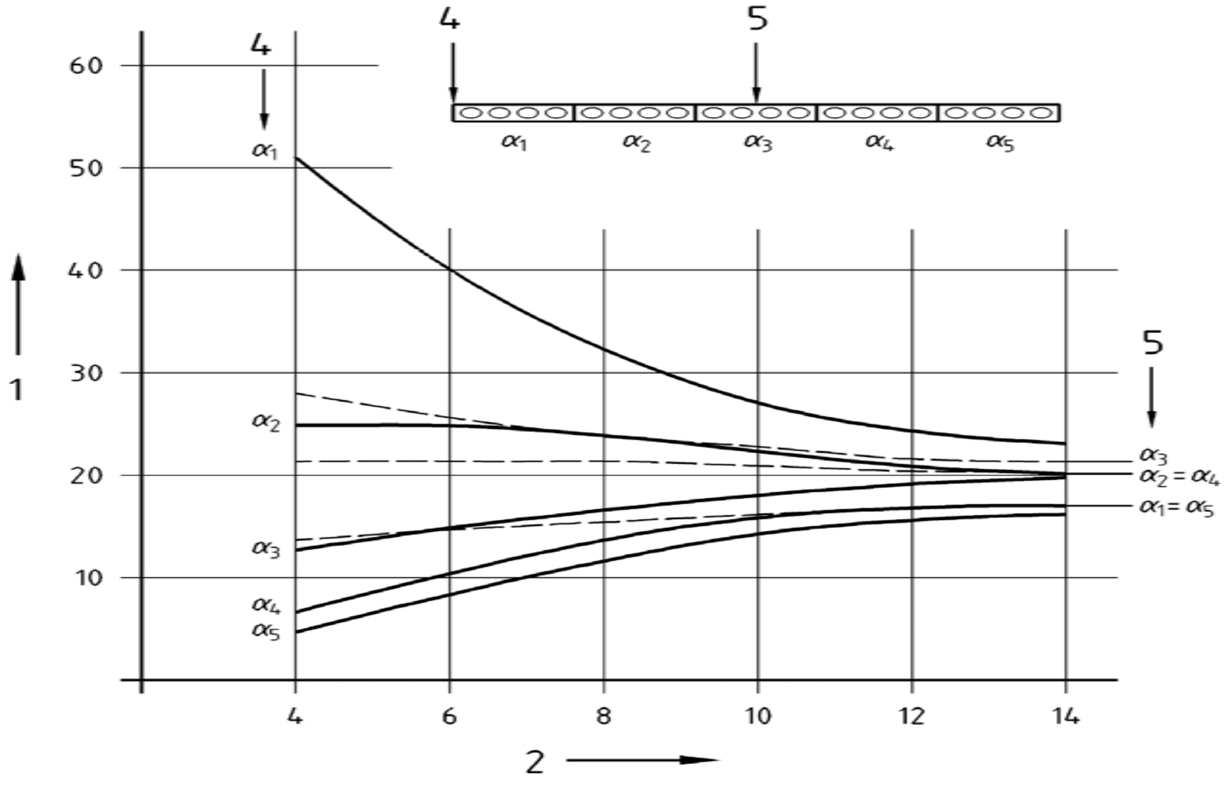
Holcotors results

- EN 1168 Distribution factors
- EN 1168 3 line support
- Shear & torsion interaction

Gösta Lindström, Dr. Sc, Technical Manager, Strängbetong

EN 1168 distribution factors

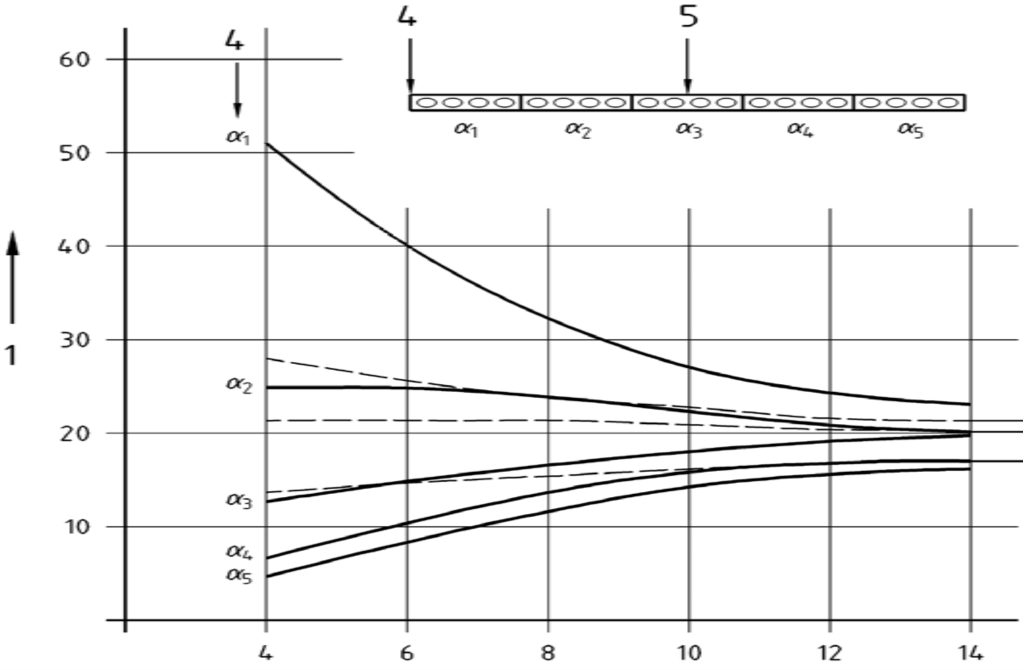


Key

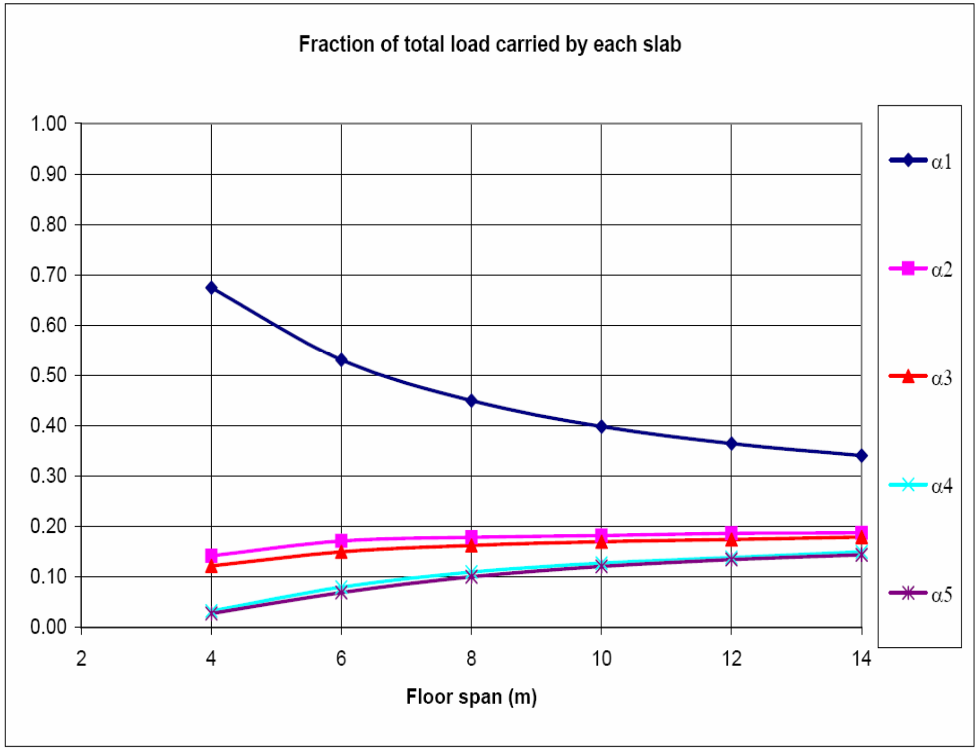
1 Loading percentage (%)
2 Span (*l*) in m
3 Linear loads
4 Edge
5 Centre

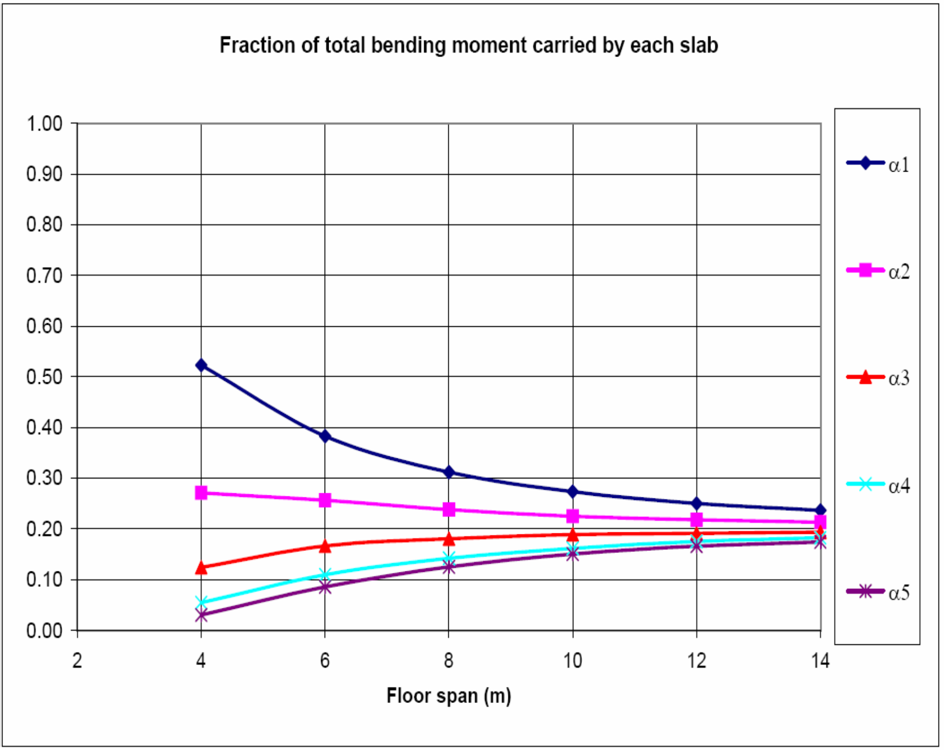
Figure C.1 — Load distribution factors for linear loads

EN 1168 distribution factors

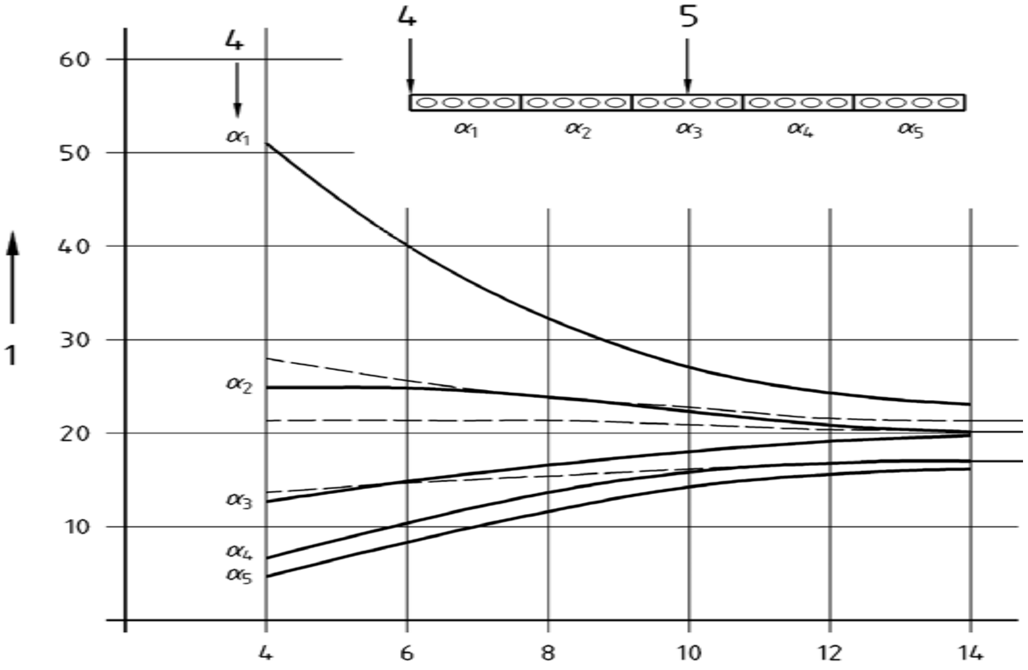


EI/GKv = 0.5 Line load on edge

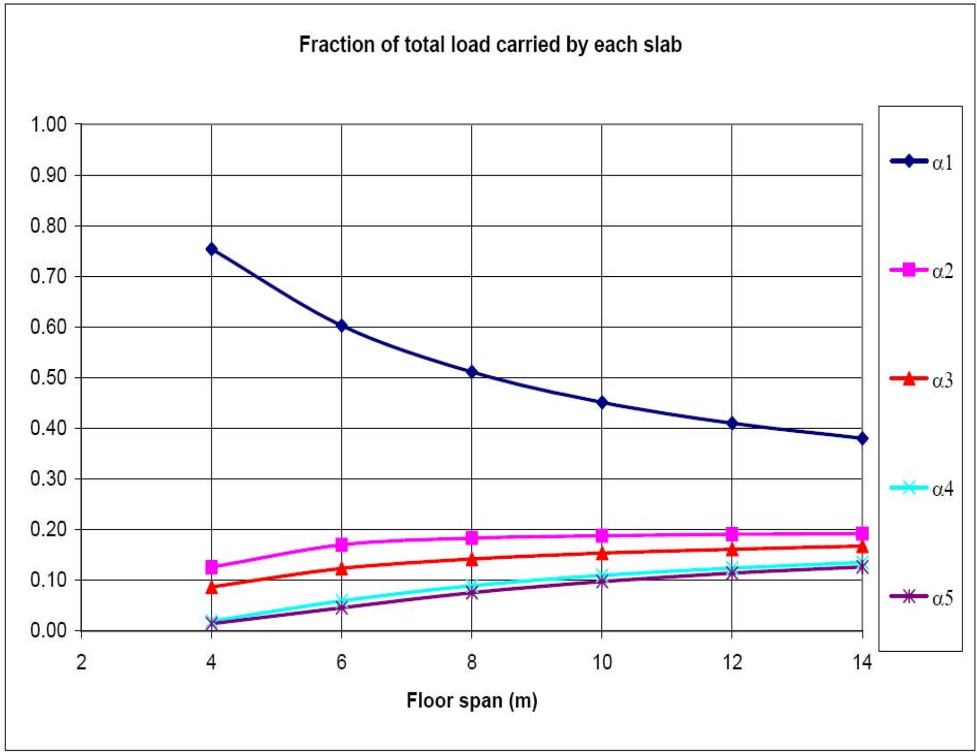

Fraction of total load carried by each slab

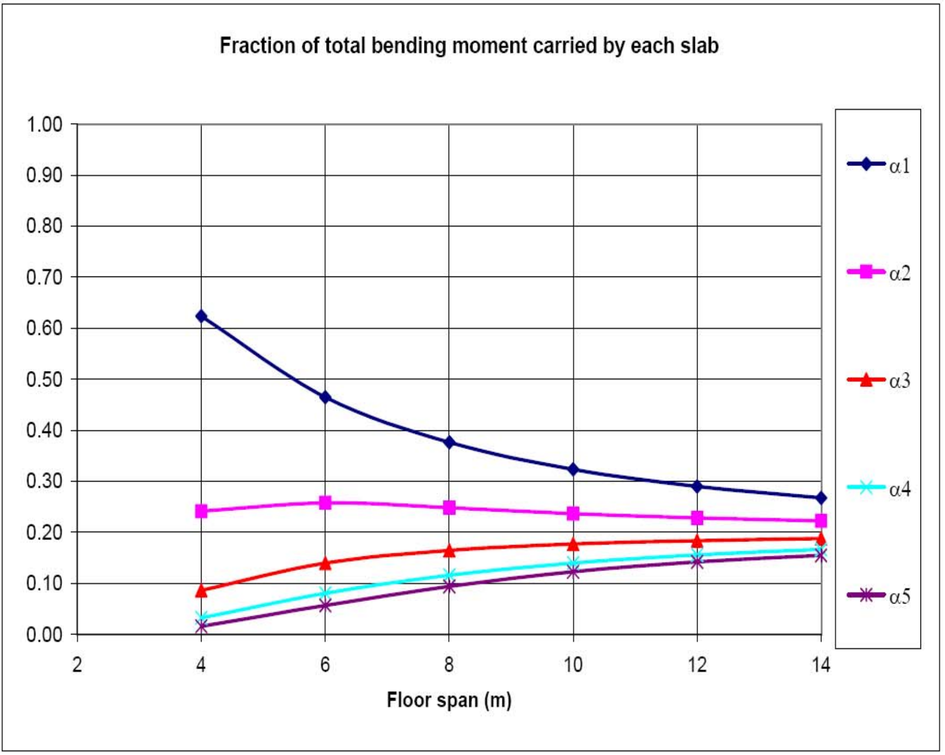

Fraction of total bending moment carried by each slab

EN 1168 distribution factors

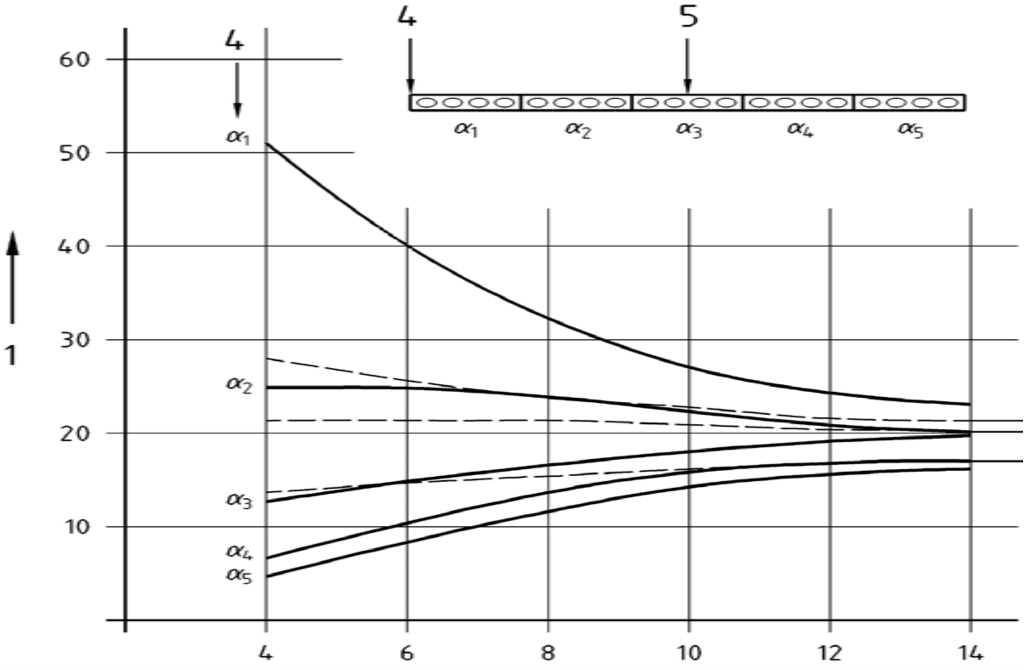


EI/GKv = **1.0** **Line load on edge**

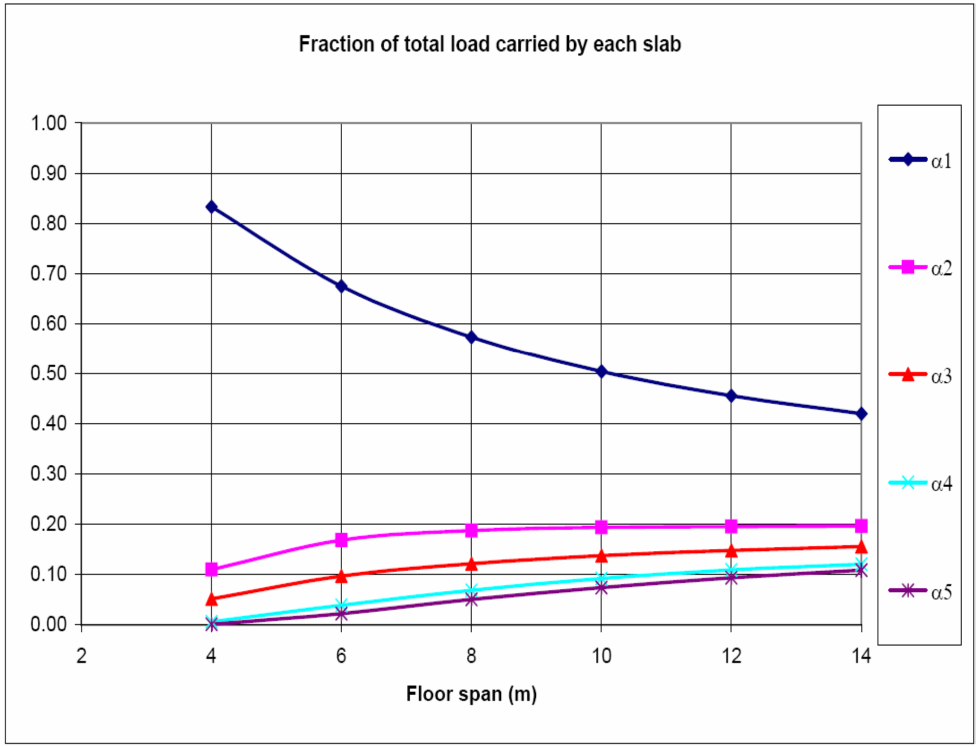

Fraction of total load carried by each slab

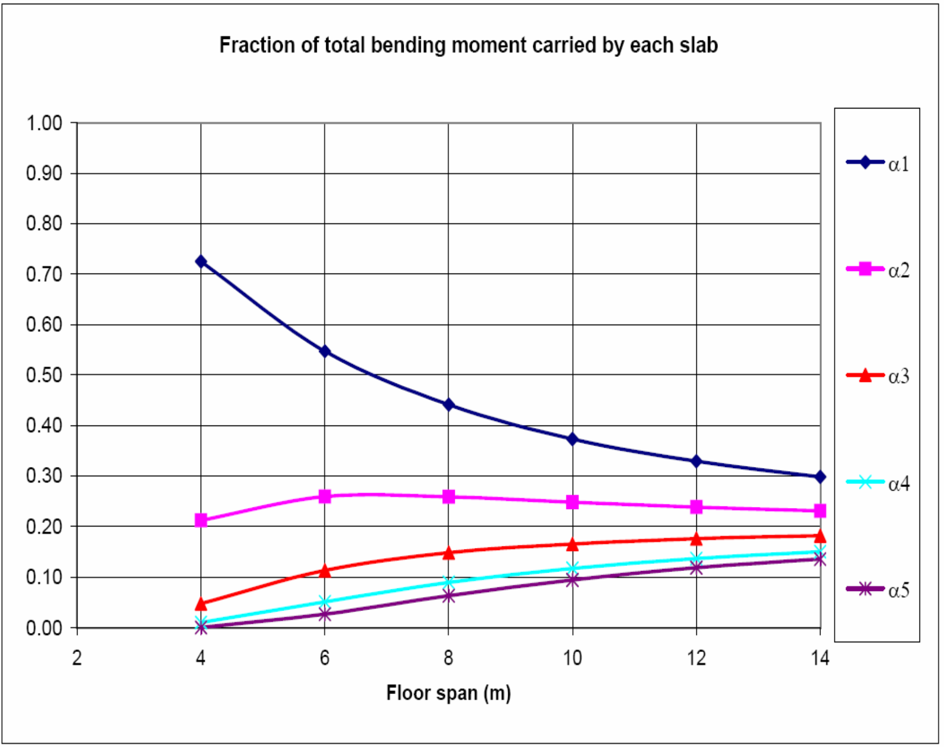

Fraction of total bending moment carried by each slab

EN 1168 distribution factors

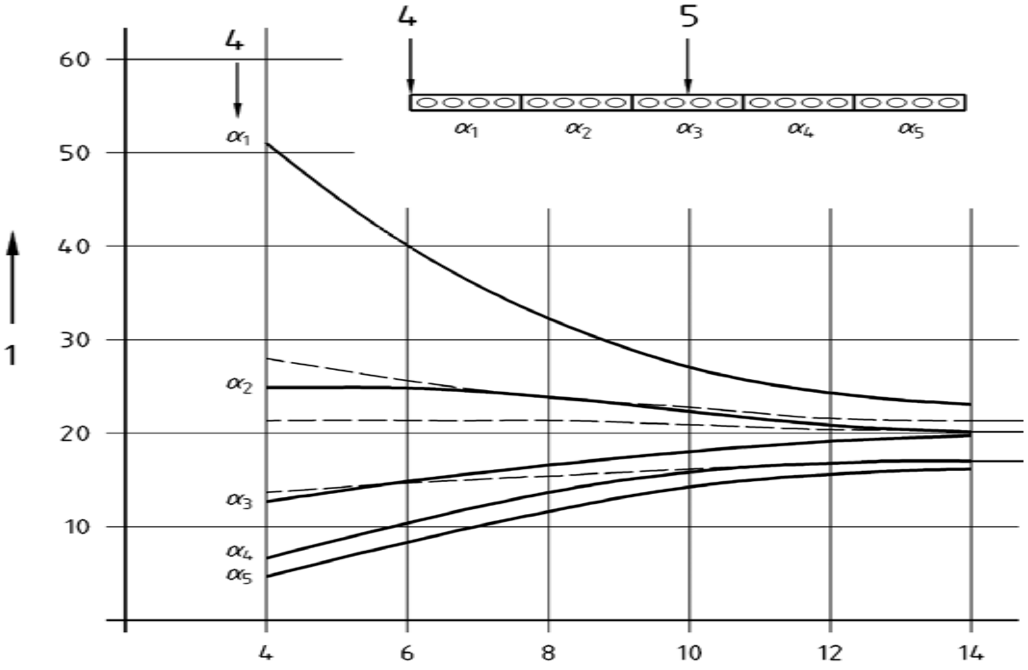


EI/GKv = **1.5** **Line load on edge**





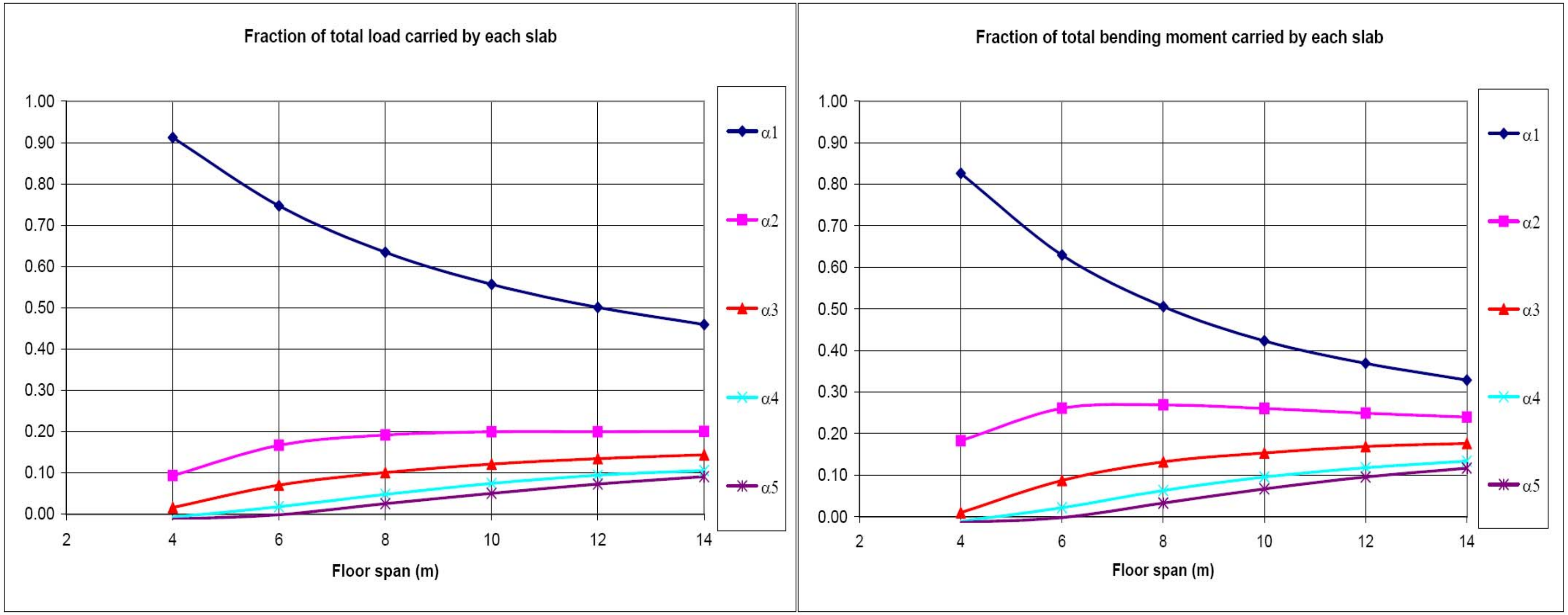
EN 1168 distribution factors



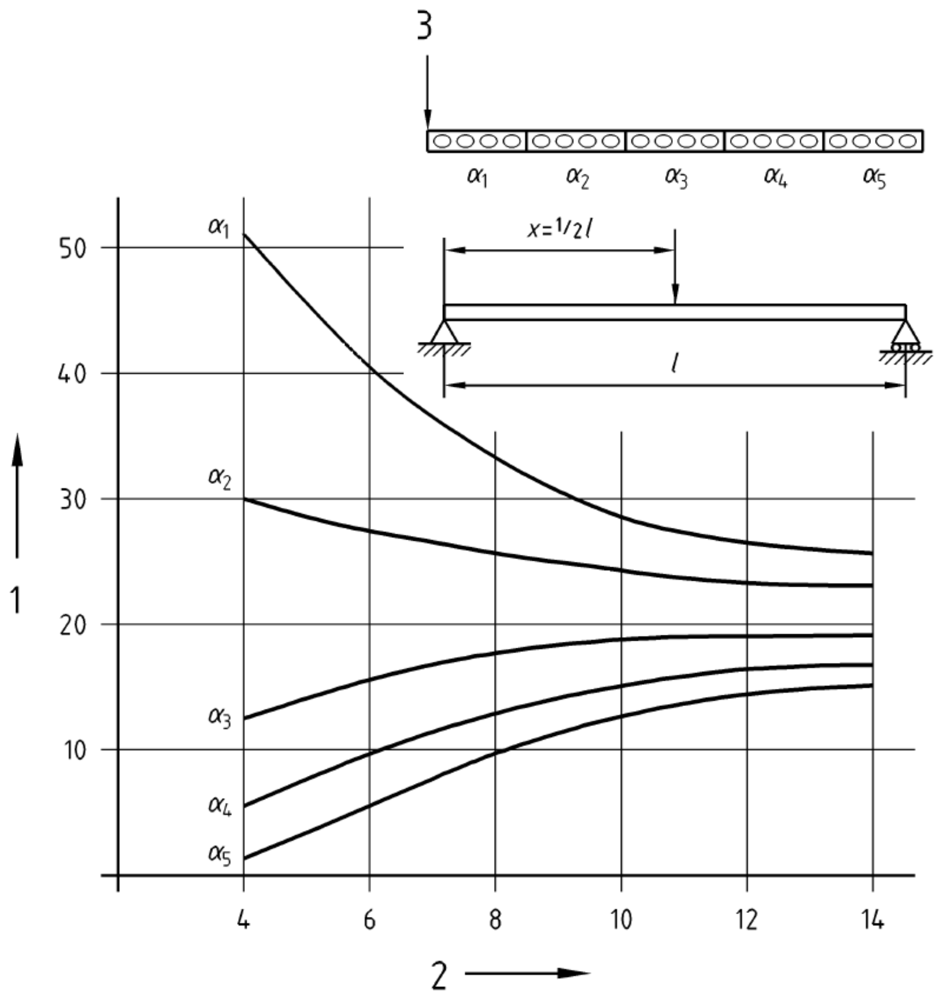
Conclusion for line load

α-factors in EN 1168 defines
the fraction of total bending moment
using EI/GKv = 0.6

EI/GKv = 2.0 Line load on edge



EN 1168 distribution factors

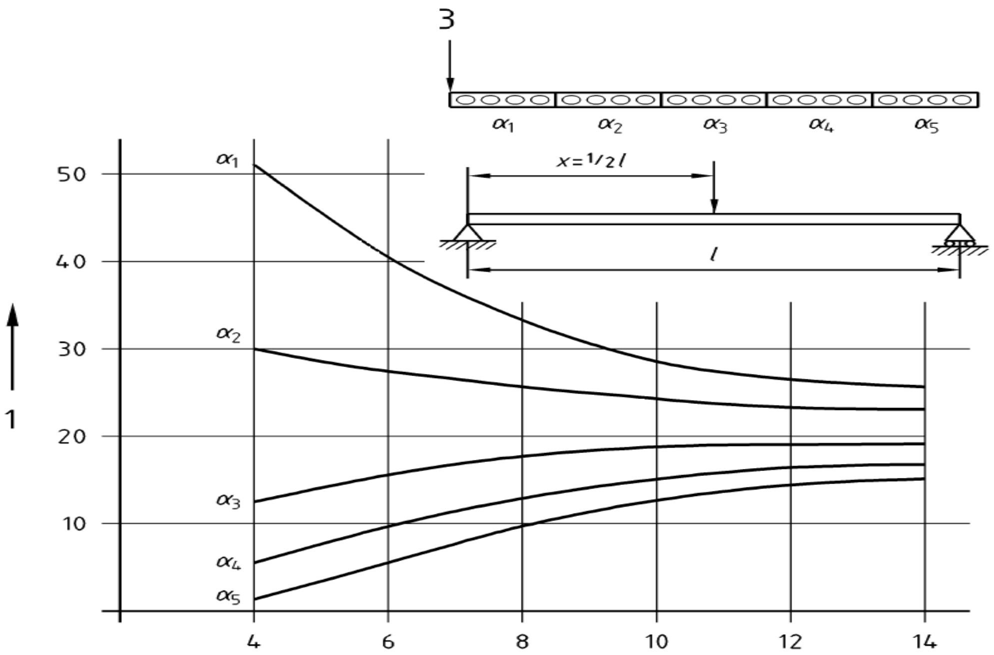


Key

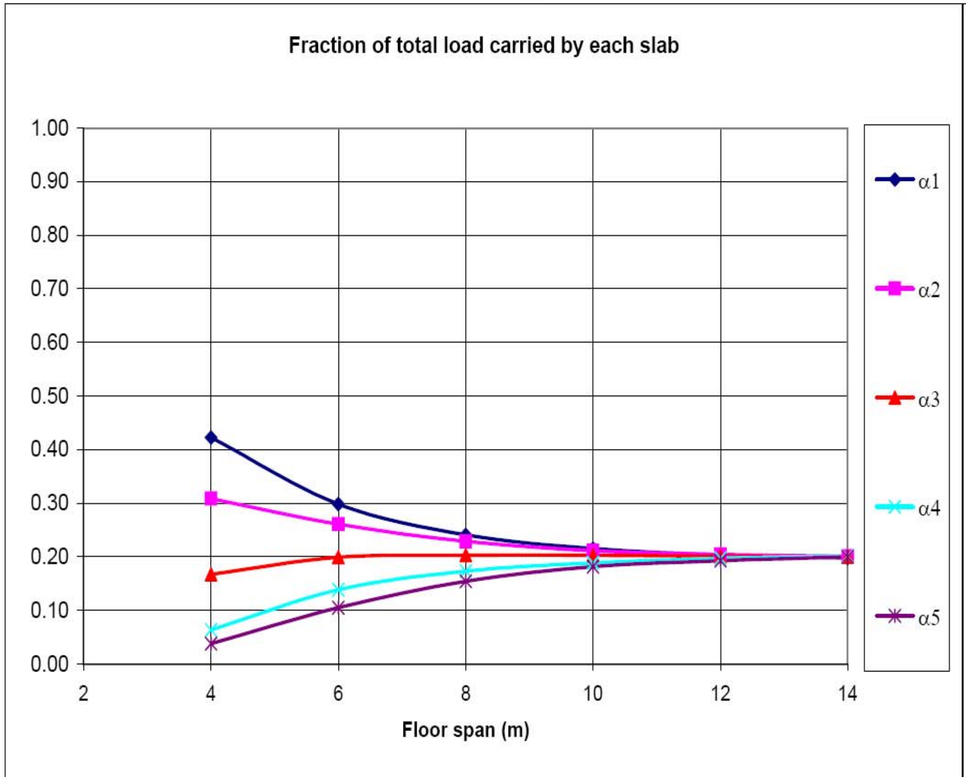
1 Loading percentage (%)
2 Span (*l*) in m
3 Point load

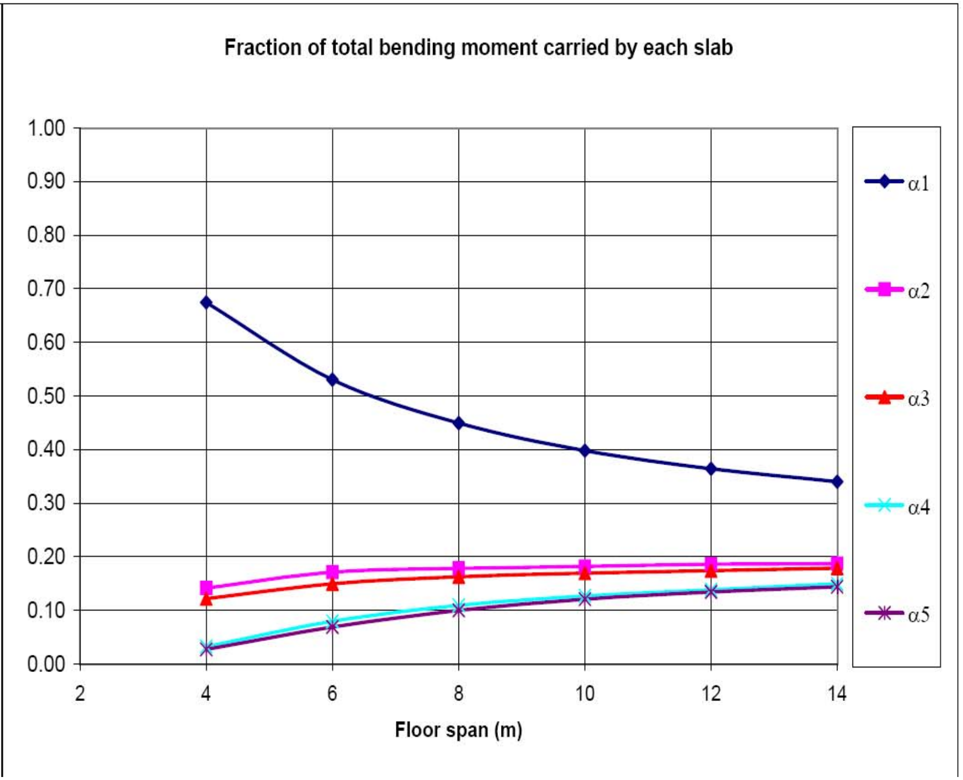
Figure C.3 — Load distribution factor for point loads at edge

EN 1168 distribution factors

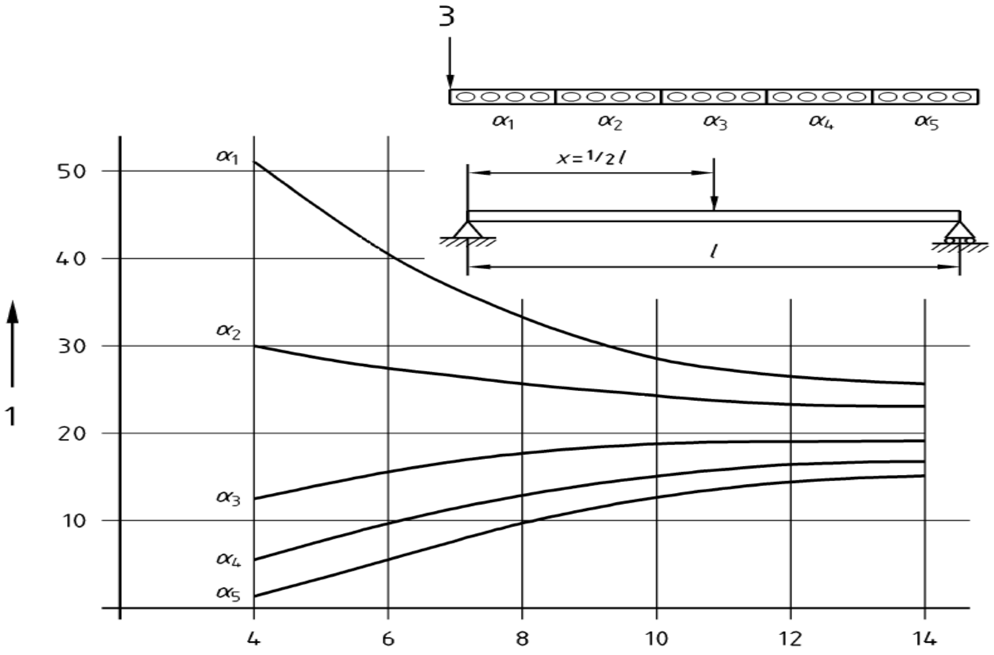


EI/GKv = 0.5 **Point load on edge**

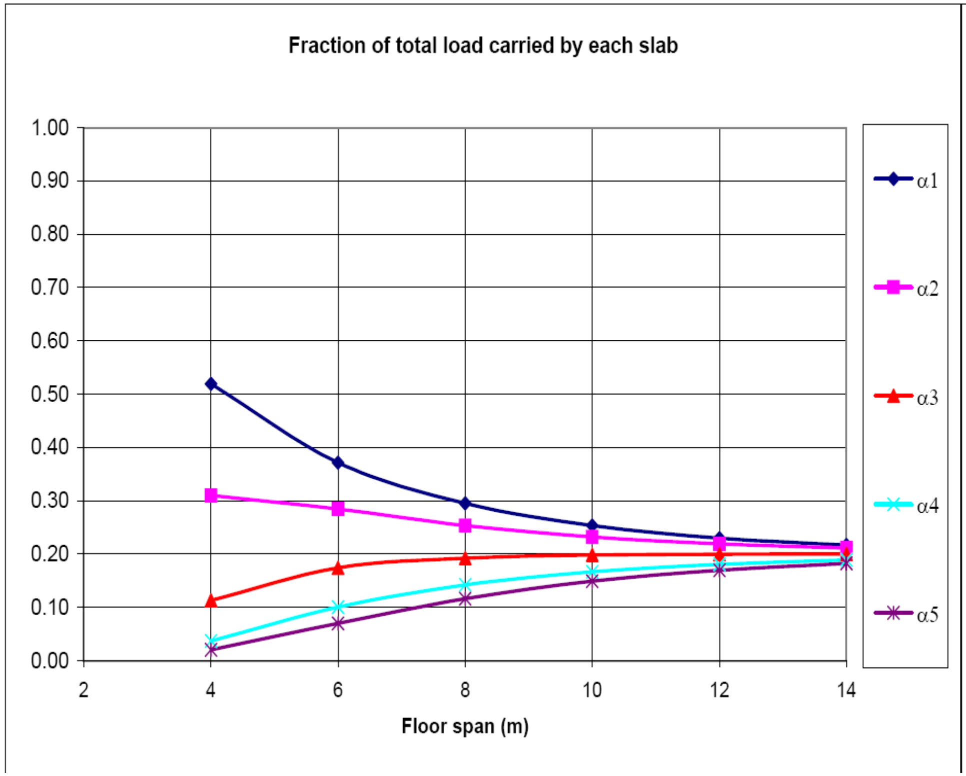

Fraction of total load carried by each slab

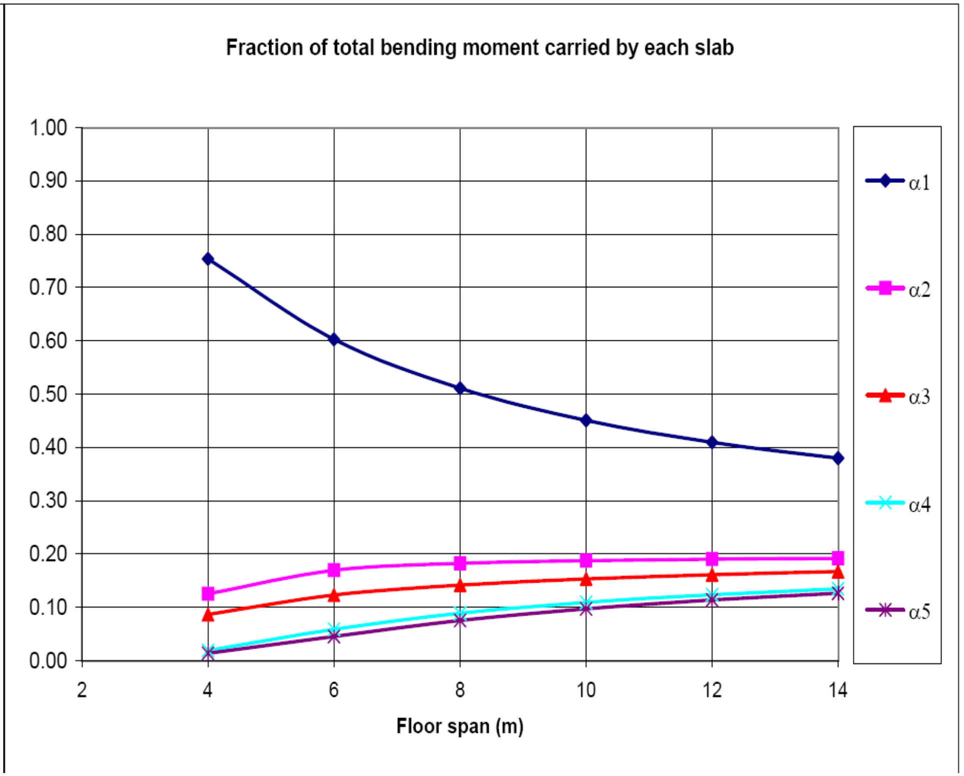

Fraction of total bending moment carried by each slab

EN 1168 distribution factors

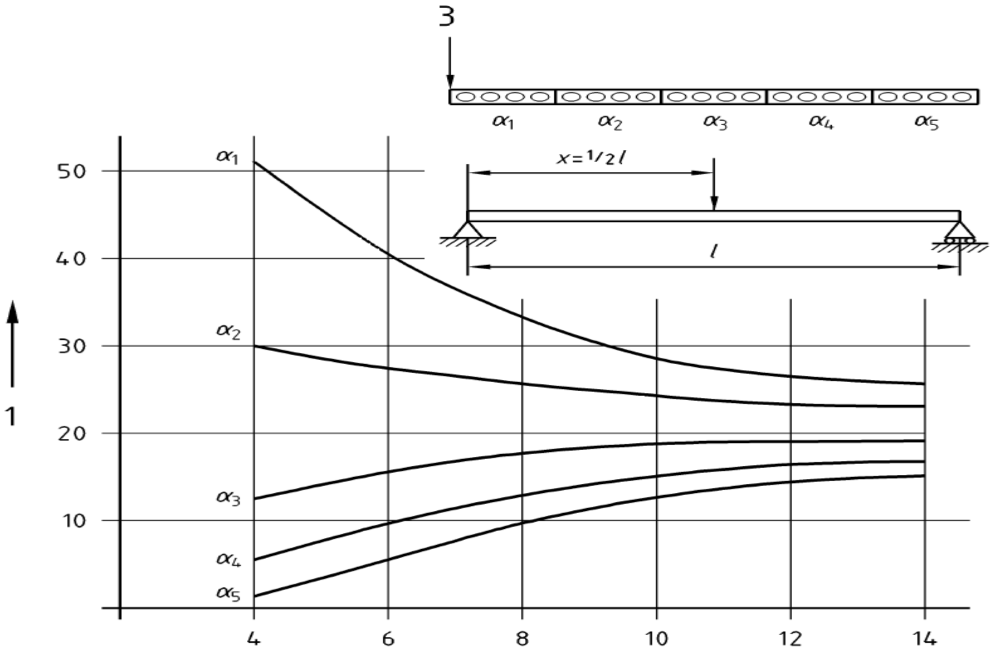


EI/GKv = **1.0** **Point load on edge**

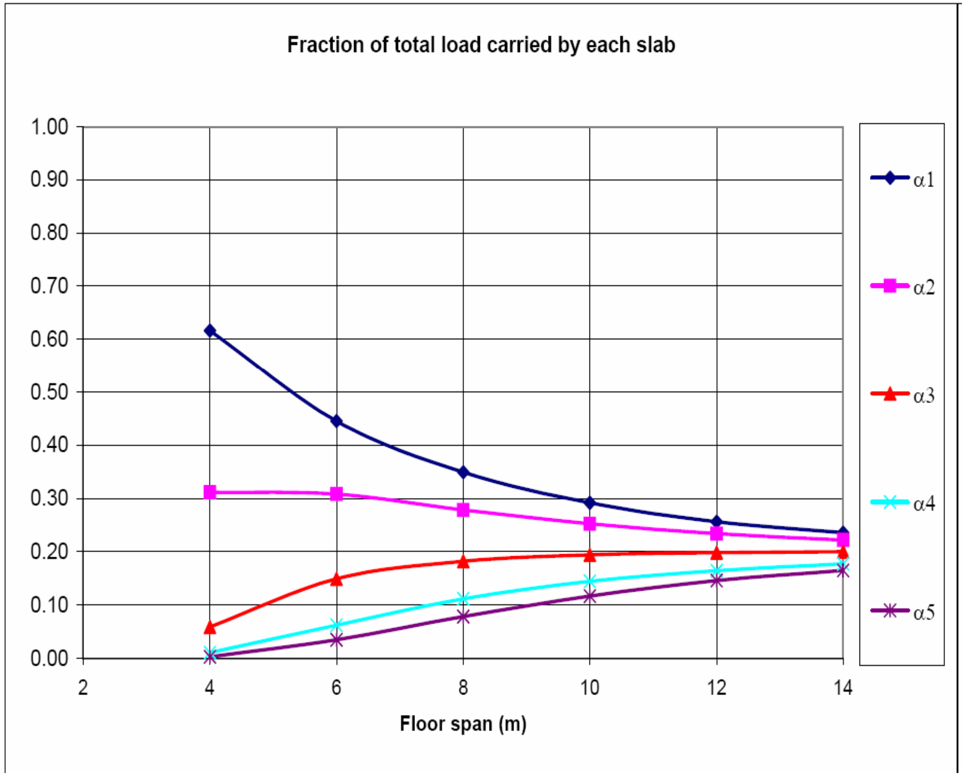


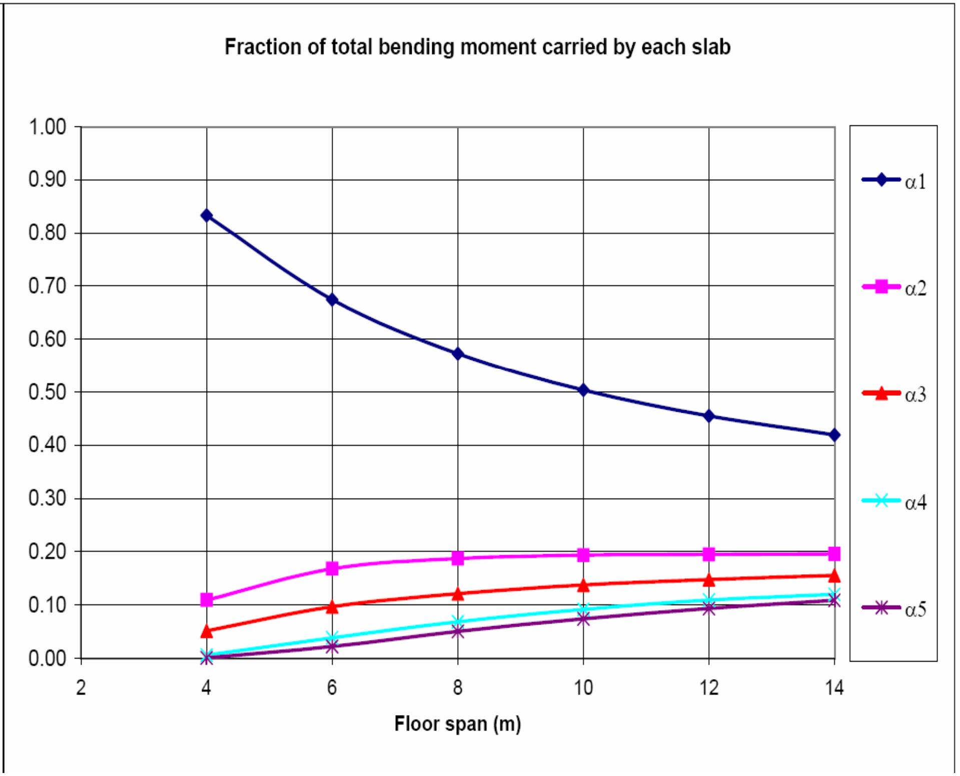


EN 1168 distribution factors



EI/GKv = **1.5** **Point load on edge**

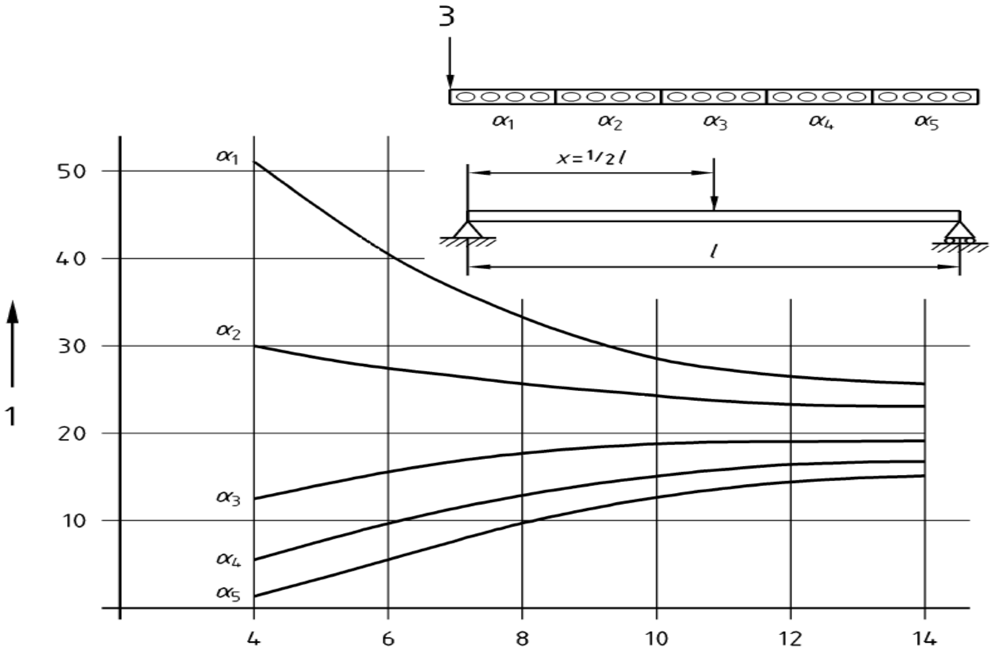

Fraction of total load carried by each slab


Fraction of total bending moment carried by each slab

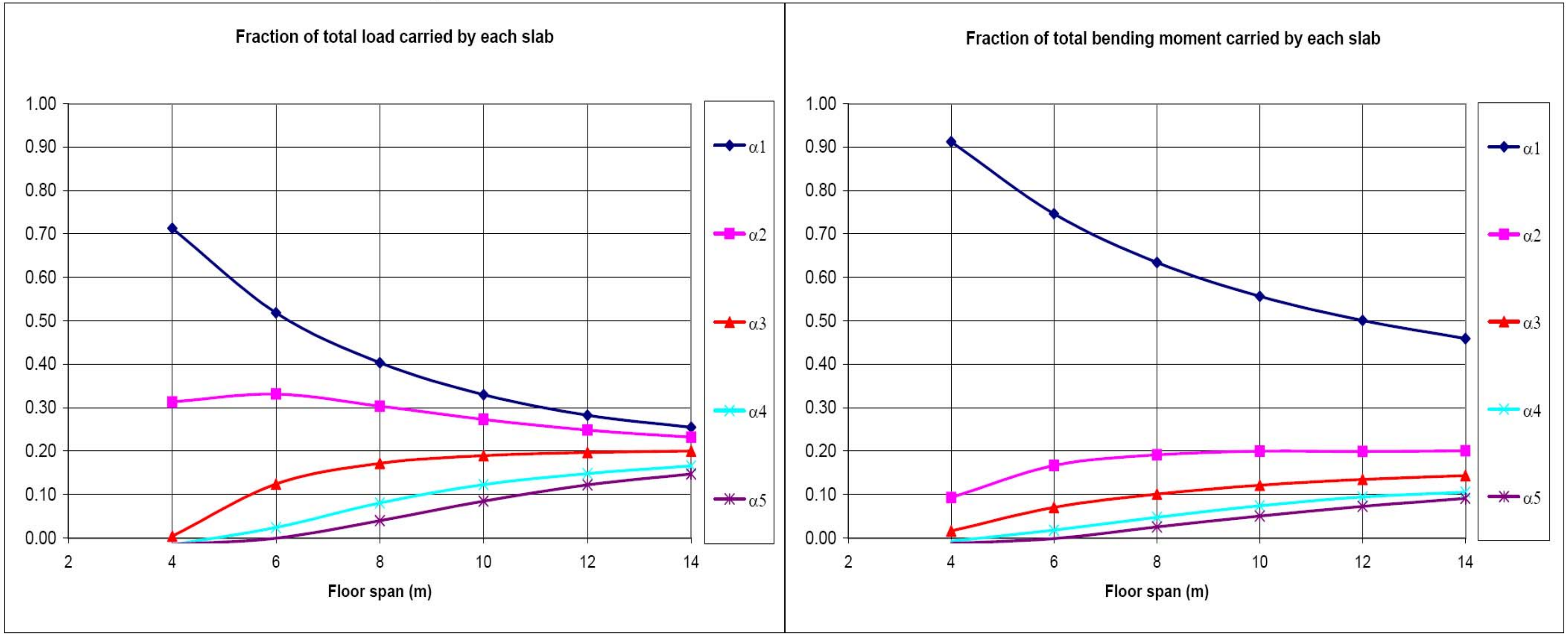
EN 1168 distribution factors

Conclusion for point load

α-factors in EN 1168 defines
the fraction of total load
using EI/GKv = 1



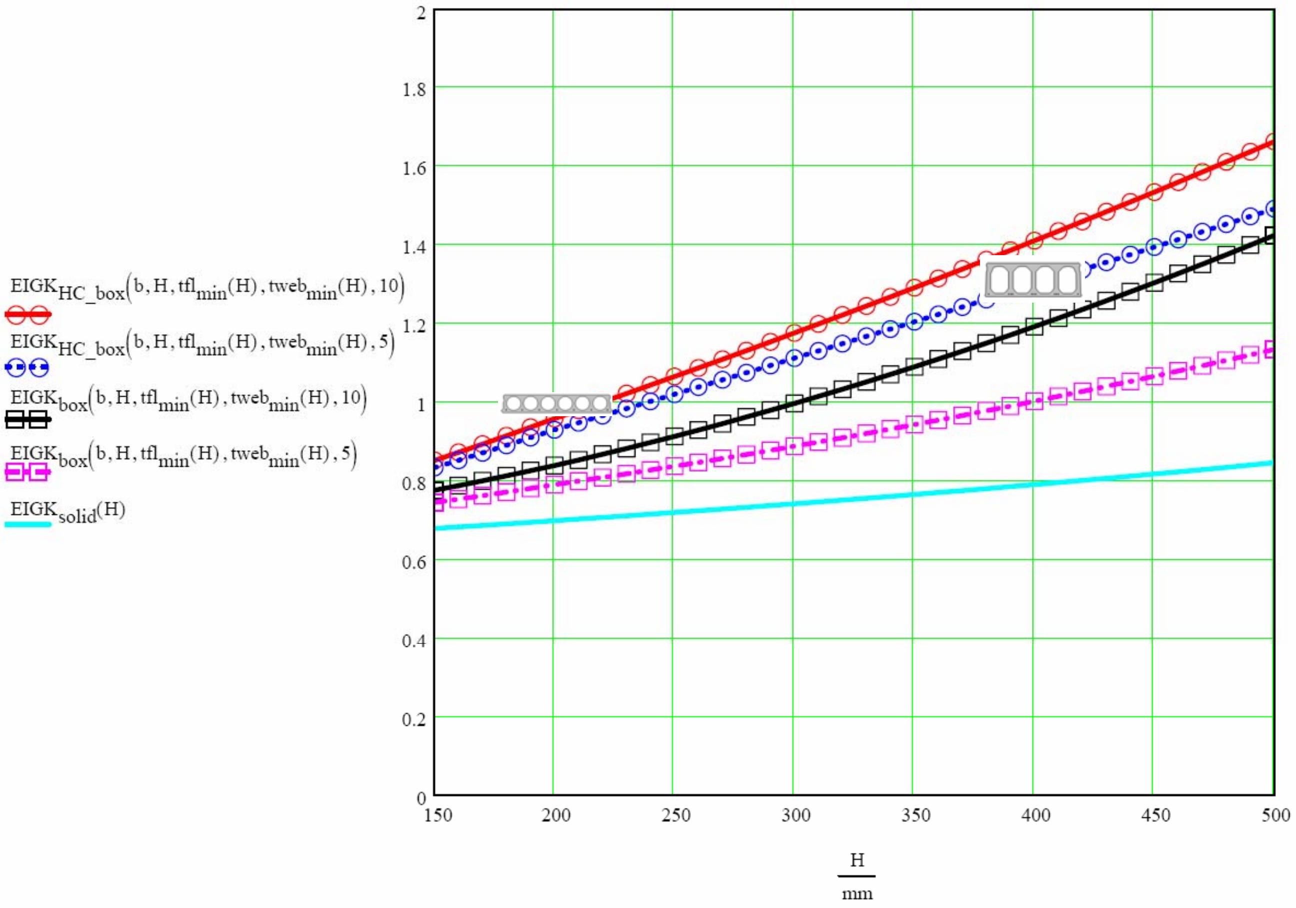
EI/GKv = **2.0** **Point load on edge**



Fraction of total load carried by each slab

Fraction of total bending moment carried by each slab

EN 1168 distribution factors



Bending / Torsional stiffness

EI/GKv

G = 0.4 E (υ=0.25)

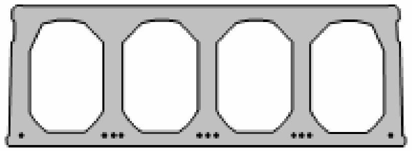
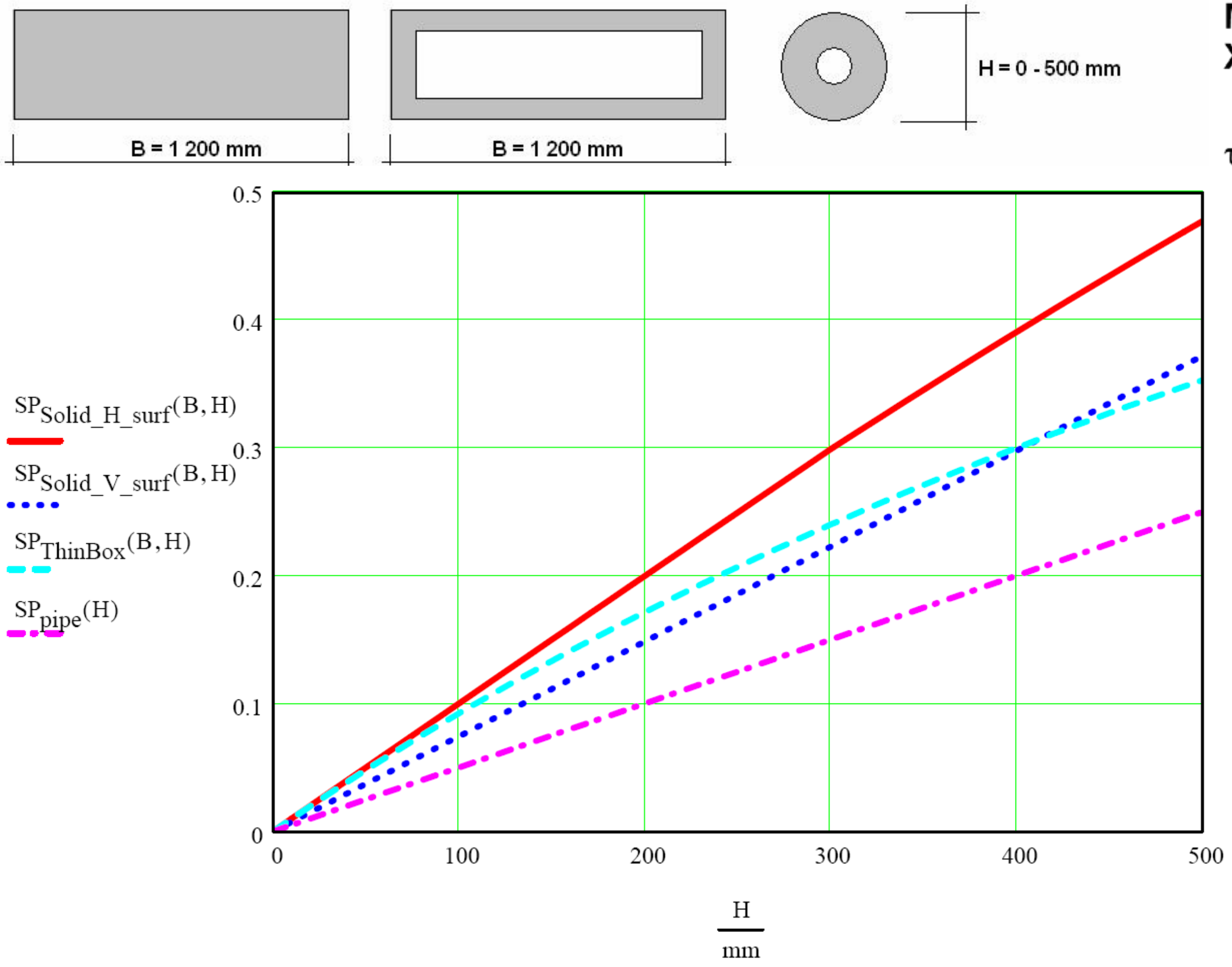


Figure The ratio between bending and torsional stiffness for some X-sections of total width 1200 mm and total depth H in the range 150 to 500 mm.
The flange and web thickness are selected as minimum according to EN 1168.
Shear modulus G = 0.4 E
The X-sections curves represents the following from top down:
- Hollow core section with 10 webs
- Hollow core section with 5 webs
- Thin walled box section with 10 webs
- Thin walled box section with 5 webs
- Homogenius cross section

For torsional stiffness of thin walled box only the contribution from outer webs are included

Some Torsion basics



Maximum shear stress for different X-sections can be expressed as

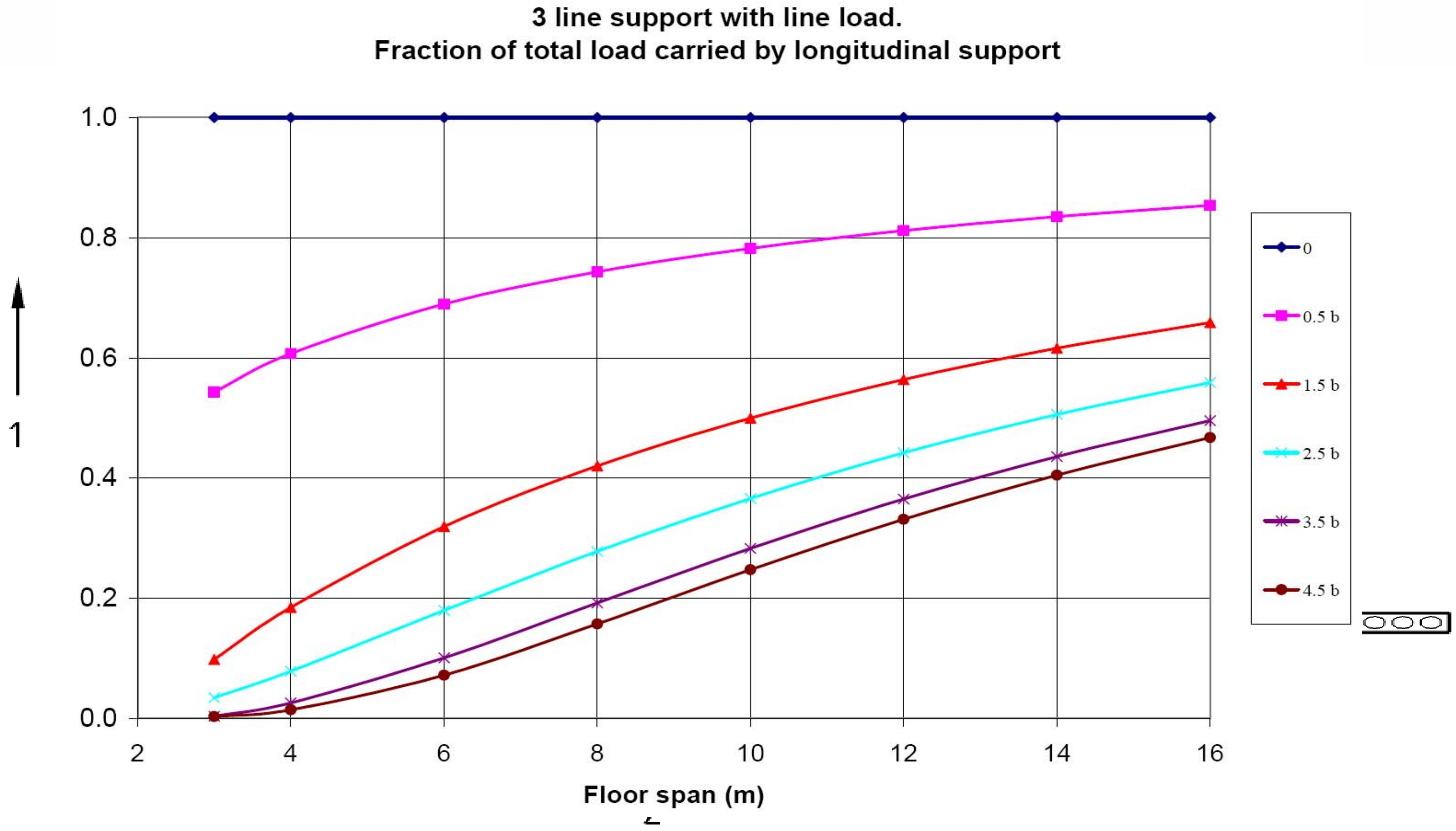
$$\tau = G \cdot d\Phi/dx \cdot Kv / Wv =$$

$$\text{const} \cdot \text{SectionProperty}$$

Figure For a constant torsional gardient the relative magnitude of shear stress for different cross-sections are presented as a function of the cross-section depth H.
The sections from top down are:
- Solid rectangular section, width 1.2 m and depth H, stress on horisontal surface (top or bottom)
- Solid rectangular section, width 1.2 m and depth H, stress on vertical sides
- Thin walled box of const thickness, width 1.2 m and depth H, stress on all walls
- Pipe section of diameter H of any wall thickness

STRÄNGBETONG

EN 1168 distribution factors (EI/GKv = 1)



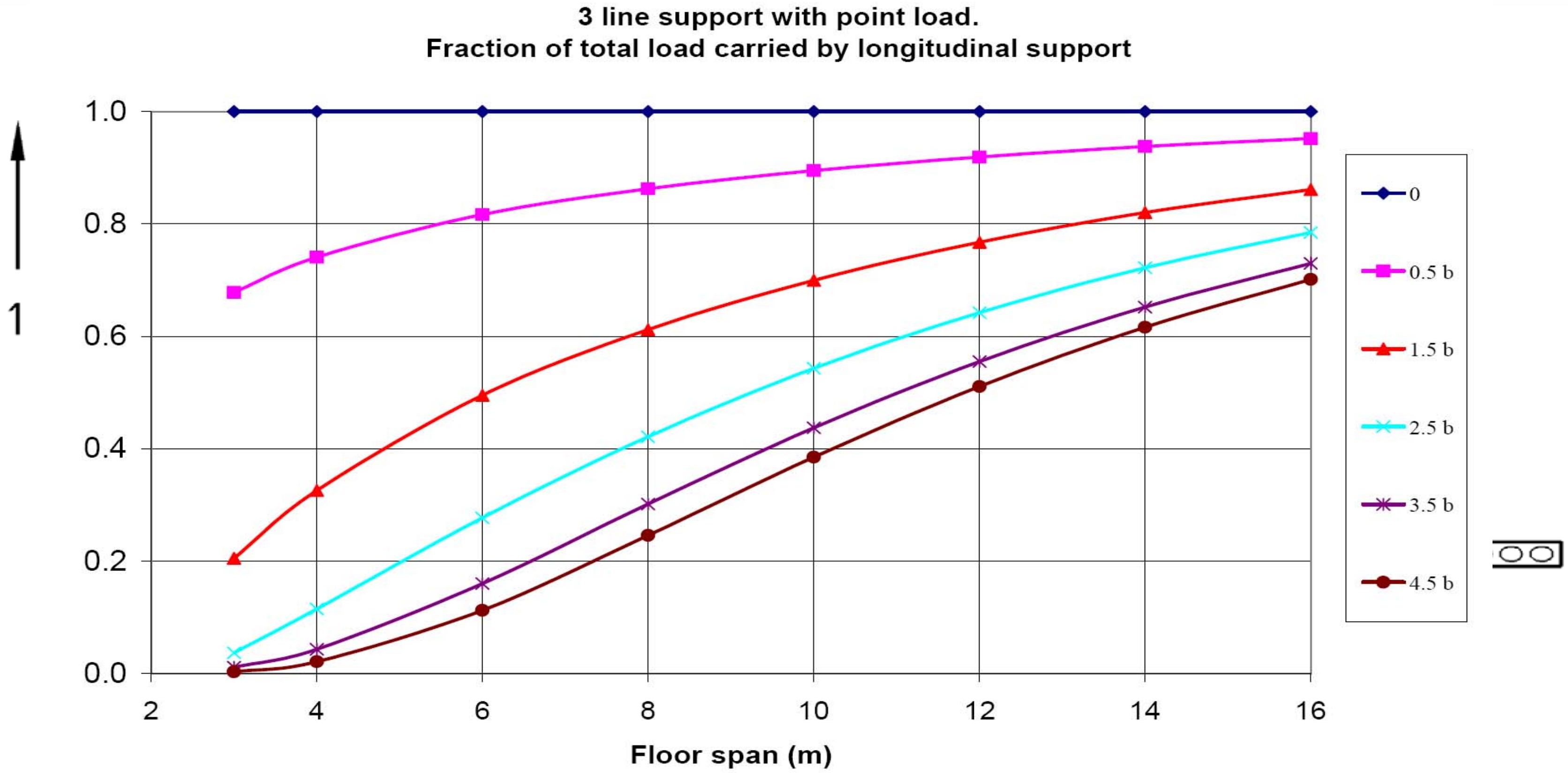
3 line support with line load.
Fraction of total load carried by longitudinal support

Key

1 Reaction force/linear load
2 Span (*l*) in m
3 Linear load
4 Reaction force

Figure C.5 — Reaction force at longitudinal support due to linear load

EN 1168 distribution factors (EI/GKv = 1)



Key

1 Reaction force x span/point load

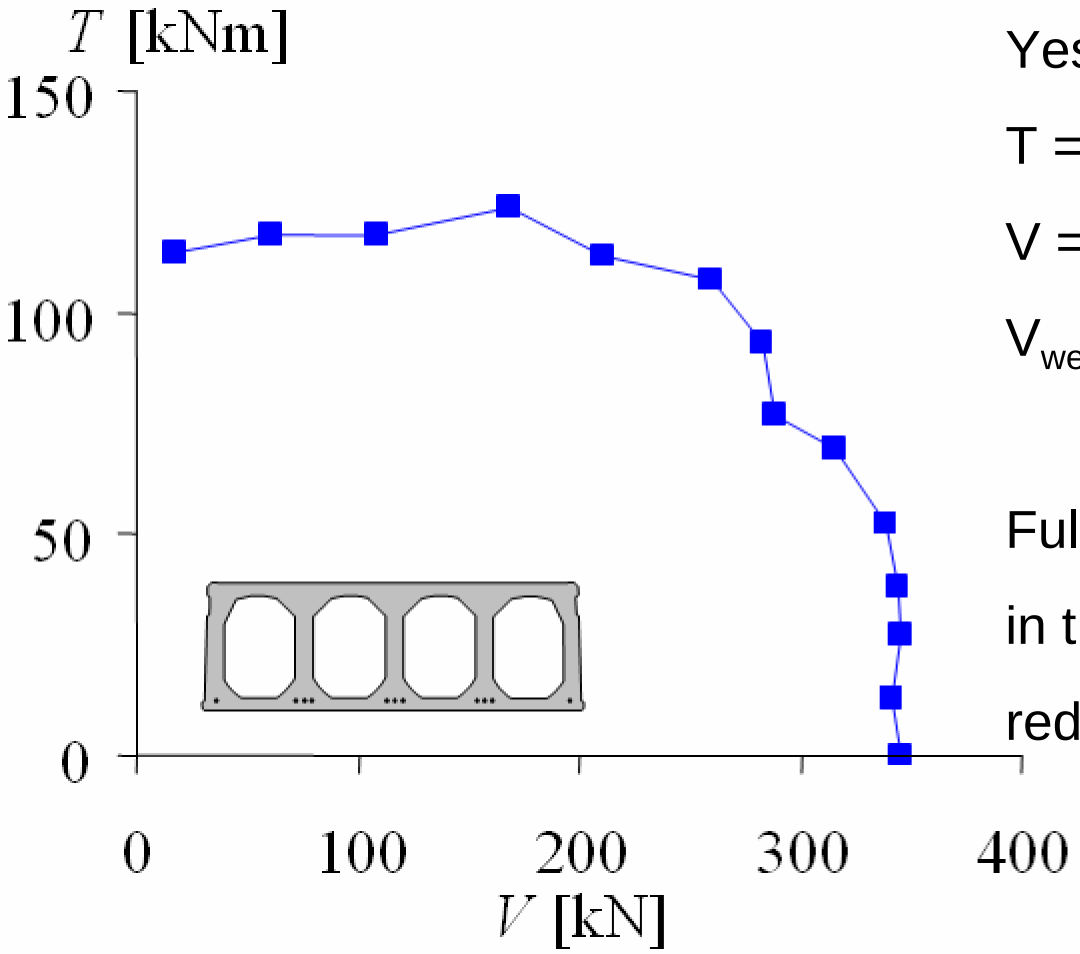
2 Span (*l*) in m

3 Point load

4 Reaction force

Figure C.6 — Reaction force at longitudinal support due to a point load at midspan

Shear torsion interaction formula



Can the improved interaction be utilized without FE analysis ?

Yes, assume:

T = 100 kNm (pure torsion)

V = 400 kN (pure shear tension)

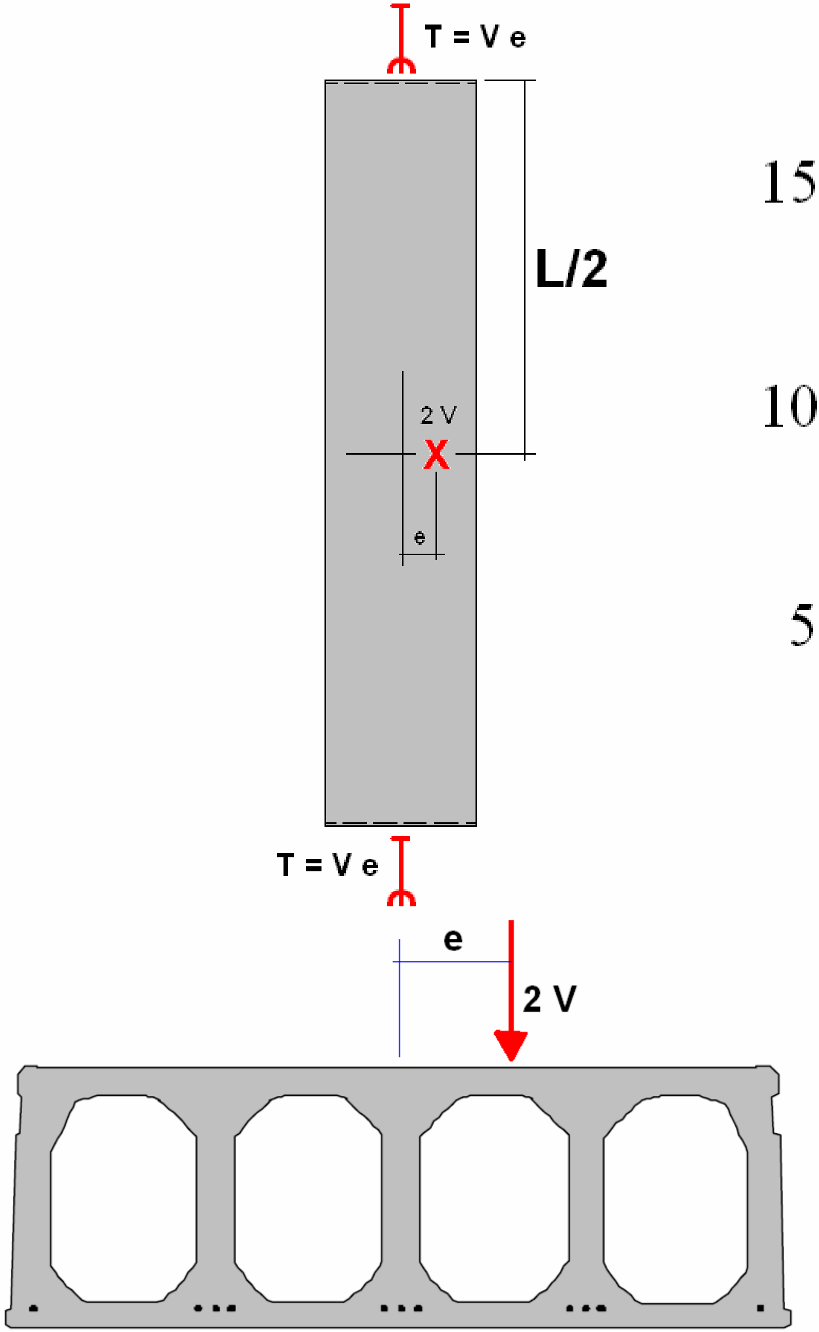
V_{web} = 400 / 5 = 80 kN each

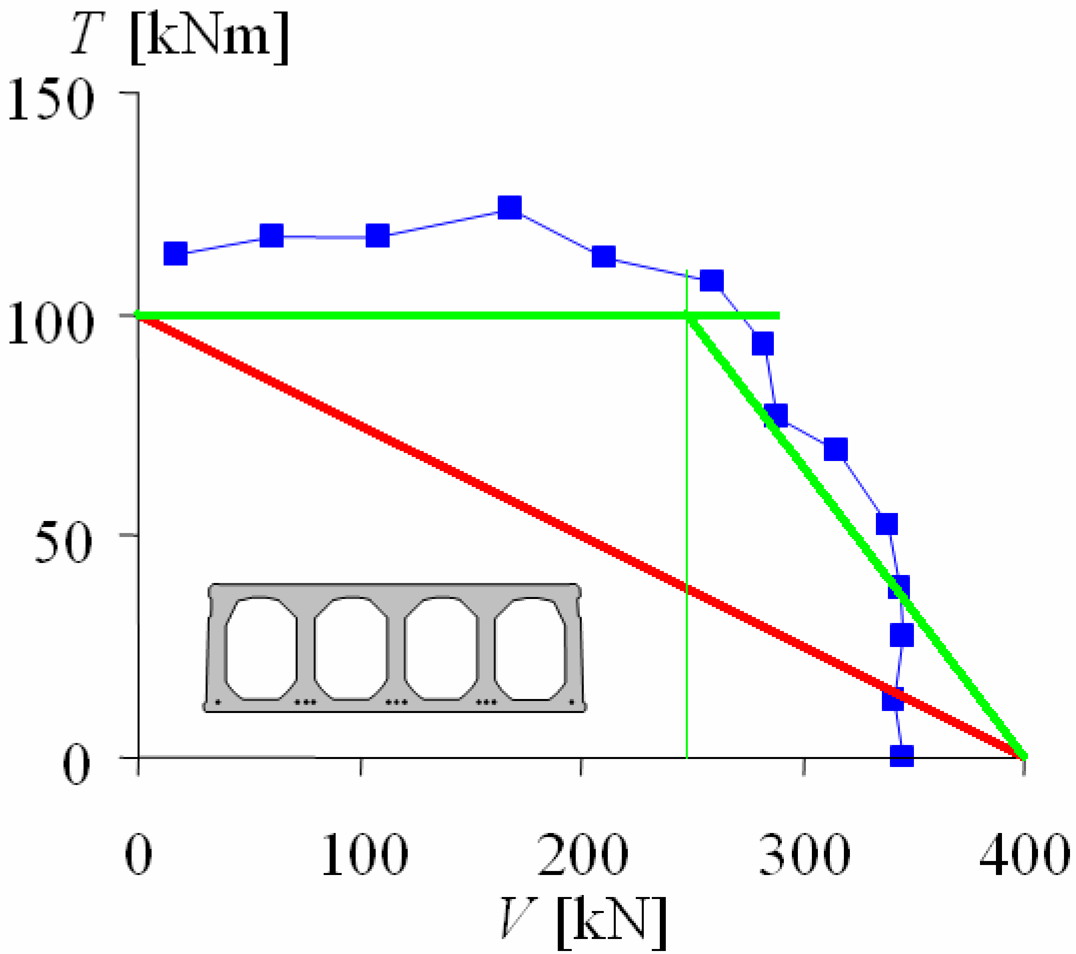
Full torsional shear flow

in thin walled box without

reduction of shear in inner webs

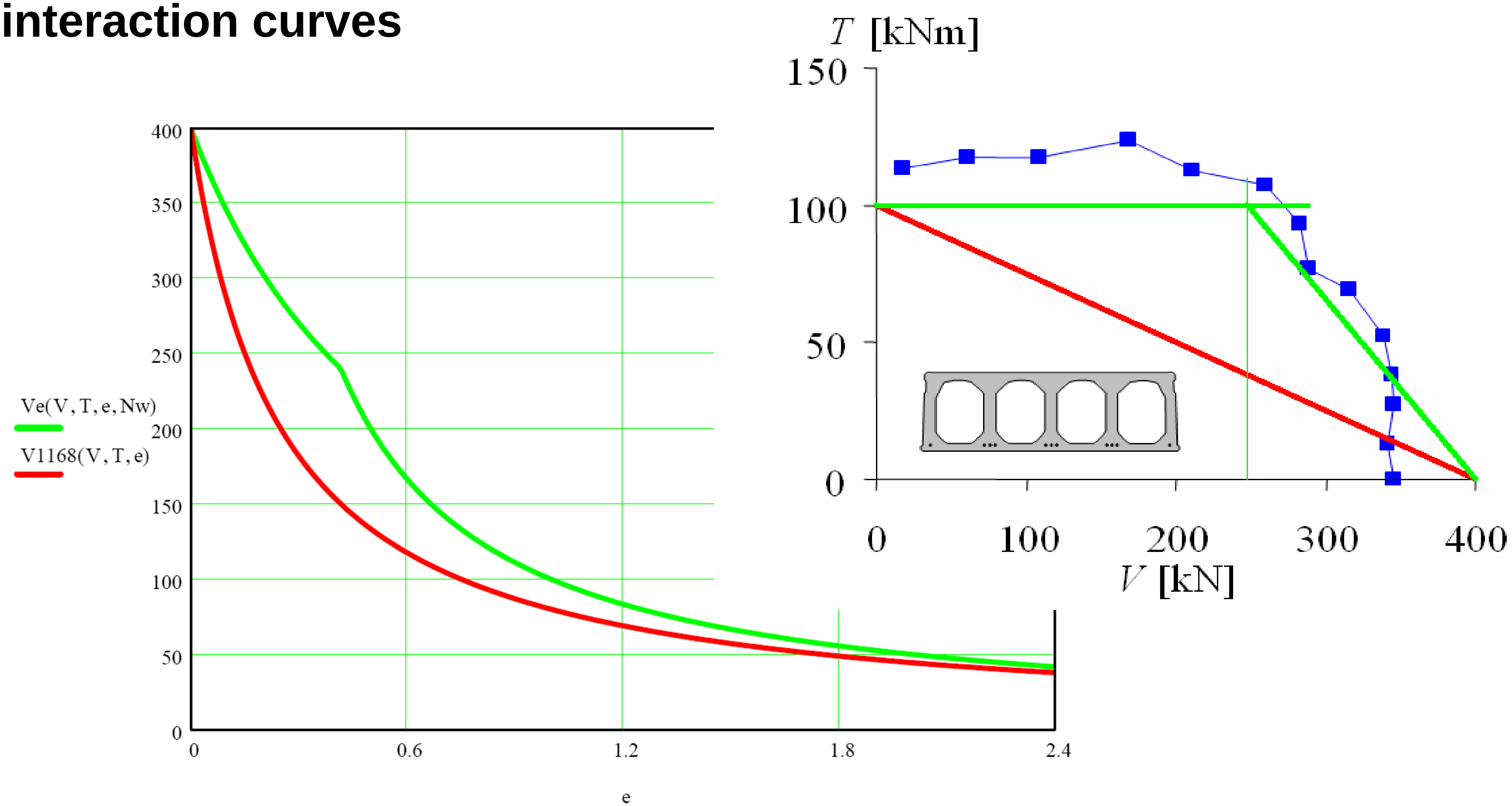
Shear torsion interaction formula

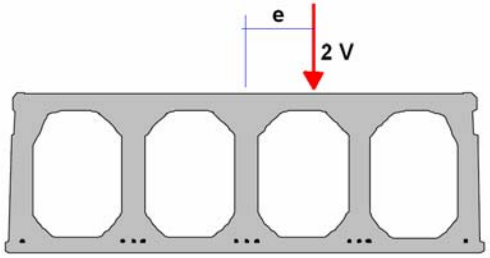




Shear torsion interaction formula

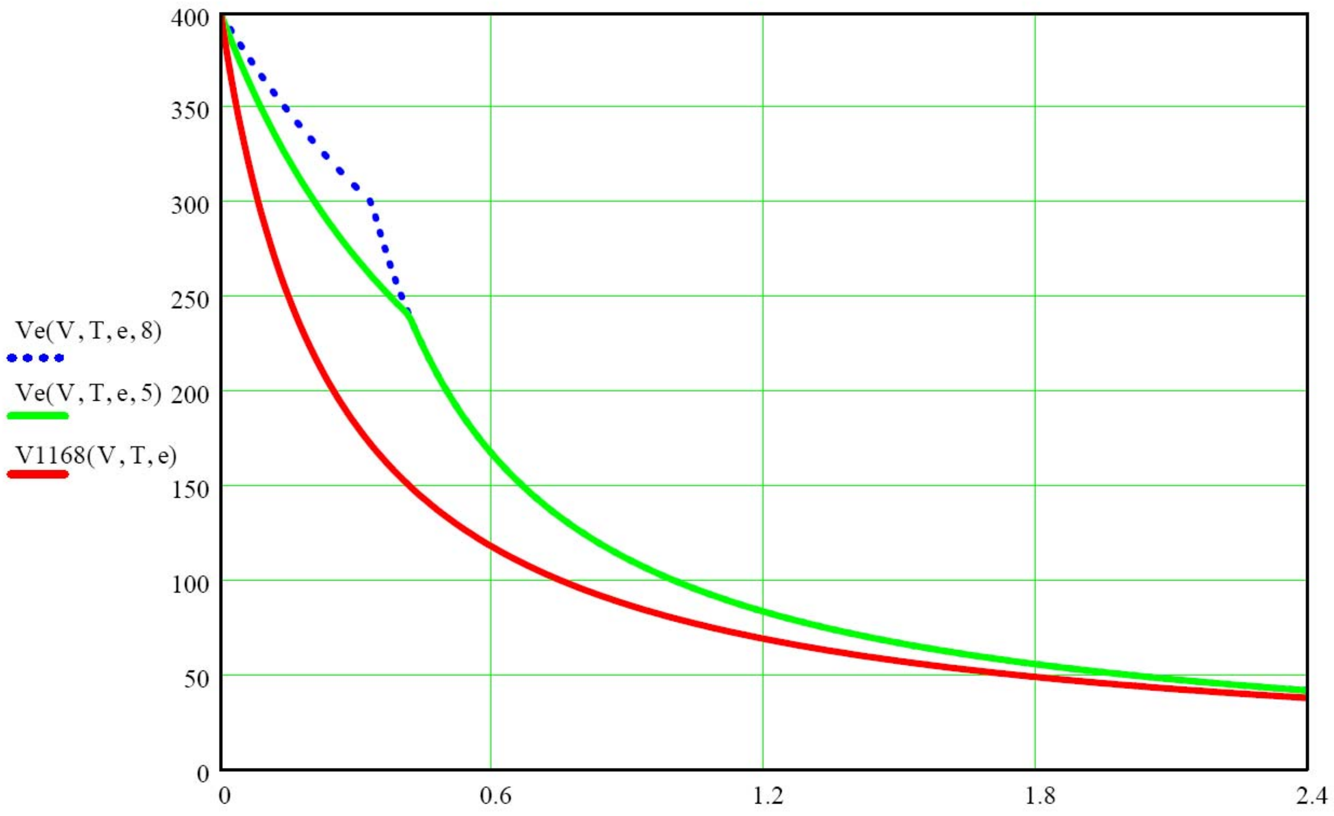
Load capacity V (kN) with different eccentricity e due to the two interaction curves

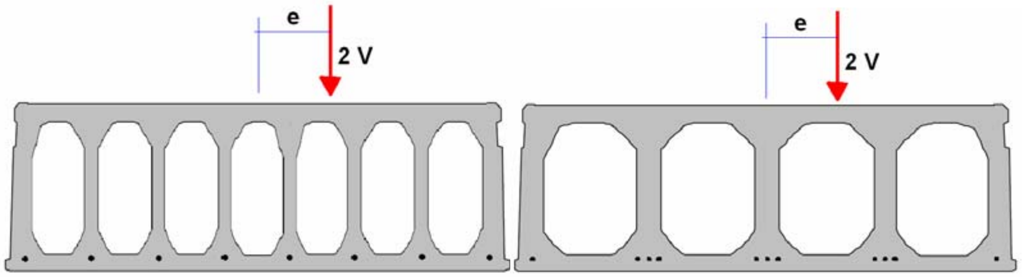




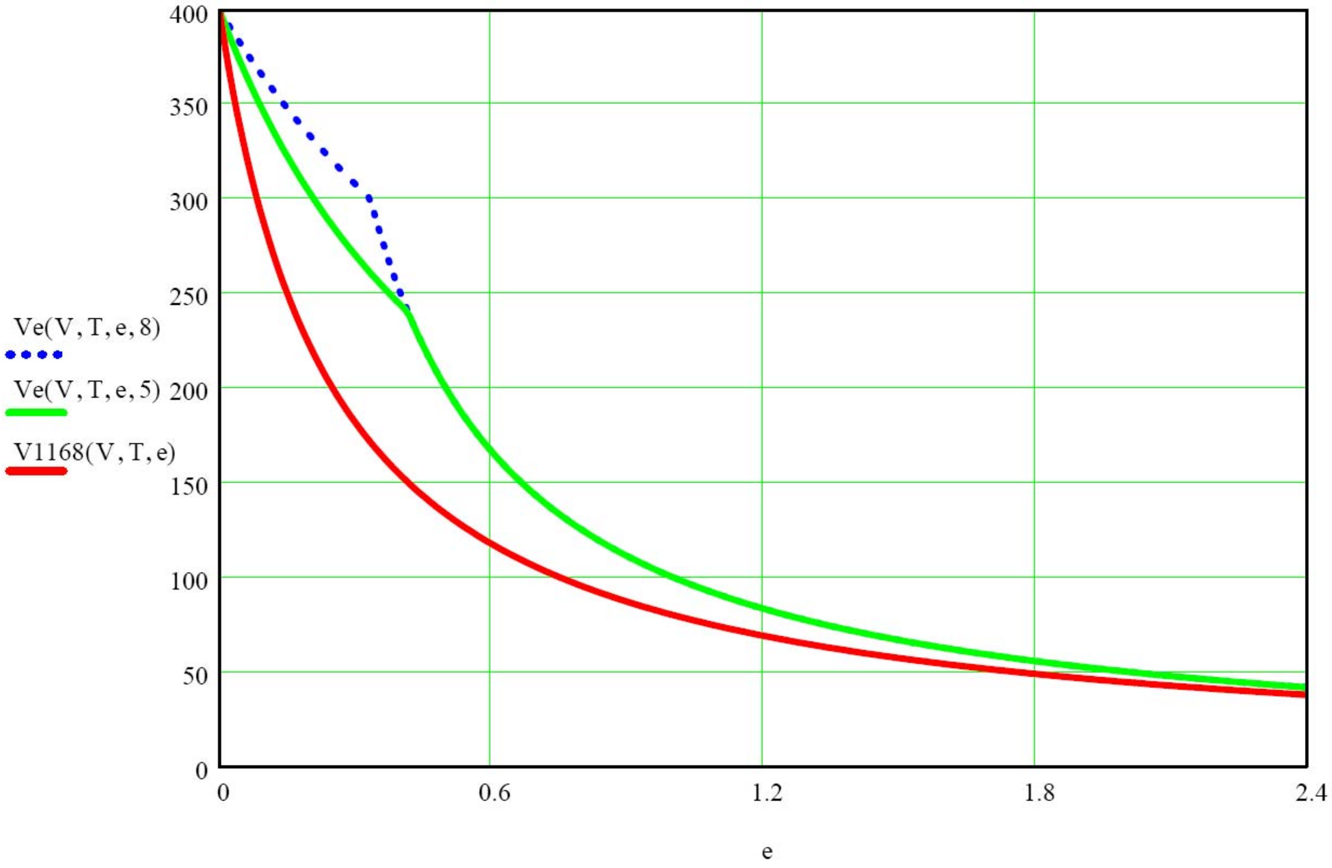
Load capacity V (kN) with different eccentricity e due to the two interaction curves

Capacity for cross-section with 8 or 5 webs



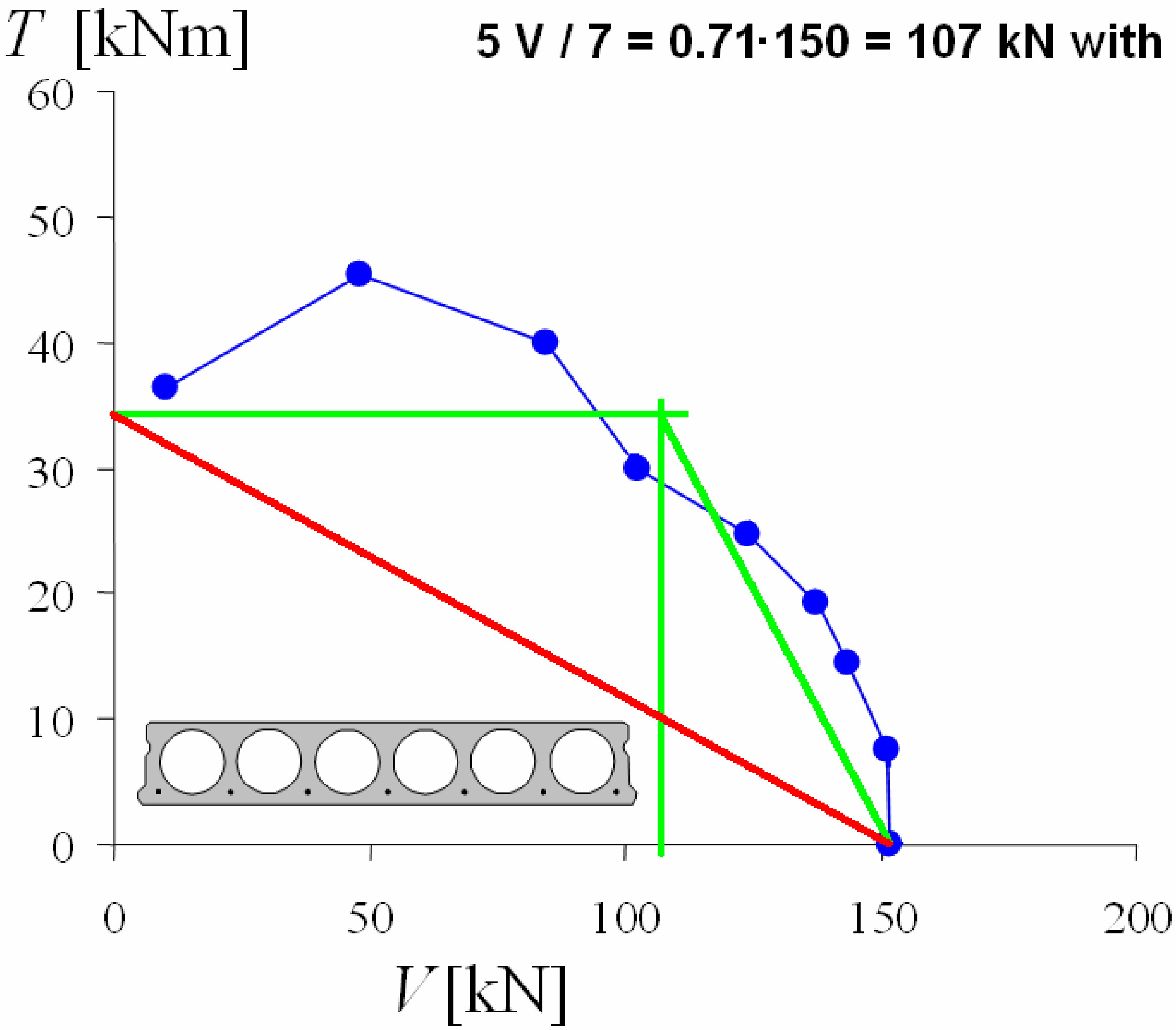


EN 1168 distribution factors, comparison



Shear torsion interaction formula

5 V / 7 = 0.71·150 = 107 kN with full torsional capacity



Shear torsion interaction

For Shear capacity calculation a method including the shear stress in the transfer zone is recommended. HOLCOTORS project, Lin Yang formula was tested

2.5 Comparison with FE-analysis

The case with slab HD/F 380 and prestressing reinforcement 1100 mm^2 has also been modelled in a FE-analysis to compare the shear stresses calculated with the suggested model.

The figure below shows the principal stresses over the cross section height. The transfer of prestress is assumed linearly along the transfer length 403 mm.

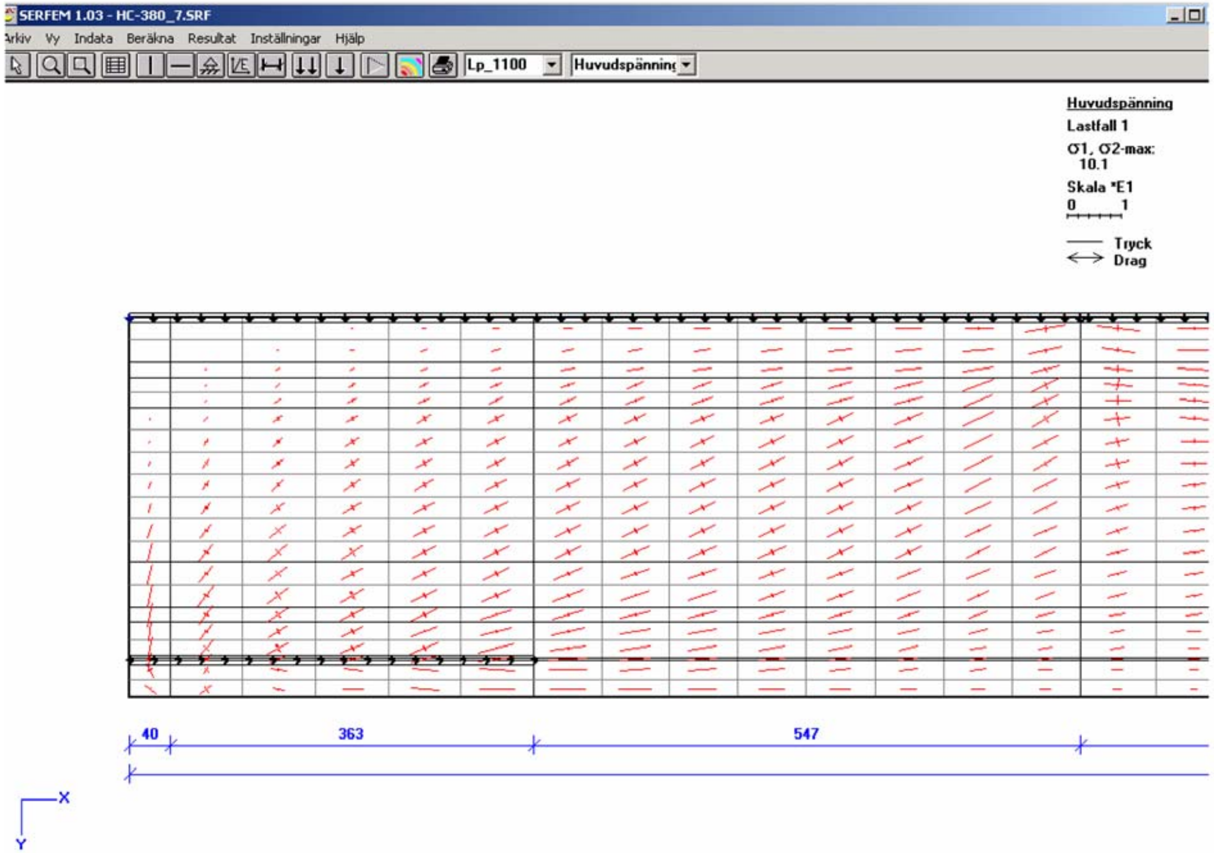


Figure 2.5:1 Principal stress in the transfer region. The slab are loaded with point load at a distance 2.5 H from the support. The shear load are set equal to the capacity calculated using the suggested model.

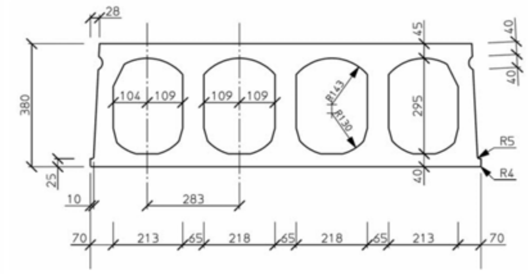
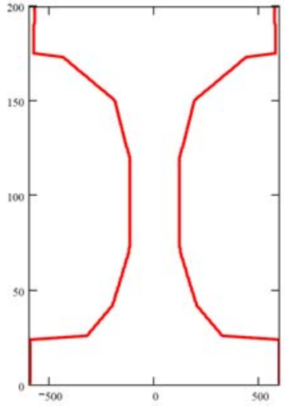


Figure 1.3:3 Cross section HD/F 380, Ap = 1100mm^2, zp = 37mm



Shear torsion interaction

Analytical calculation gives very good agreement with FE-analysis

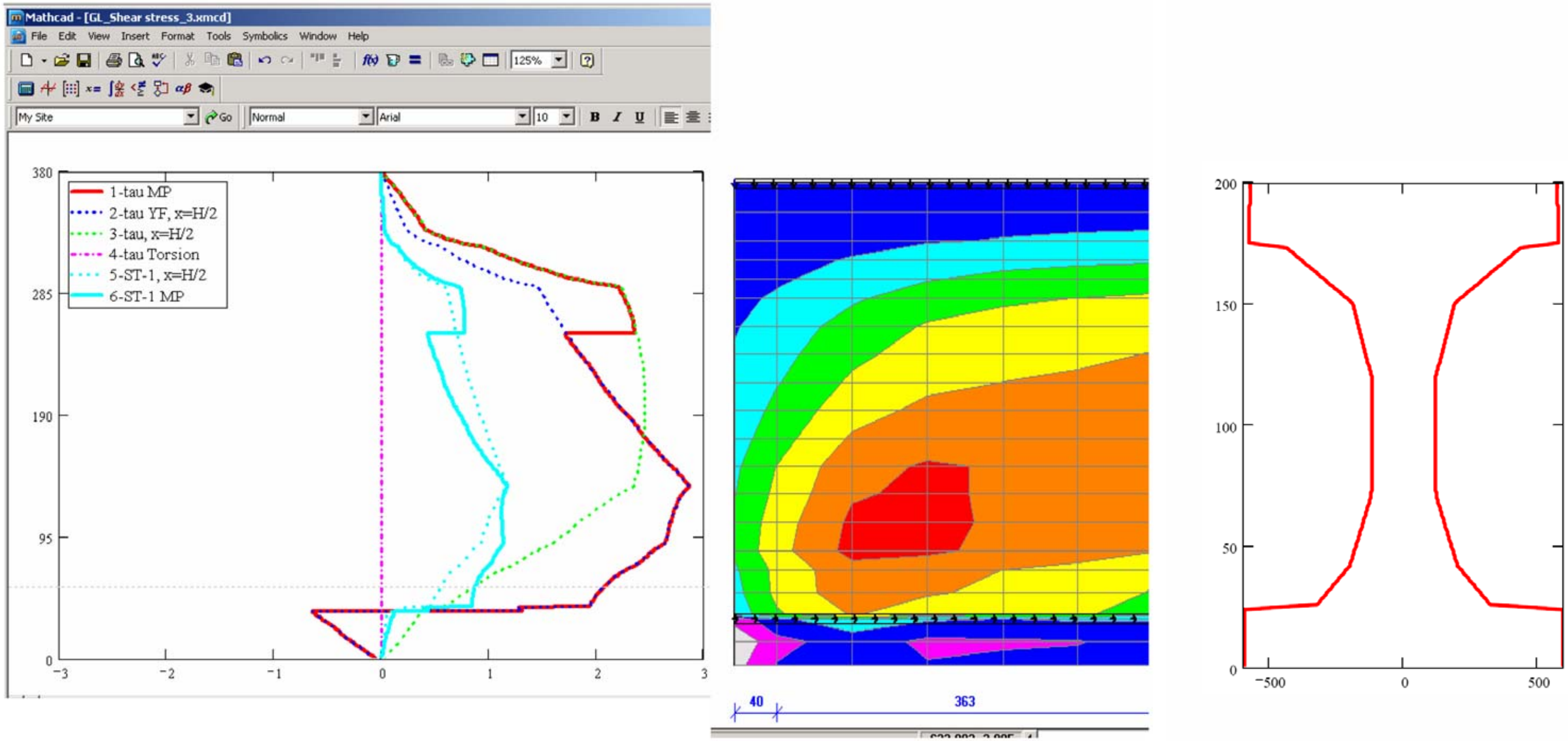


Figure 2.5:3 Comparison between the suggested model and EF-analysis, for the case HC 380 mm and 1100 mm2. Initial prestress 1100 MPa and during analysis the prestress 850 MPa has been used for both cases. Max shear stress in FE-model is 2.89 MPa, which is almost identical with the suggested model.

Shear torsion interaction

Principal stress σ_I due to nomal stress, torsion and or shear

σ_c = Normal stress in the HC section (positive in tension)

τ_{T_top} = Shear stress in top flange due to torsion

τ_{T_web} = Shear stress in outer web due to torsion

τ_{T_bot} = Shear stress in bottom flange due to torsion

τ_{V_web} = Shear stress in outer web due to shear

Top flange of box

$$\sigma_{I\_top} := \frac{\sigma_c}{2} + \sqrt{\left(\frac{\sigma_c}{2}\right)^2 + \left(\tau_{T\_top}\right)^2} \qquad \text{....(1)}$$

Outer web of box

$$\sigma_{I\_web} := \frac{\sigma_c}{2} + \sqrt{\left(\frac{\sigma_c}{2}\right)^2 + \left(\tau_{T\_web} + \tau_{V\_web}\right)^2} \qquad \text{....(2)}$$

Bottom flange of box

$$\sigma_{I\_bot} := \frac{\sigma_c}{2} + \sqrt{\left(\frac{\sigma_c}{2}\right)^2 + \left(\tau_{T\_bot}\right)^2} \qquad \text{....(3)}$$

Shear torsion interaction

For pure torsion normally the top flange is critical

with a failure condition $\sigma_{I\_top} = f_{ct}$ **inserted in eq 1 gives**

Top flange shear stress at cracking

$$\tau_{T\_top} := f_{ct} \cdot \sqrt{1 - \frac{\sigma_c}{f_{ct}}}$$

Torsion capacity at cracking on top flange

$$T := W_{top} \cdot f_{ct} \cdot \sqrt{1 - \frac{\sigma_c}{f_{ct}}}$$

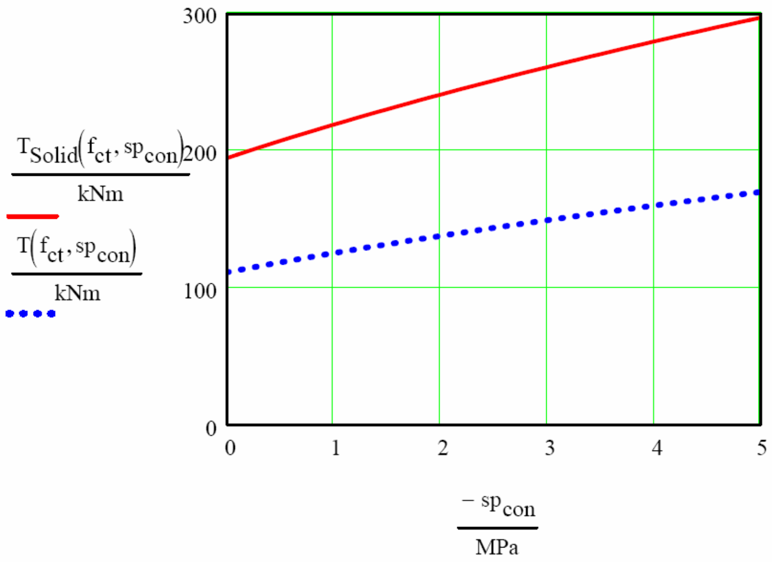
Which can be expressed

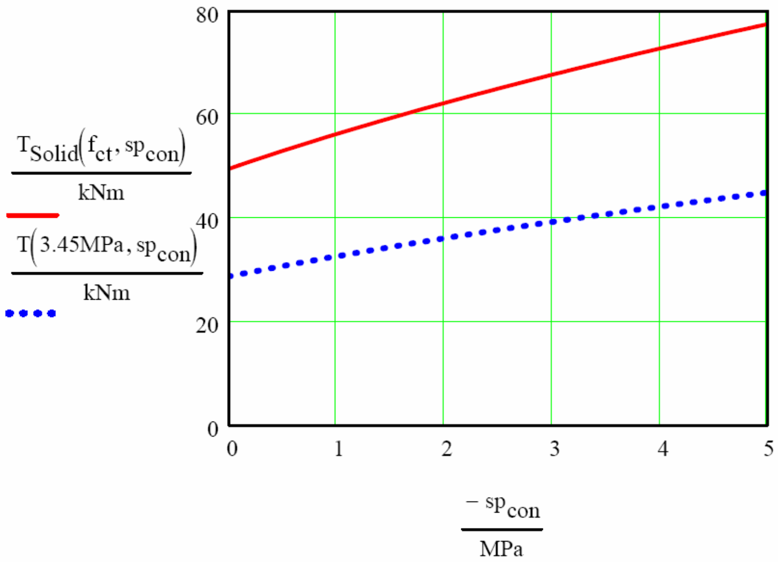
$$T := 2 \cdot B_m \cdot H_m \cdot t_{fl\_top} \cdot f_{ct} \cdot \sqrt{1 - \frac{\sigma_c}{f_{ct}}}$$

where $B_m = b - t_{web}$

$H_m = H - (t_{fl\_top} + t_{fl\_bot})/2$

Shear torsion interaction





Using the above eq. for T results in

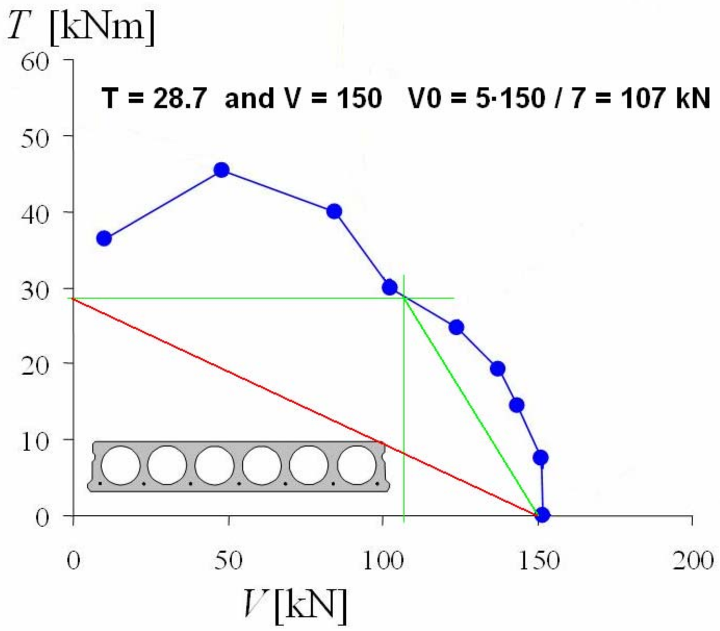
Pure torsional capacity:

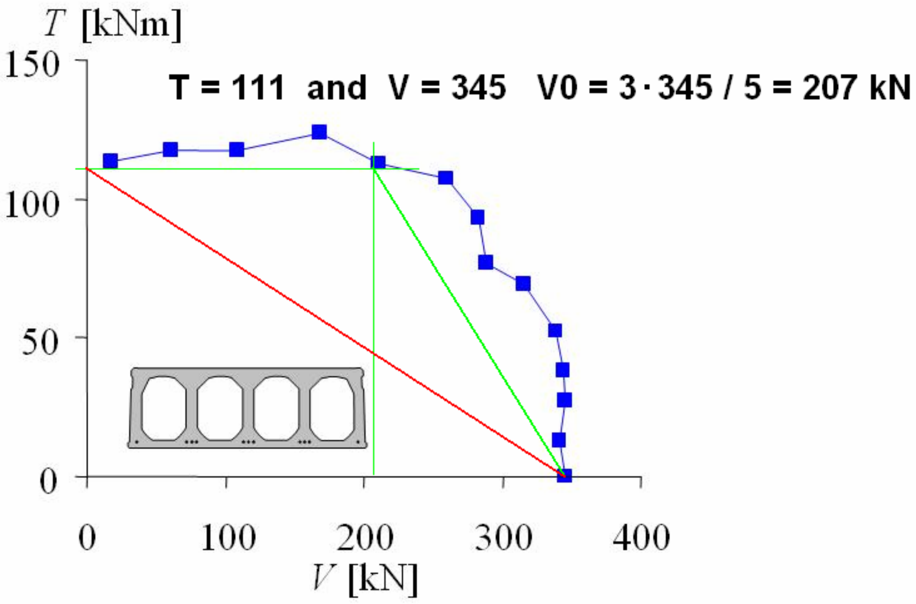
T = 111 kNm for HC 400 using f_{ct} = 3.75 MPa

T = 28.7 kNm for HC 200 using f_{ct} = 3.45 MPa

By including the compression stress in the top flange the torsional capacity is increased.

Shear torsion interaction





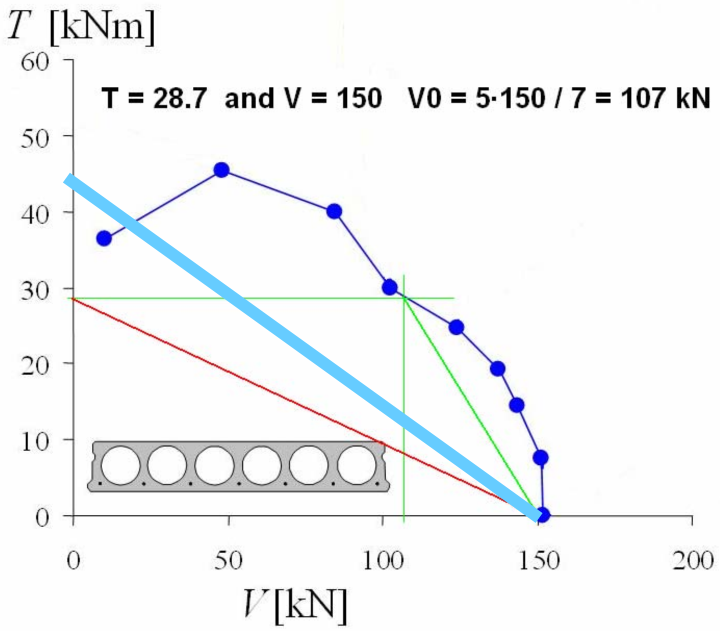
Provided pure Shear and Torsional capacity is calculated in a proper way. The interaction formula as indicated with green lines could be utilized.

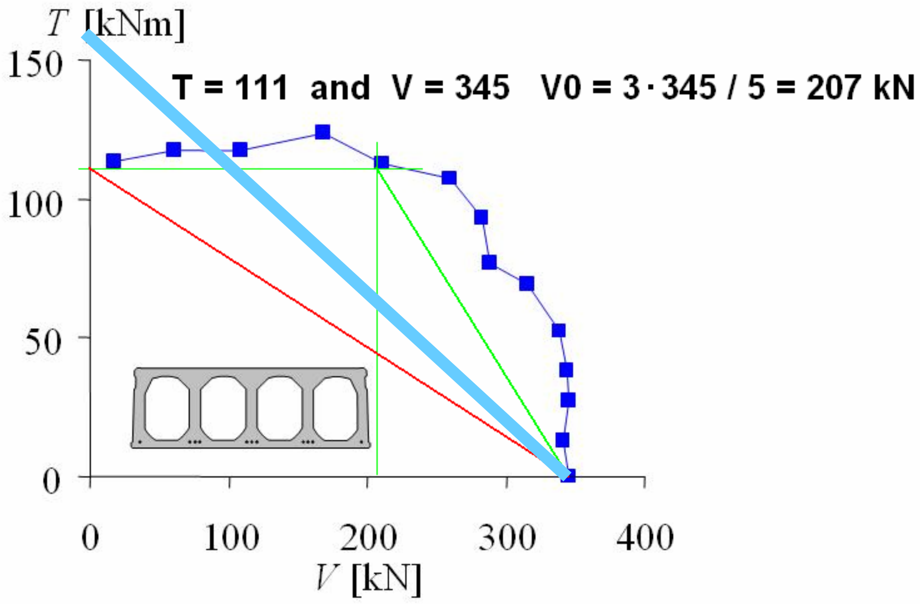
This can be used independent of Eurocode or the product standard, as it is well supported by the documented results of HOLCOTORS

Refinement can be done by:

- If top flange is critical for torsional capacity the margin not used in outer web could be included in V0
- Calculation of V0 should be based on the sum of web thickness in inner and outer webs
- Including compression stress in top flange which increases with increased shear (has to be used case by case for proper stress analysis and X-section change in the end due to grouting)

Shear torsion interaction


T = 28.7 and V = 150 V0 = 5·150 / 7 = 107 kN


T = 111 and V = 345 V0 = 3·345 / 5 = 207 kN

The expression in EN 1168 today

$$V_{Rdn} = V_{Rd,c} - V_{ETd}$$

$$\text{with } V_{ETd} = \frac{T_{Ed}}{2b_w} \times \frac{\Sigma b_w}{b - b_w}$$

Gives an indication on how the shearing force is reduced but it makes no check of torsional capacity. For the present sections

$T_{maxH200} = 0.298 \times V = 44.7$ kNm

$T_{maxH400} = 0.458 \times V = 158$ kNm

V (Lin Yang) = 339.2 kN for H400 (Lp = 0.48m)

Thanks for the attention

Shear torsion interaction