GENERALIZATION OF UNIQUE GLOBAL AND LOCAL INITIAL IMPERFECTION USED IN EN 1993-1-1 AND EN 1999-1-1




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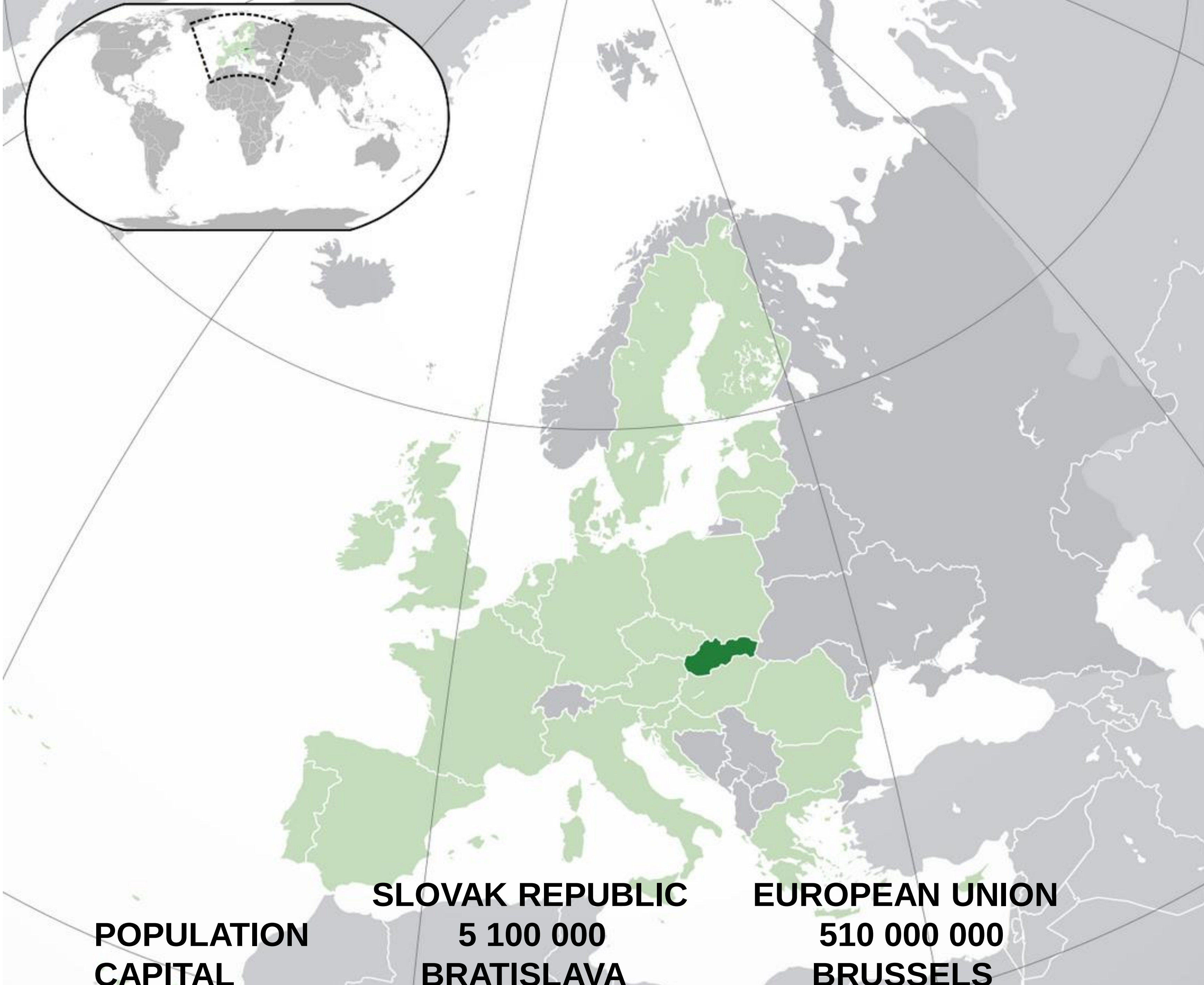
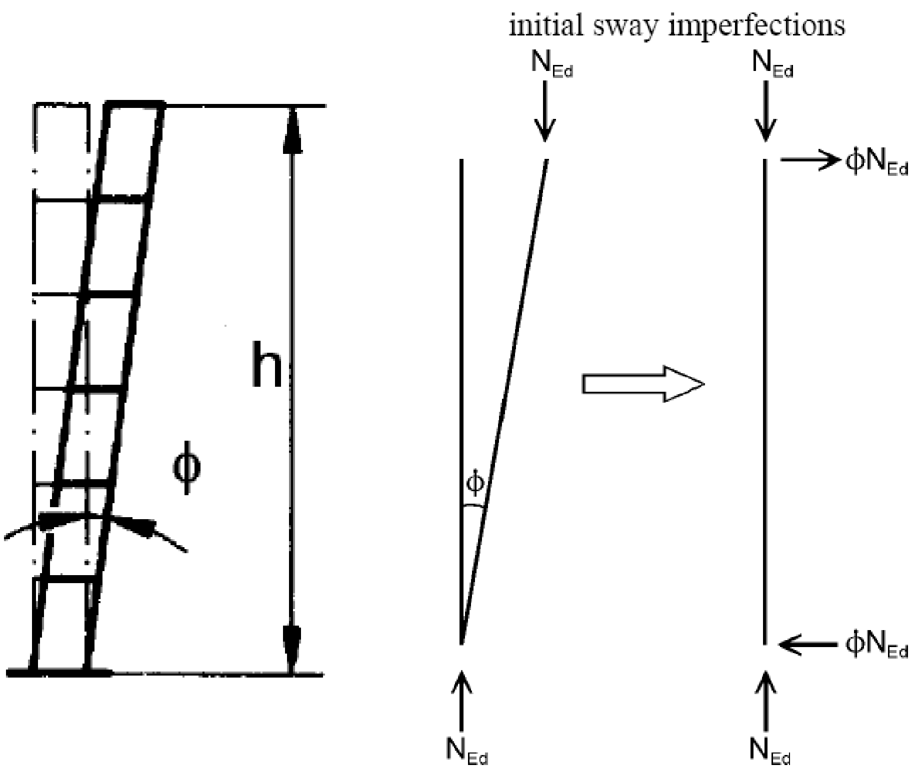


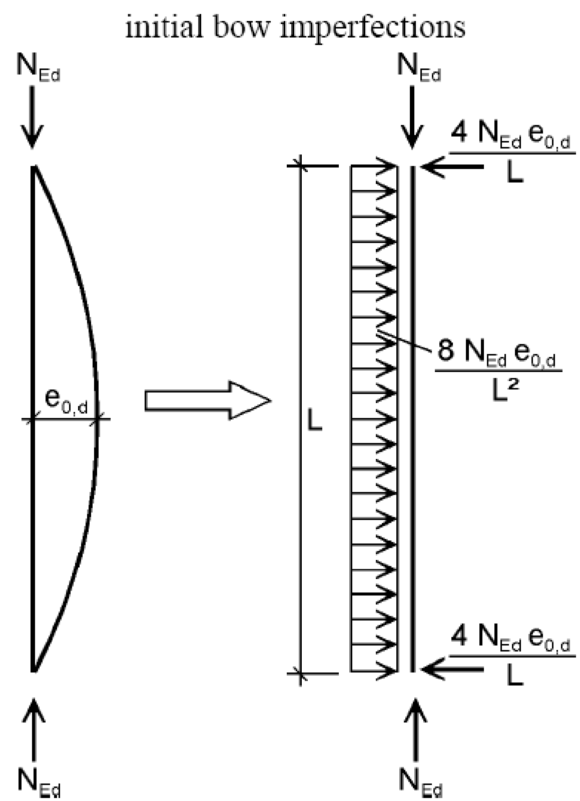
	SLOVAK REPUBLIC	EUROPEAN UNION
POPULATION	5 100 000	510 000 000
CAPITAL	BRATISLAVA	BRUSSELS

Imperfections in EN 1993-1-1 Design of steel structures & in EN 1999-1-1 Design of aluminum structures

a) global initial sway imperfections

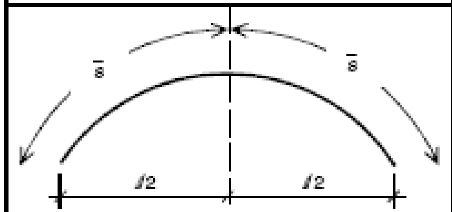
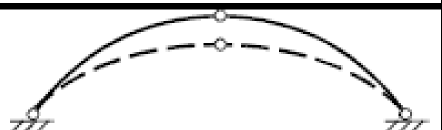
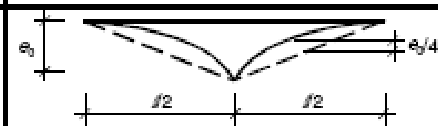
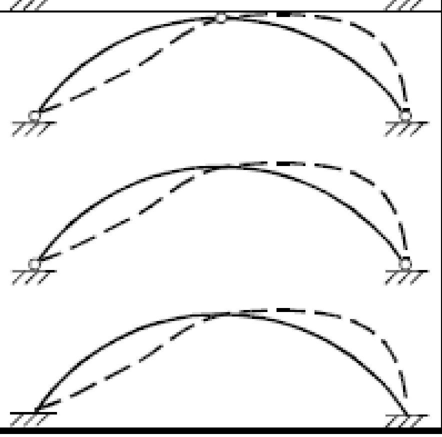
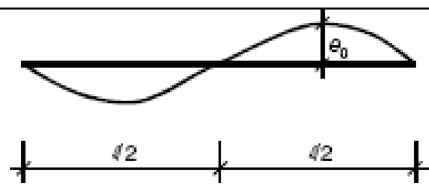


b) initial local bow imperfection



Imperfections in EN 1993-2 Design of steel bridges

Table D.8: Shape and amplitudes of imperfections for in plane buckling of arches

	1	2	3			
		shape of imperfection (sinus or parabola)	e_0 according to classification of cross section to buckling curve			
			a	b	c	d
1			$\frac{s}{300}$	$\frac{s}{250}$	$\frac{s}{200}$	$\frac{s}{150}$
2			$\frac{\ell}{600}$	$\frac{\ell}{500}$	$\frac{\ell}{400}$	$\frac{\ell}{300}$

Beautiful UGLI imperfection according to 5.3.2(11)

As an alternative, the shape of the elastic critical buckling mode η_{cr} of the structure may be applied as a

Unique Global and Local Initial (UGLI) imperfection

The advantages of such an approach are:

- this form is the most effective compared with other shapes of the initial lack of straightness
- this form of the $\eta_{init,m}$ imperfection can be adopted for all types and forms of frame structure
- the shape of the elastic critical buckling mode is very suitable for second-order calculations of deformations and internal forces in compressed members with imperfections and in frame structures with such members

Differencies between 5.3.2(11) in EN 1993-1-1 and 5.3.2(11) in EN 1999-1-1

- 5.3.2(11) in EN 1993-1-1 is limited to the cases with uniform member cross-sections and uniform distributions of normal force.

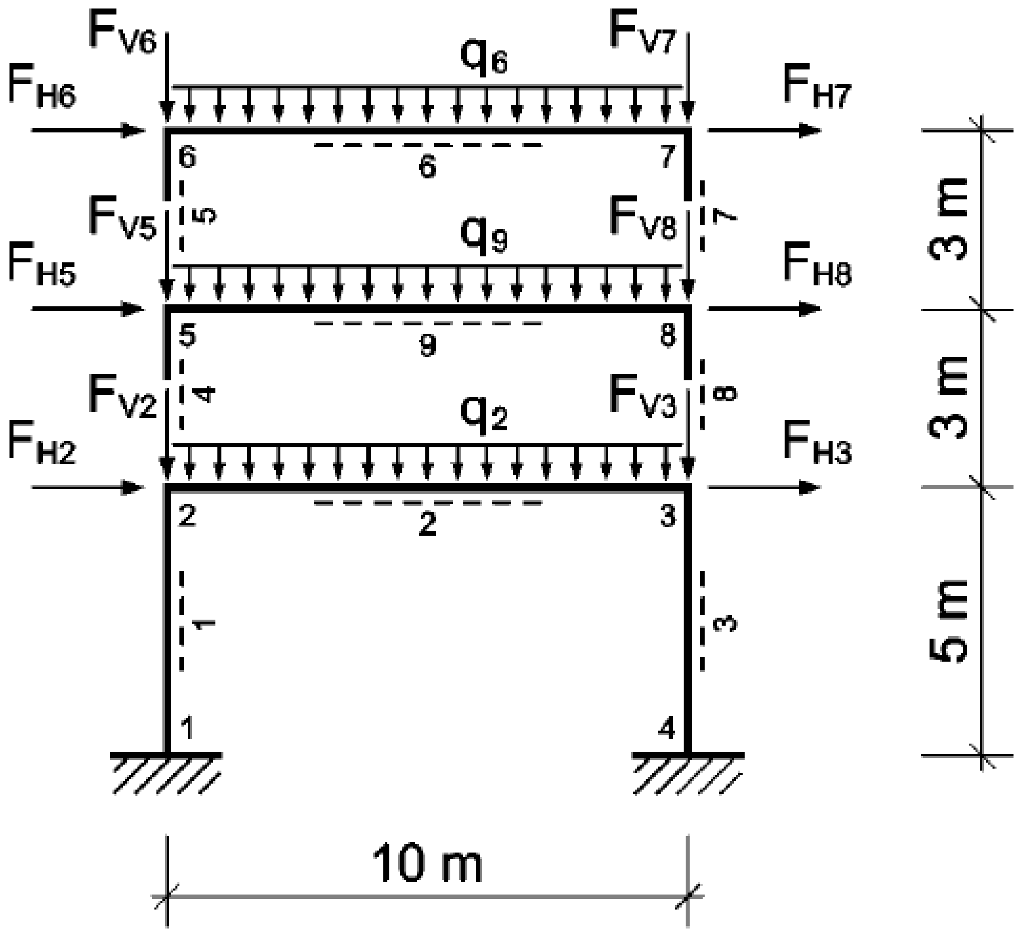
- 5.3.2(11) in EN 1999-1-1 is more general without above restrictions and written in more clear way.

Author of this approach

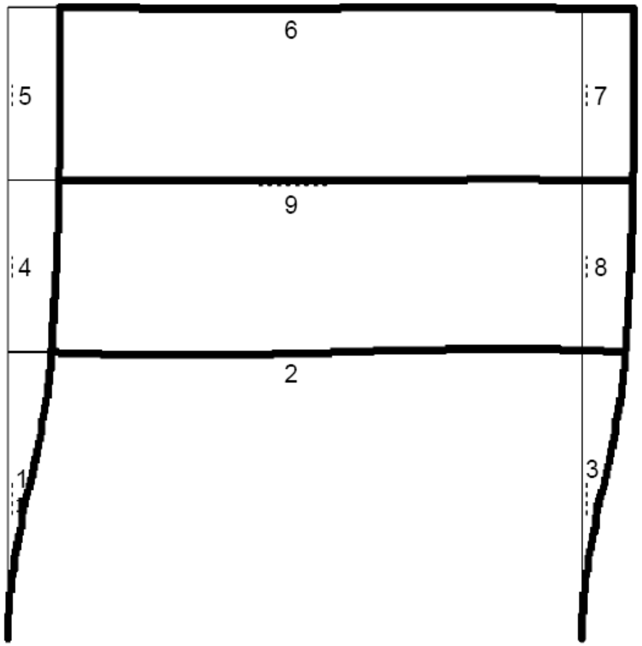
Prof. Emeritus Ing. Eugen Chladný, PhD., (*1928)
STU in Bratislava, Slovak Republic

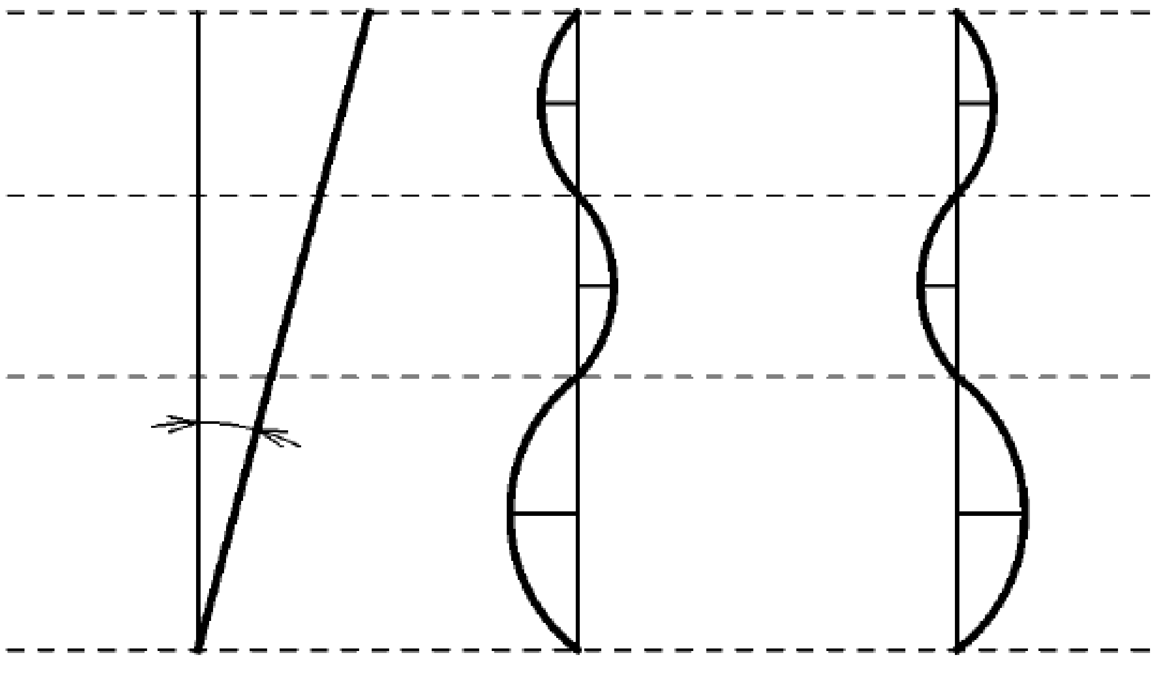
Bridge of SNP in BRATISLAVA,
r.1972, 303 m, 3 spans, 431,6 m,
6 500 tons of steel, 37 000 vehicles / day.

Application of 5.3.2(11) No. 1

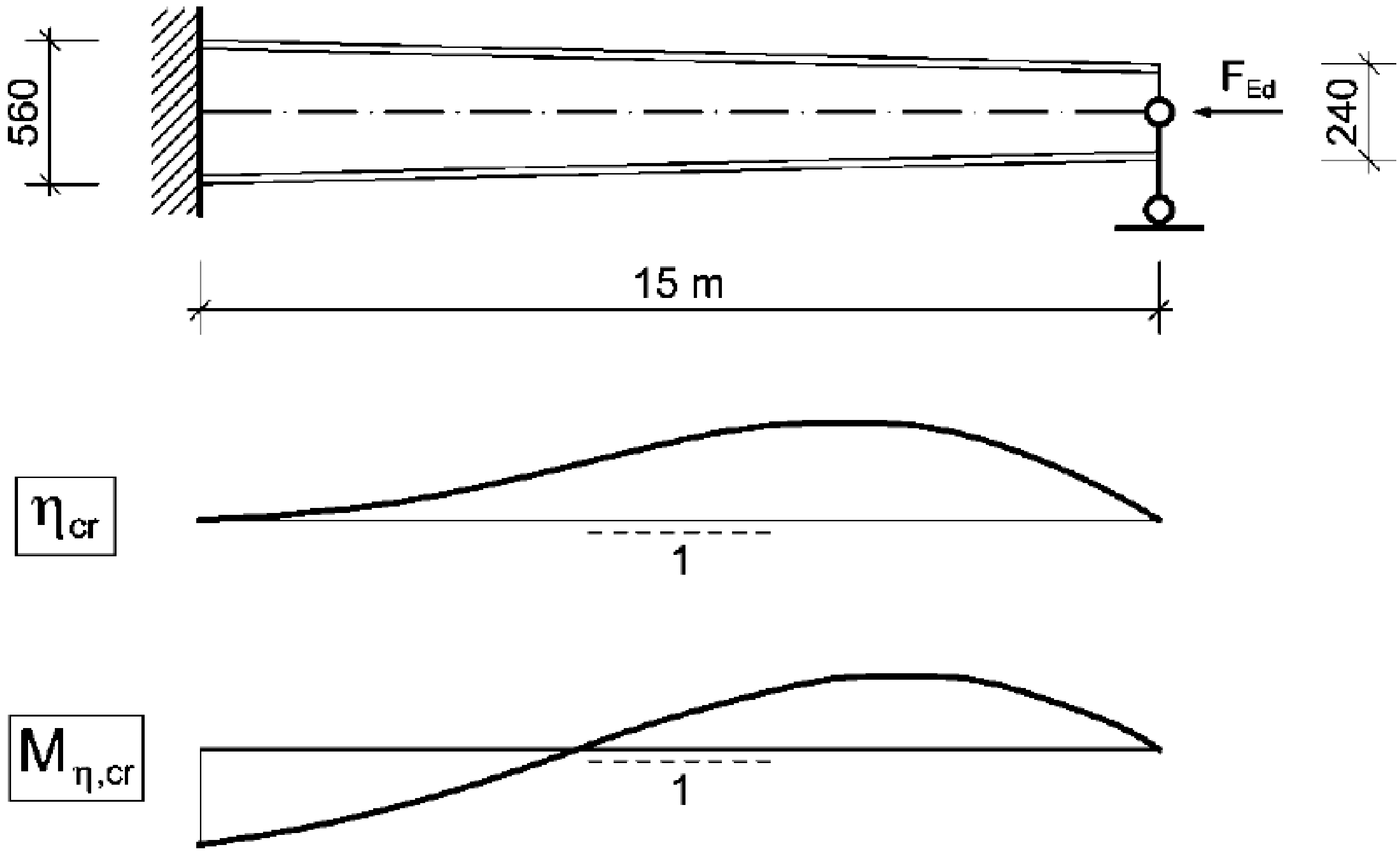


Including comparison of results valid for different kinds of imperfections





Application of 5.3.2(11) No. 2



Application of 5.3.2(11) No. 3

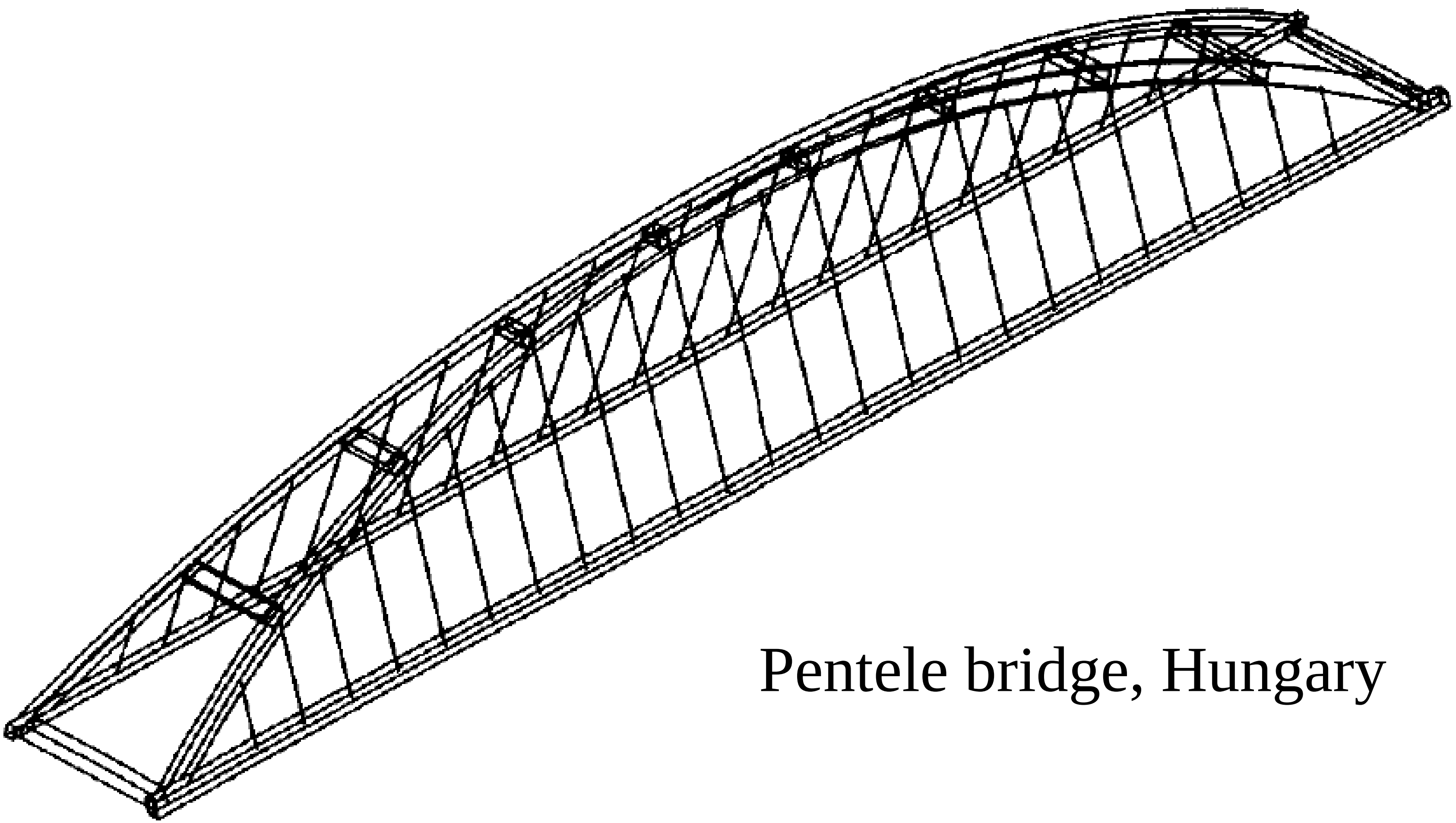
Apollo Bridge over Danube River in Bratislava (2005)

European Steel Design Awards in 2005 for outstanding design.
The only European project named one of five finalists for the 2006 Outstanding Civil Engineering Achievement Award (OPAL Award) by the American Society of Civil Engineers

Application of 5.3.2(11) No. 4

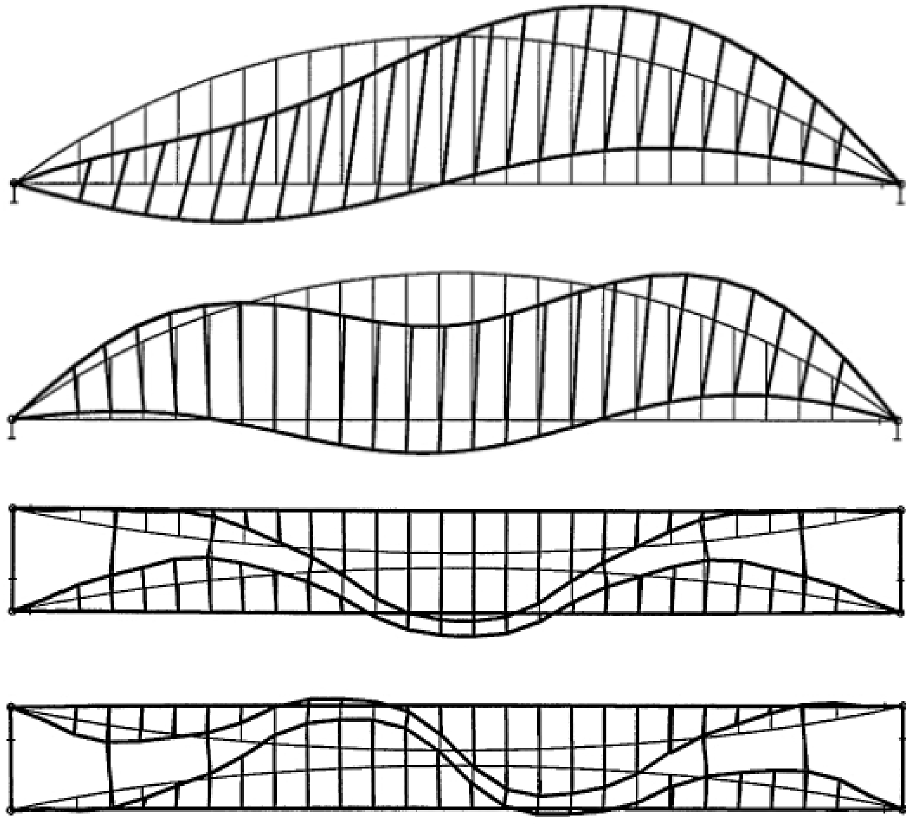
Pentele Bridge over Danube River near Dunaújváros, Hungary (2007).
The preliminary design was made at STU in Bratislava, Slovakia.

Application of 5.3.2(11) No. 4



Pentele bridge, Hungary

First two buckling modes of Pentele arch bridge in vertical and horizontal directions

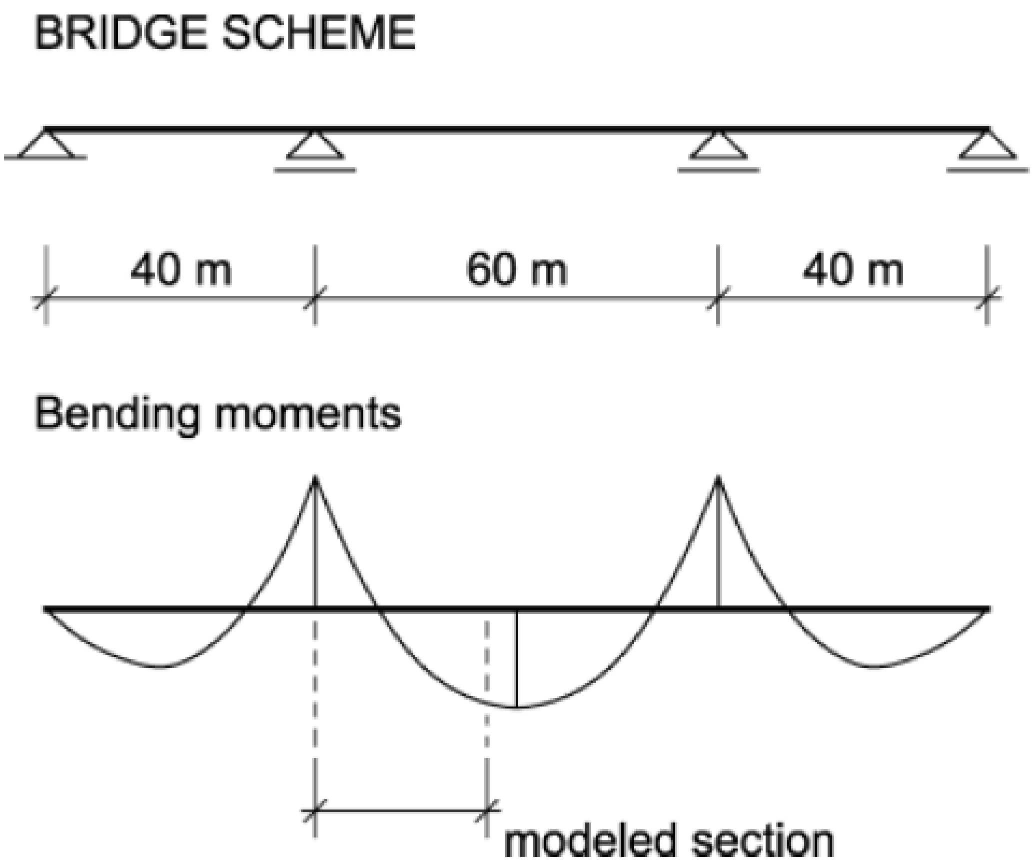


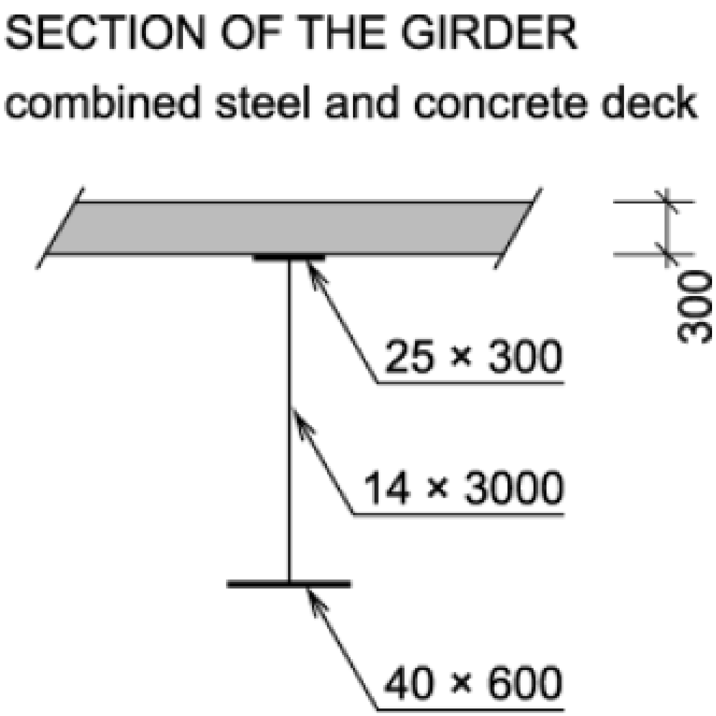
Application of 5.3.2(11) No. 5

Stability problems in the bottom flanges of road continuous bridge girders

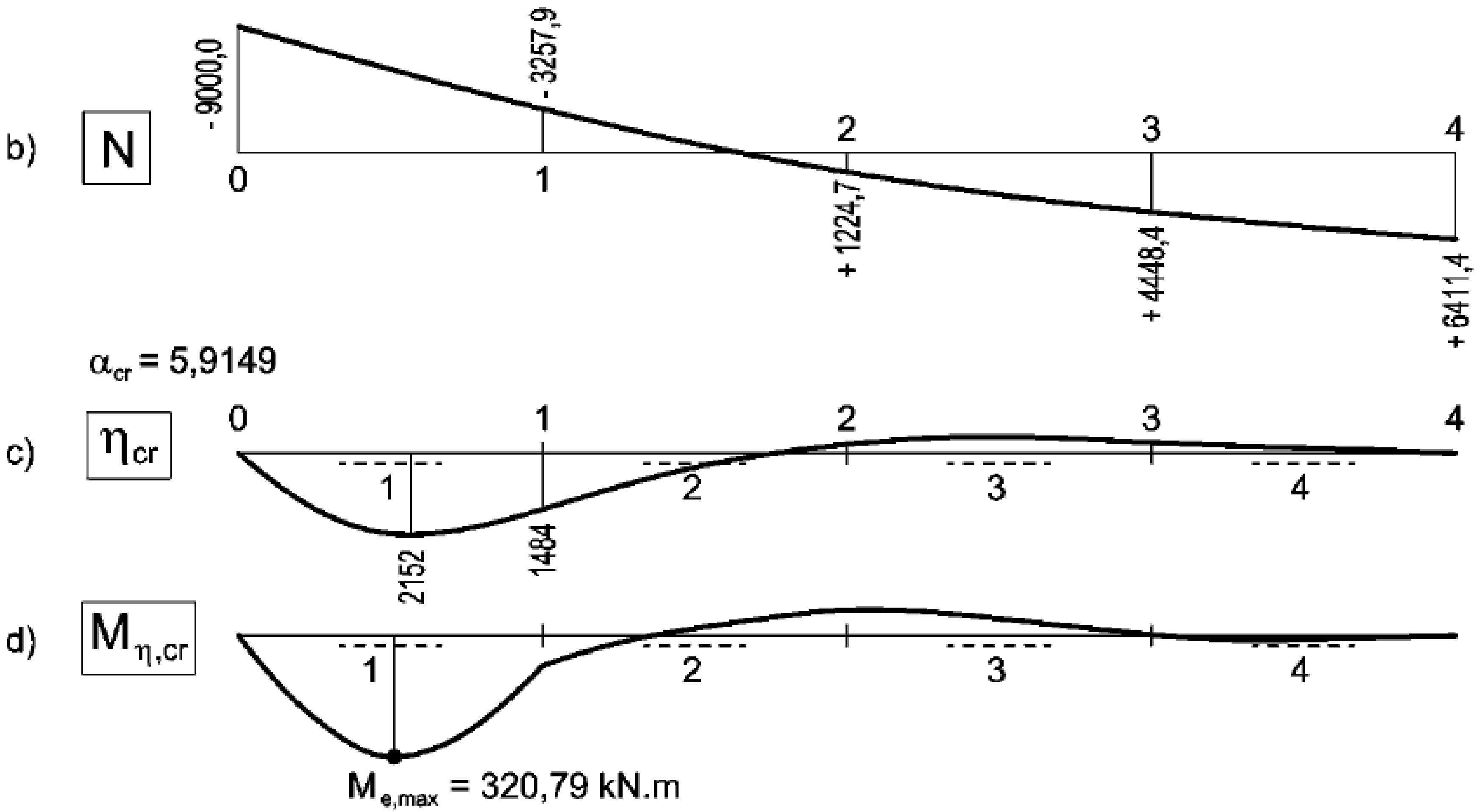
A three-span continuous road bridge with main span L = 60 m will be considered (Fig. 9). The bridge has an upper deck connected to the upper flanges of the three main girders and rigid cross-bracing at the supports only. Between the supports, elastic U-frames prevent distortional deformation of bridge cross-section and restrain the bottom, compression, flanges of the main girders. The U-frames are spaced 6 m apart in the main span. The material used for the main girders is steel grade S 355, $\gamma_{M1} = 1.1$.

Application No. 5 of 5.3.2(11)



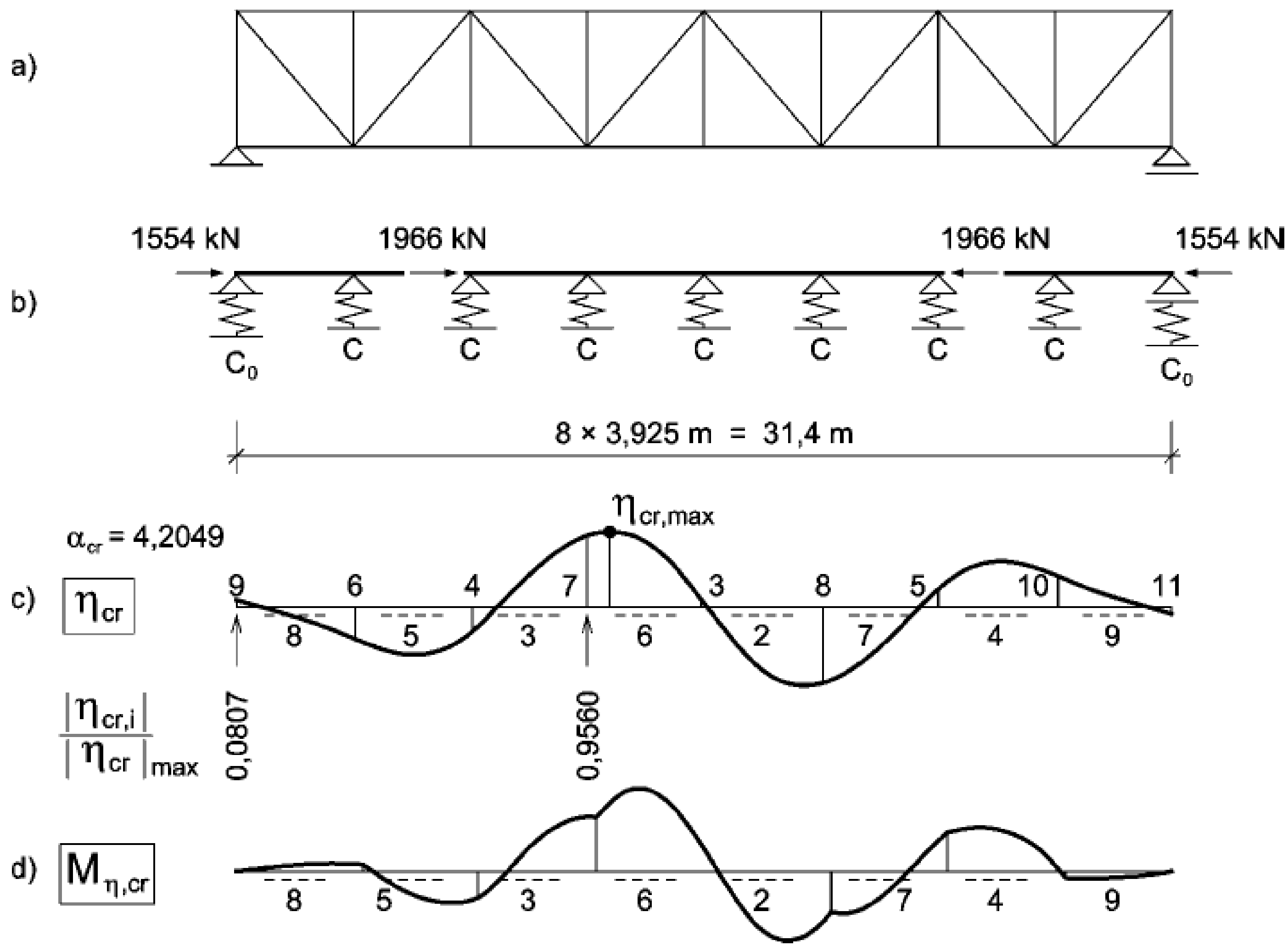


Application of 5.3.2(11) No. 5



Application of 5.3.2(11) No. 6

Upper chord of the railway bridge with open section

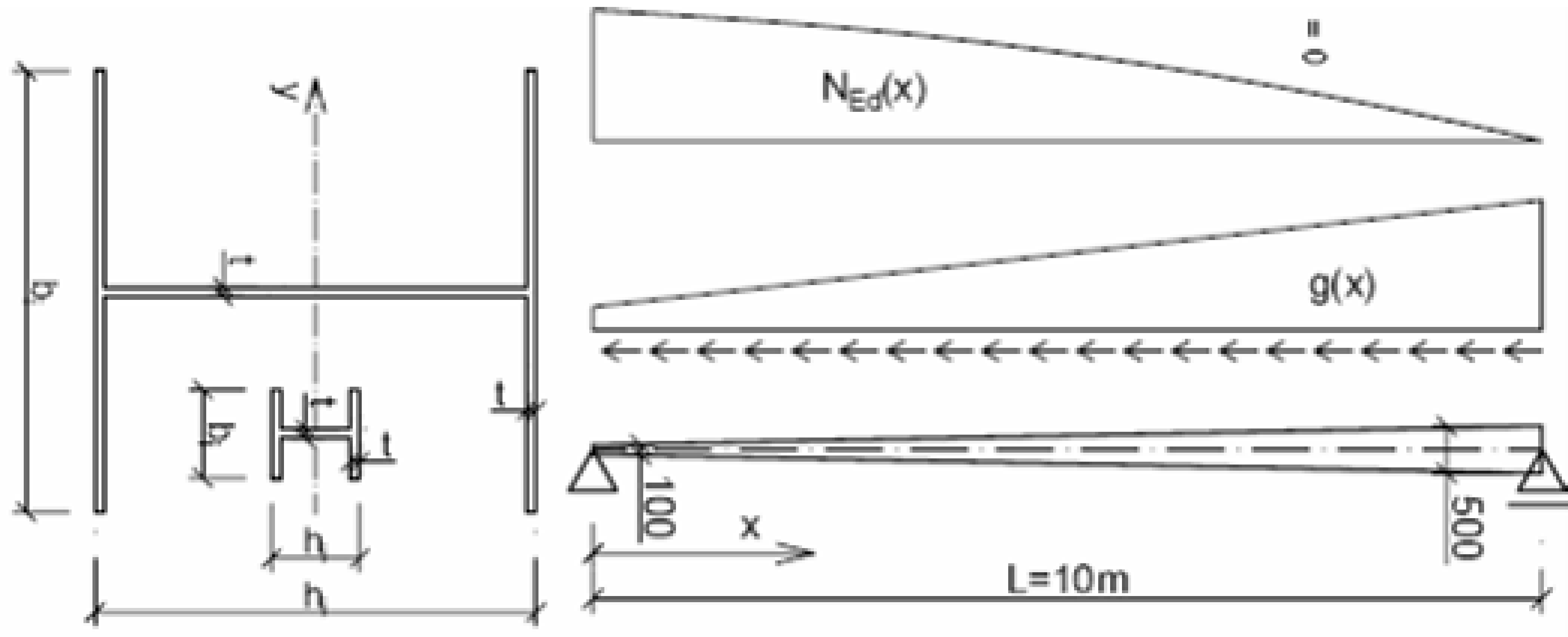


Application of 5.3.2(11) No. 7

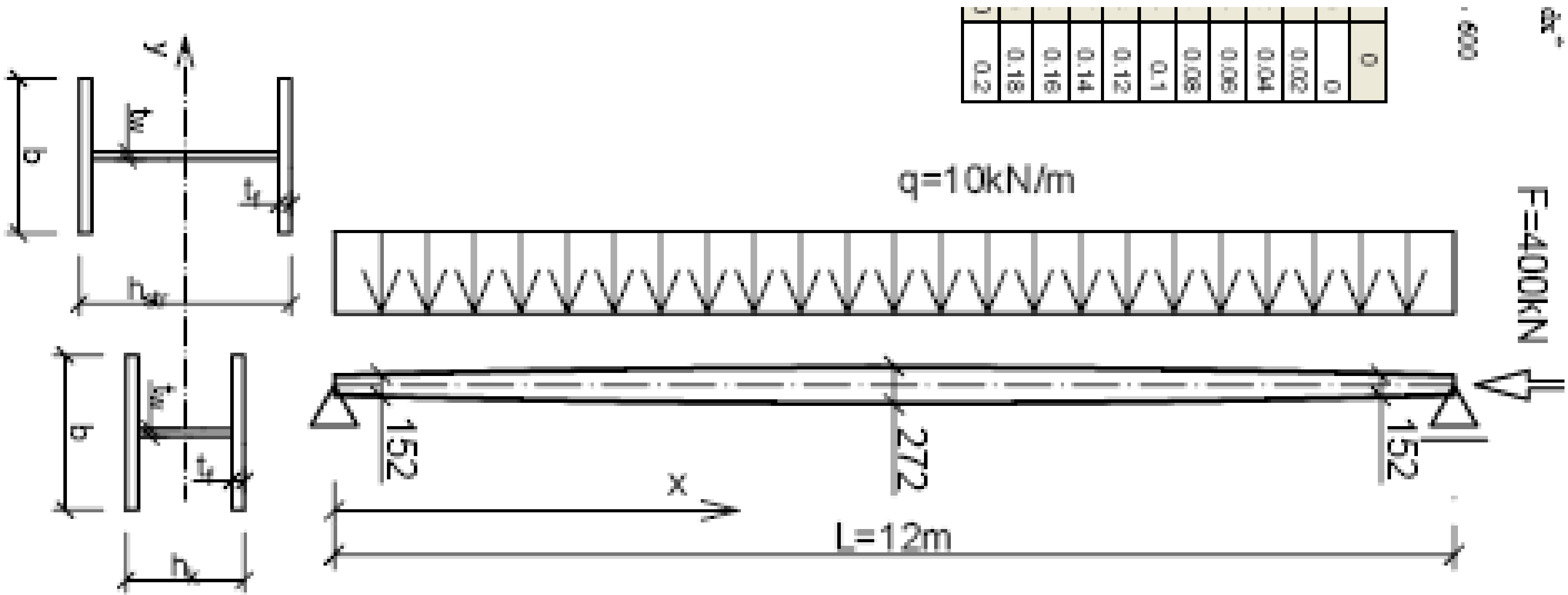
Parameters of the famous Žďákov Bridge, Czech Republic (1965): span $L = 330$ m, rise $f = 42.5$ m

Application of 5.3.2(11) No. 8

SEDLACEK, G. - NAUMES, J. *Excerpt from the Background Document to EN 1993-1-1 – Flexural buckling and lateral buckling on a common basis: Stability assessments according to Eurocode 3.* Aachen: CEN/TC250/SC3. Report N1639E – rev2. March 2009.



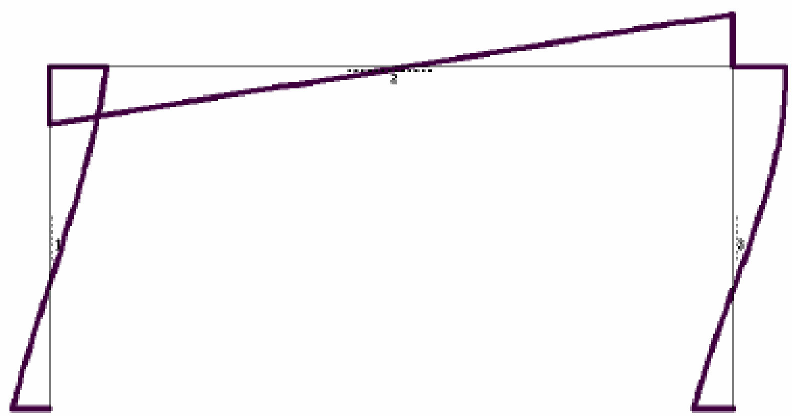
Application of 5.3.2(11) No. 9



Application of 5.3.2(11) No. 10

Frame with flexible supports

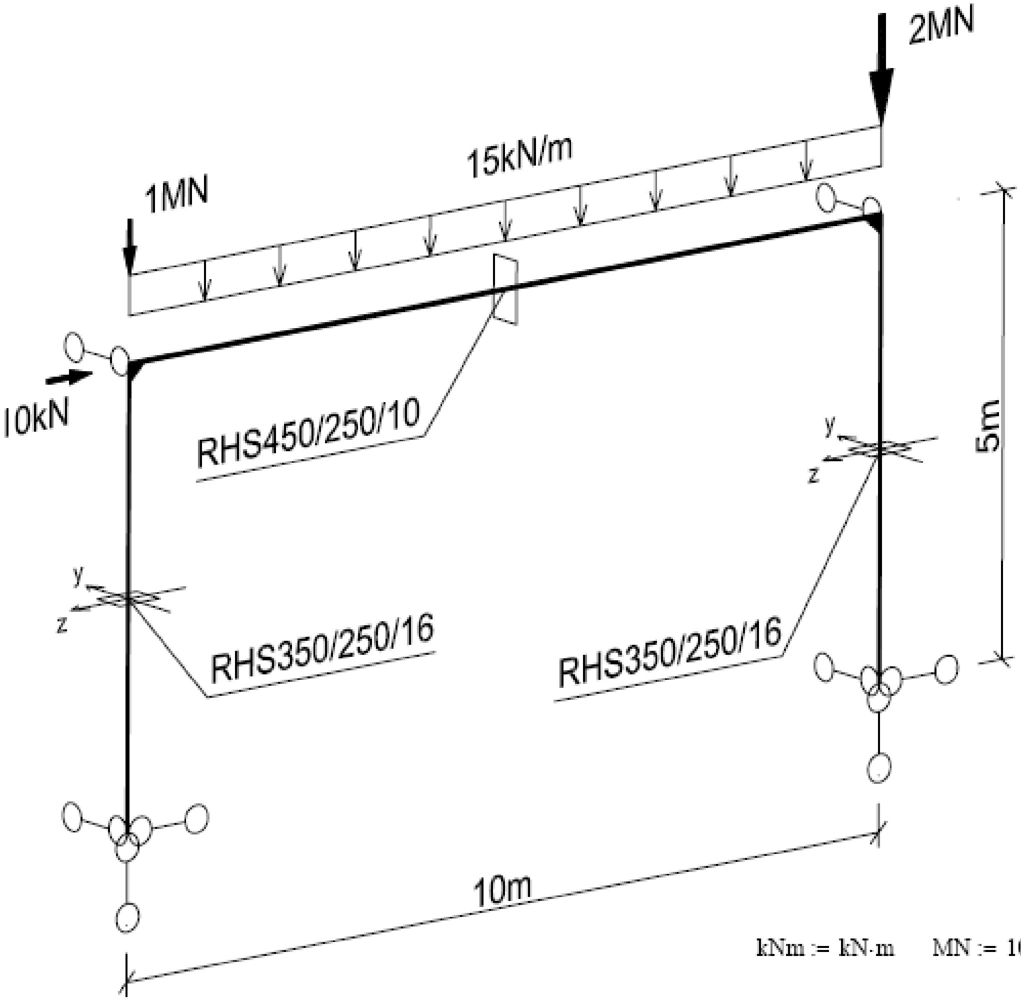
1st buckling mode



point “m”

Bending moments from “ugli” imperfection

Application of 5.3.2(11) No. 11

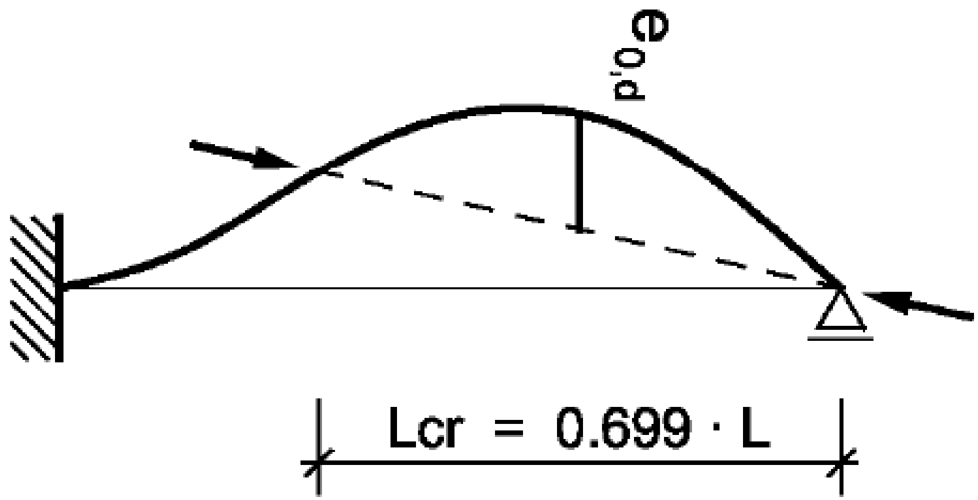


kNm := kN·m   MN := 10^6N

Similar frame was calculated in Stahlbau-Kalender by Lindner, J. – Heyde, S. (2009)

cross-section HE 260 B (ARBED)

$$\alpha_{cr} = \frac{N_{cr,m}}{N_{Ed}} = 3.534, \quad k = \frac{\alpha_{cr}}{\alpha_{cr} - 1} = 1.395, \quad \varepsilon = \frac{\pi}{\beta} = 4.494, \quad \xi = \frac{x}{L}$$



$$\eta_{cr}(x) := \frac{\left[\left(1 - \cos\left(\frac{\varepsilon \cdot x}{L}\right)\right) \cdot \varepsilon + \sin\left(\frac{\varepsilon \cdot x}{L}\right) - \frac{\varepsilon \cdot x}{L}\right]}{C}$$

$$\bar{\eta}(\xi) = \varepsilon(1-\xi) - \varepsilon\cos(\varepsilon\xi) + \sin(\varepsilon\xi)$$

$$\eta 2_{cr}(x) := \frac{\cos\left(\varepsilon \cdot \frac{x}{L}\right) \cdot \frac{\varepsilon^3}{L^2} - \sin\left(\varepsilon \cdot \frac{x}{L}\right) \cdot \frac{\varepsilon^2}{L^2}}{C}$$

cross-section HE 260 B (ARBED)

$$\eta_{ugli}(\xi) = \eta_{0,ugli,m}\eta_{cr}(\xi) = \frac{\alpha_{cr} e_{0,d,m} N_{Ed}}{EI_{z,m}\left|-\eta''_{cr}(\xi_m)\right|}\eta_{cr}(\xi) = \frac{e_{0,d,m} N_{cr,m}}{EI_{z,m}\left|-\eta''_{cr}(\xi_m)\right|}\eta_{cr}(\xi)$$

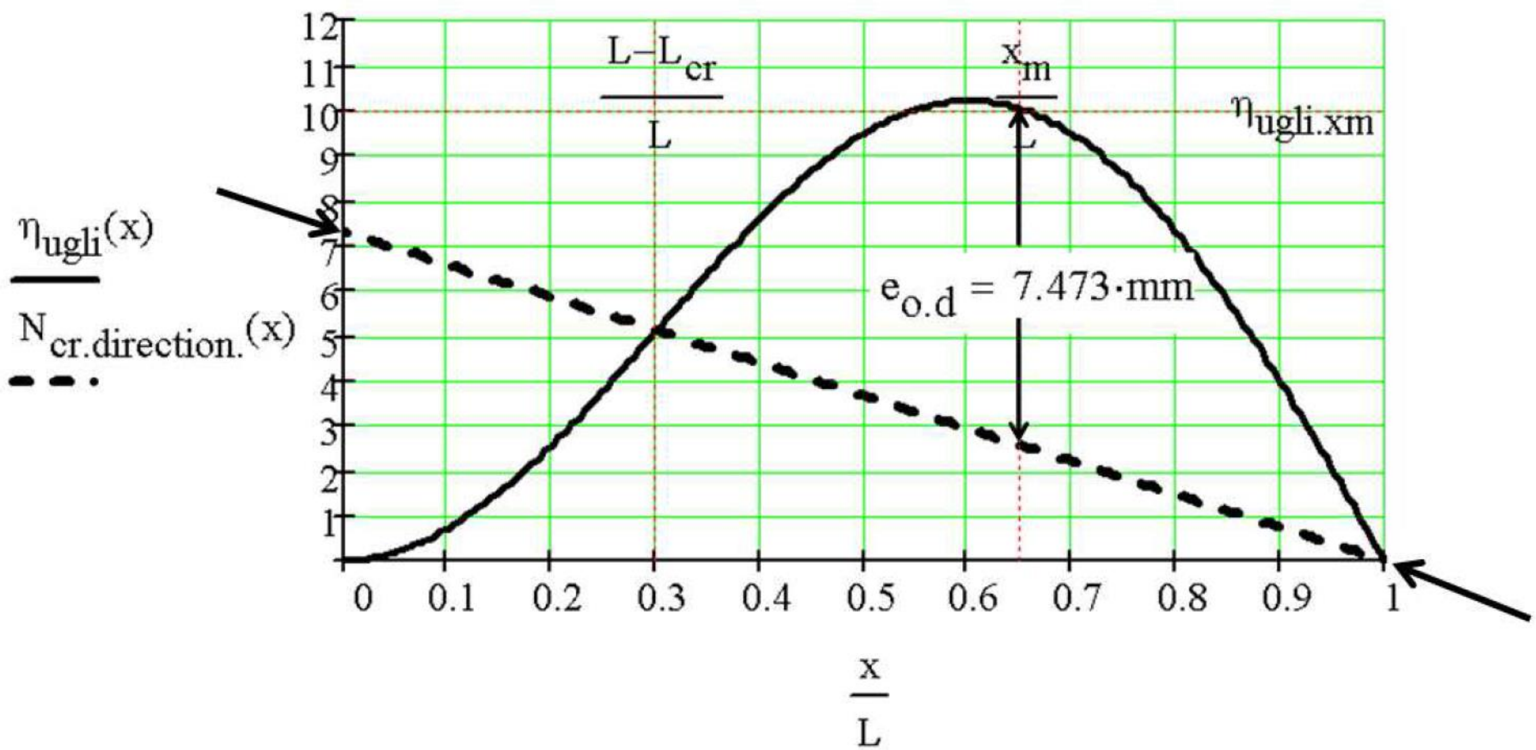


Figure 1: Uniform global and local initial ("ugli") imperfection valid for buckling about z

$$\eta_{II}(\xi) = \frac{\eta_{0,ugli,m}}{\alpha_{cr} - 1}\eta_{cr}(\xi) \tag{39}$$

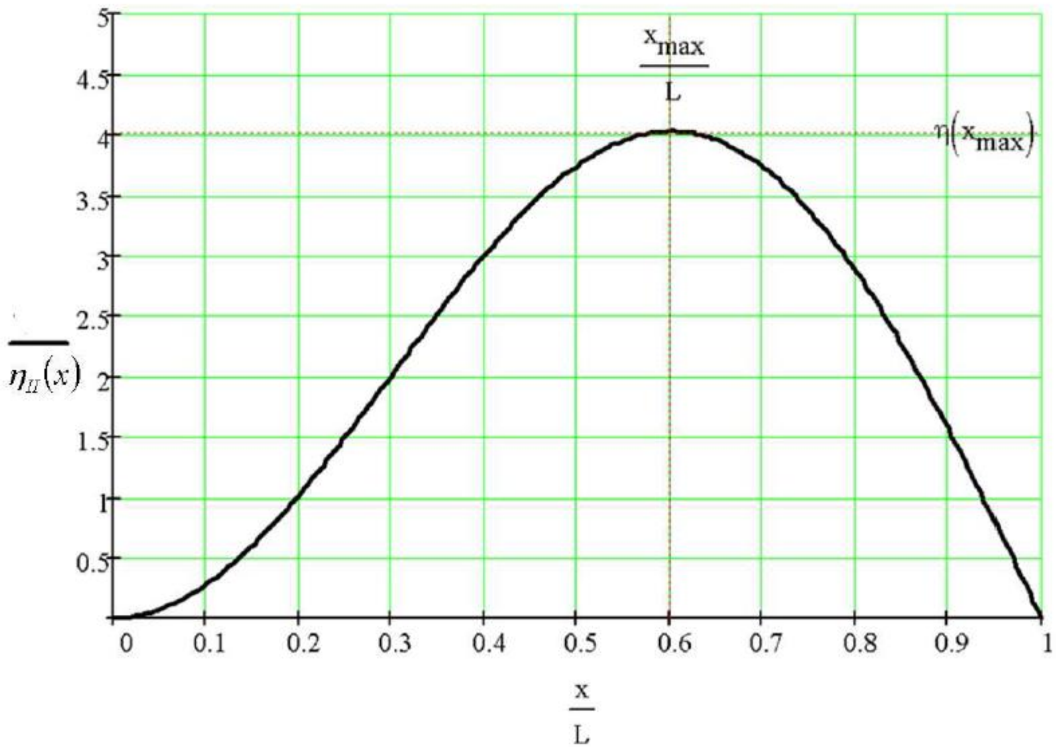


Figure 2: Additive deflection $\eta_{II}(x)$ due to N_{Ed} for flexural buckling about minor axis z-z

The utility measure in the critical section "*m*".

$$U^{II}(\xi_m) = \frac{N_{Ed}}{N_{Rd}} + \left| \frac{M^{II}_{\eta_{ugli}}(\xi_m)}{M_{Rd}} \right| = 0.762 + 0.238 = 1.0$$

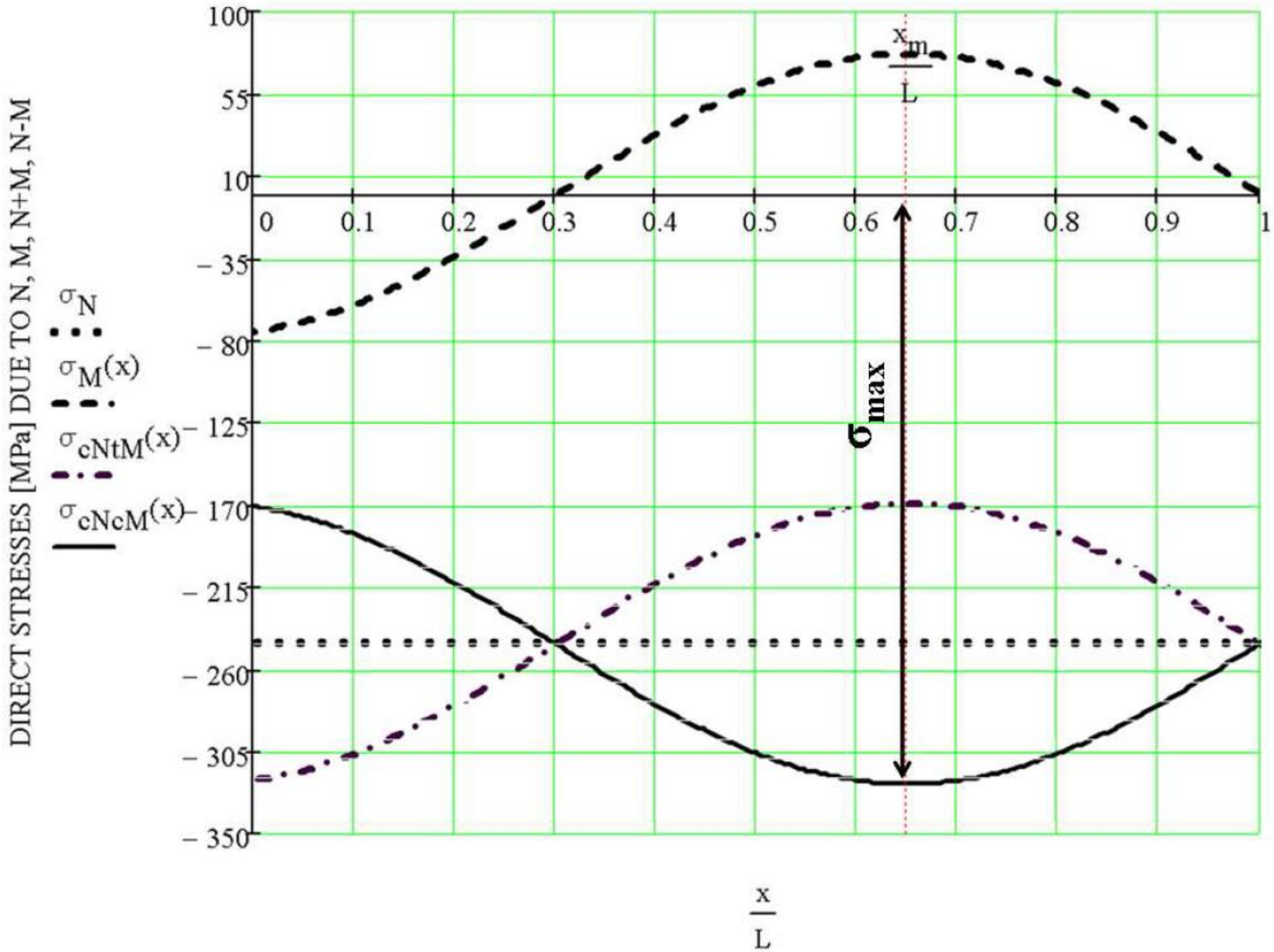


Figure 3: Direct stresses distributions for flexural buckling about minor axis z-z

The utility measure $U^{II}(\xi)$ in the critical section "m"

$$U^{II}(\xi_m) = \frac{N_{Ed}}{N_{Rd}} + \left| \frac{M^{II}_{\eta_{ugli}}(\xi_m)}{M_{Rd}} \right| = 0.762 + 0.238 = 1.0$$

must be the same as the utility measure

in equivalent member method when $N_{Ed} = N_{b,Rd}$.

$$U^{I} = \frac{N_{Ed}}{N_{b,Rd}} = 1.0$$

The buckling resistance in the critical cross-section "m"

$$\overline{\lambda}_m = \sqrt{\frac{N_{Rk,m}}{N_{cr,m}}} = 0.639, \quad \Phi_m = 0.5\left[1 + \alpha_m\left(\overline{\lambda}_m - \overline{\lambda}_0\right) + \overline{\lambda}_m^2\right] = 0.812$$

$$\chi_m = \frac{1}{\Phi_m + \sqrt{\Phi_m^2 - \overline{\lambda}_m^2}} = 0.762, \quad N_{b,Rd,m} = \chi_m N_{Rd,m} = 2911.5kN$$

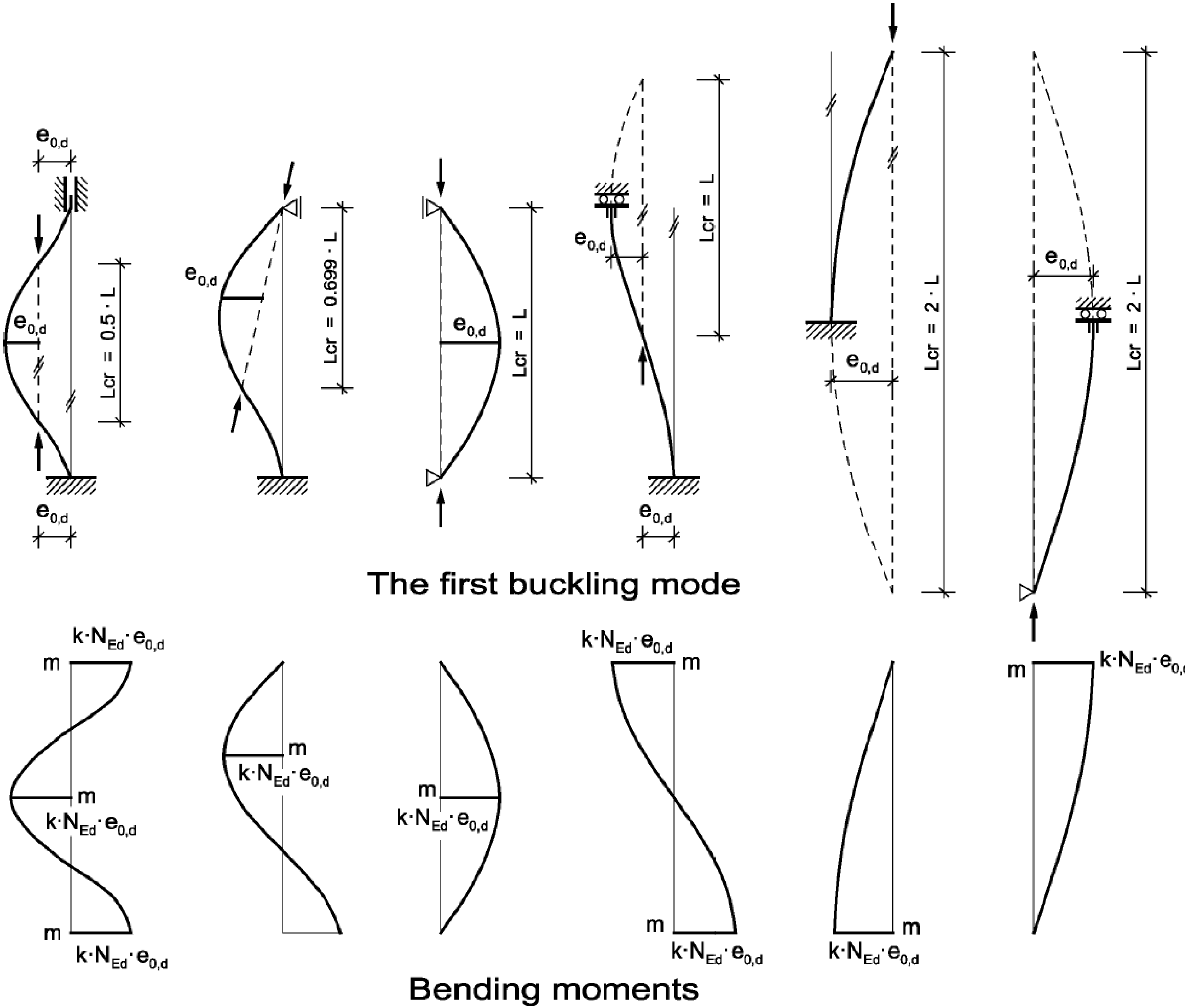
$$\alpha_{cr} = N_{cr}(x) / N_{Ed}(x)$$

$$k = \frac{\alpha_{cr}}{\alpha_{cr} - 1} = \frac{1}{1 - \frac{1}{\alpha_{cr}}}$$

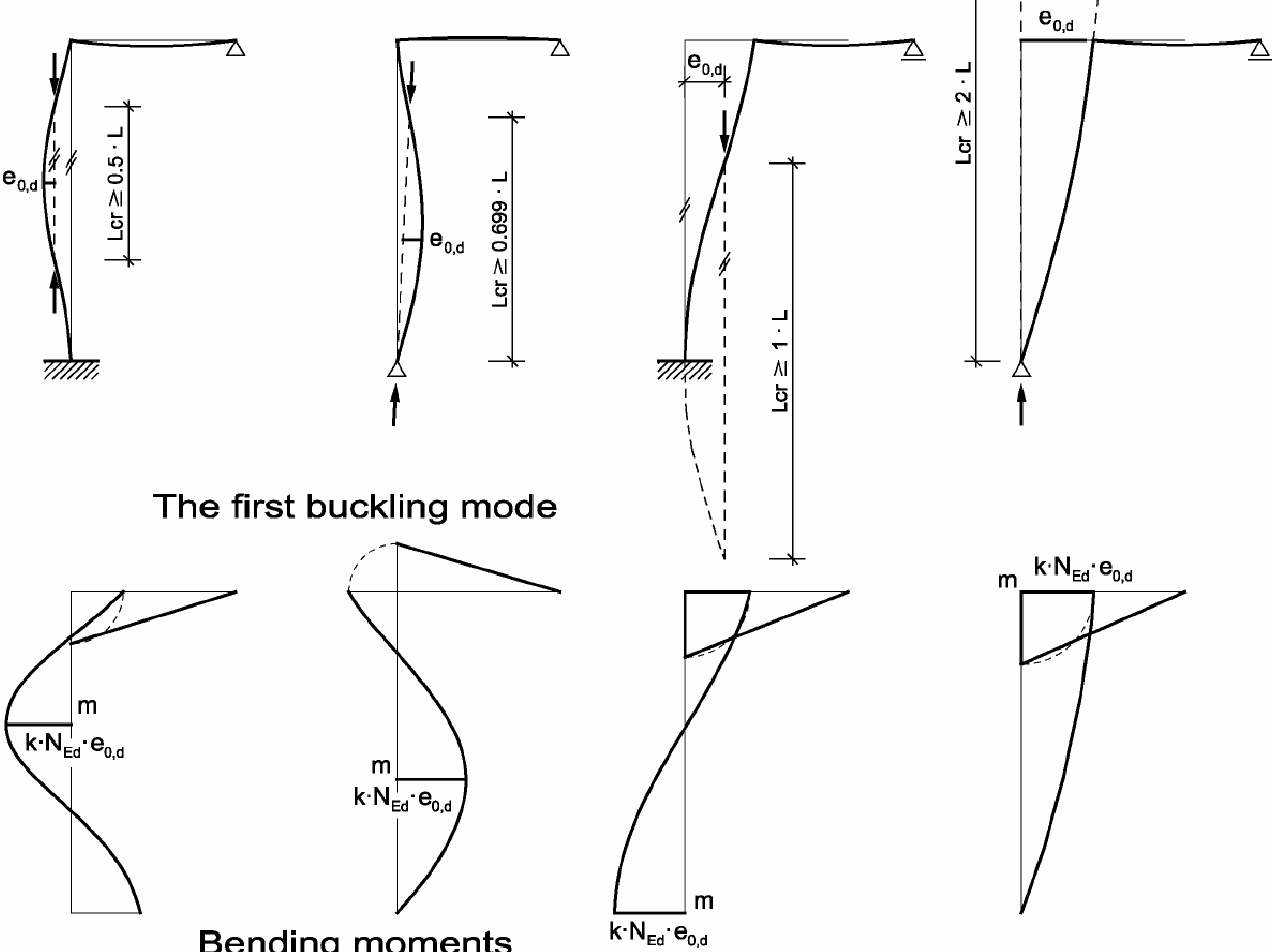
$$M_{II}(x) := -E \cdot I \cdot \eta 2(x)$$

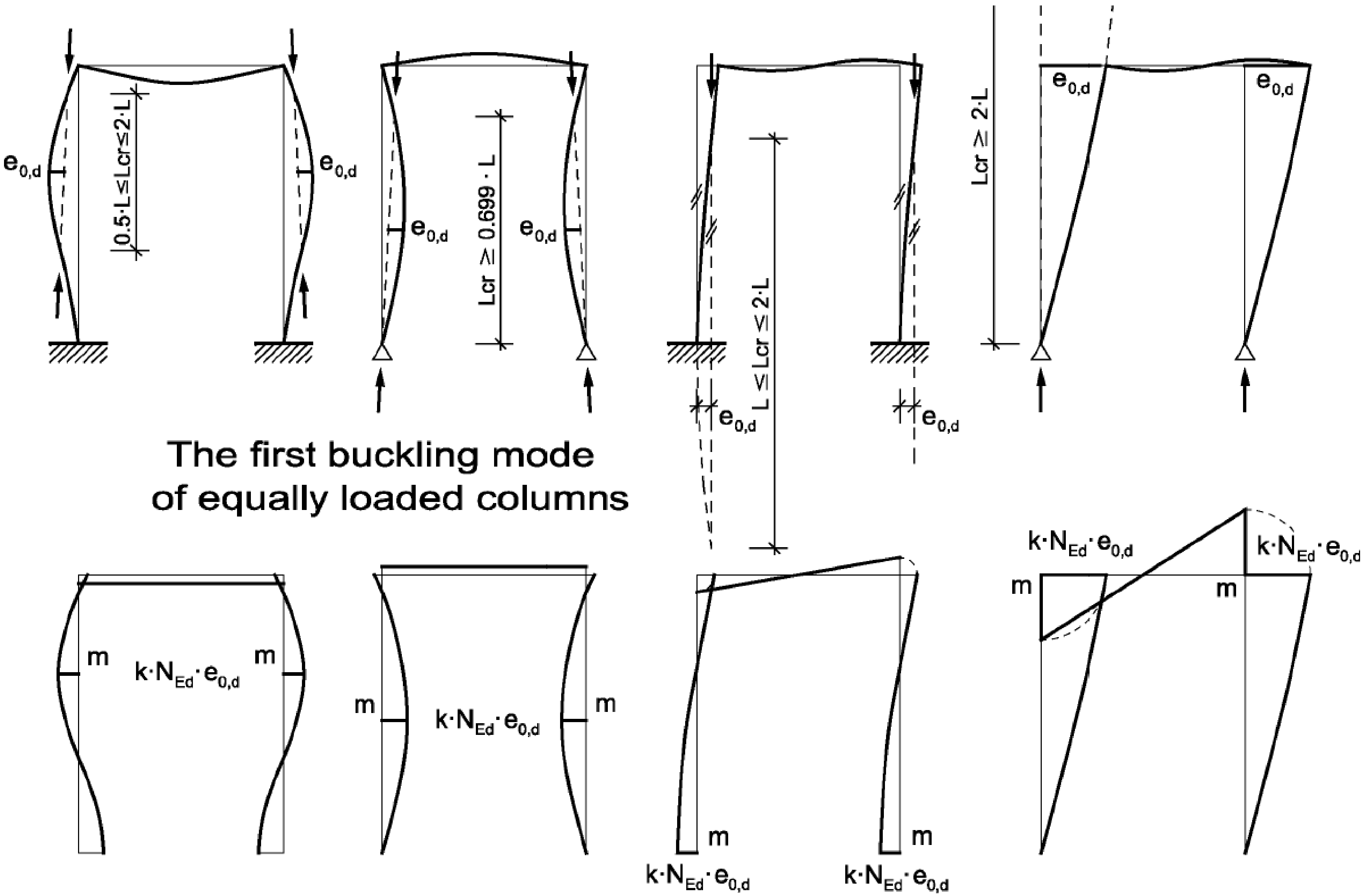
$$M_{II}(x_m) = 23.751 \cdot kN \cdot m$$

$$k \cdot N_{Ed} \cdot e_{o.d} = 23.751 \cdot kN \cdot m$$



e0,d
Lcr = 0.5 · L
Lcr = 0.699 · L
Lcr = L
Lcr = L
Lcr = 2 · L
Lcr = 2 · L
The first buckling mode
m
k·NEd·e0,d
Bending moments


e0,d
Lcr ≥ 0.5 · L
Lcr ≥ 0.699 · L
e0,d
e0,d
Lcr ≥ 1 · L
e0,d
Lcr ≥ 2 · L
The first buckling mode
m
k·NEd·e0,d
m
k·NEd·e0,d
m
k·NEd·e0,d
m
k·NEd·e0,d
Bending moments



Bending moments

The comparison with ω-method

$$\omega(x) = \frac{1}{\chi + (1-\chi)\sin\left[\frac{\pi(L-x)}{L_{cr}}\right]}$$

$$\Delta M(x) = -N_{Ed}\frac{M_{Rd}}{N_{Rd}}\left(\frac{1}{\chi\omega(x)} - 1\right)$$

$$\Delta M(x_m) = -30.347\,kNm$$

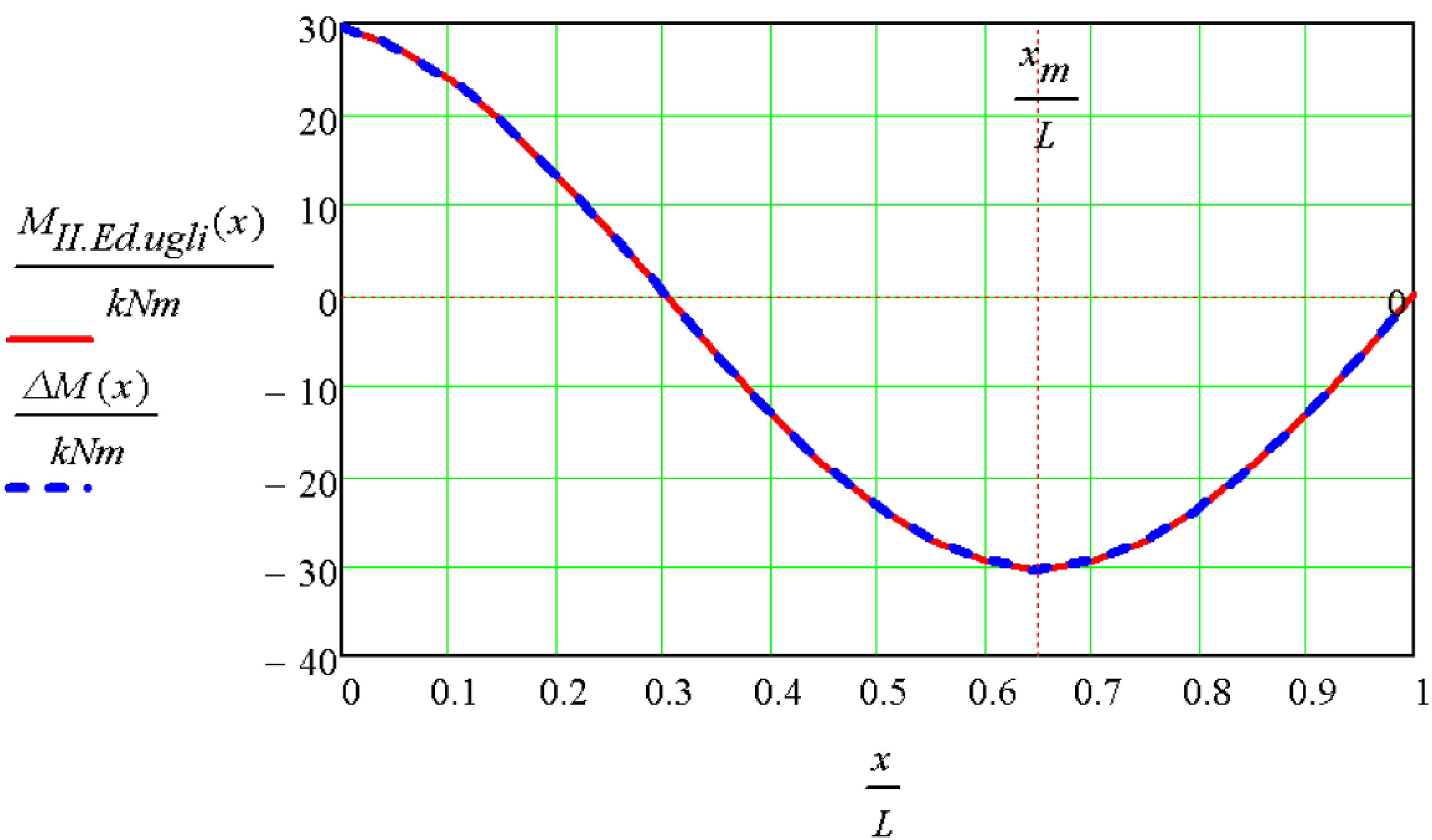


Figure 4: The comparison of the bending moments distributions for $N_{Ed} = N_{b,Rd}$

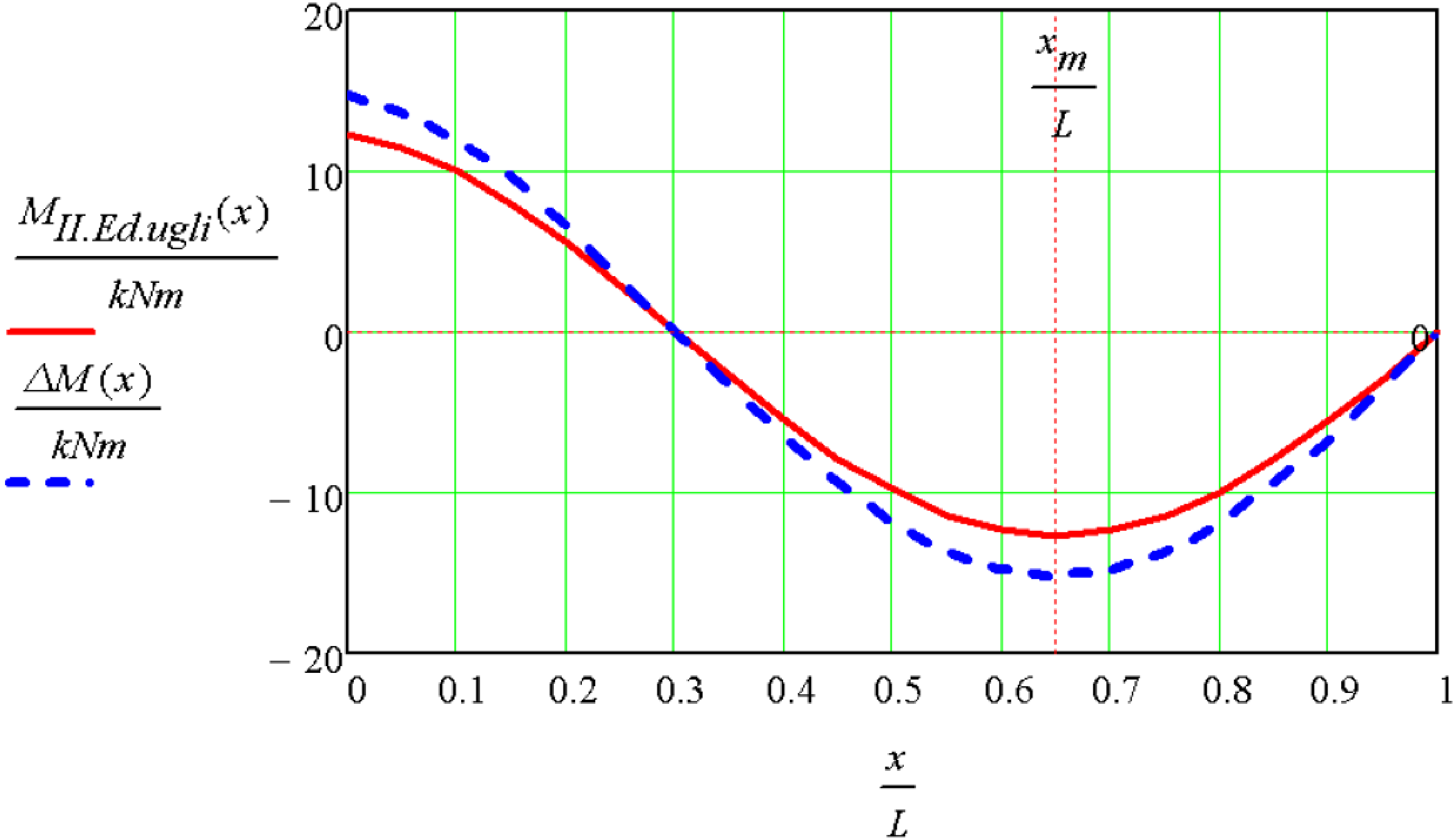


Figure 5: The comparison of the bending moments distributions for $N_{Ed} = 0.5 N_{b,Rd}$

Thank you for your kind attention