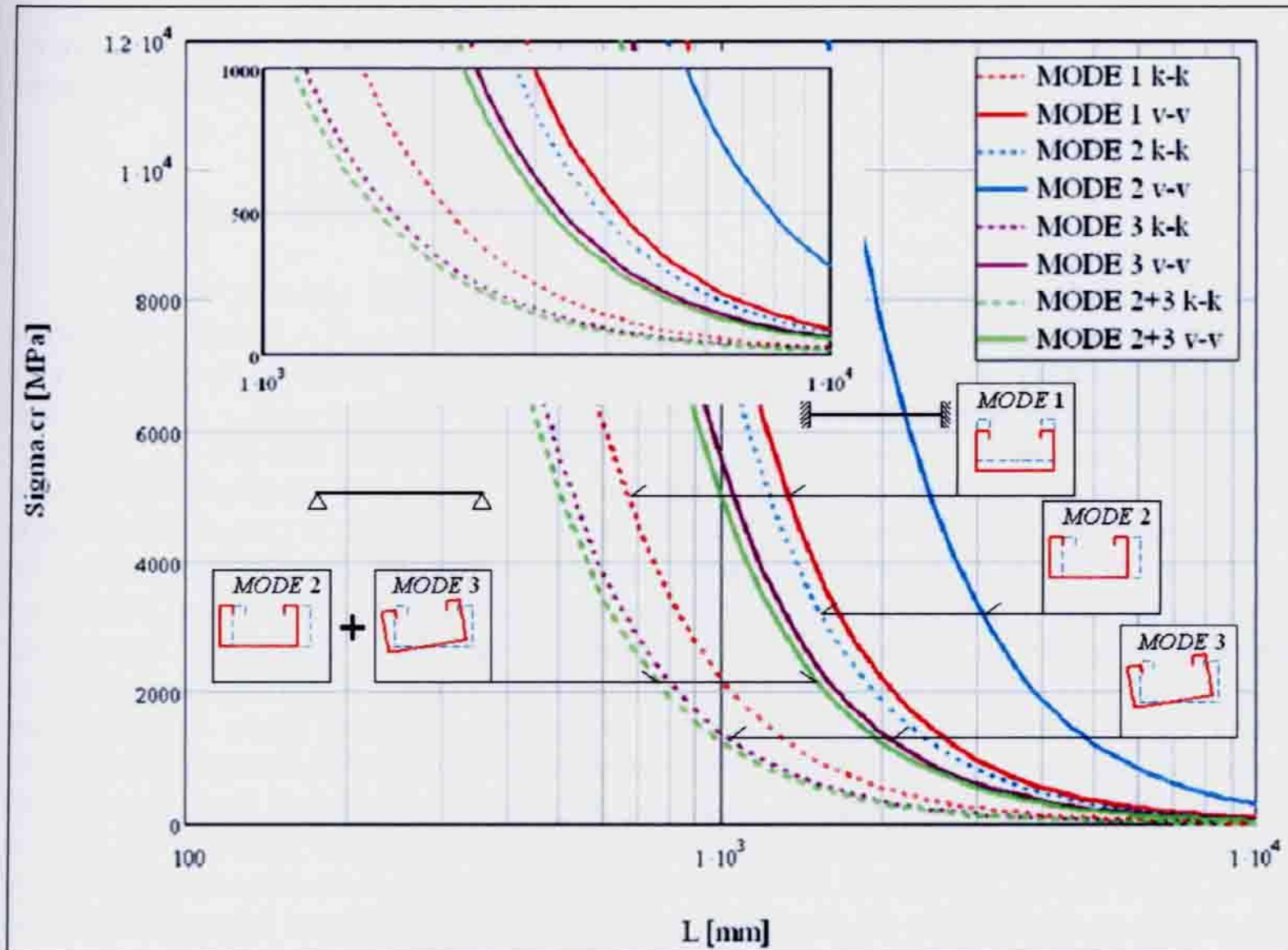
Mode 8



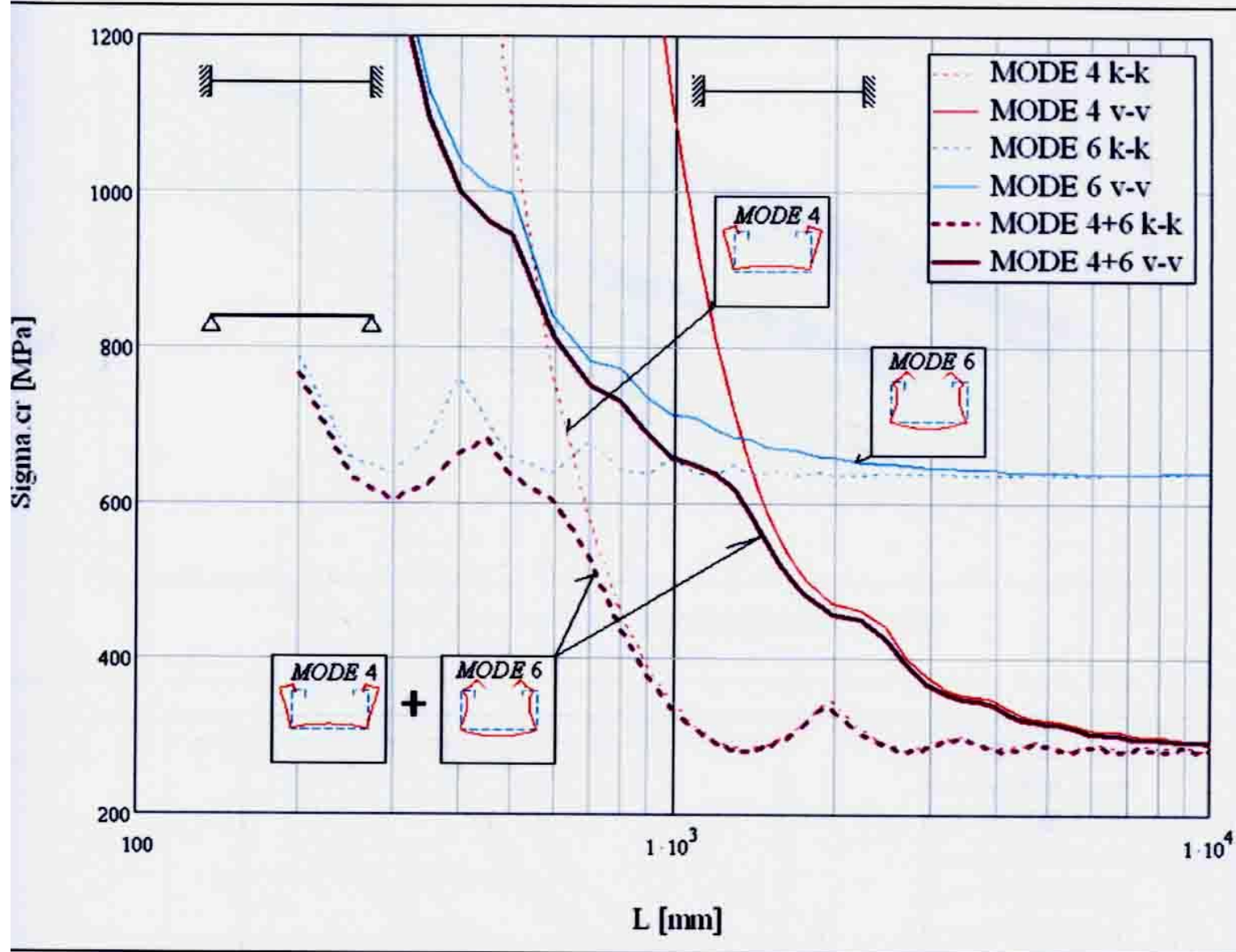
Mode 9



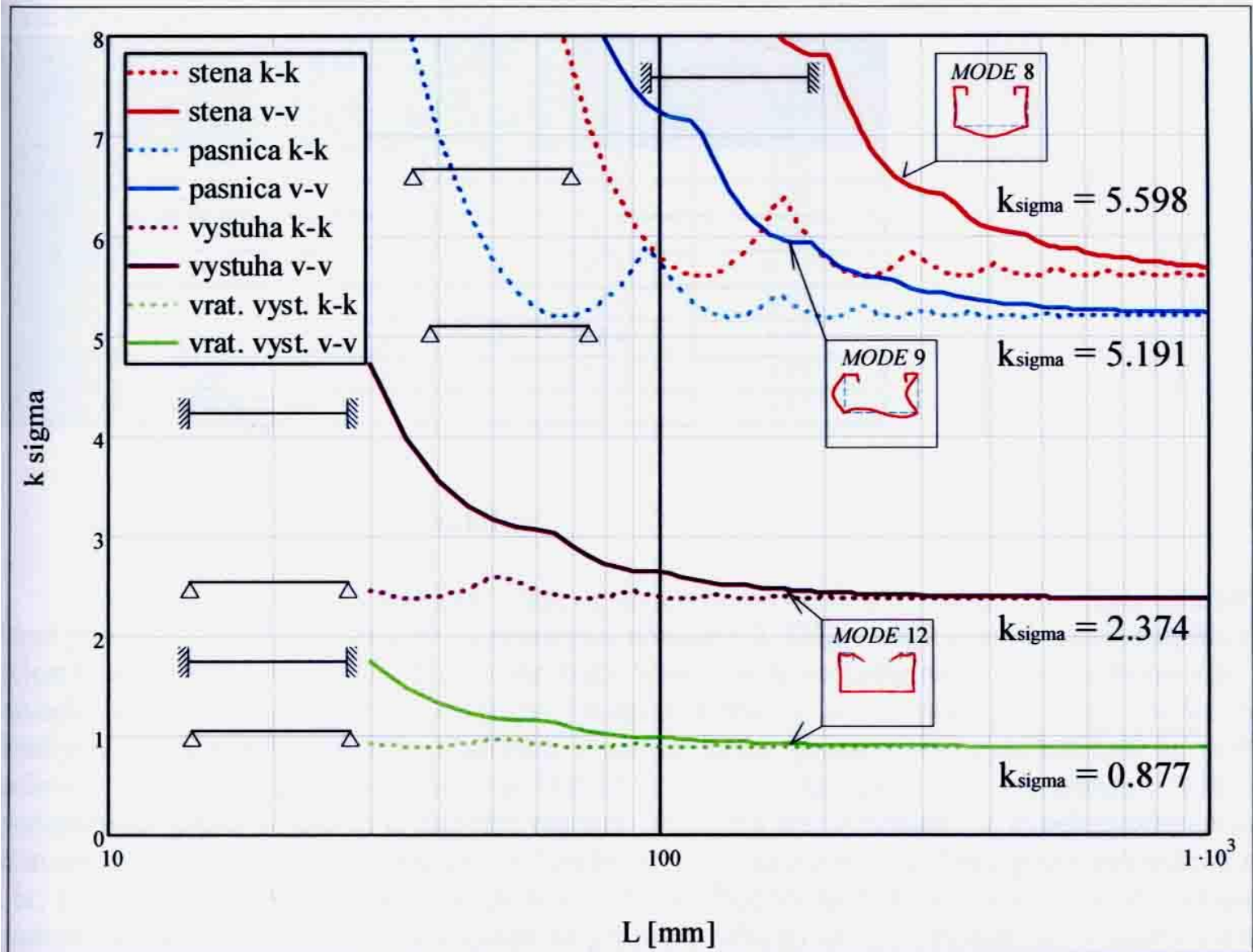
Obr. 4.3 Jednotkové pretvorenia priečného rezu v jeho rovine pre deformačné tvary 0 až 9.



Obr. 6.11 Závislosť kritického napätia σ_{cr} globálneho vzperu od dĺžky prúta. (Dĺžka je vykreslená v logaritmickej mierke).



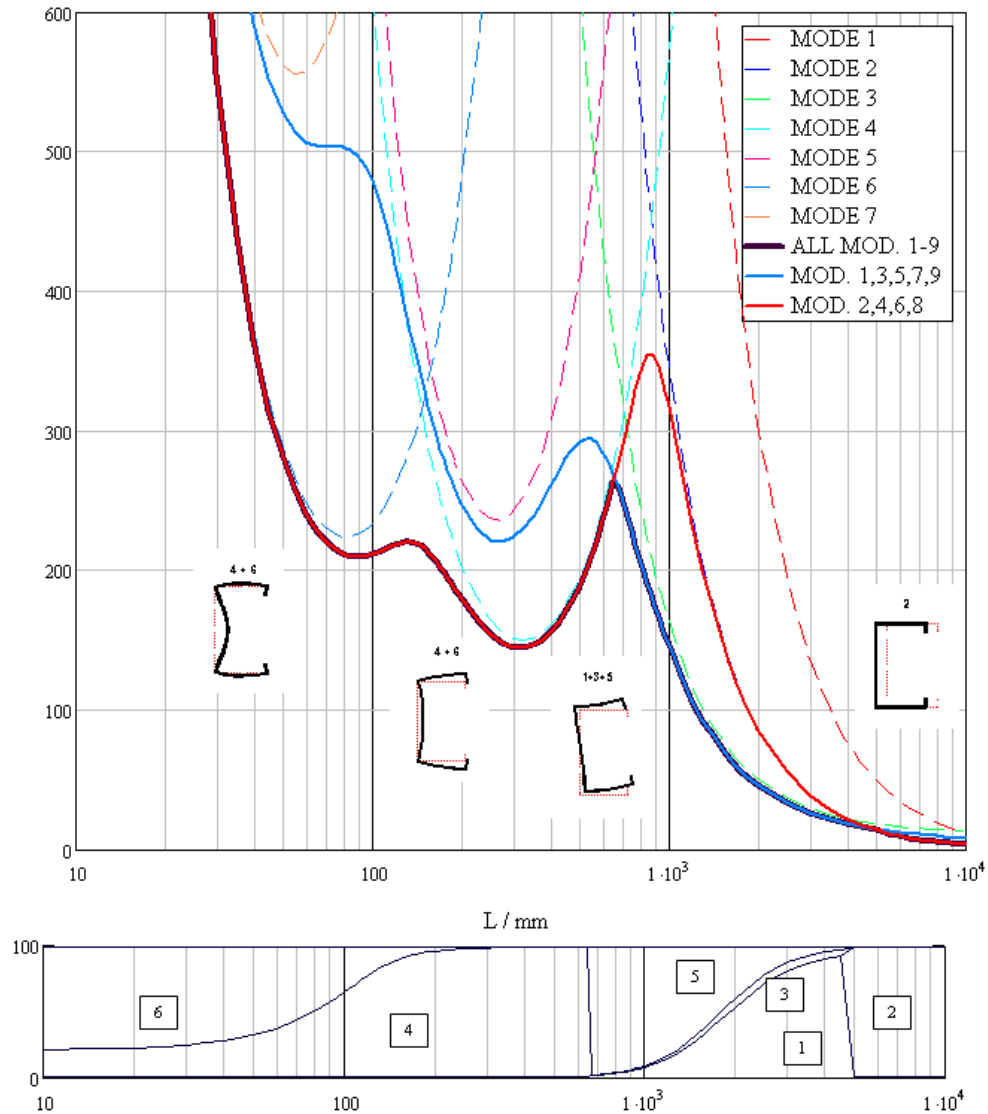
Obr. 6.9 Závislosť kritického napätia σ_{cr} distorzného vzperu od dĺžky prúta. (Dĺžka je vykreslená v logaritmickej mierke).



Obr. 6.7 Závislosť súčiniteľa vydúvania k_{σ} tvoriacich stien prierezu od dĺžky prúta. (Dĺžka je vykreslená v logaritmickej mierke).

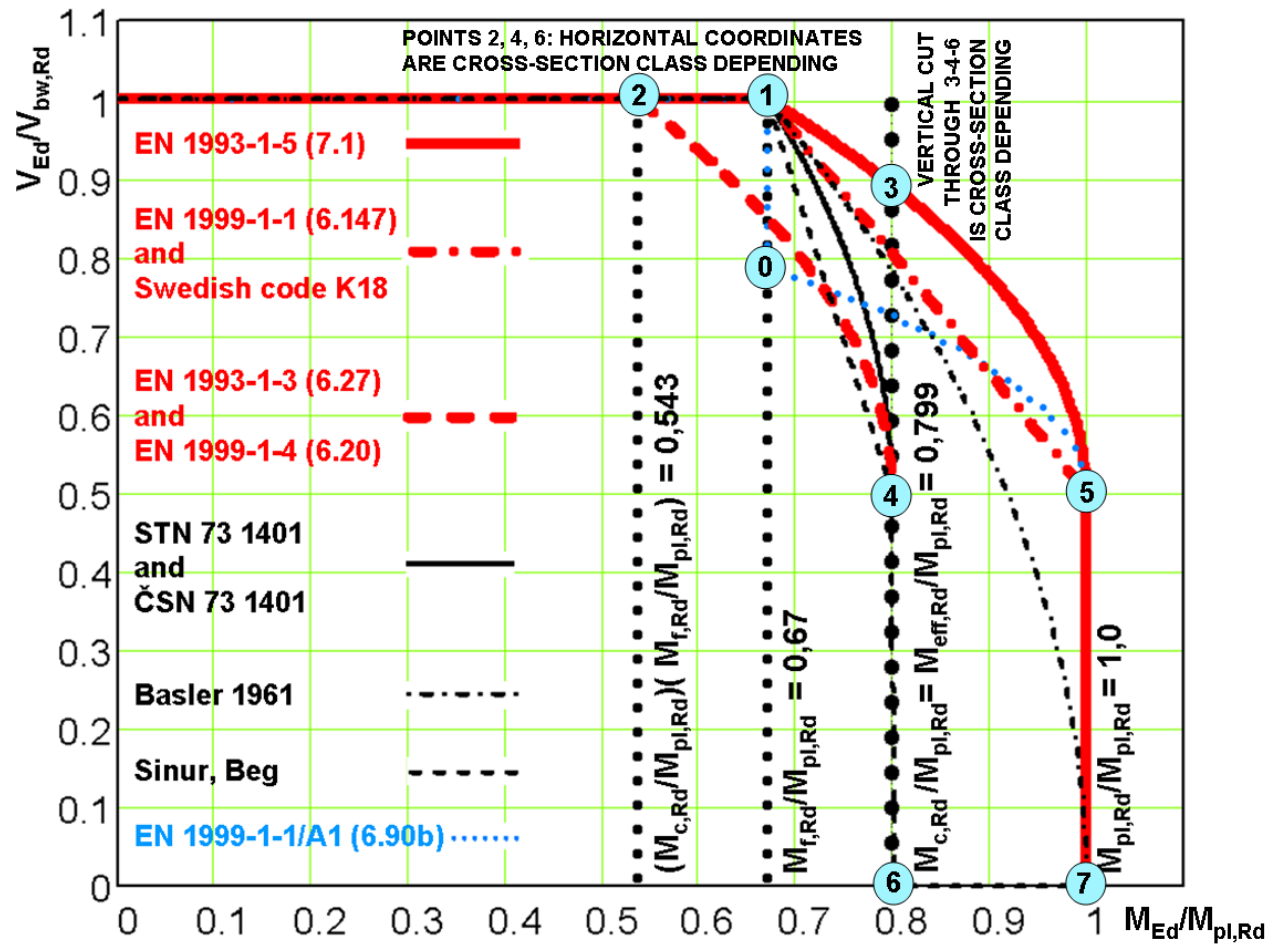
σ_{cr} / MPa

MULTI MODE BUCKLING



Obr.4.6 Závislosť kritického napätia od dĺžky prúta a podiel deformačných tvarov na výslednej deformácii prúta pre vybočenie v tvare jednej polovlny.

Odolnosti prierezu kombinovane namáhaného



IMPROVEMENT PROPOSALS FOR EUROCODES

$$\frac{T_{Ed}}{T_{Rd}} \leq 1,0 \quad \text{EC 3 and EC 9}$$

PROPOSAL

$$T_{Rd} = W_{T,pl} f_0 / (\sqrt{3} \gamma_{M1})$$

$$\left(\frac{T_{t,Ed}}{I_{el,t}} t + \frac{T_{\omega,Ed}}{I_{\omega}} \frac{S_{\omega}}{t} \right)_{\max} \leq \frac{1}{\sqrt{3}} \frac{f_y}{\gamma_{M0}}$$

$$\frac{T_{t,Ed}}{T_{el,t,Rd}} \leq 1.0 \quad \text{if } T_{\omega,Ed} = 0$$

$$\frac{T_{\omega,Ed}}{T_{el,\omega,Rd}} \leq 1.0 \quad \text{if } T_{t,Ed} = 0$$

$$T_{el,t,Rd} = W_{el,t} \frac{1}{\sqrt{3}} \frac{f_y}{\gamma_{M0}}$$

$$T_{el,\omega,Rd} = W_{el,\omega} \frac{1}{\sqrt{3}} \frac{f_y}{\gamma_{M0}}$$

$$W_{el,t} = \frac{I_{el,t}}{t_{\max}}$$

$$W_{el,\omega} = I_{\omega} \left(\frac{t}{S_{\omega}} \right)_{\min}$$

EC3 and EC9

$$\frac{V_{Ed}}{V_{pl,T,Rd}} \leq 1,0$$

- for an I or H section:

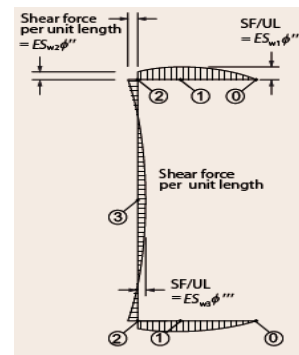
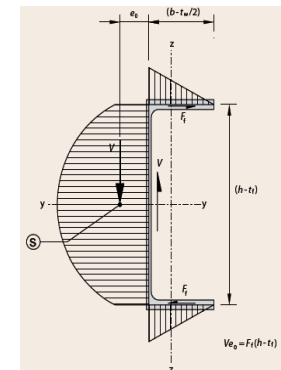
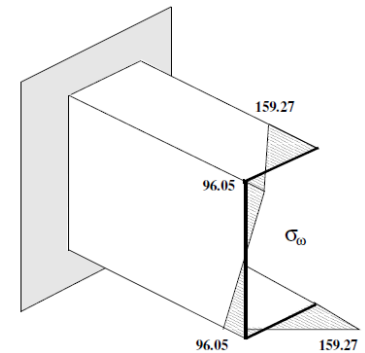
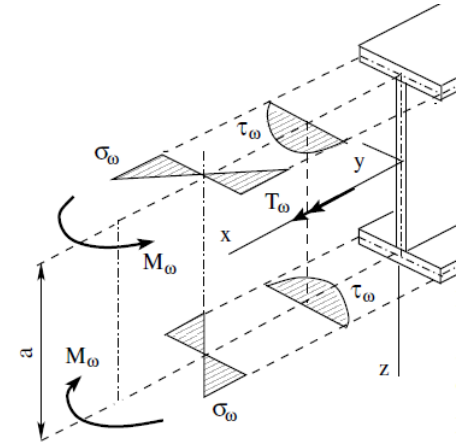
$$V_{pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,Ed}}{1,25 (f_y/\sqrt{3})/\gamma_{M0}}} V_{pl,Rd}$$

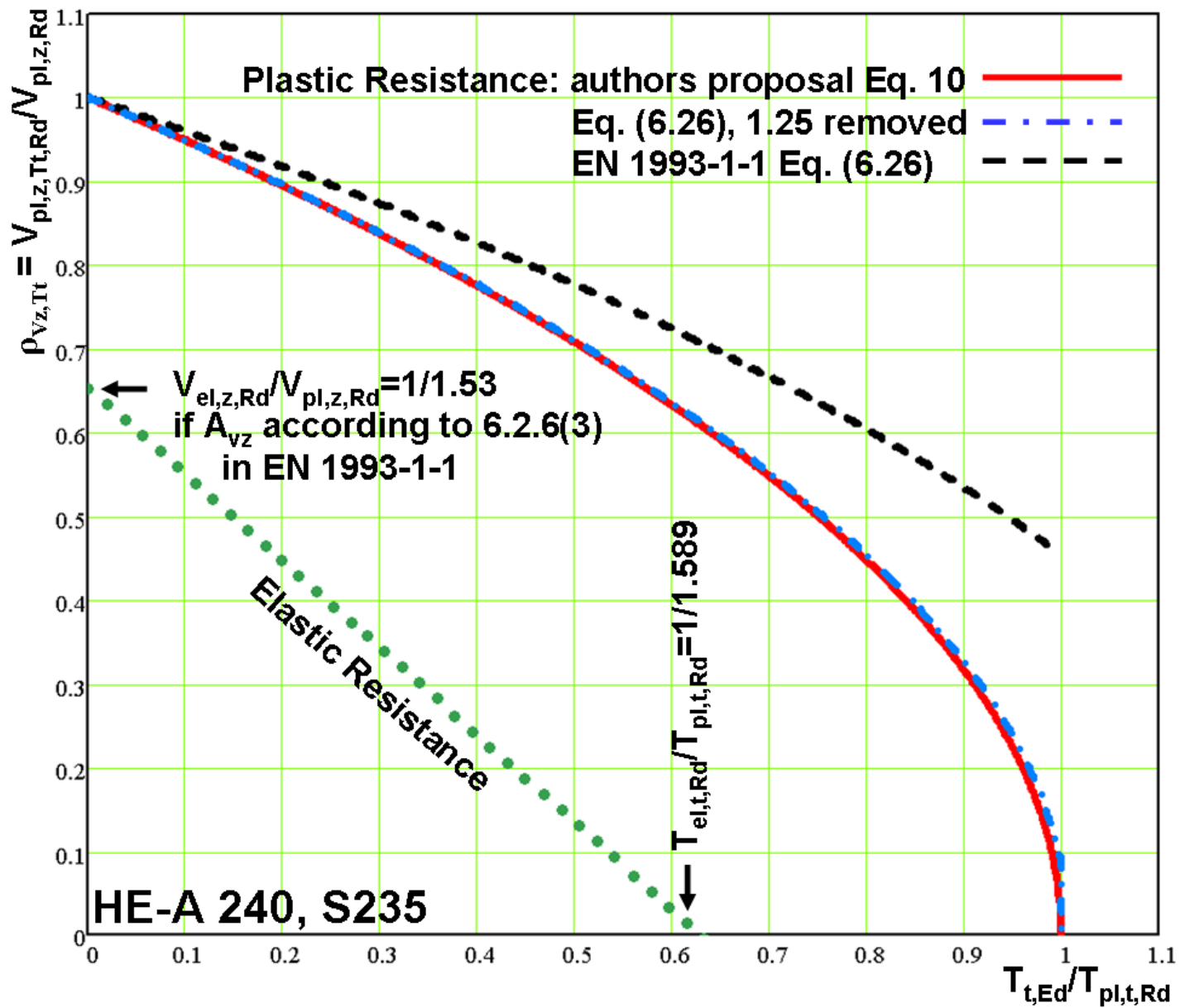
- for a channel section:

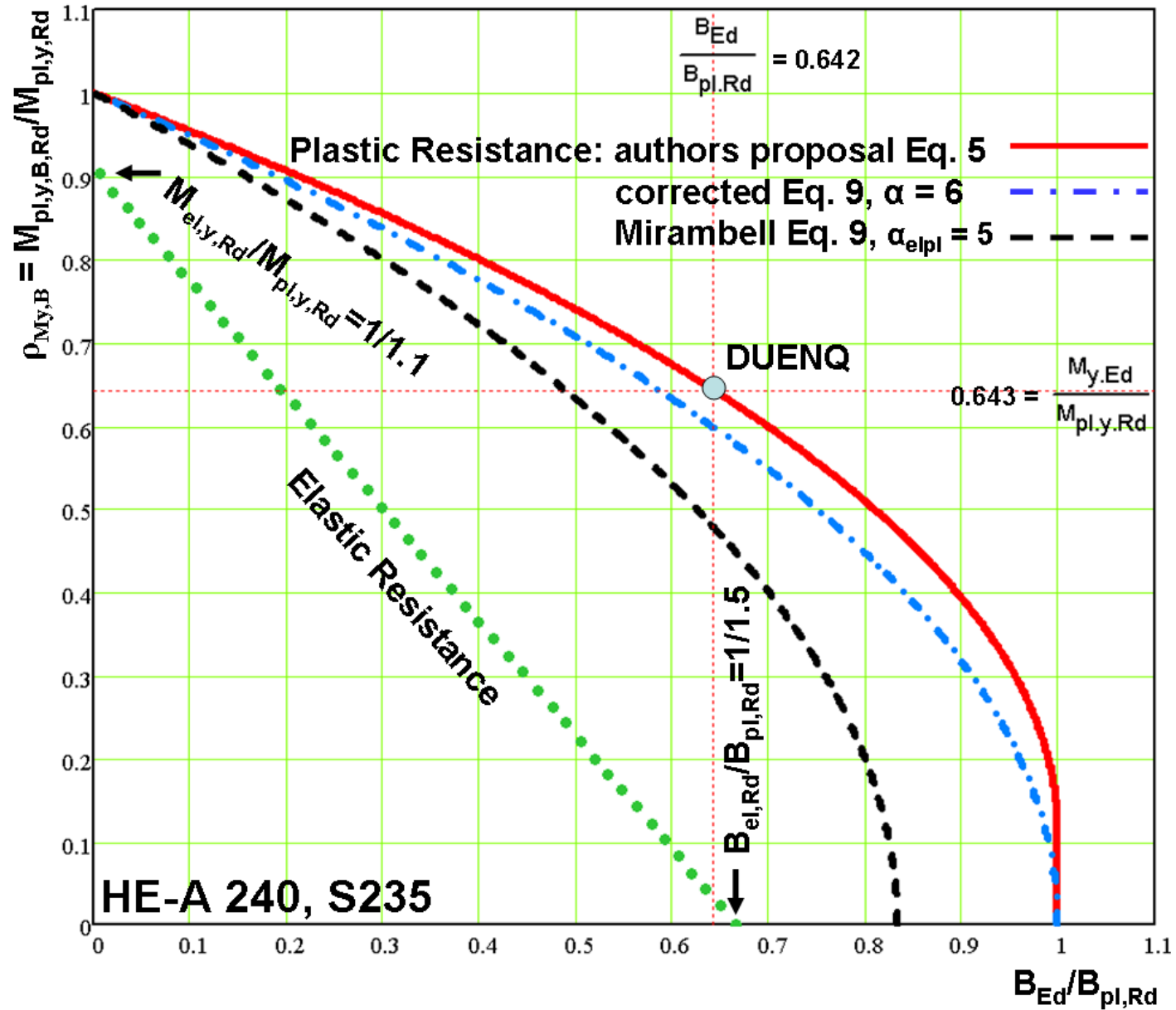
$$V_{pl,T,Rd} = \left[\sqrt{1 - \frac{\tau_{t,Ed}}{1,25 (f_y/\sqrt{3})/\gamma_{M0}}} - \frac{\tau_{w,Ed}}{(f_y/\sqrt{3})/\gamma_{M0}} \right] V_{pl,Rd}$$

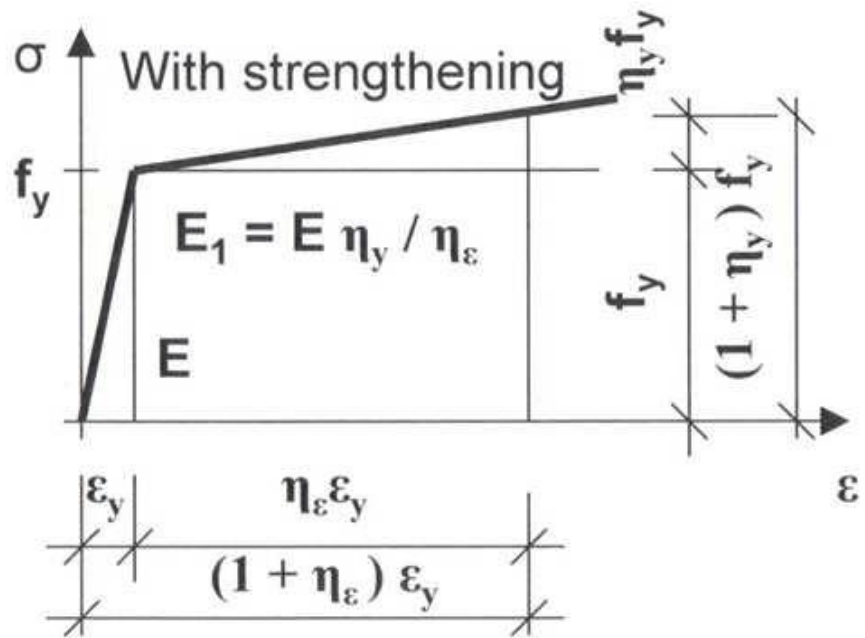
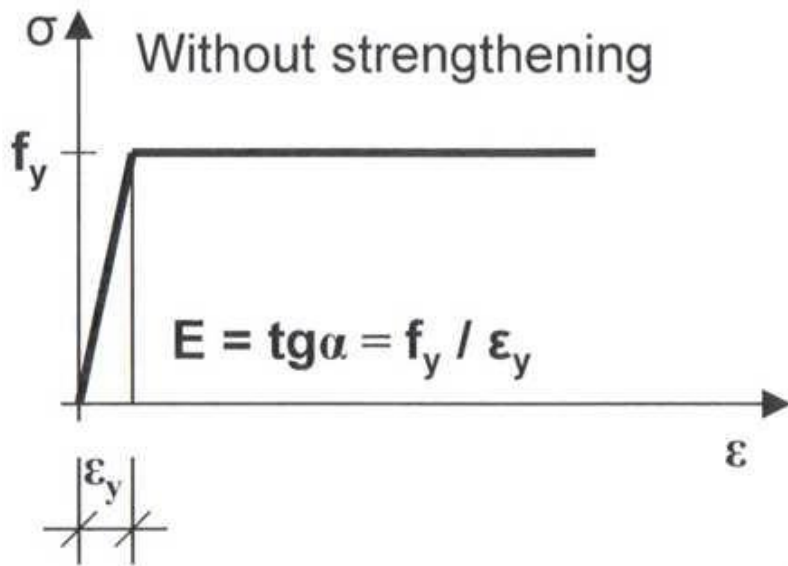
- for a structural hollow section:

$$V_{pl,T,Rd} = \left[1 - \frac{\tau_{t,Ed}}{(f_y/\sqrt{3})/\gamma_{M0}} \right] V_{pl,Rd}$$









Continuous Strength Method

$$\sigma_{csm} = \varepsilon_{csm} E \quad \text{for } \varepsilon_{csm} / \varepsilon_y < 1$$

$$\sigma_{csm} = f_y + E_{sh} (\varepsilon_{csm} - \varepsilon_y) \quad \text{for } \varepsilon_{csm} / \varepsilon_y \geq 1$$

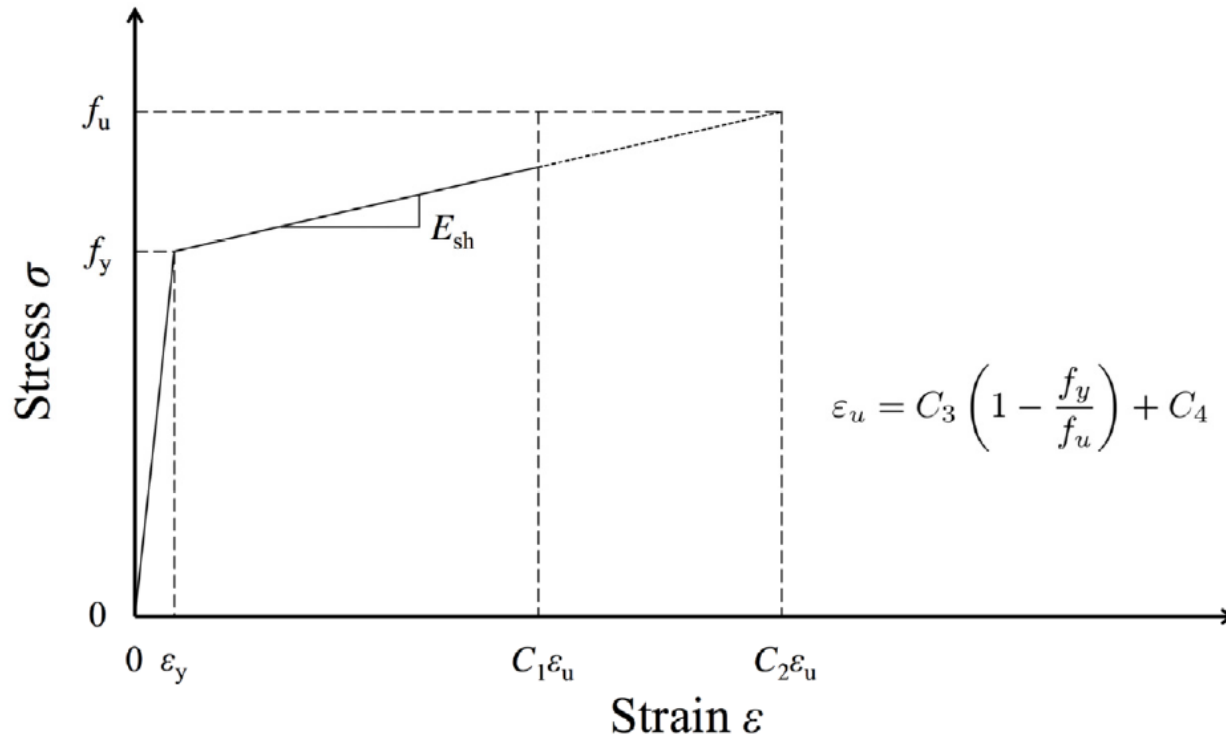
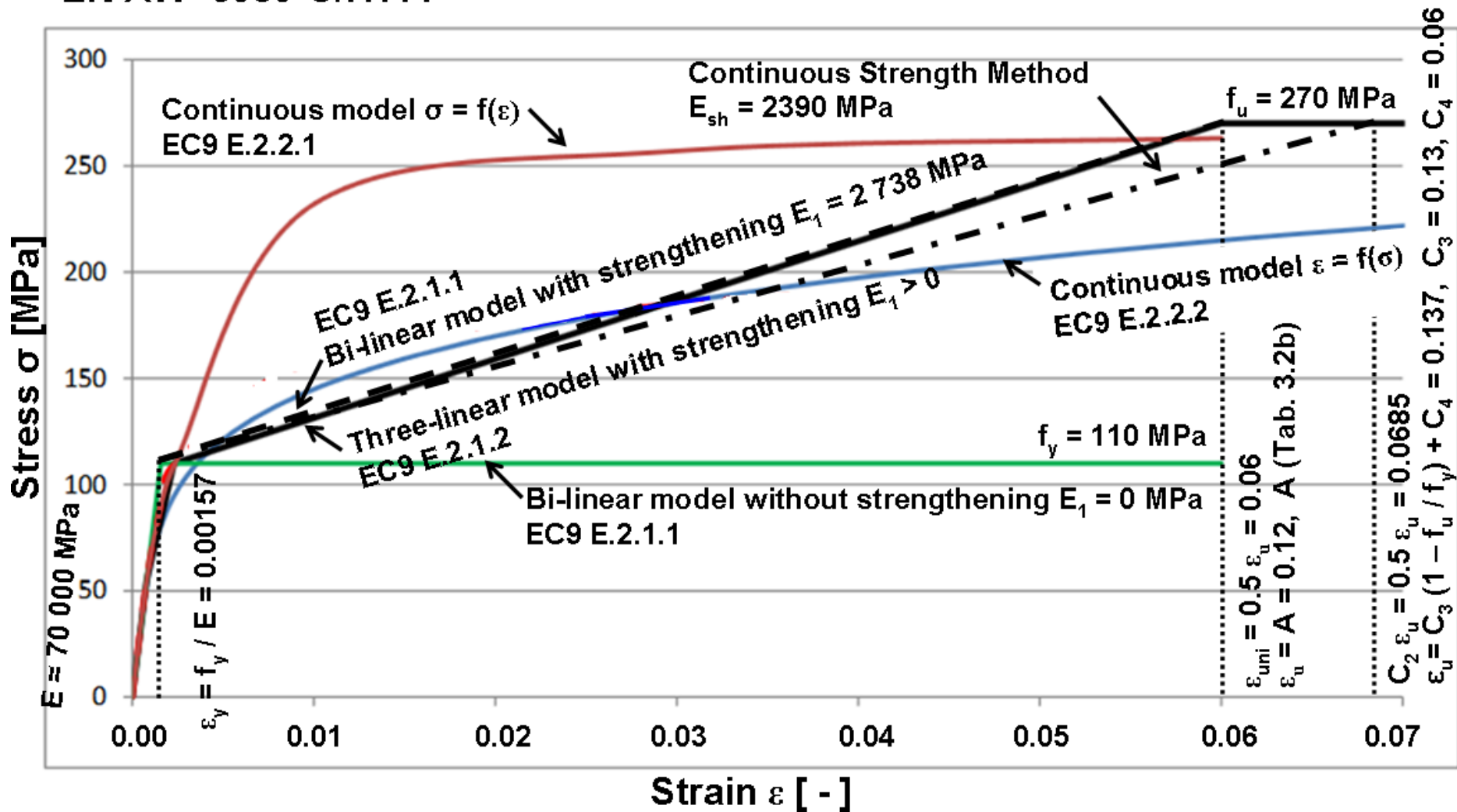
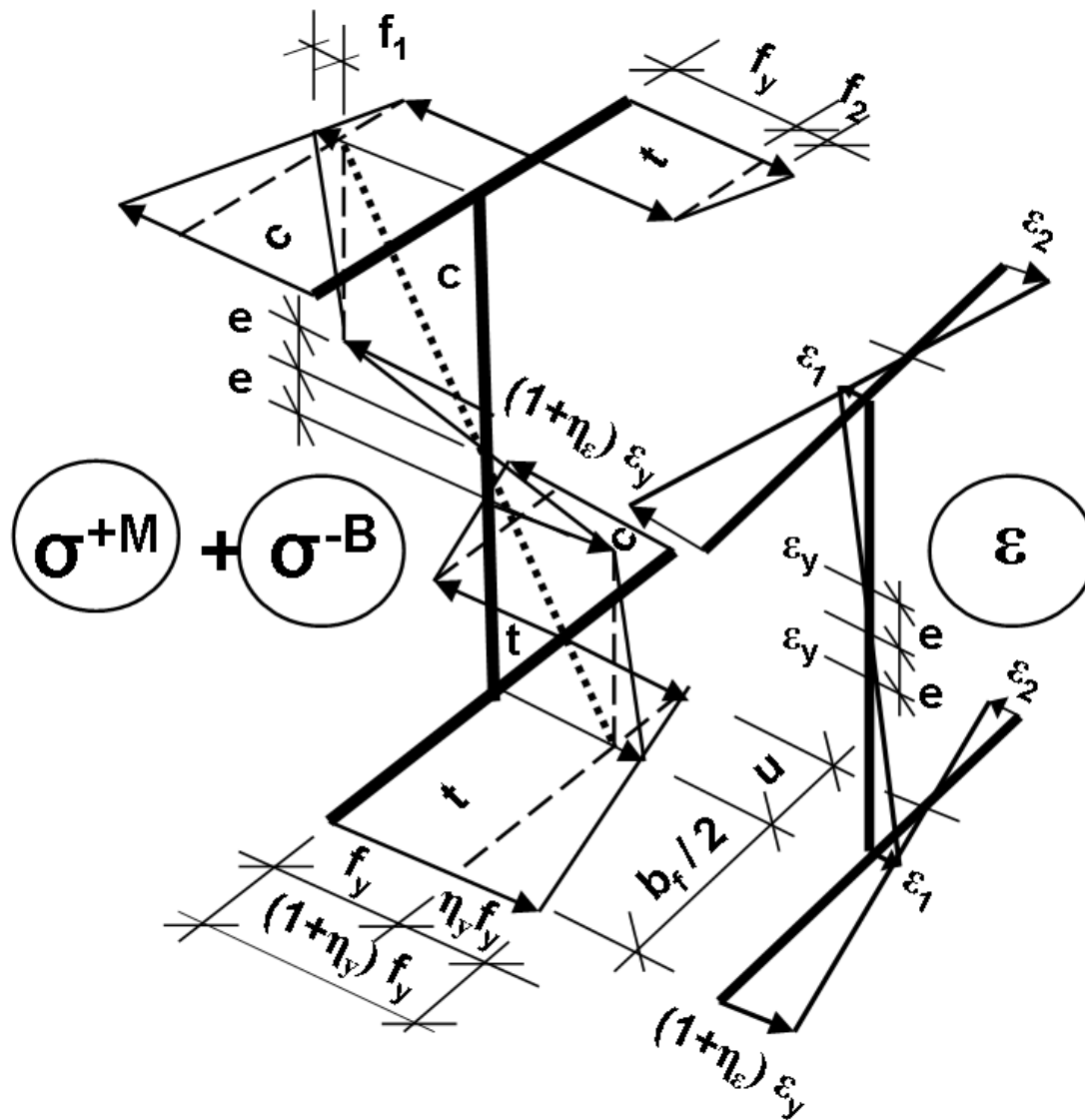


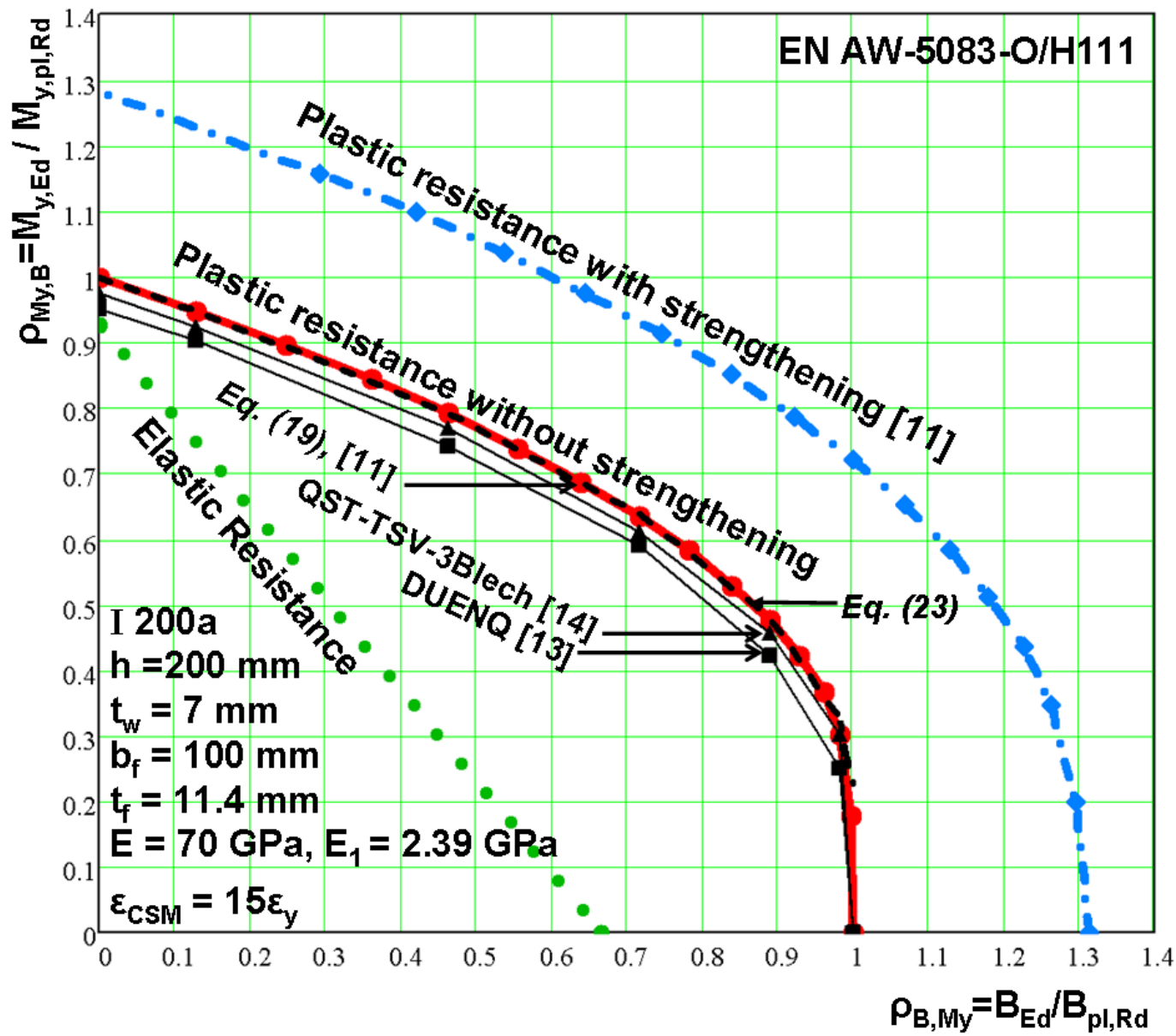
Table 1: Summary of coefficients for CSM material model

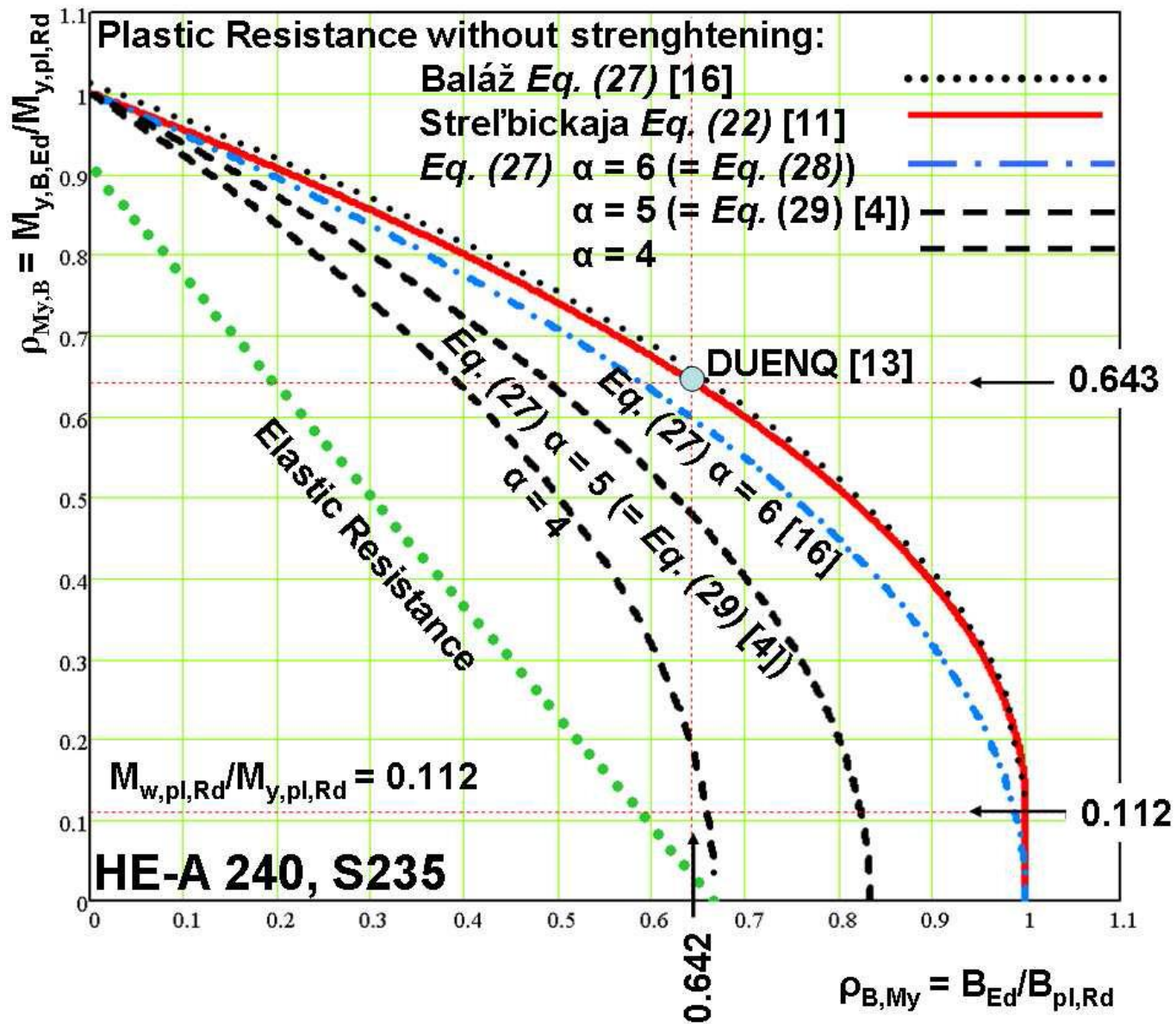
	C_1	C_2	C_3	C_4
Cold-formed steel	0.40	0.45	0.60	0
Austenitic and duplex stainless steel	0.10	0.16	1.00	0
Ferritic stainless steel	0.40	0.45	0.60	0
Aluminium	0.50	0.50	0.13	0.06

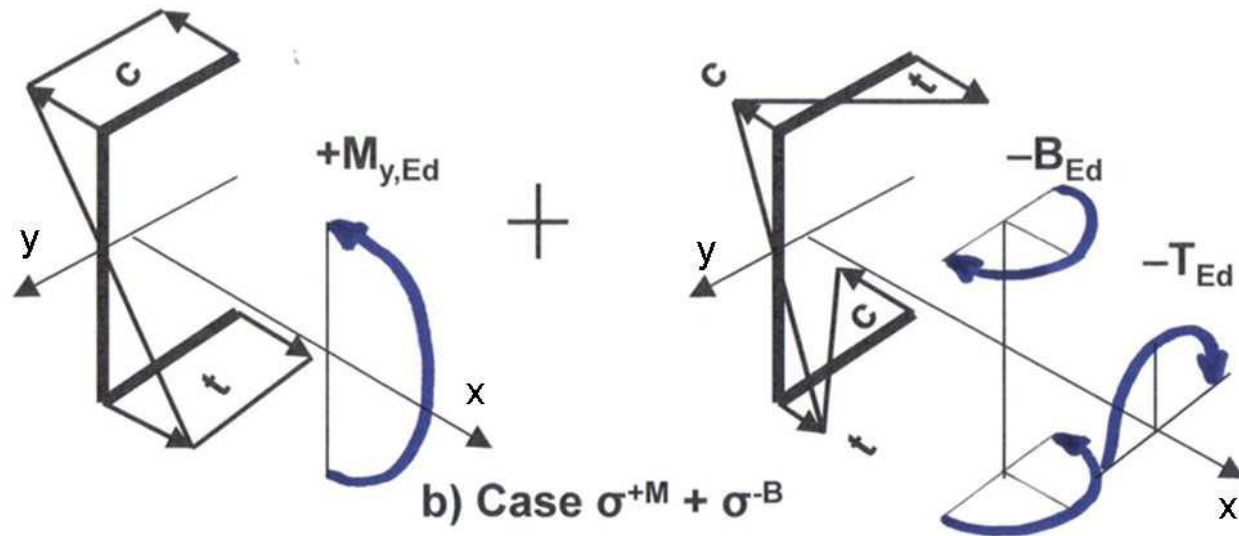
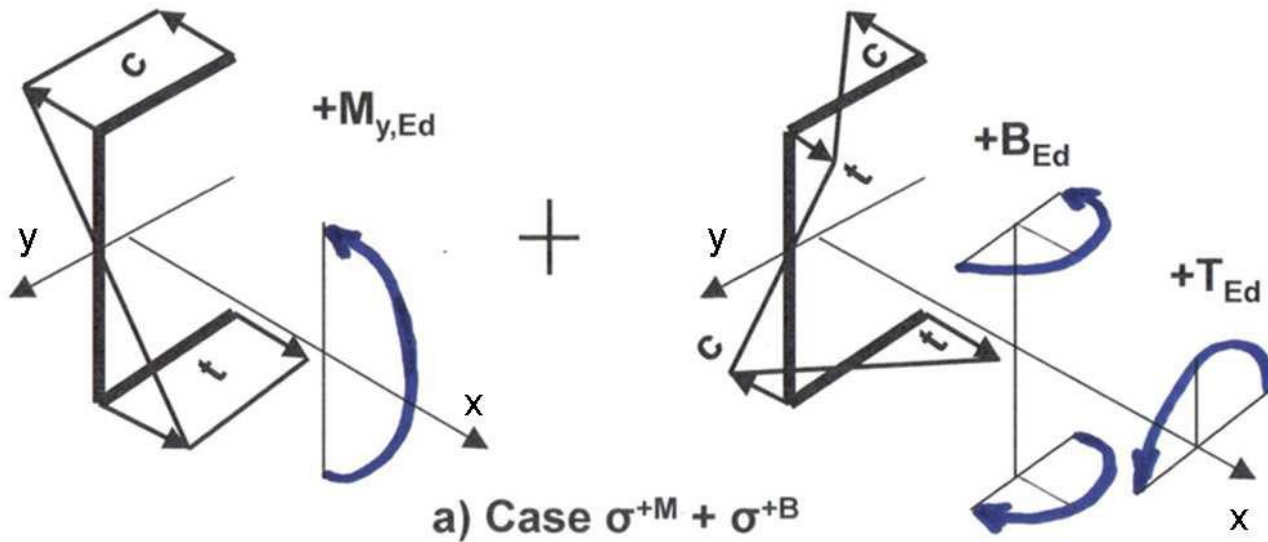
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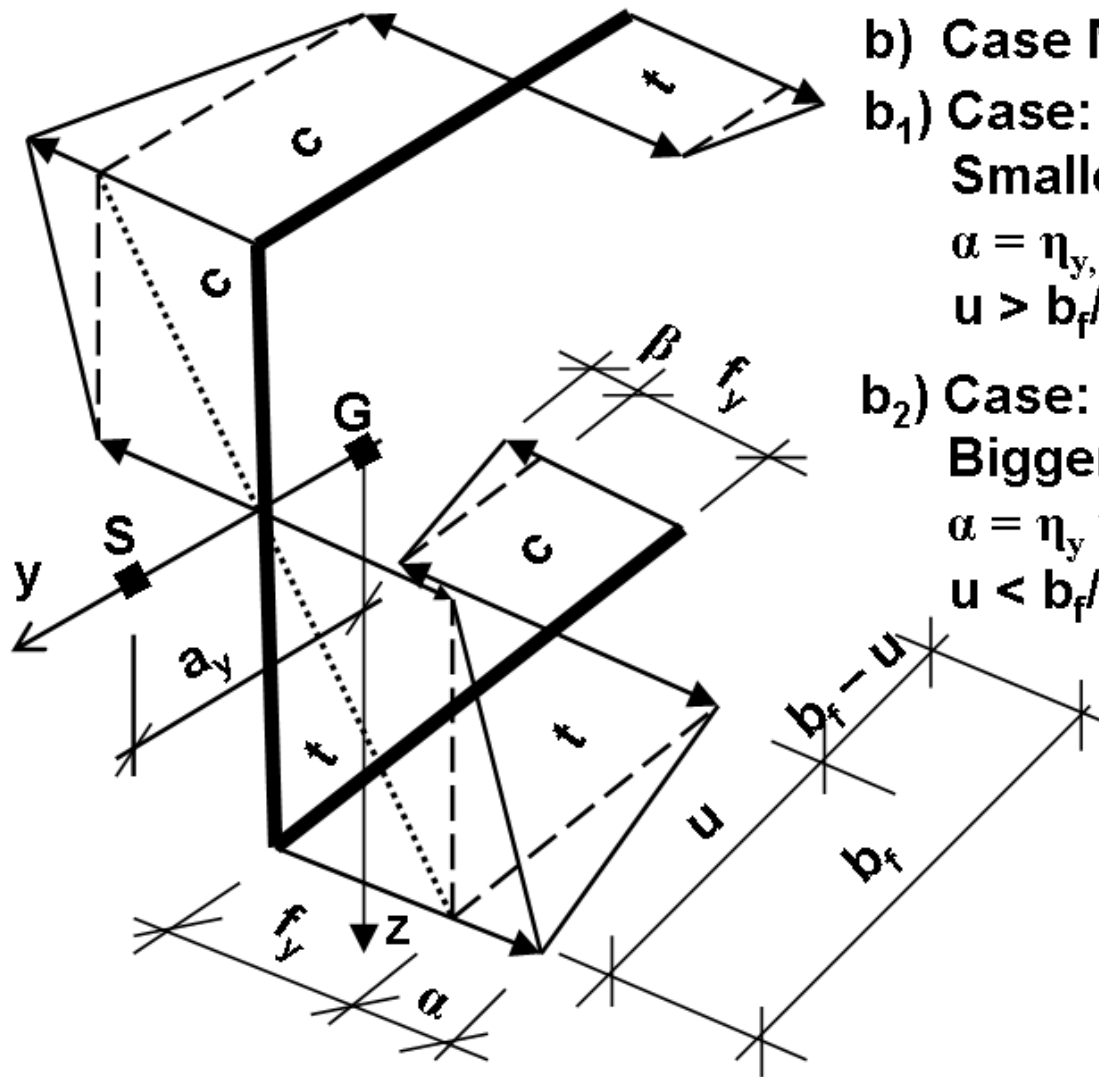












b) Case $M_{y,Ed} +$ negative B_{Ed}

b₁) Case:

Smaller bimoment

$$\alpha = \eta_y, \quad \beta = \eta_y (b_f - u) / u$$

$$u > b_f/2, \quad \alpha > \beta$$

b₂) Case:

Bigger bimoment

$$\alpha = \eta_y u / (b_f - u), \quad \beta = \eta_y$$

$$u < b_f/2, \quad \alpha < \beta$$

