Composite bridge design (EN1994-2)

Bridge modelling and structural analysis

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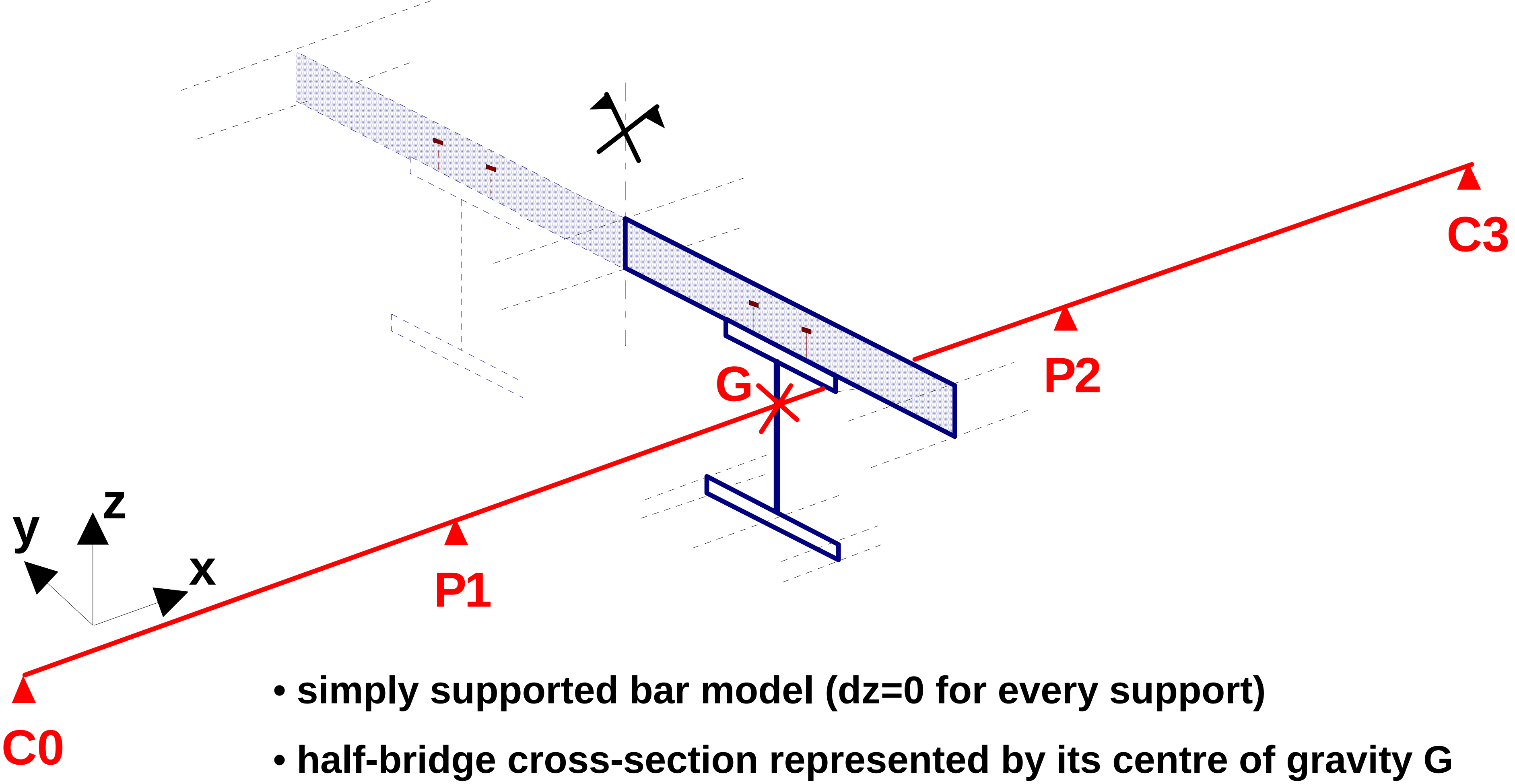
Contents

1. Bridge modelling
    - Geometry
    - Effective width (shear lag effect)
    - Modular ratios (concrete creep)
    - Transversal distribution

} ⇒ Cross-sectional mechanical properties

2. The global cracked analysis according to EN 1994-2
    - Determination of the cracked zones on internal supports
    - Results from the global analysis

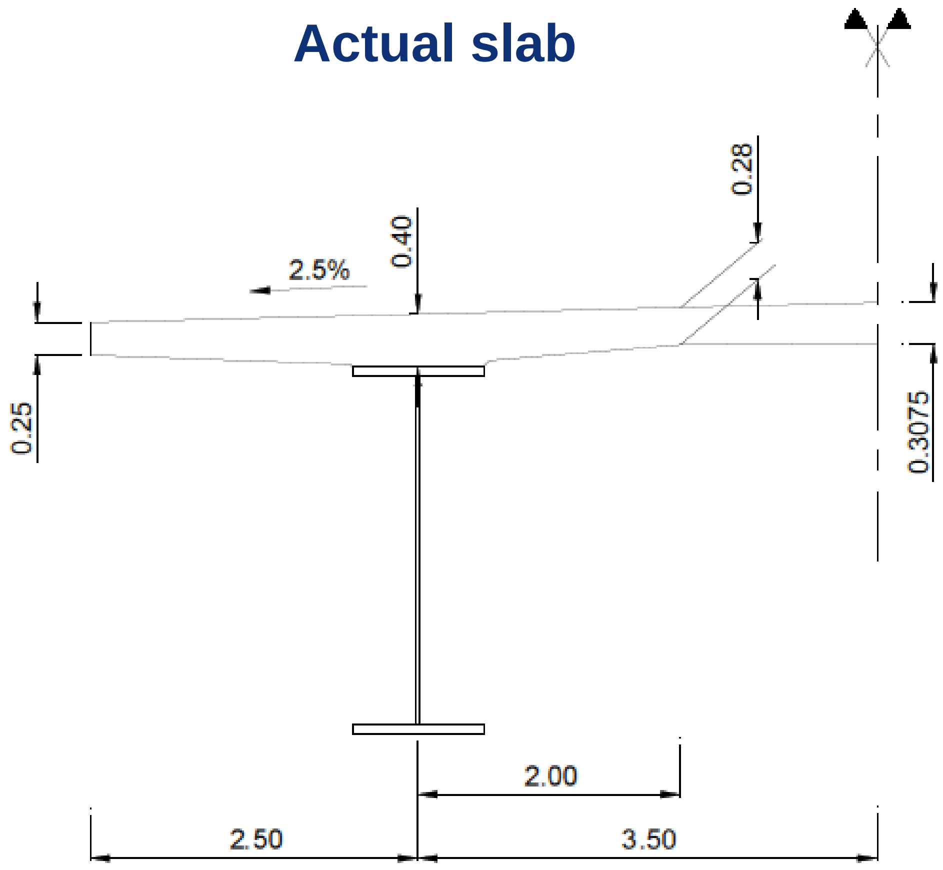
Twin-girder bridge modelling



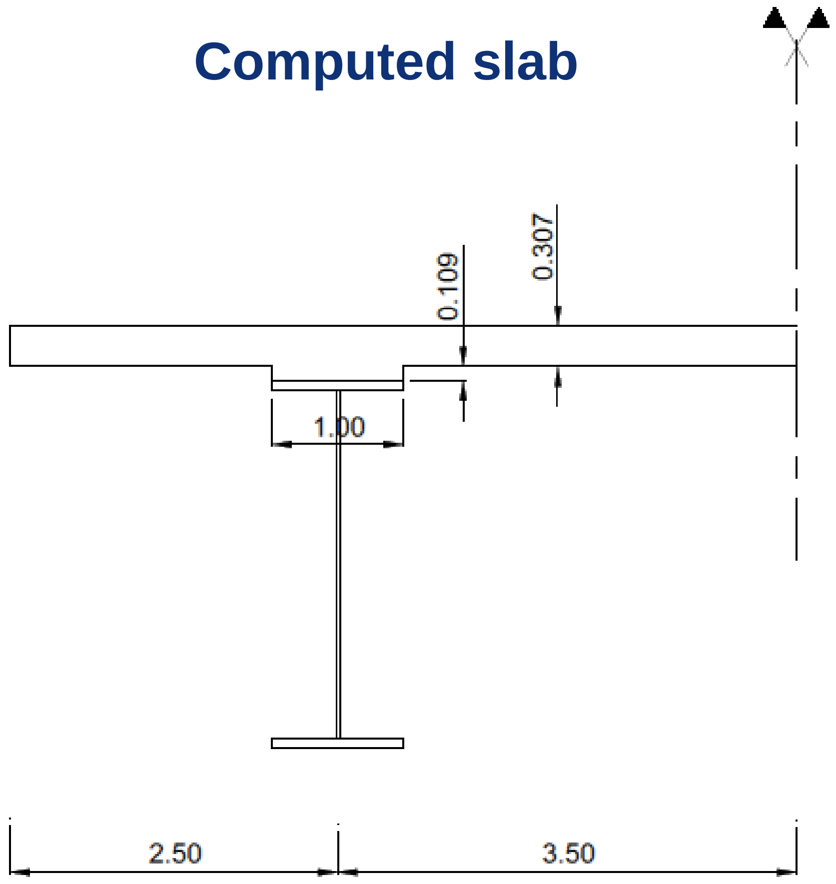
- simply supported bar model (dz=0 for every support)
- half-bridge cross-section represented by its centre of gravity G (neutral fibre)
- structural steel alone, or composite, mechanical properties according to the construction phases of the bridge slab

Concrete slab thickness

Actual slab



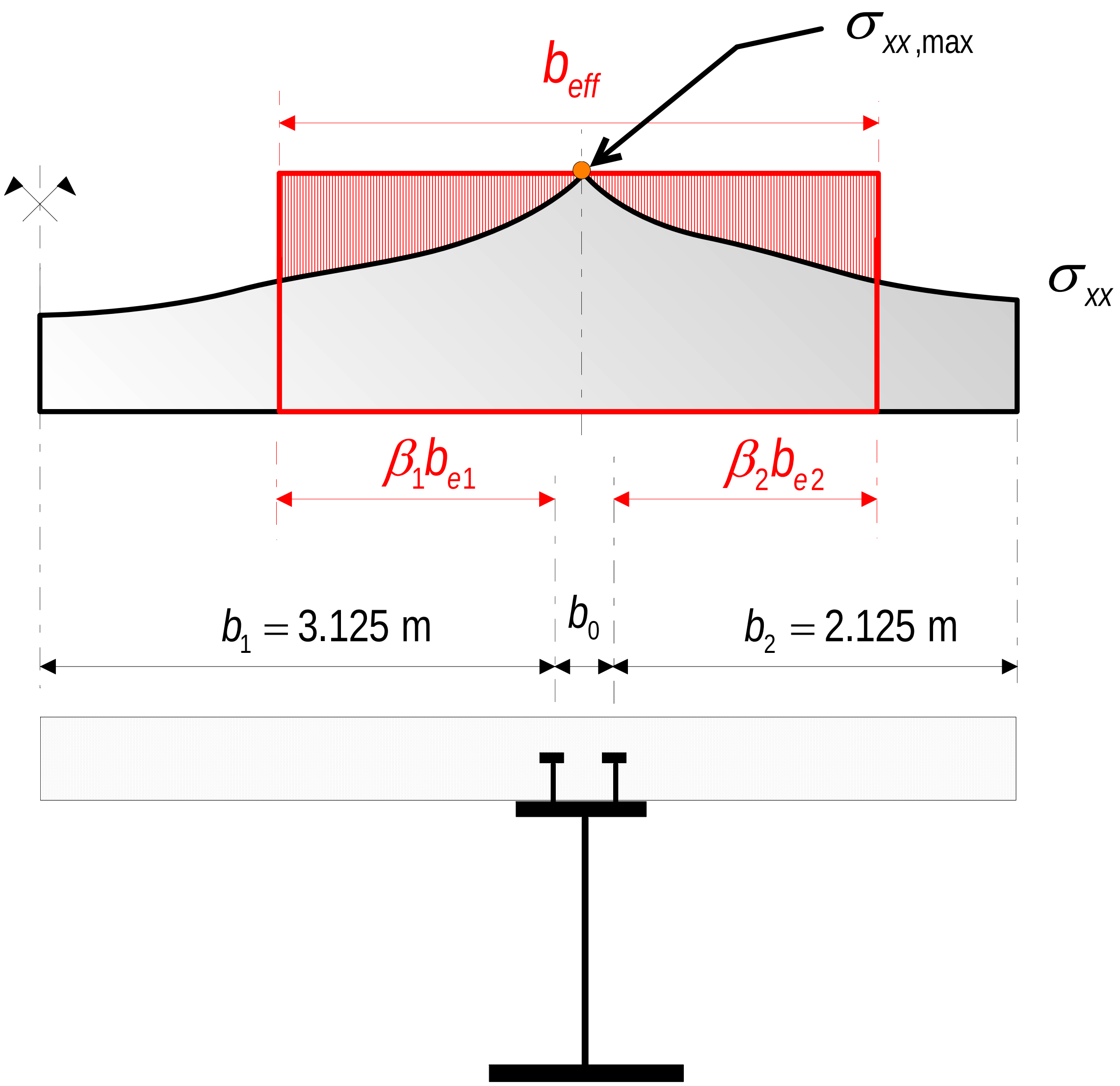
Computed slab



$S_{actual} = S_{computed}$ (same area)

$\mu_{actual} = \mu_{computed}$ (same location of the slab gravity centre G_c)

Shear lag in the concrete slab according to EN 1994-2



Non-uniform transverse distribution of the longitudinal stresses

$$b_0 = 750 \text{ mm}$$

$$b_{eff} = b_0 + \sum_i \beta_i b_{ei}$$

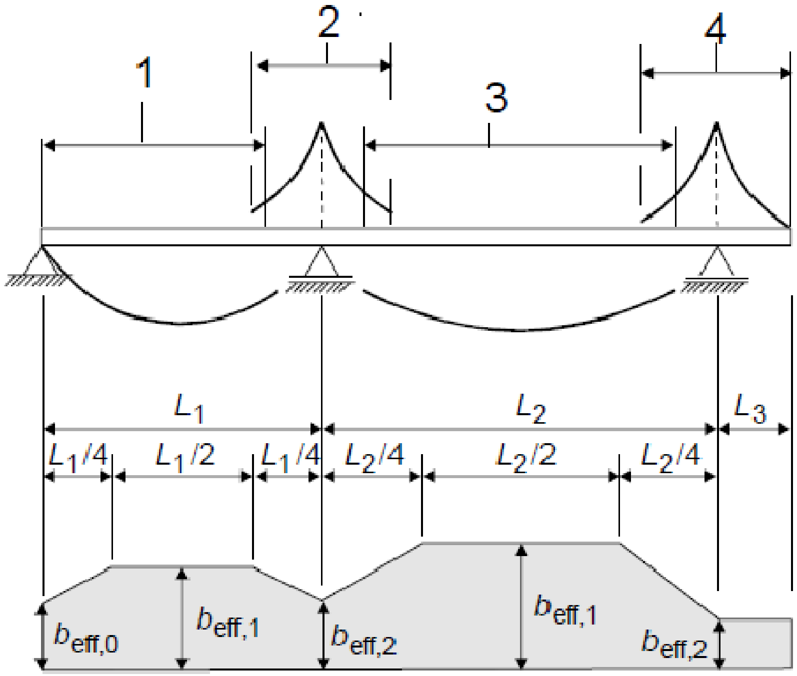
$$b_{ei} = \min\left(\frac{L_e}{8}; b_i\right)$$

$\beta_i = 1$ except for end supports where

$$\beta_i = 0.55 + 0.025 \frac{L_e}{b_{ei}} \leq 1.0$$

Shear lag in the concrete slab according to EN 1994-2

- **Equivalent span length L_e**



Key:

1 $L_e = 0{,}85\, L_1$ for $b_{eff,1}$

2 $L_e = 0{,}25(L_1 + L_2)$ for $b_{eff,2}$

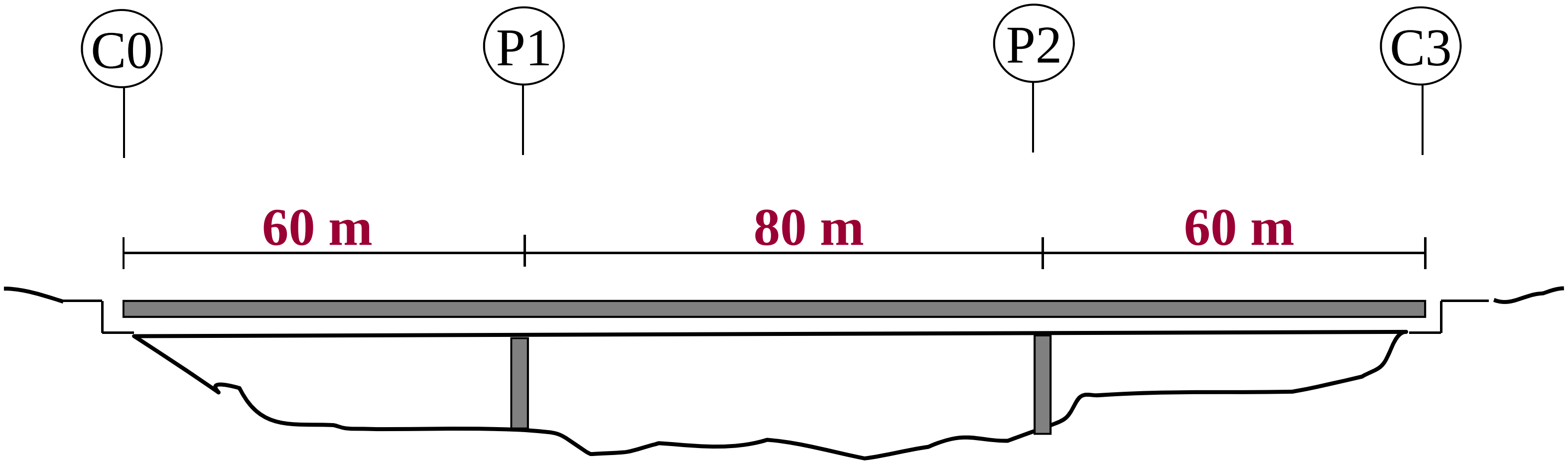
3 $L_e = 0{,}70\, L_2$ for $b_{eff,1}$

4 $L_e = 2\, L_3$ for $b_{eff,2}$

- **Global analysis (calculation of internal forces and moments)** : constant along each span (equal to the value at mid-span)

- **Section analysis (calculation of stresses)** : linearly variable along $L_i/4$ surrounding the internal supports

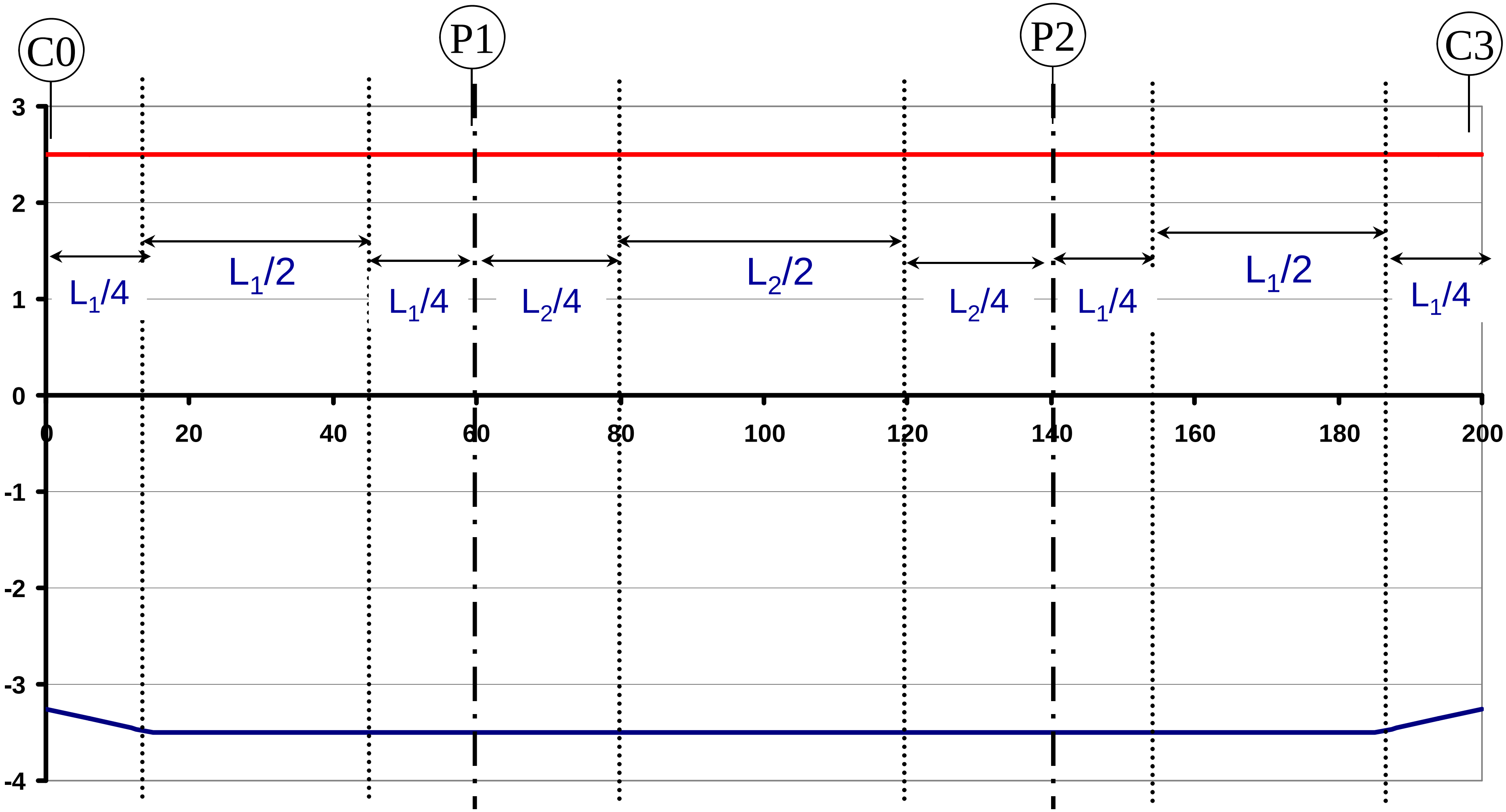
Application to the twin-girder bridge example



L_e (m)	0.85x60 = 51	0.7x80 = 56	0.85x60 = 51
	0.25 x (60+80) = 35		0.25 x (60+80) = 35

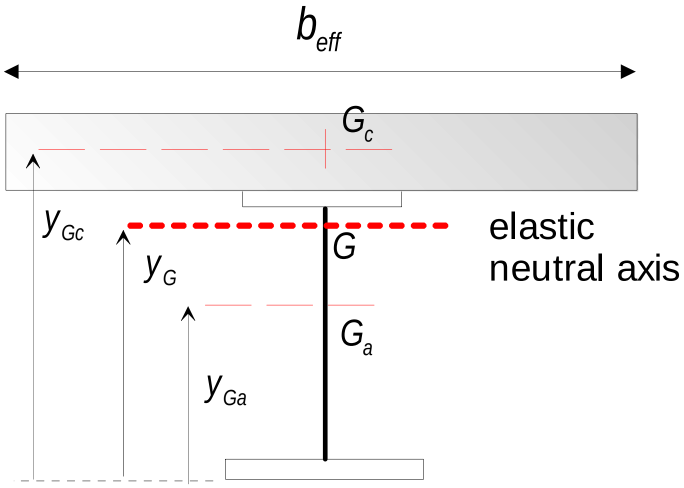
	L_e (m)	b_{e1} (m)	b_{e2} (m)	β_1	β_2	b_{eff} (m)
In-span 1 and 3	**48**	**3.125**	**2.125**	**1**	**1**	**6.0**
In-span 2	**56**	**3.125**	**2.125**	**1**	**1**	**6.0**
Internal supports P1 and P2	**35**	**3.125**	**2.125**	**1**	**1**	**6.0**
End supports C0 and C3	**48**	**3.125**	**2.125**	**0.958**	**1.15 but < 1.0**	**5.869 < 6.0**

Application to the twin-girder bridge example



Composite cross-sections mechanical properties

- **Un-cracked behaviour (mid-span regions, $M_{c,Ed} > 0$)**

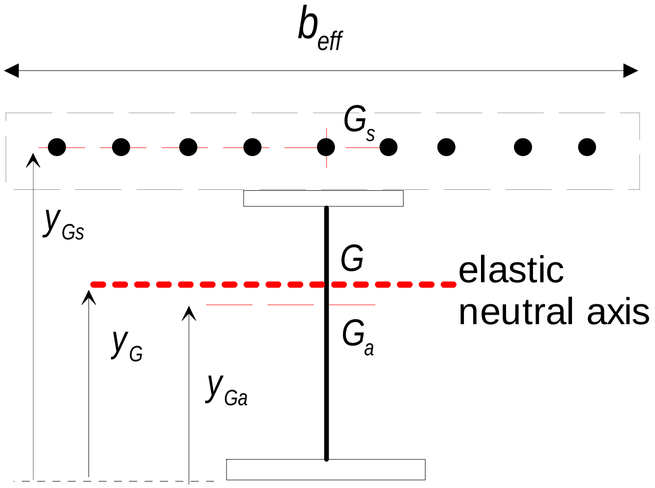


Reinforcement neglected (in compression)

$$A = A_a + \frac{A_c}{n} \qquad A y_G = A_a y_{Ga} + \frac{A_c}{n} y_{Gc}$$

$$I = I_a + A_a (y_G - y_{Ga})^2 + \frac{1}{n}\left[I_c + A_c \left(y_G - y_{Gc} \right)^2 \right]$$

- **Cracked behaviour (support regions, $M_{c,Ed} < 0$)**



$E_a = E_s = 210\,000$ N/mm² $(n = 1)$

$$A = A_a + A_s \qquad A y_G = A_a y_{Ga} + A_s y_{Gs}$$

$$I = I_a + A_a (y_G - y_{Ga})^2 + I_s + A_s \left(y_G - y_{Gs} \right)^2$$

$$\left(I_s \simeq 0 \right)$$

Modular ratios (creep effect)

Short-term modular ratio: $n_0 = \frac{E_a}{E_{cm}}$ $E_{cm} = 22000\left(\frac{f_{cm}}{10}\right)^{0.3}$

Long-term modular ratio: $n_L = n_0.\left(1+\psi_L \phi_t\right)$

$\phi_t = \phi\left(t - t_0\right)$ Creep coefficient according to EN 1992-1-1 with :

- t = age of concrete at the considered time during the bridge life
- t_0 = age of concrete when the considered loading is applied to the bridge

t_0 = 1 day for shrinkage

t_0 = mean value of age of concrete segments, in case of composites structures cast in several stages (permanent load)

ψ_L depends on the load case :

Permanent loads	1.1
Shrinkage	0.55
Imposed deformations	1.5

Creep coefficient according to Annex B in EN 1992-1-1

$$\phi_t = \phi_0.\beta_c\left(t - t_0\right) = \phi_0.\left(\frac{t - t_0}{\beta_H + t - t_0}\right)^{0.3} \xrightarrow[t \longrightarrow +\infty]{} \phi_0$$

(end of bridge life)

$$\left\{ \beta_H = 1.5.\left[1 + \left(0.012 \cdot RH\right)^{18}\right].h_0 + 250.\alpha_3 \leq 1500.\alpha_3 \right\}$$

$$\phi_0 = \phi_{RH}.\beta\left(f_{cm}\right).\beta\left(t_0\right) = \left[1 + \frac{1 - \frac{RH}{100}}{0.10\sqrt[3]{h_0}}.\alpha_1\right].\alpha_2.\left[\frac{16.8}{\sqrt{f_{cm}}}\right].\left[\frac{1}{0.1 + t_0^{\,0.2}}\right]$$

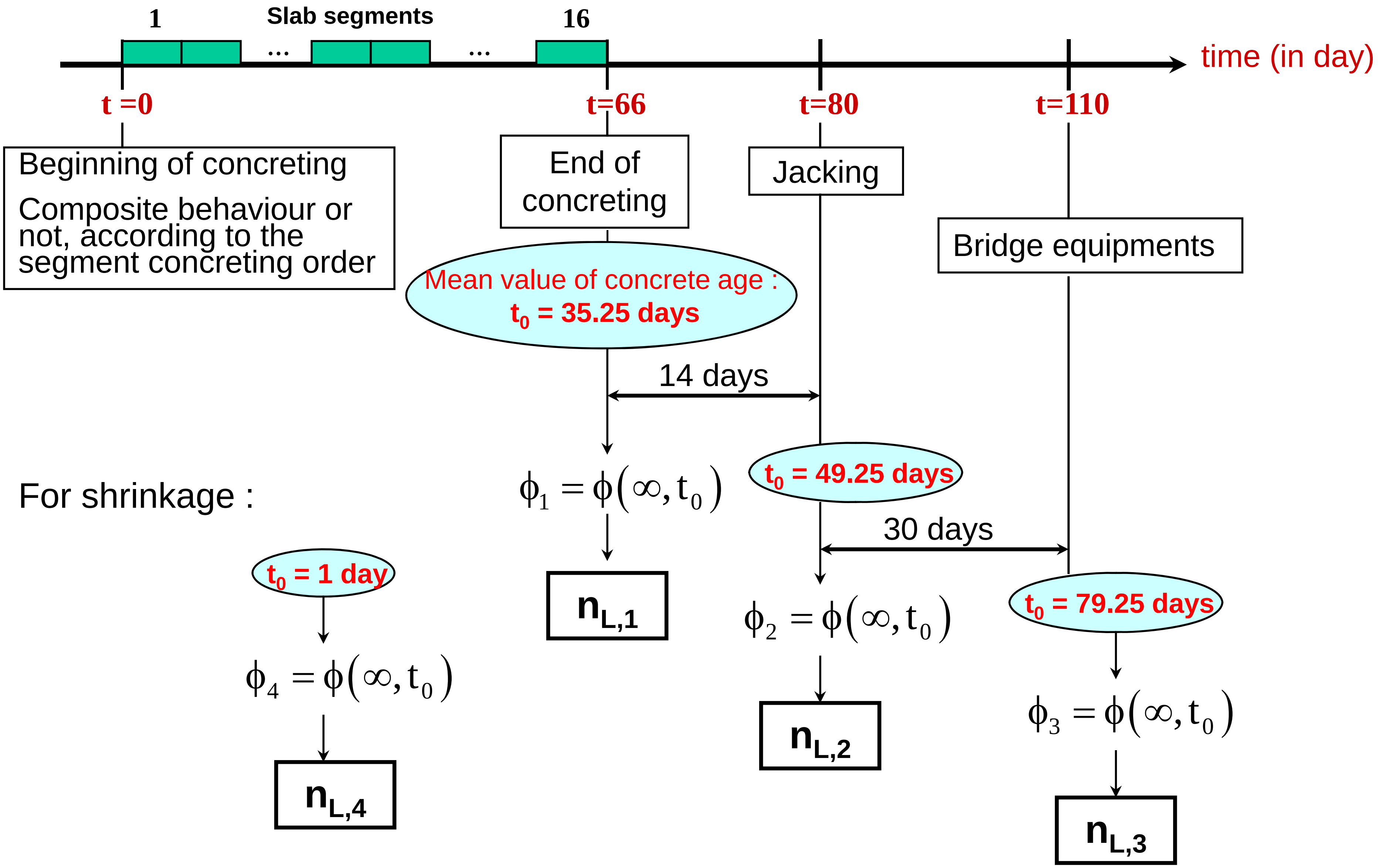
with : RH = 80 % (relative humidity in the bridge area)

$$h_0 = \frac{2A_c}{u}$$

notional size (u is the concrete slab perimeter exposed to drying)

$$\alpha_1 = \left(\frac{35}{f_{cm}}\right)^{0.7} = 0.8658 \qquad \alpha_2 = \left(\frac{35}{f_{cm}}\right)^{0.2} = 0.9597 \qquad \alpha_3 = \left(\frac{35}{f_{cm}}\right)^{0.5} = 0.9022$$

Application to the twin-girder bridge example



Beginning of concreting

Composite behaviour or not, according to the segment concreting order

End of concreting

Jacking

Bridge equipments

Mean value of concrete age : t_0 = 35.25 days

t_0 = 49.25 days

t_0 = 79.25 days

For shrinkage :

t_0 = 1 day

$$\phi_1 = \phi(\infty, t_0)$$

$n_{L,1}$

$$\phi_2 = \phi(\infty, t_0)$$

$n_{L,2}$

$$\phi_3 = \phi(\infty, t_0)$$

$n_{L,3}$

$$\phi_4 = \phi(\infty, t_0)$$

$n_{L,4}$

Application to the twin-girder bridge example

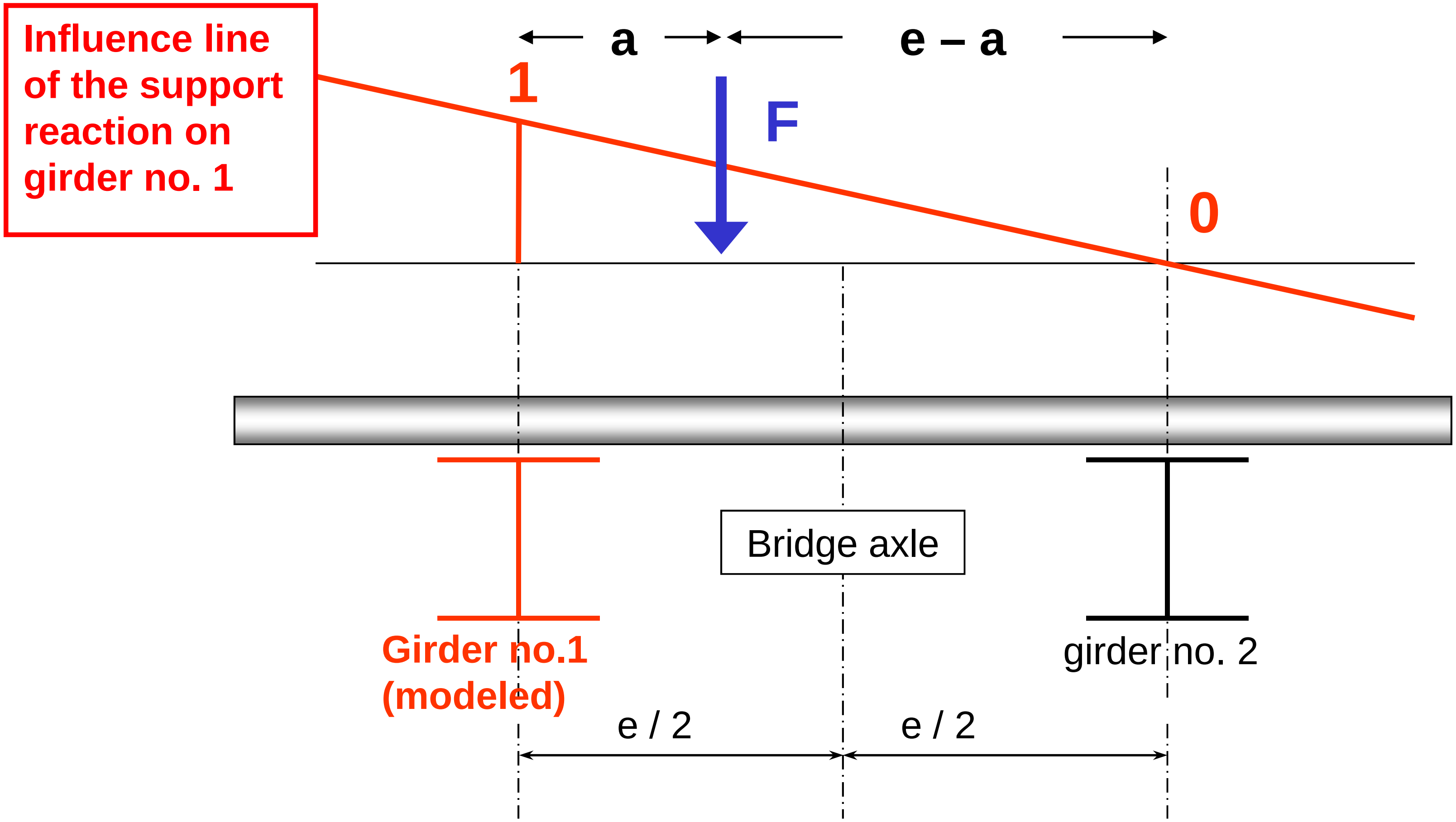
- **Short-term modular ratio**

For all load cases : $n_0 = \frac{E_a}{E_{cm}} = 6.1625$

- **Long-term modular ratio**

Load case	ψ_L	t_0 (days)	$\phi_t = \phi_0$	n_L
Concrete slab segment (selfweight)	1.10	35.25	1.394	**15.61**
Settlement	1.50	49.25	1.291	**18.09**
Shrinkage	0.55	1	2.677	**15.24**
Bridge equipments	1.10	79.25	1.179	**14.15**

Transversal distribution between the two girders



Influence line of the support reaction on girder no. 1

Bridge axle

Girder no.1 (modeled)

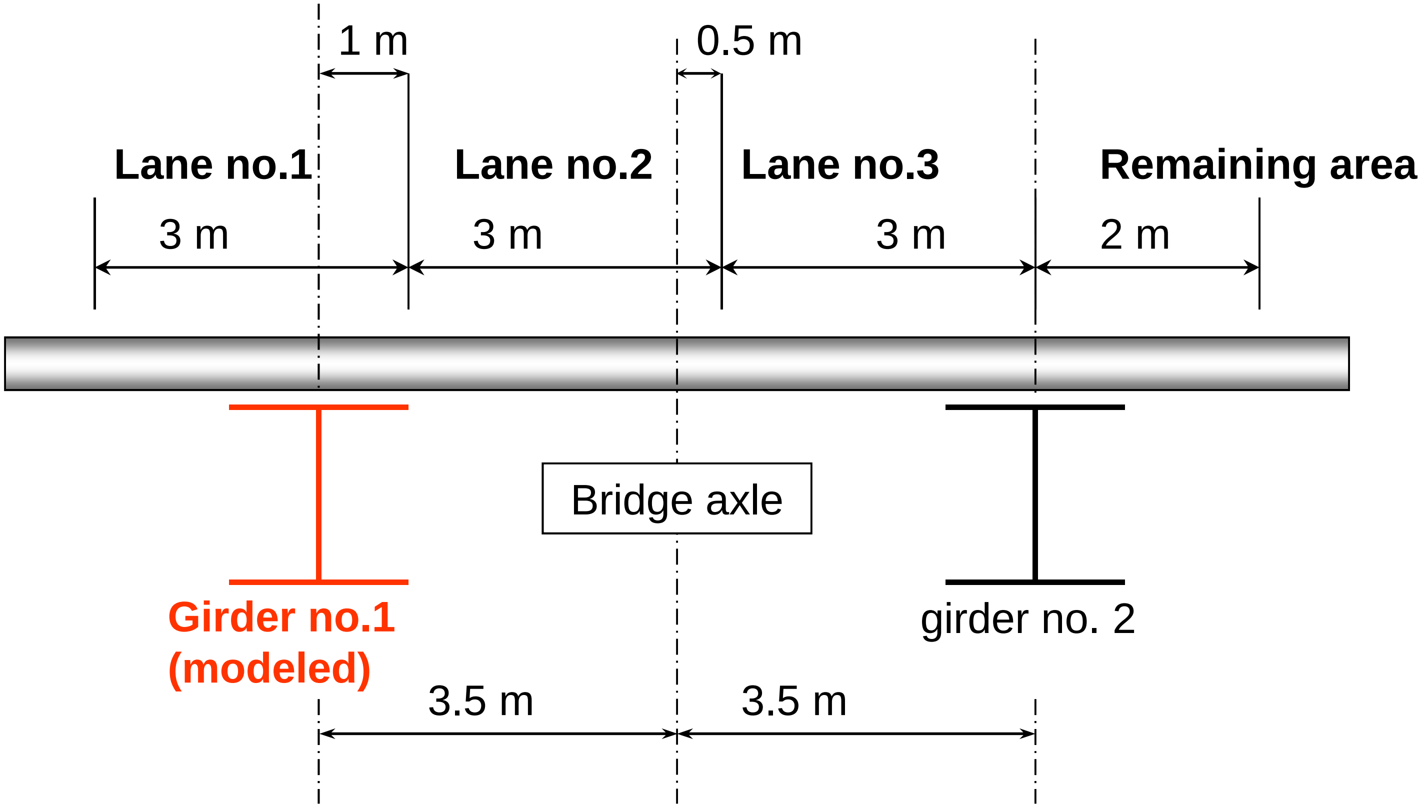
girder no. 2

$$R_1 = F\left(1 - \frac{a}{e}\right)$$

$$R_2 = F\frac{a}{e}$$

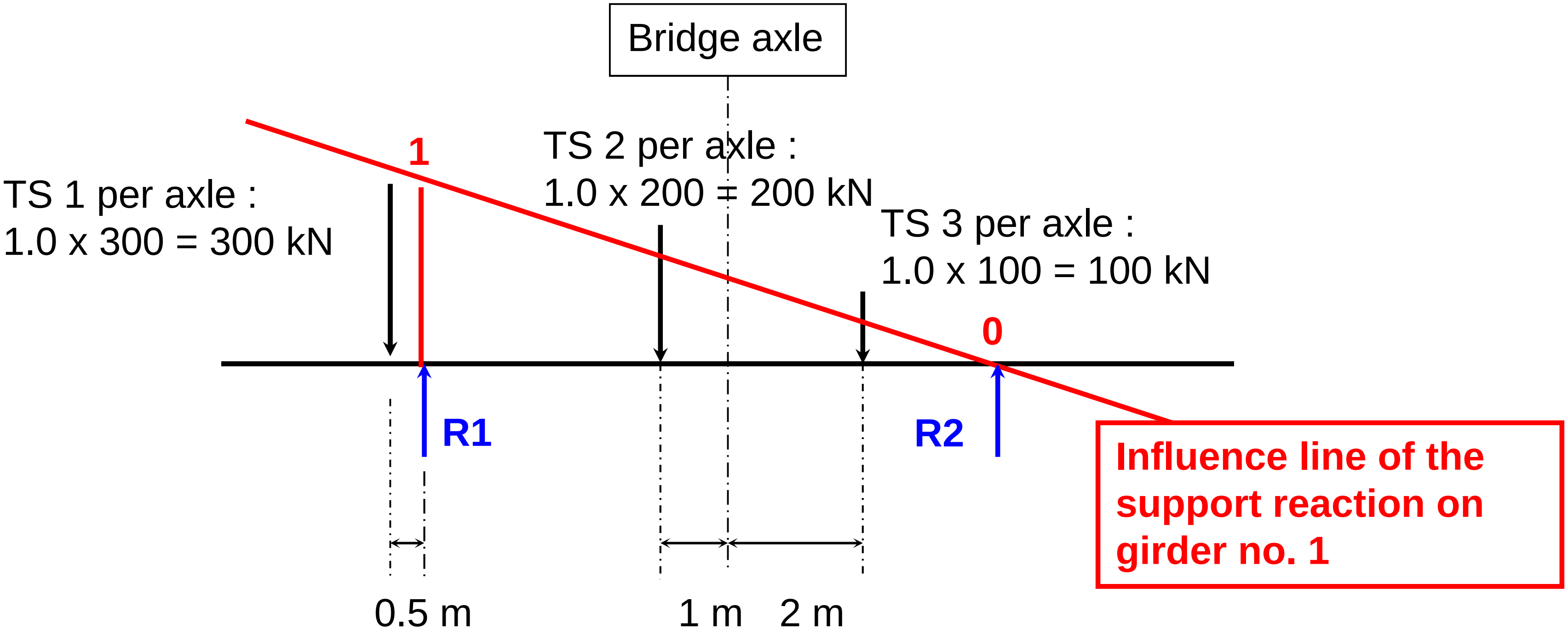
Application to the traffic load model LM1

1. Conventional traffic lanes positioning



Application to the traffic load model LM1

2. Tandem TS



Influence line of the support reaction on girder no. 1

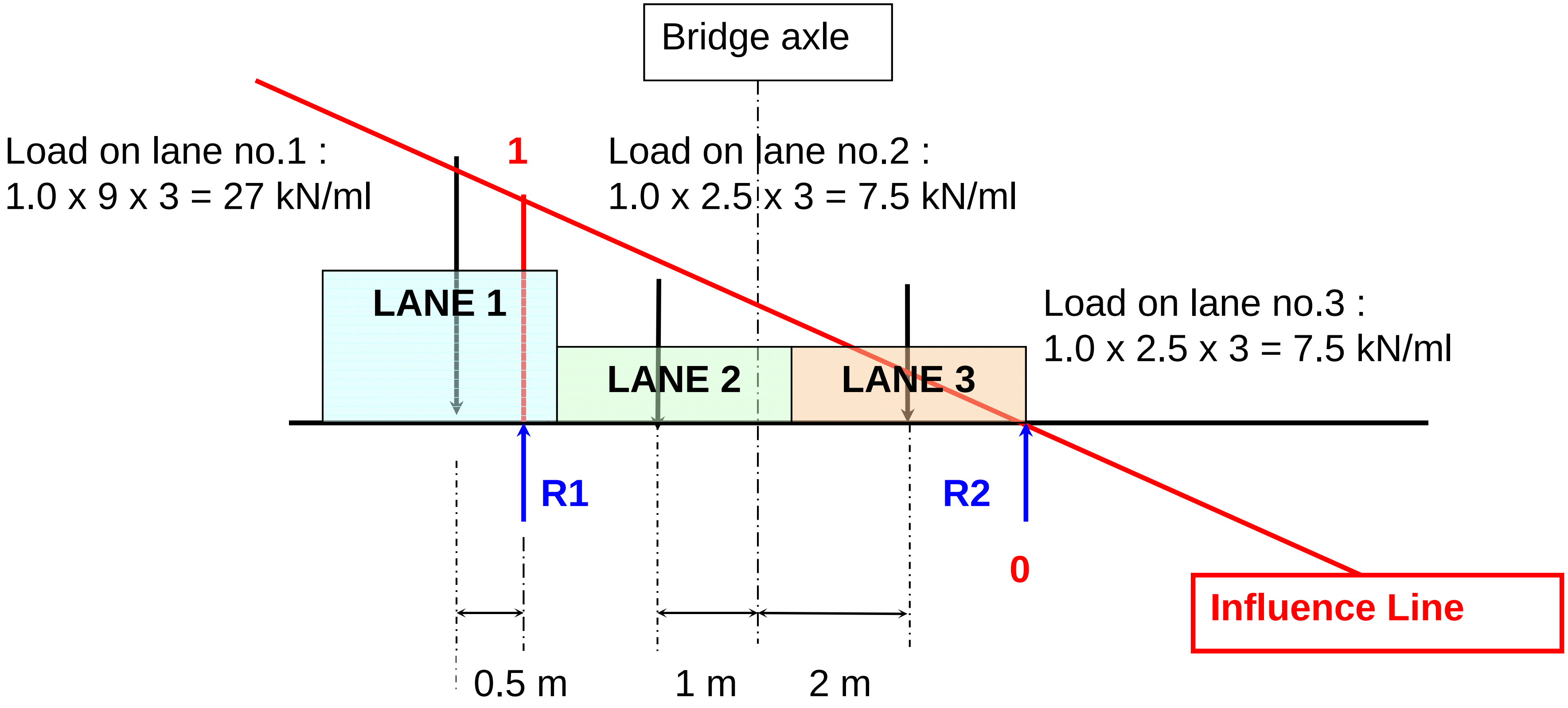
Support reaction on each main girder :

$R_1 = 471.4$ kN

$R_2 = 128.6$ kN

Application to the traffic load model LM1

3. Uniform Design Load UDL



Load on lane no.1 :
1.0 x 9 x 3 = 27 kN/ml

Load on lane no.2 :
1.0 x 2.5 x 3 = 7.5 kN/ml

Load on lane no.3 :
1.0 x 2.5 x 3 = 7.5 kN/ml

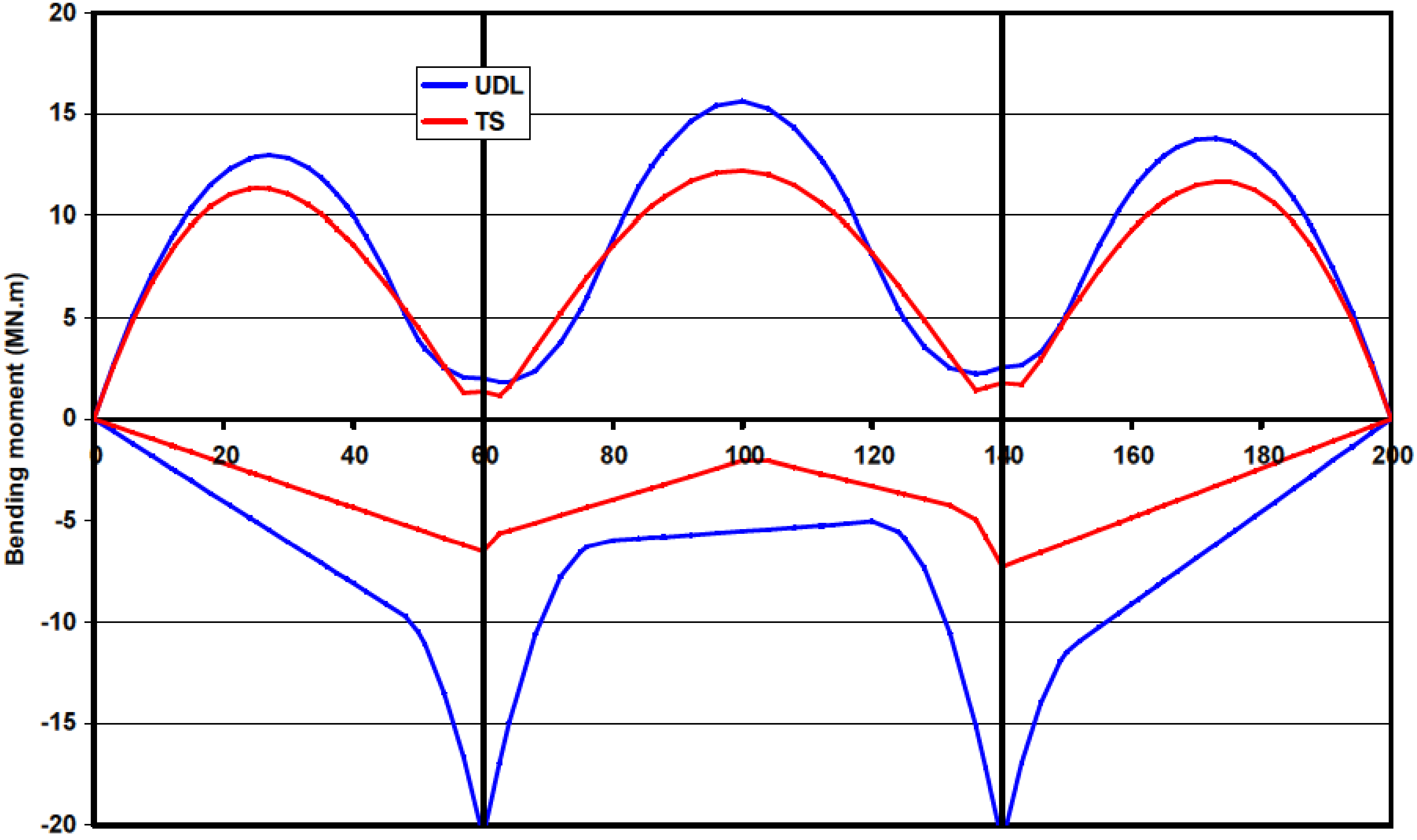
Support reaction for each main girder :

R_1 = 35.36 kN/ml

R_2 = 6.64 kN/ml

Application to the traffic load model LM1

4. Bending Moment (MN.m) for UDL and TS



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    - **Determination of the cracked zones on internal supports**
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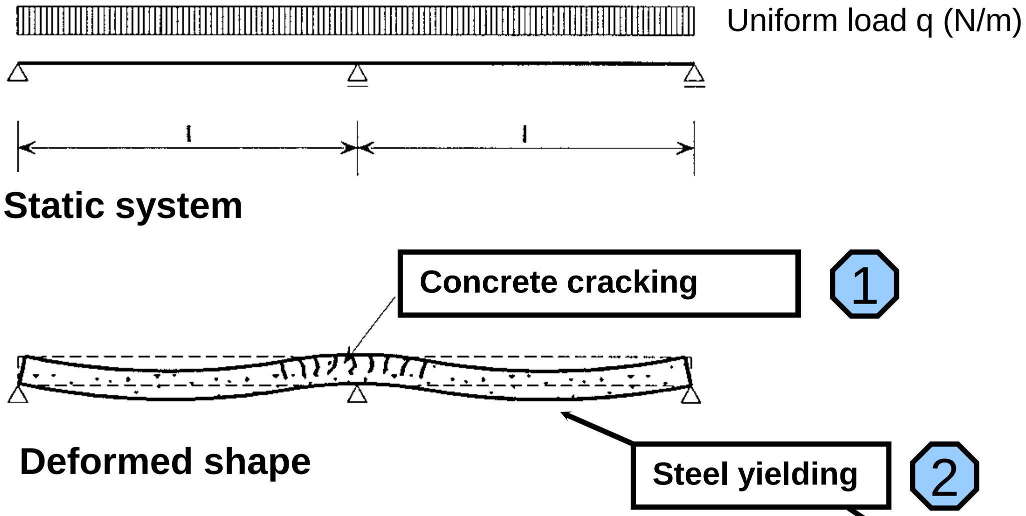
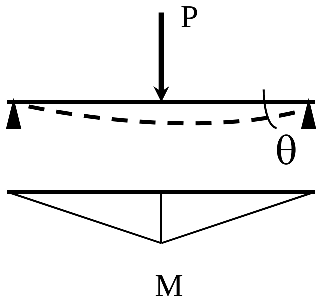
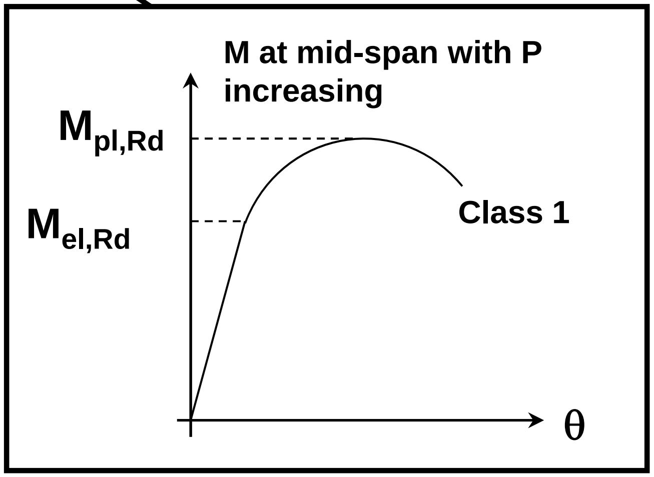
Structural analysis of a composite bridge girder



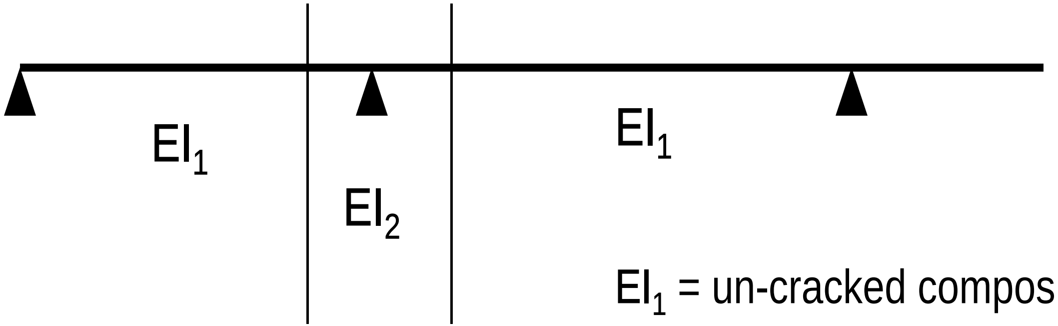




- Linear elastic global analysis (except for accidental loads)
- No bending redistribution is allowed
- Concrete cracking near internal support and steel yielding near mid-span are taken into account through simplified methods
- Plate buckling is neglected in the global analysis except if the effective^{p} area of one of the panel is lower than half its gross area ($A_{eff} < 0.5\ A_{gross}$)

Global cracked analysis

- Stress distribution σ_c in the concrete slab for the characteristic SLS combination of actions assuming the concrete resists in every cross section (EI_1)
- In the zones where $\sigma_c < -2 f_{ctm}$, the concrete is assumed to be cracked (and then neglected) for the bending stiffness distribution (EI_2)



EI_1 = un-cracked composite second moment of area (structural steel + concrete slab in compression)

EI_2 = cracked composite second moment of area (structural steel + reinforcement in tension)

This approach is not iterative (the cracked zones are determined only once).

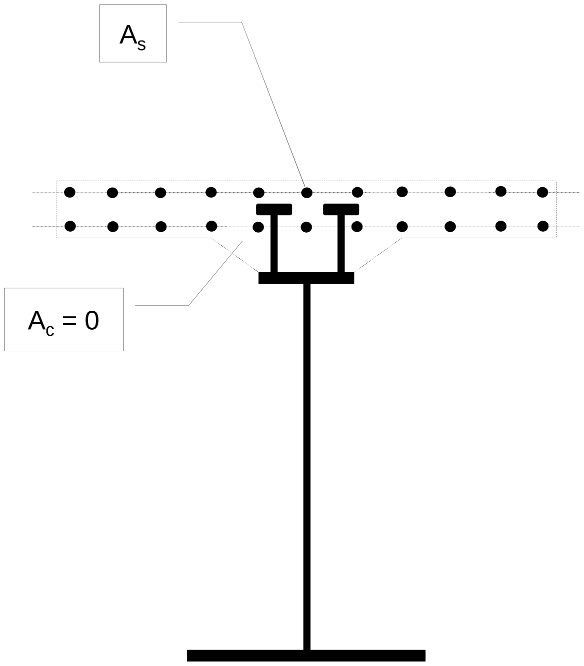
Global cracked analysis

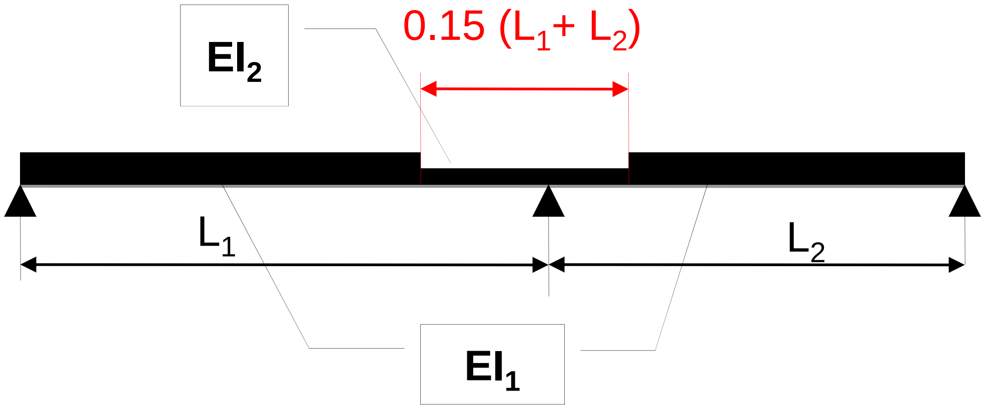
①

<u>Simplified</u> method is possible if :

- no pre-stress

- $L_{min}/L_{max} > 0.6$





In the stiffness zones EI_2 :

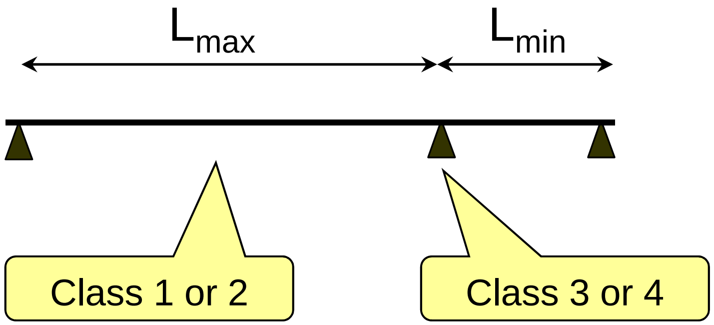
- concrete in tension is neglected
- reinforcement are included

In-span steel yielding

②

Mid-span eventual yielding is taken into account if :

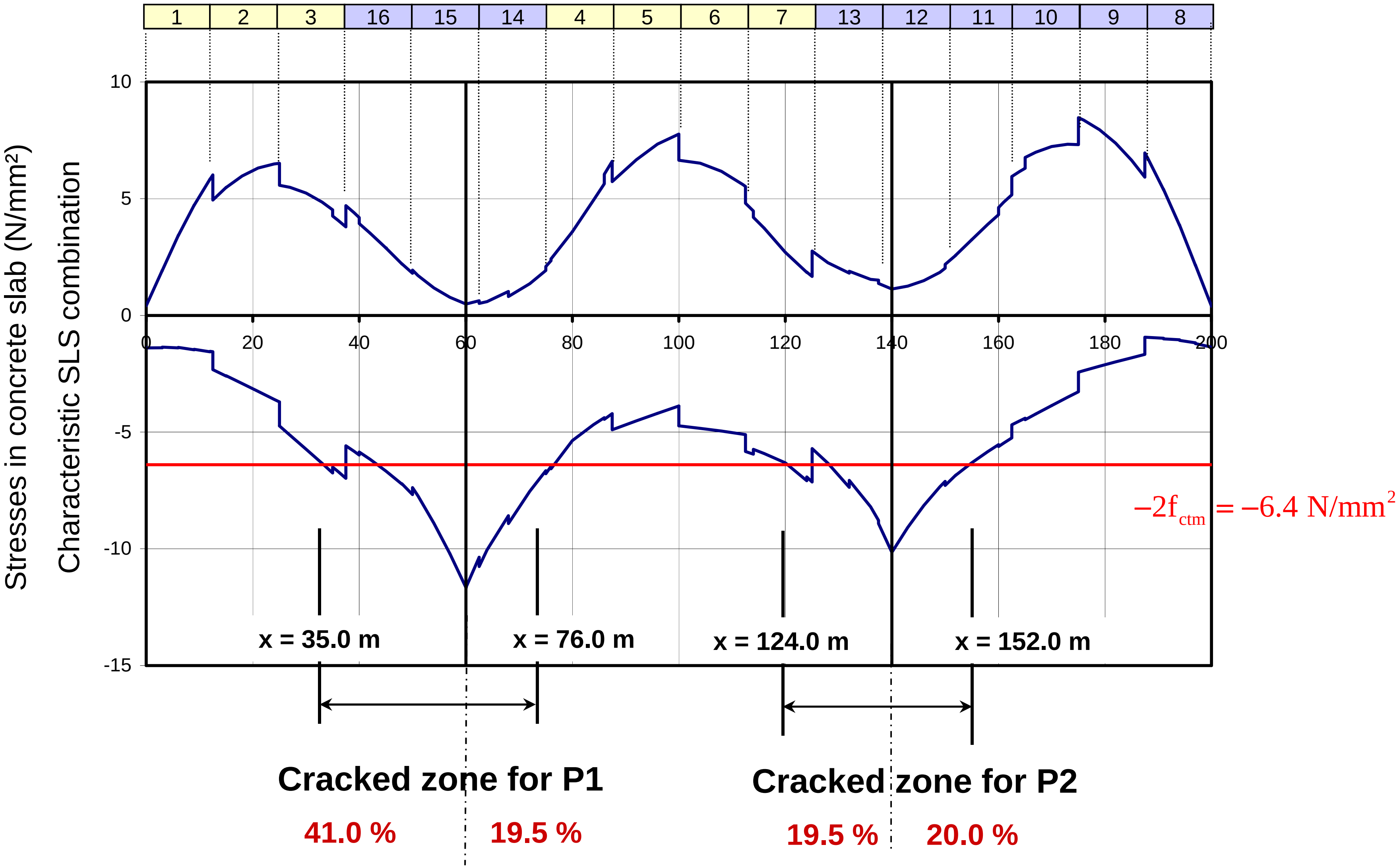
- Class 1 or 2 at mid span (and $M_{Ed} > M_{el,Rd}$)
- Class 3 or 4 on internal support
- $L_{min}/L_{max} < 0.6$



As $L_{min}/L_{max} > 0.6$ in the example, the redistribution due to yielding near mid-span is not taken into account.

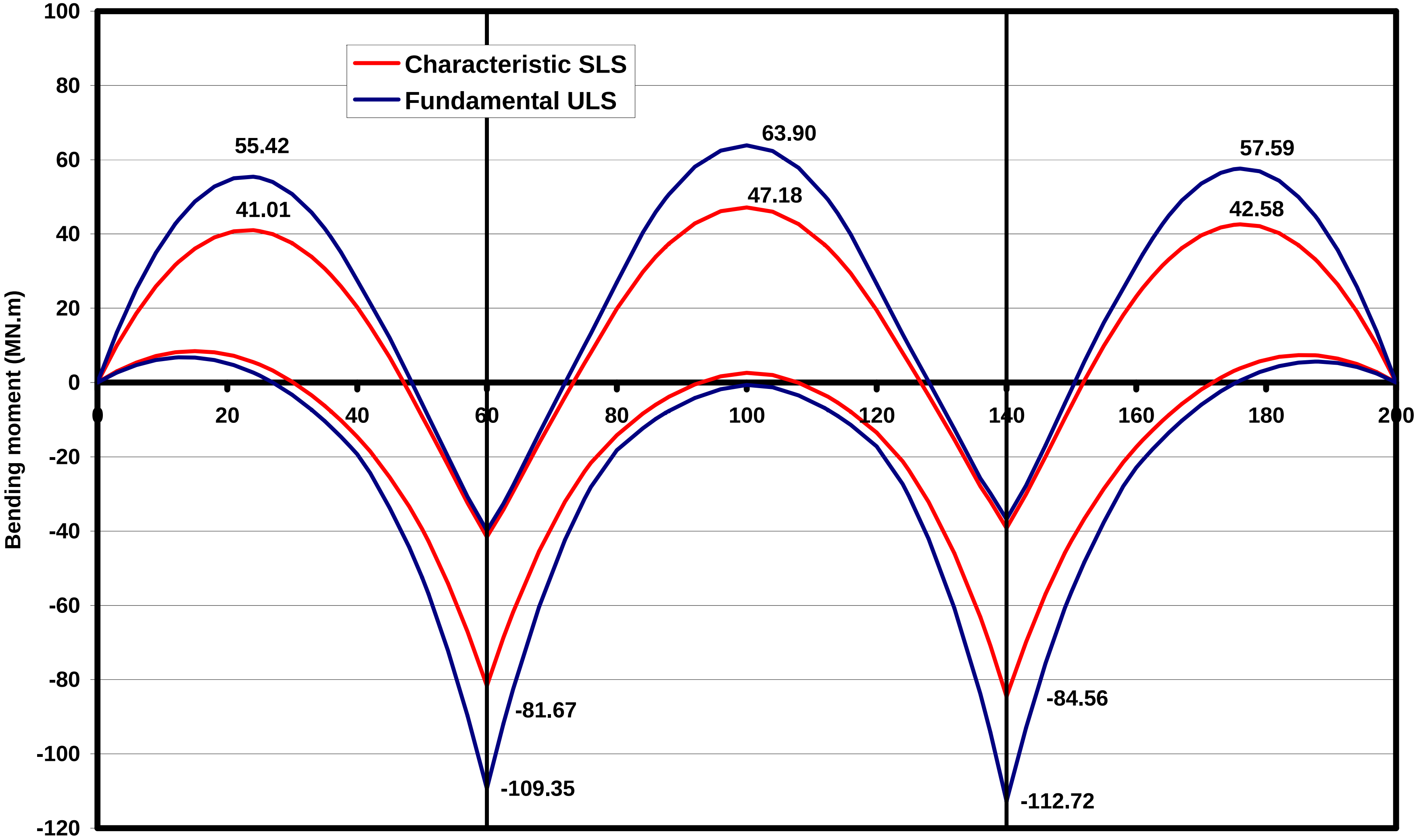
Application to the twin-girder bridge example

Concreting phases, Slab segments order:



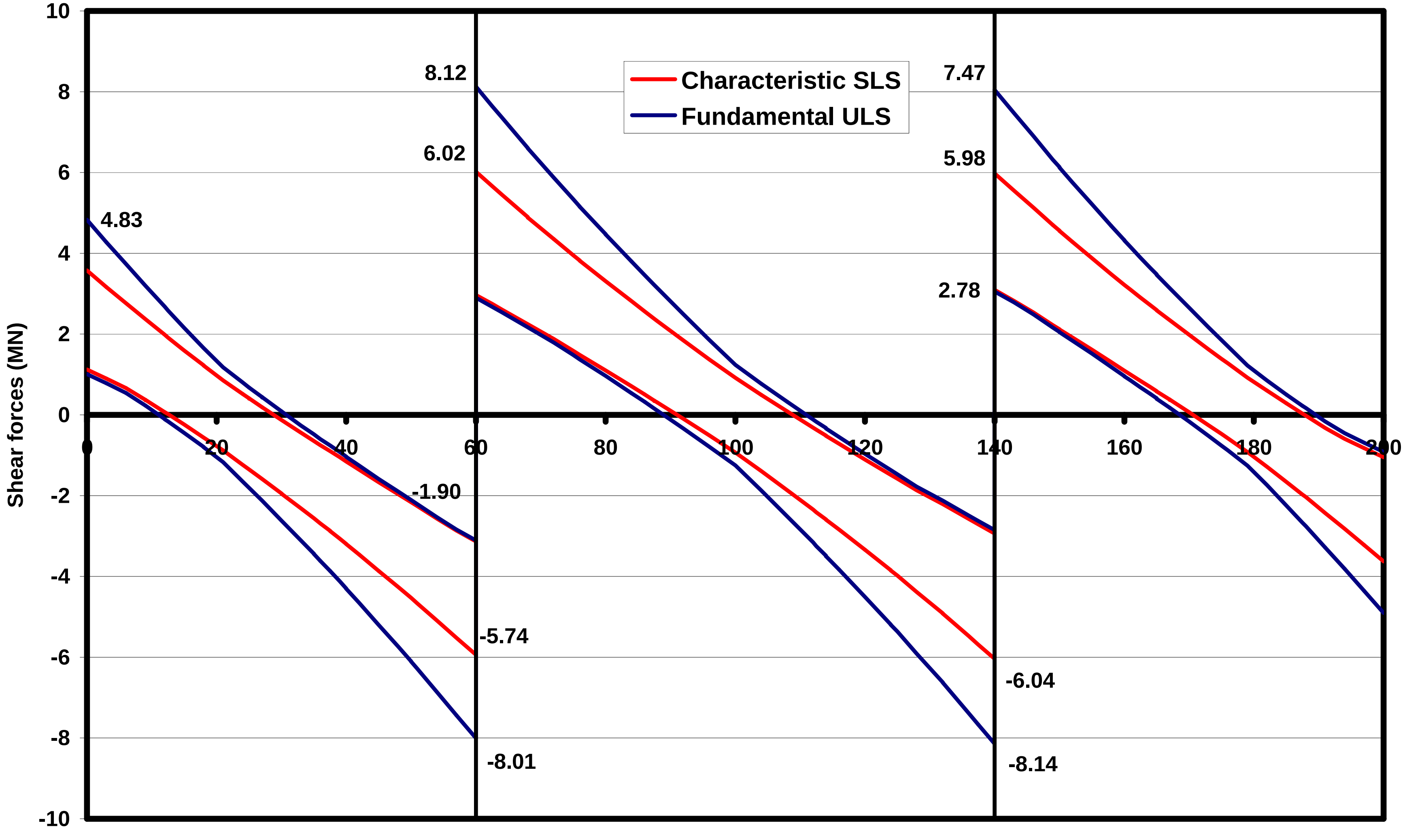
Application to the twin-girder bridge example

SLS and ULS bending moment distribution M_{Ed} (= $M_{a,Ed}$ + $M_{c,Ed}$)



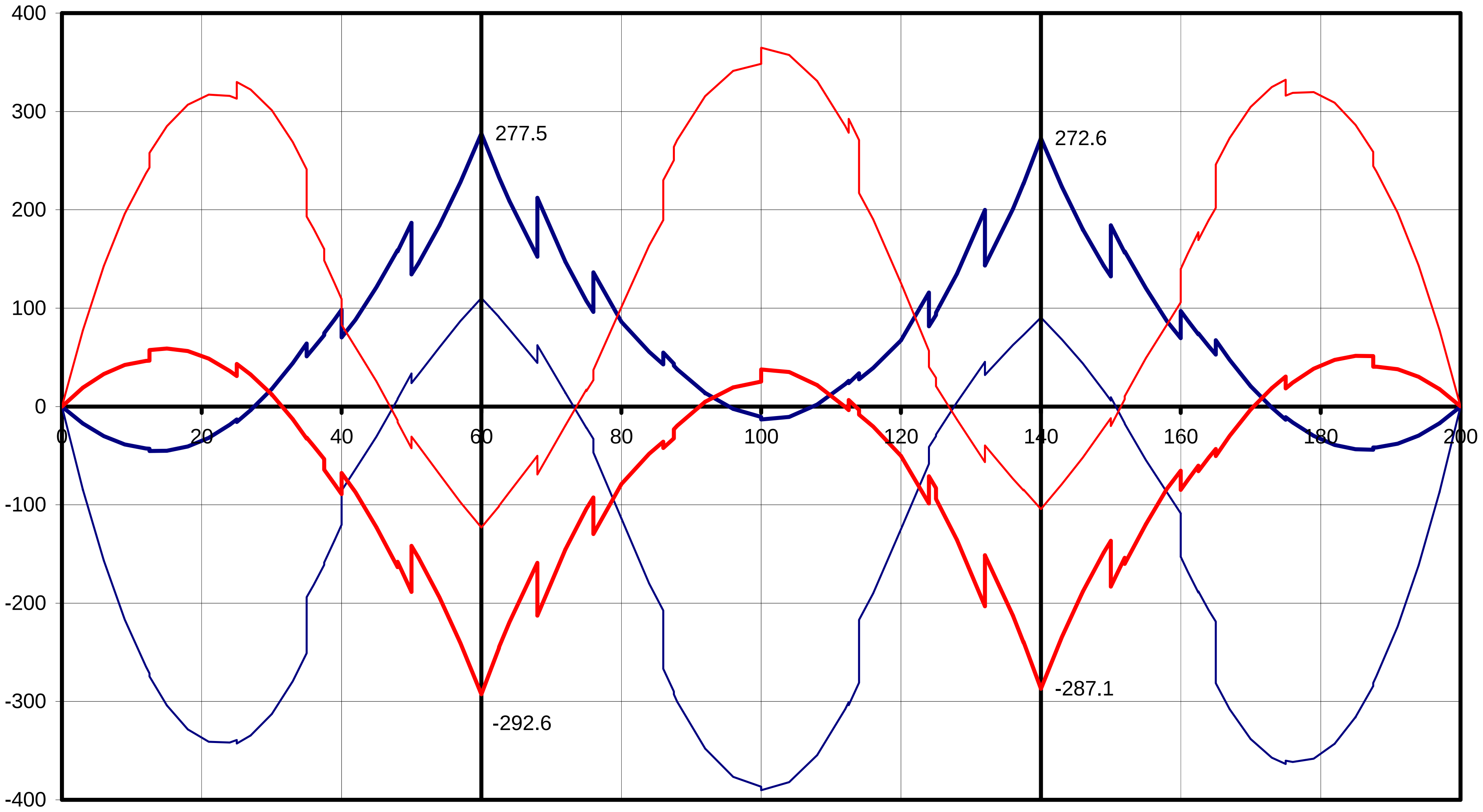
Application to the twin-girder bridge example

SLS and ULS shear force distribution V_{Ed}



Application to the twin-girder bridge example

ULS stresses (N/mm²) along the steel flanges, calculated without concrete resistance



Thank you for your kind attention !