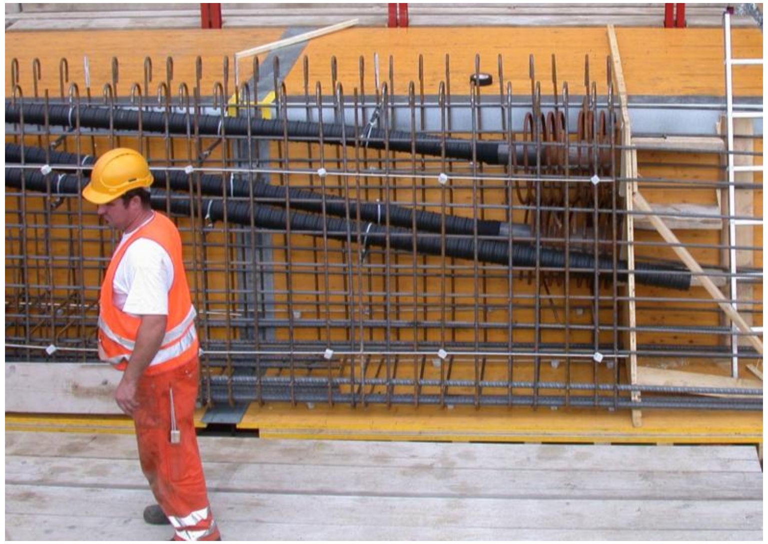
Prestressing 1 Conceptual design

Literatures :
- Polycopié *Structures en béton : Conception, dimensionnement et vérification* chap. 6
- *Prestressed Concrete Bridges*, C. Menn
- TGC 7, *Dimensionnement des structures en béton*
- TGC 8, *Dimensionnement des structures en béton*



Introduction

Concrete → in compression during constructive stage

Bridges → Fundamental
Buildings → Large span or large loads

Advantages

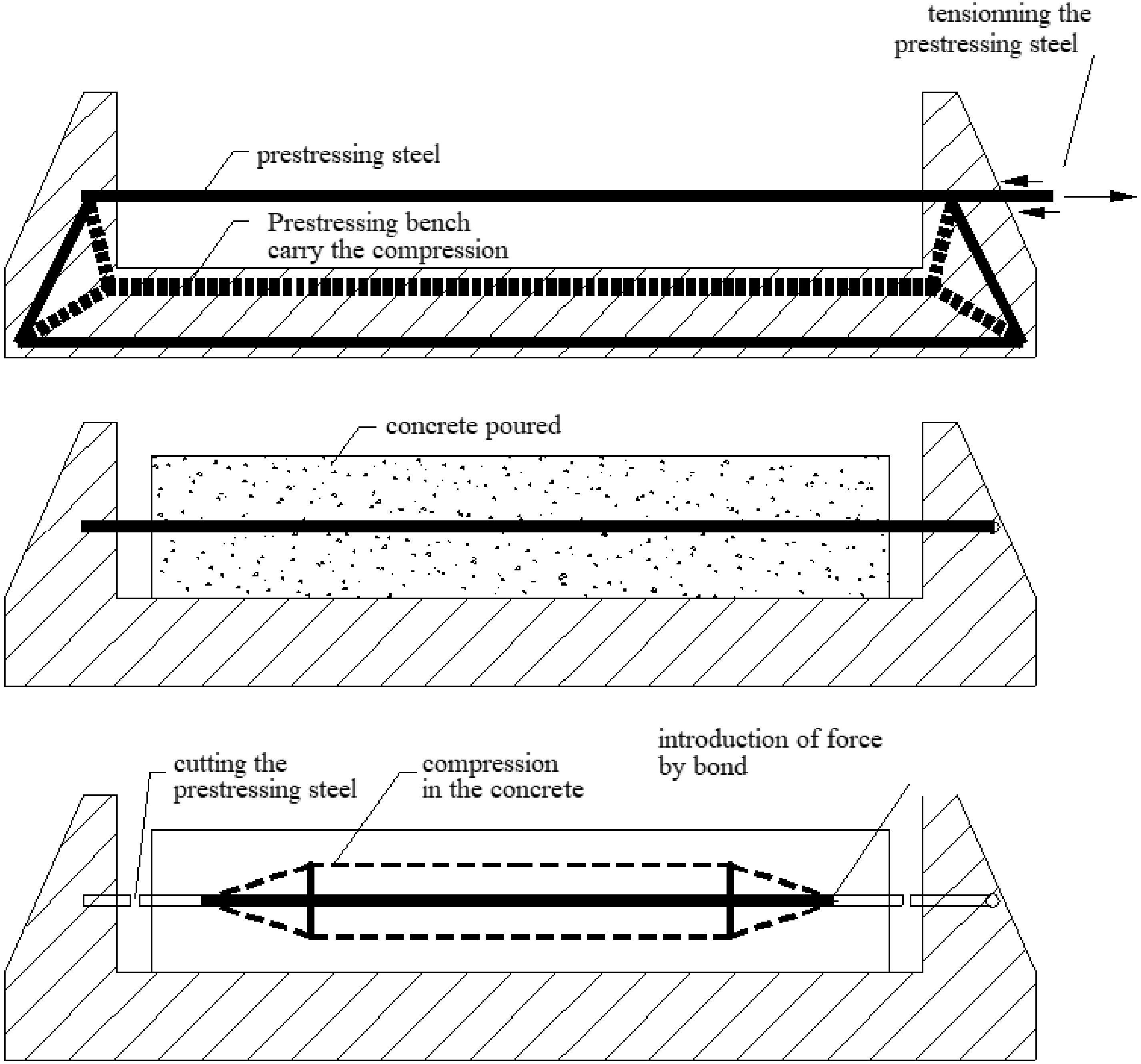
- Slenderness ↑
- Cracking ↓
- Stiffness ↑
- Use of high steel strength

Invention → XIX century - start of XXe
Main patent → 1928 (Eugène Freysssinet)

Types of prestressing

Pre-tensioning

Prestressing Process
- Placing of the tendons
- Tensionning
- Concrete
- Curing and demoulding
- Detensioning (cutting)



Types of prestressing

Pre-tensioning

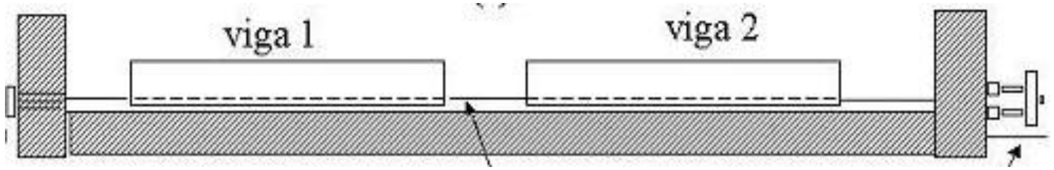
Types of prestressing

Pre-tensioning

Types of prestressing

Pre-tensioning

Discontinuous



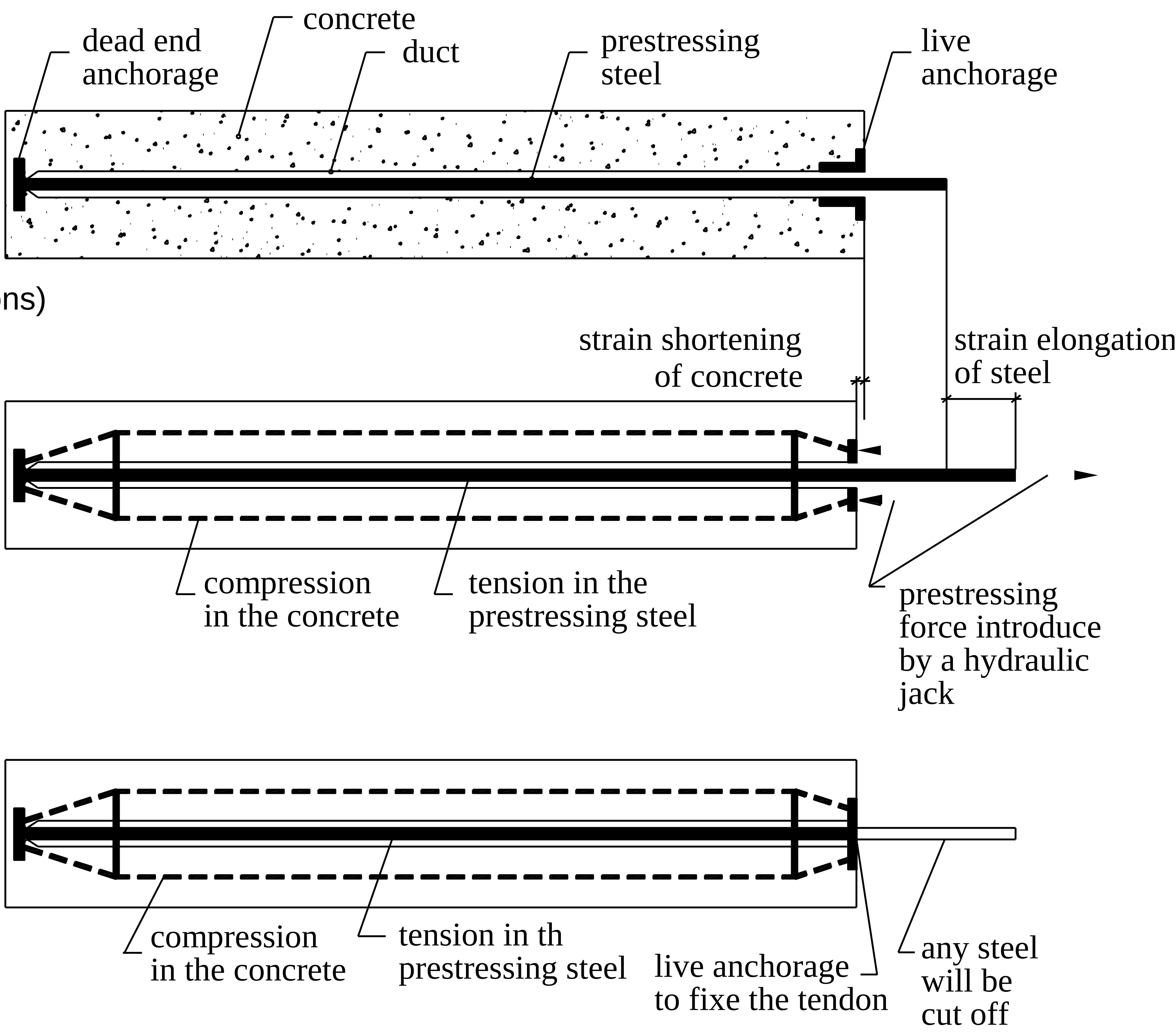
Continuous

Types of prestressing

Post-tensioning

Prestressing Process

- Concrete with the duct + anchorages (+ tendons)
- Curing and demoulding
- Tensionning



Types of prestressing

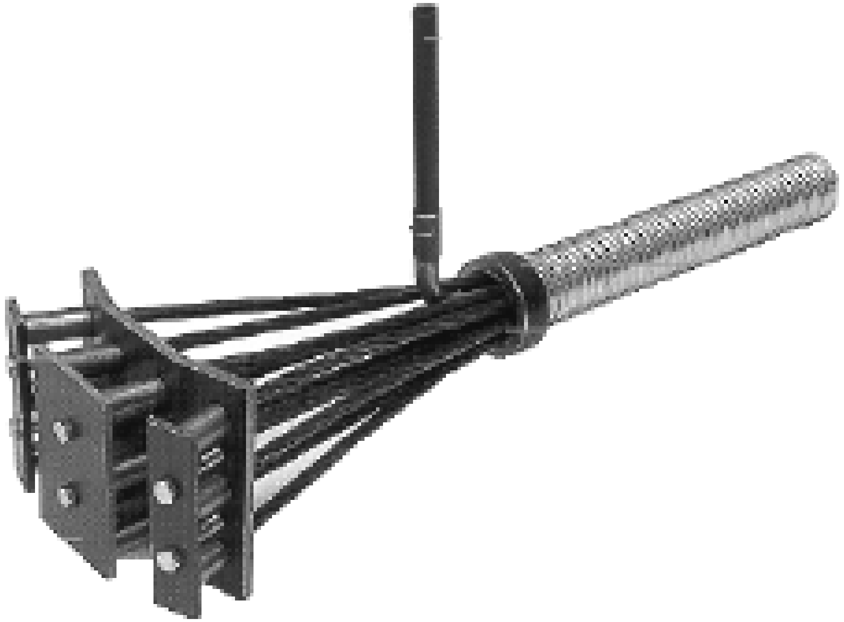
Post-tensioning

Tendon = prestressing steel (e.g. strands) + anchorages + duct + grout

(câble = acier de précontrainte + têtes + gaine + coulis d’injection)

Live anchorage (tête mobile)

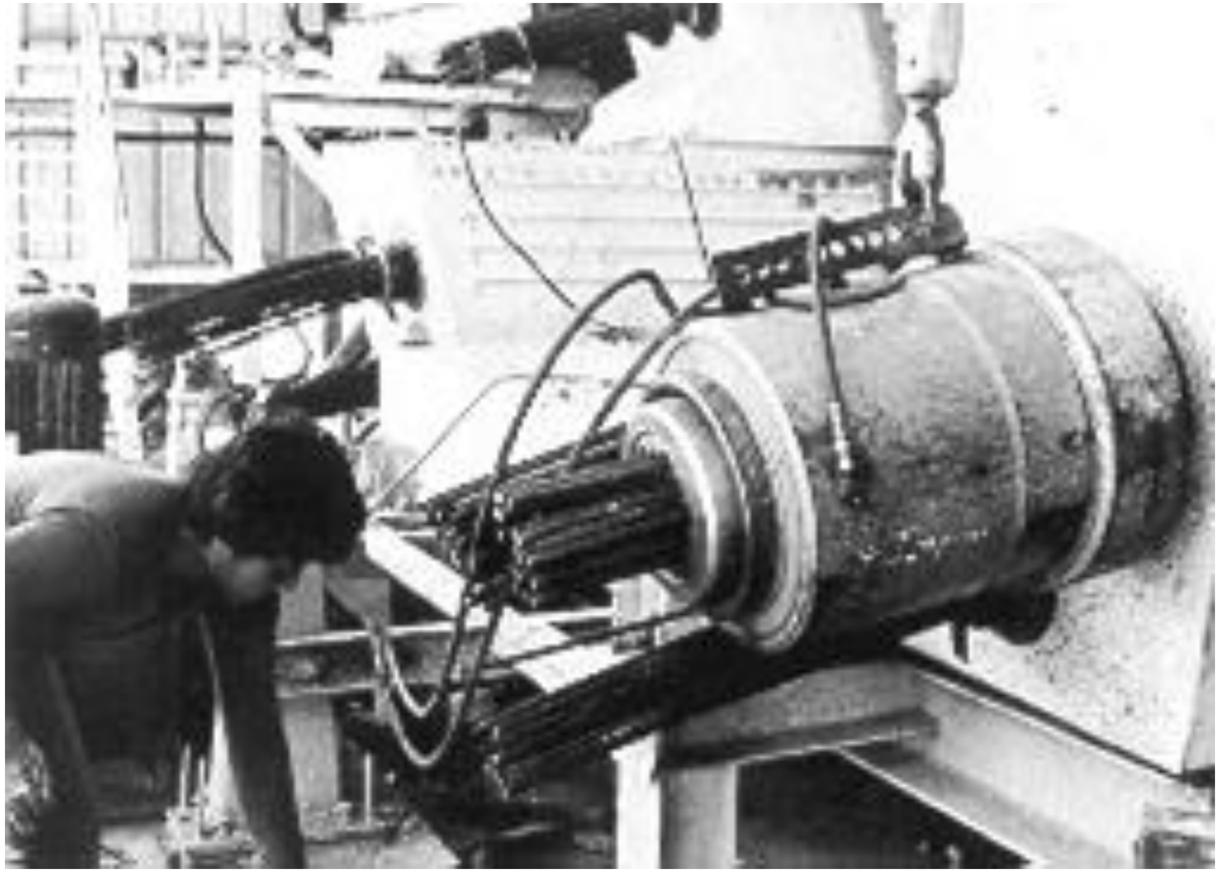
Dead end anchorage (tête fixe)



Types of prestressing

Post-tensioning

Jack



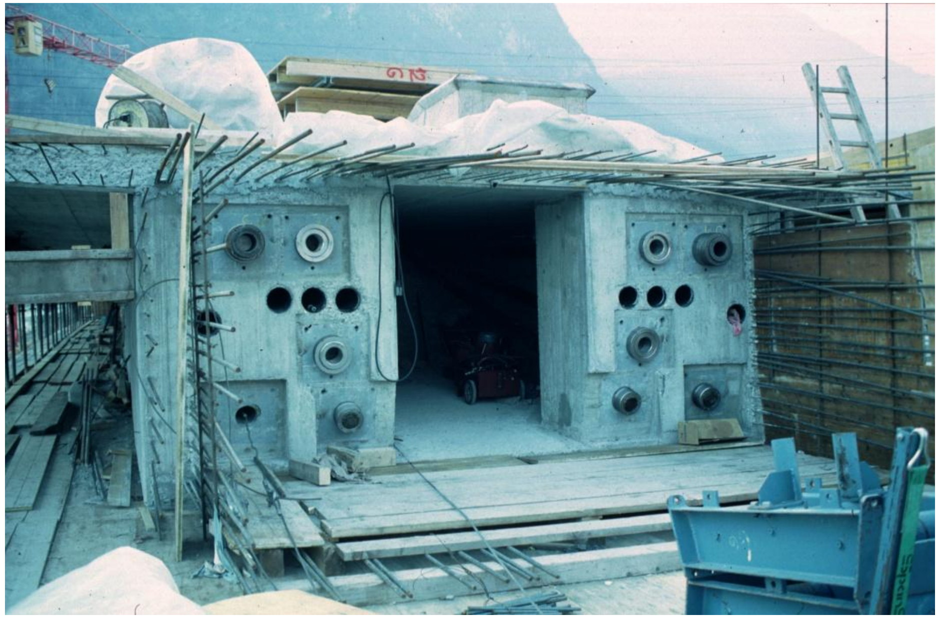
Types of prestressing

Post-tensioning

Internal

With or without bond

External

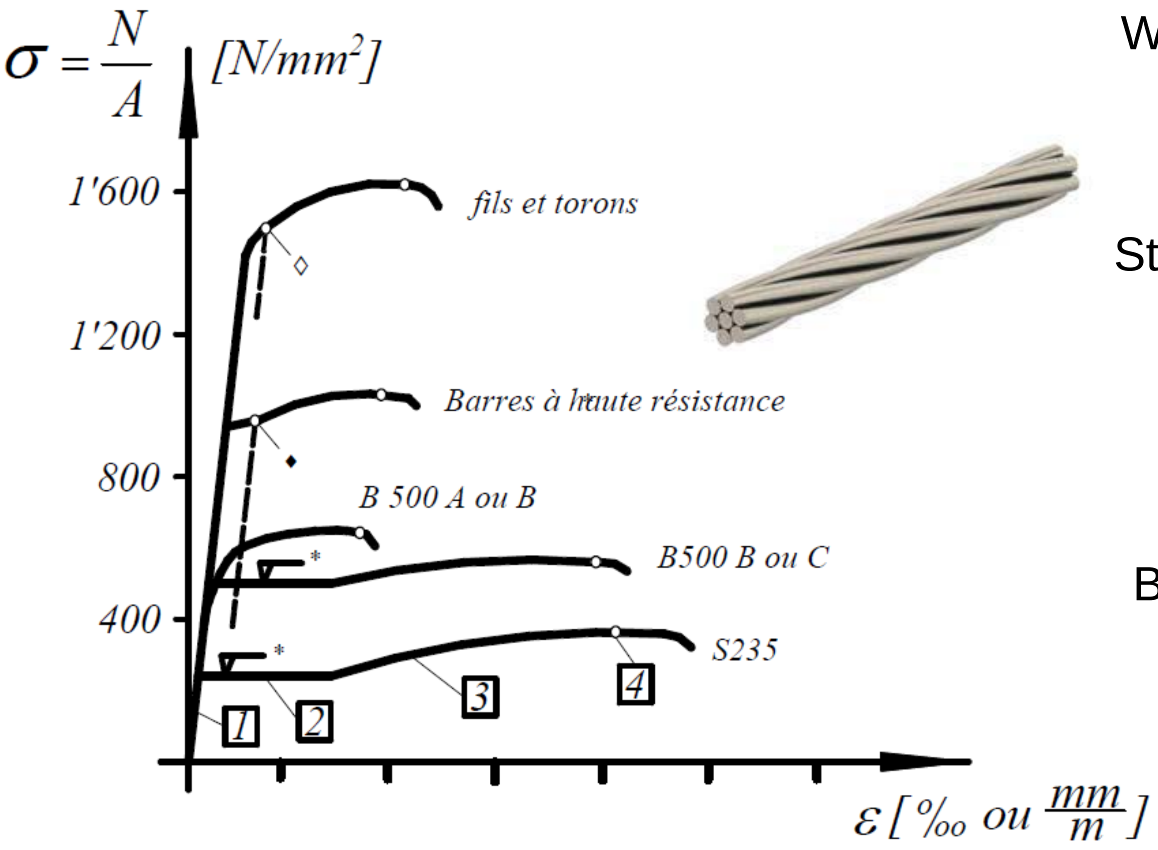


Without bond

Types of prestressing

- Prestressing
  - Post-tensioning
    - Internal prestressing
      - With bond
      - Without bond
    - external prestressing (without bond)
  - Pre-tensioning

Prestressing steel



Wires

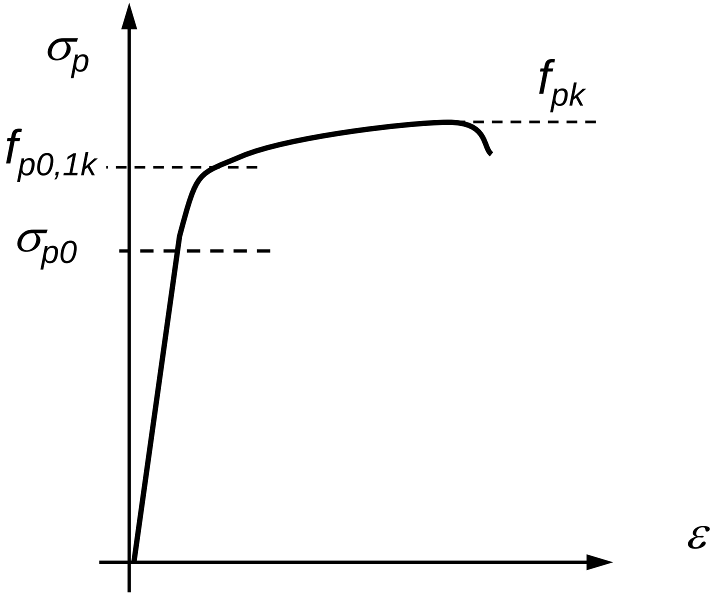
Strands

Bars

Produit	Diamètre Ø [mm]	Section A_p [mm²]	Résistance à la traction f_{pk} [N/mm²]	Limite d'écoulement $f_{p0,1k}$ [N/mm²]	Désignation
Fils	3,0 4,0 5,0 6,0 7,0 8,0 10,0	7,1 12,6 19,6 28,3 38,5 50,3 78,5	1860 1860 1860 1770 1670 1670 1570	1600 1600 1600 1520 1440 1440 1300	Y1860C-3,0 Y1860C-4,0 Y1860C-5,0 Y1770C-6,0 Y1670C-7,0 Y1670C-8,0 Y1570C-10,0
Torons	12,9	100	1860	1600	Y1860S7-12,9
	15,3	140	1770 1860	1520 1600	Y1770S7-15,3 Y1860S7-15,3
	15,7	150	1770 1860	1520 1600	Y1770S7-15,7 Y1860S7-15,7
Barres (lisses ou nervurées)	20,0	314	1100	900	Y1100H-20,0
	26,0	531	1030 1050 1230	830 950 1080	Y1030H-26,0 Y1050H-26,0 Y1230H-26,0
	26,5	552	1030 1050 1230	830 950 1080	Y1030H-26,5 Y1050H-26,5 Y1230H-26,5
	32,0	804	1030 1050 1230	830 950 1080	Y1030H-32,0 Y1050H-32,0 Y1230H-32,0
	36,0	1018	1030 1050 1230	830 950 1080	Y1030H-36,0 Y1050H-36,0 Y1230H-36,0

[SIA 262, 2013]

Initial prestressing force



$\sigma_{p0} \leq 0.70 \cdot f_{pk}$ After the intinal prestressing force

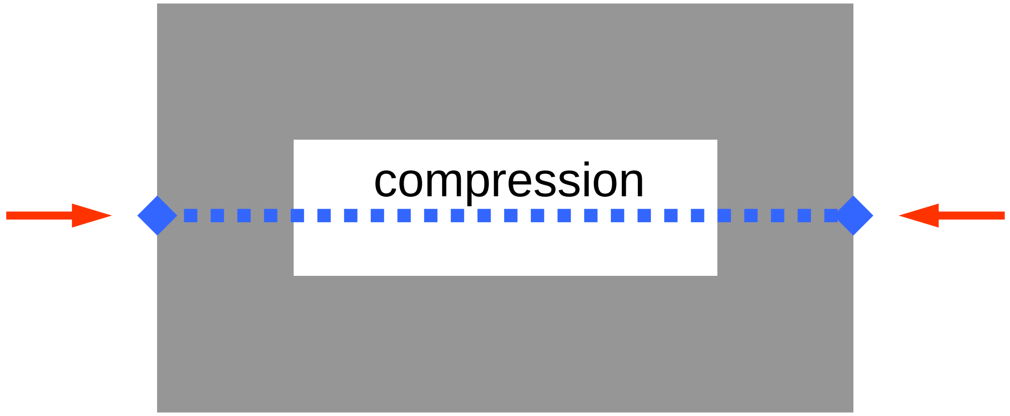
$\sigma_{p0} \leq 0.75 \cdot f_{pk}$ During the initial prestressing force

$\sigma_{p\infty} \geq 0.45 \cdot f_{pk}$ at $t = \infty$

Approaches to considering prestressing

Self-equilibrated **system** of **Forces**

(prestressing considered as external action)



Forces exerted by the tendon on the concrete

Forces exerted by the concrete on the tendon

Self-equilibrated **state** of **stresses**

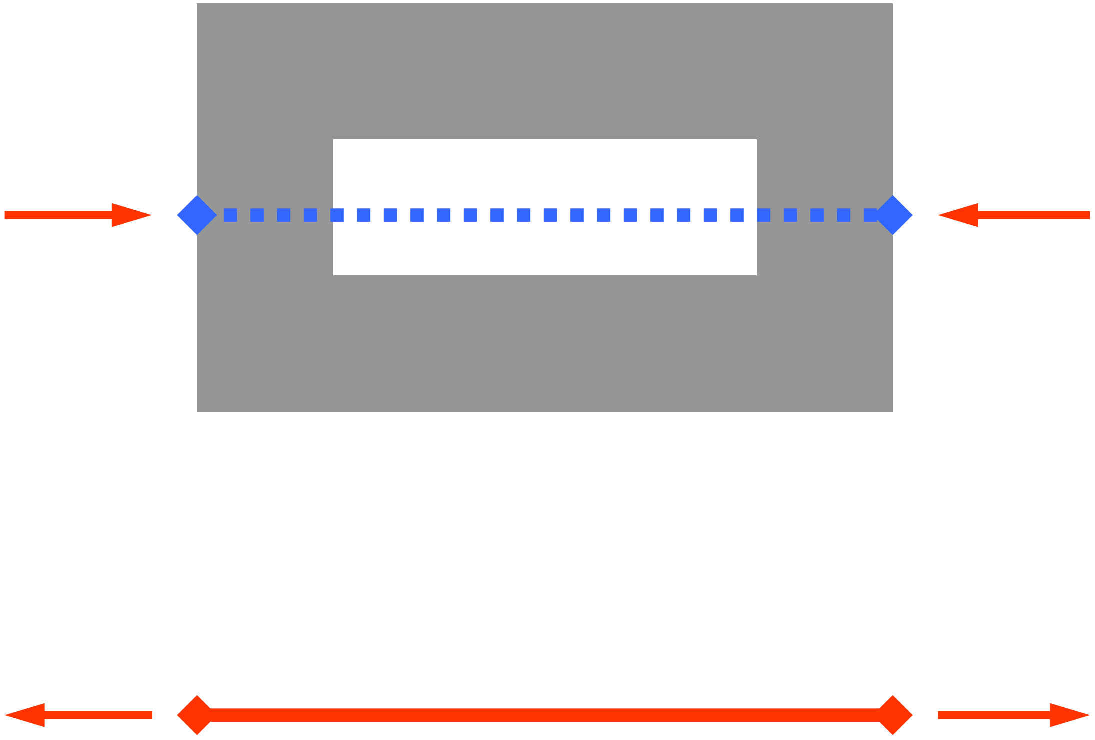
(prestressing considered on the side of the resistance)

The systeme is composed by the concrete with the tendon. Prestressing induce internal forces et so deformation.

Approaches to considering prestressing

1) Anchorage forces

Self-equilibrated **system** of **Forces**

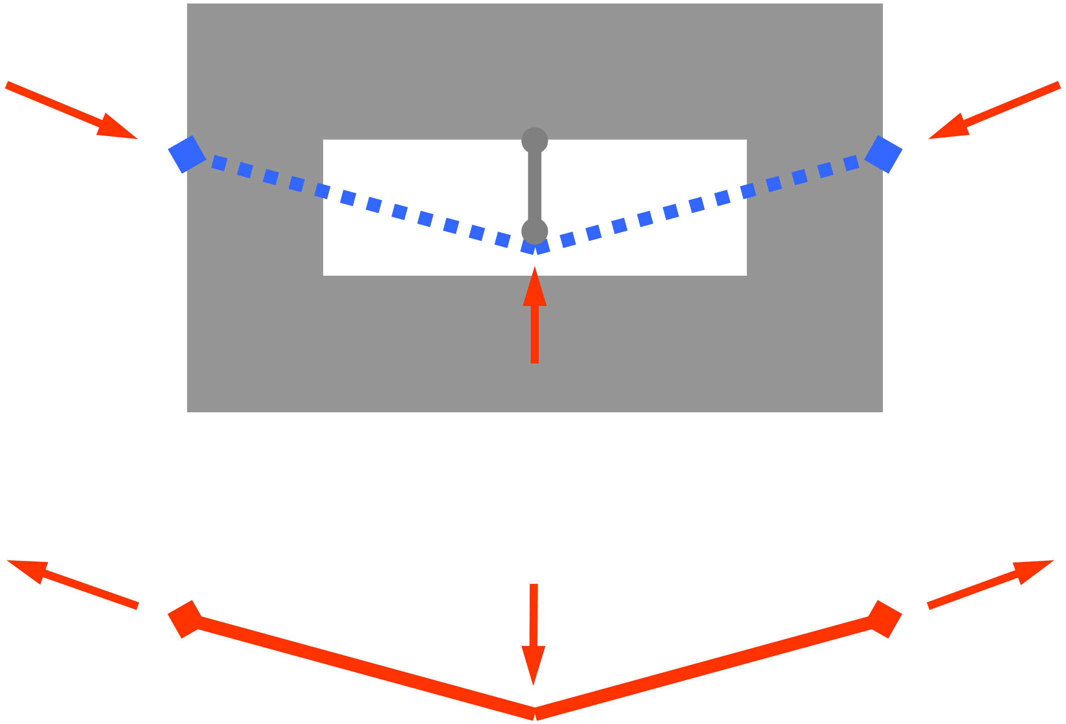


Self-equilibrated **state** of **stresses**

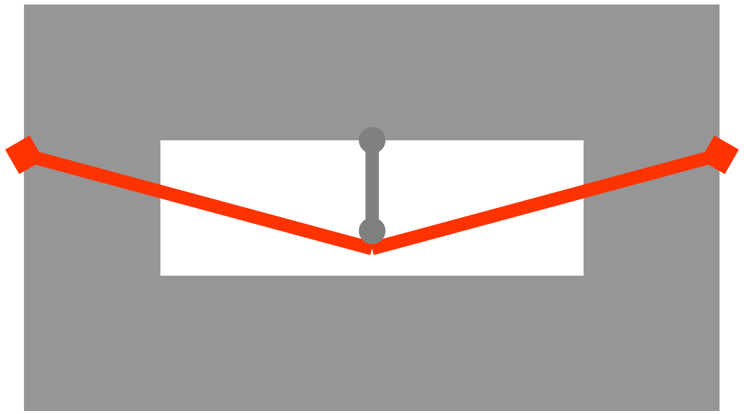
Approaches to considering prestressing

2) Deviation forces

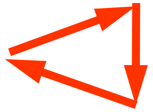
Self-equilibrated **system** of **Forces**



Self-equilibrated **state** of **stresses**



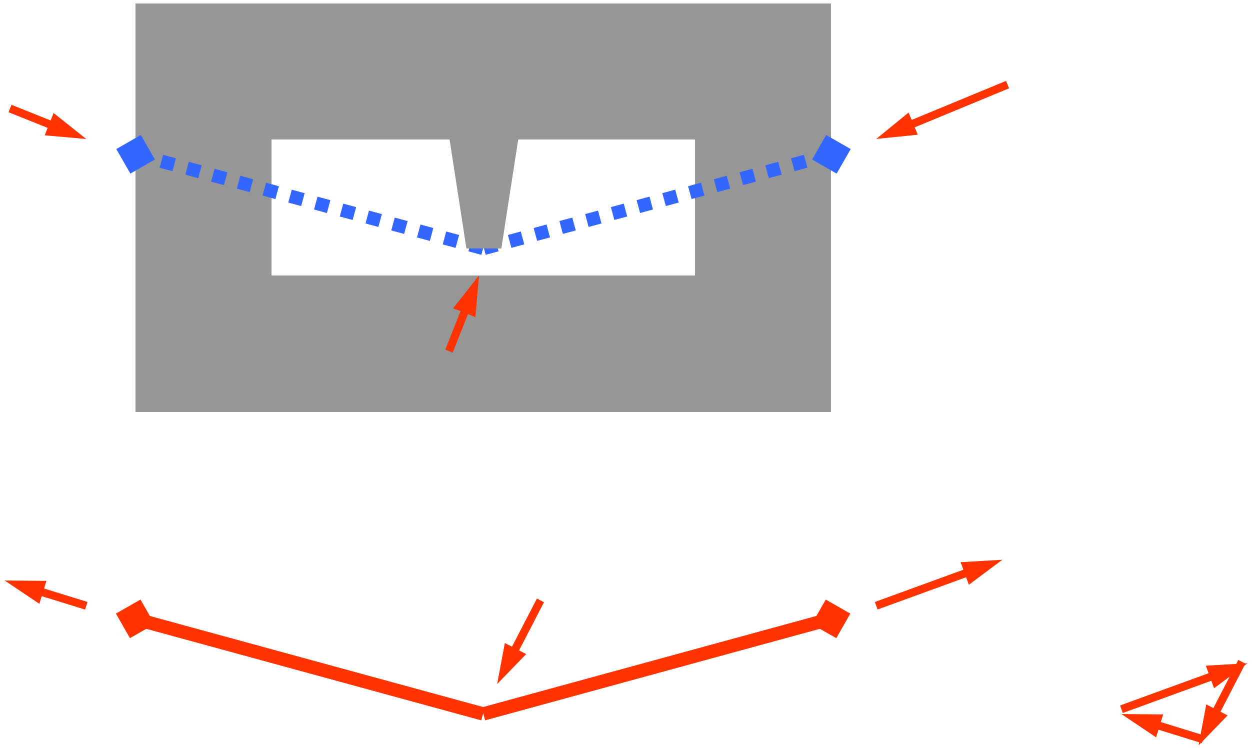
Deviation forces are in equilibrium with the anchorage forces



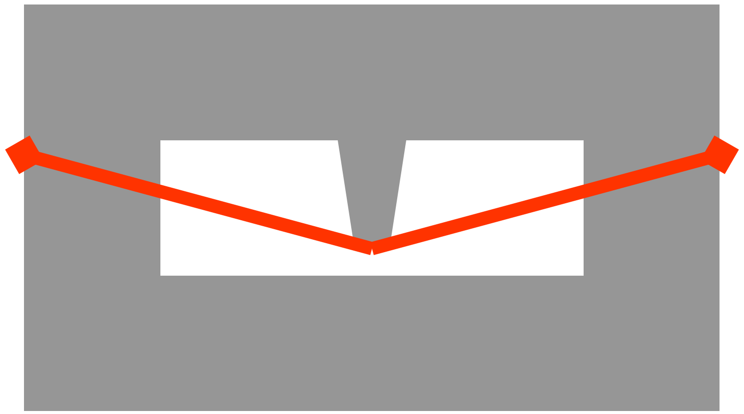
Approaches to considering prestressing

3) Friction forces

Self-equilibrated **system** of **Forces**



Self-equilibrated **state** of **stresses**

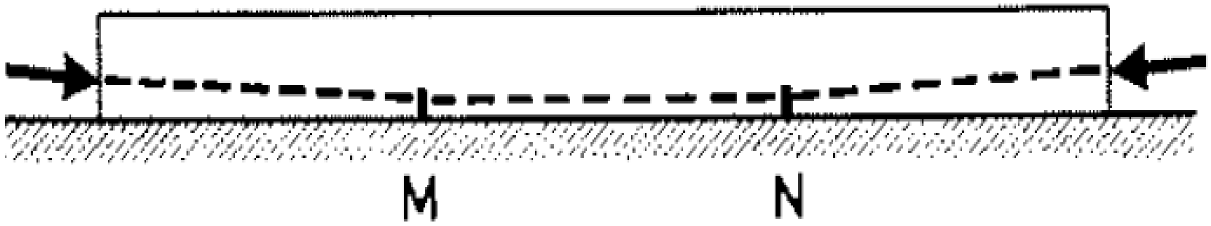


friction forces derive from a relative displacement between the tendon and the deviation element (when the tendon is tensioned for example)

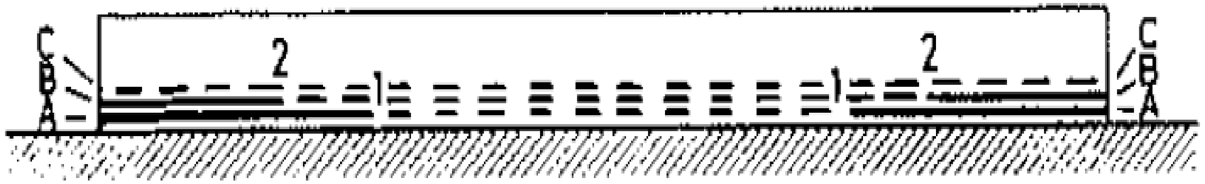
Prestressing tendon geometry

Pre-tensioning

Deviators in intermediate cross sections (M y N) in the mould or the bench. They should resist vertical forces

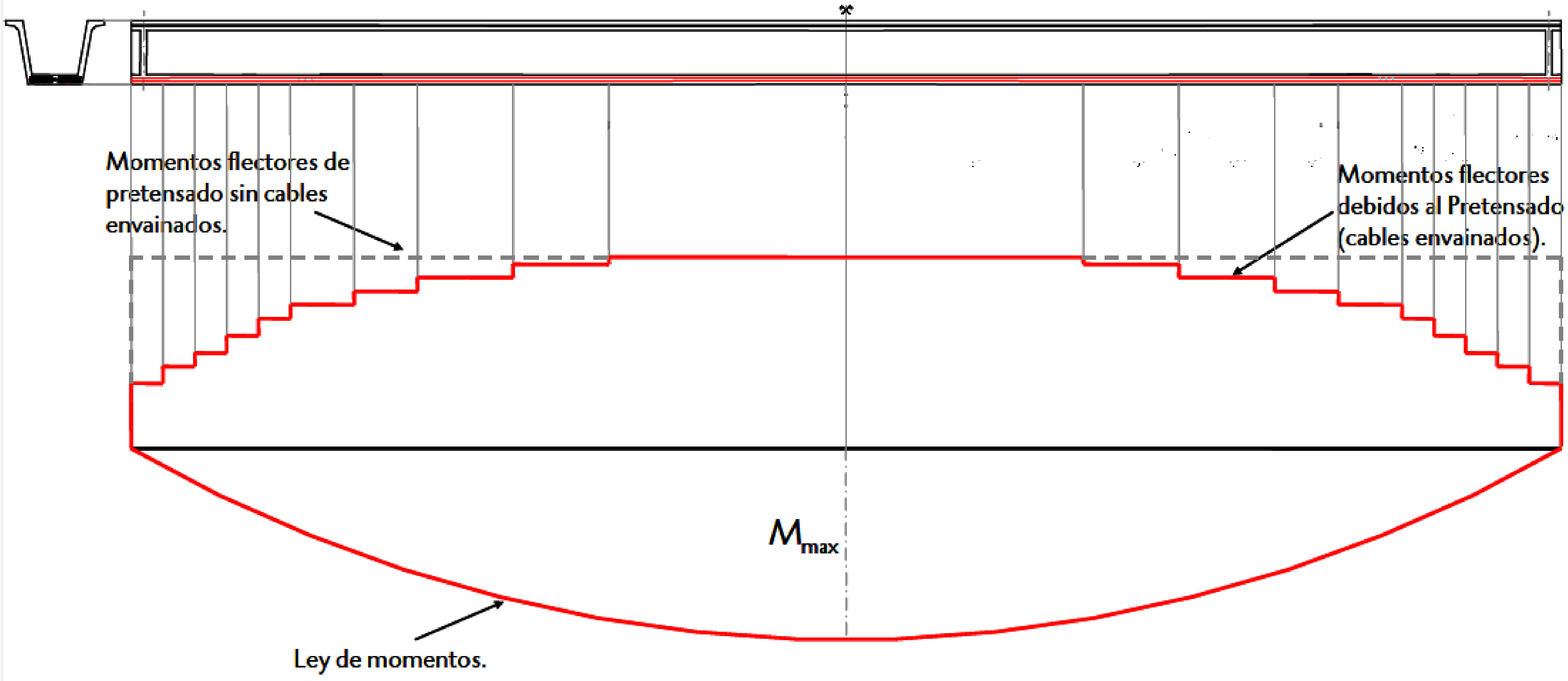


With several layers of **debonding** of strands



Prestressing tendon geometry

Pre-tensioning - Debonding



Prestressing tendon geometry

Pre-tensioning – Debonding : anchorage length

EN 1992-1-1:2004 (E)

Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings

8.10.2 Anchorage of pre-tensioned tendons

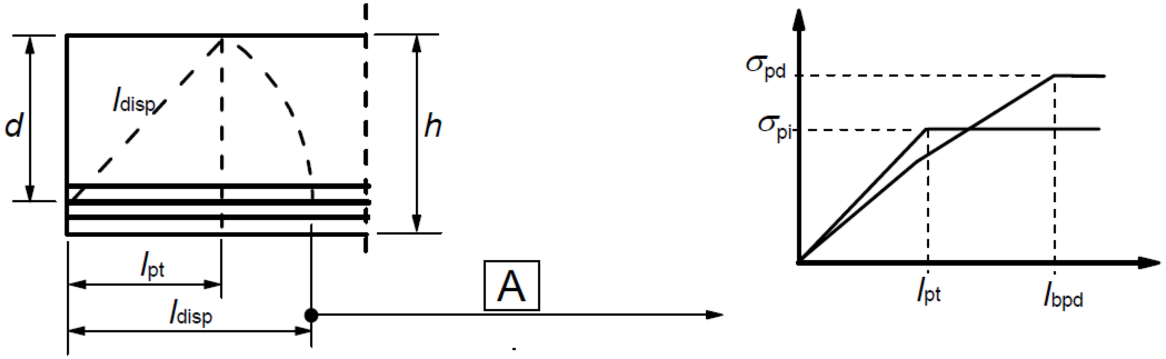
8.10.2.1 General

(1) In anchorage regions for pre-tensioned tendons, the following length parameters should be considered, see Figure 8.16:

a) Transmission length, l_{pt}, over which the prestressing force (P_0) is fully transmitted to the concrete; see 8.10.2.2 (2),

b) Dispersion length, l_{disp} over which the concrete stresses gradually disperse to a linear distribution across the concrete section; see 8.10.2.2 (4),

c) Anchorage length, l_{bpd}, over which the tendon force F_{pd} in the ultimate limit state is fully anchored in the concrete; see 8.10.2.3 (4) and (5).

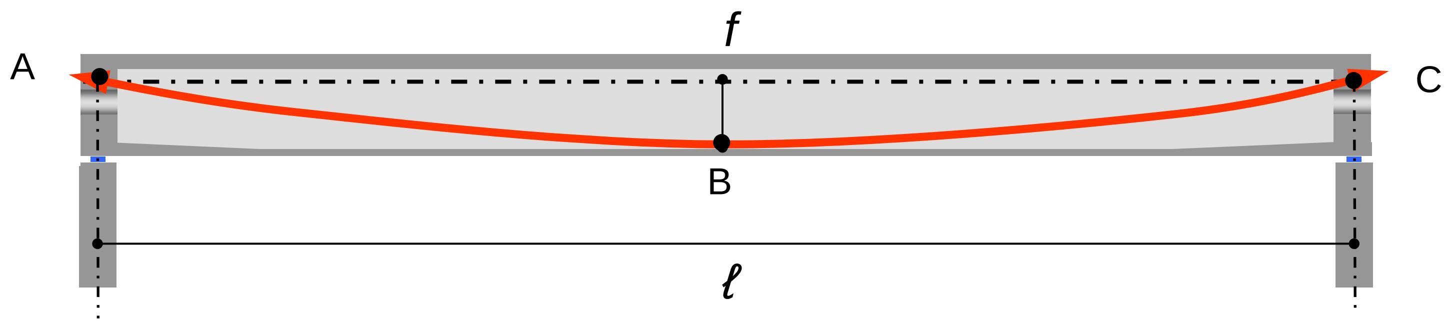


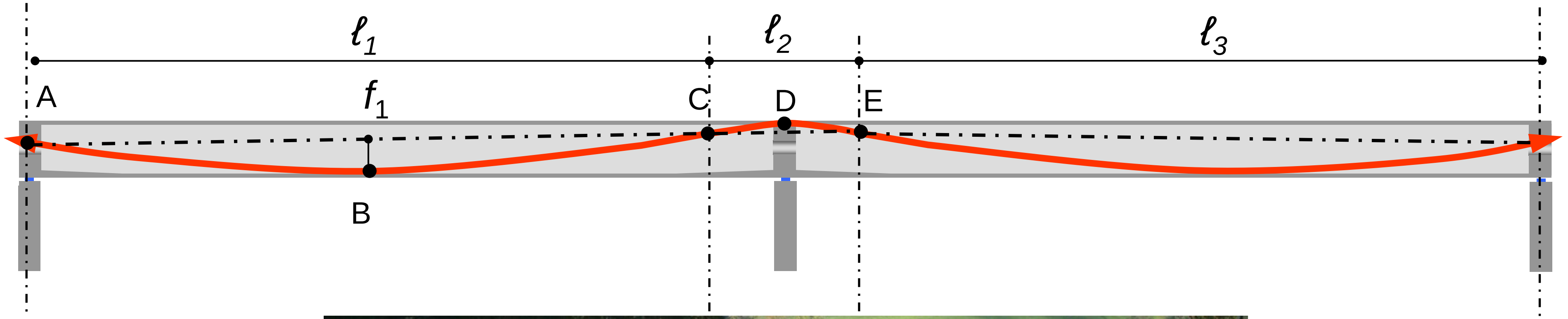
A - Linear stress distribution in member cross-section

Figure 8.16: Transfer of prestress in pretensioned elements; length parameters

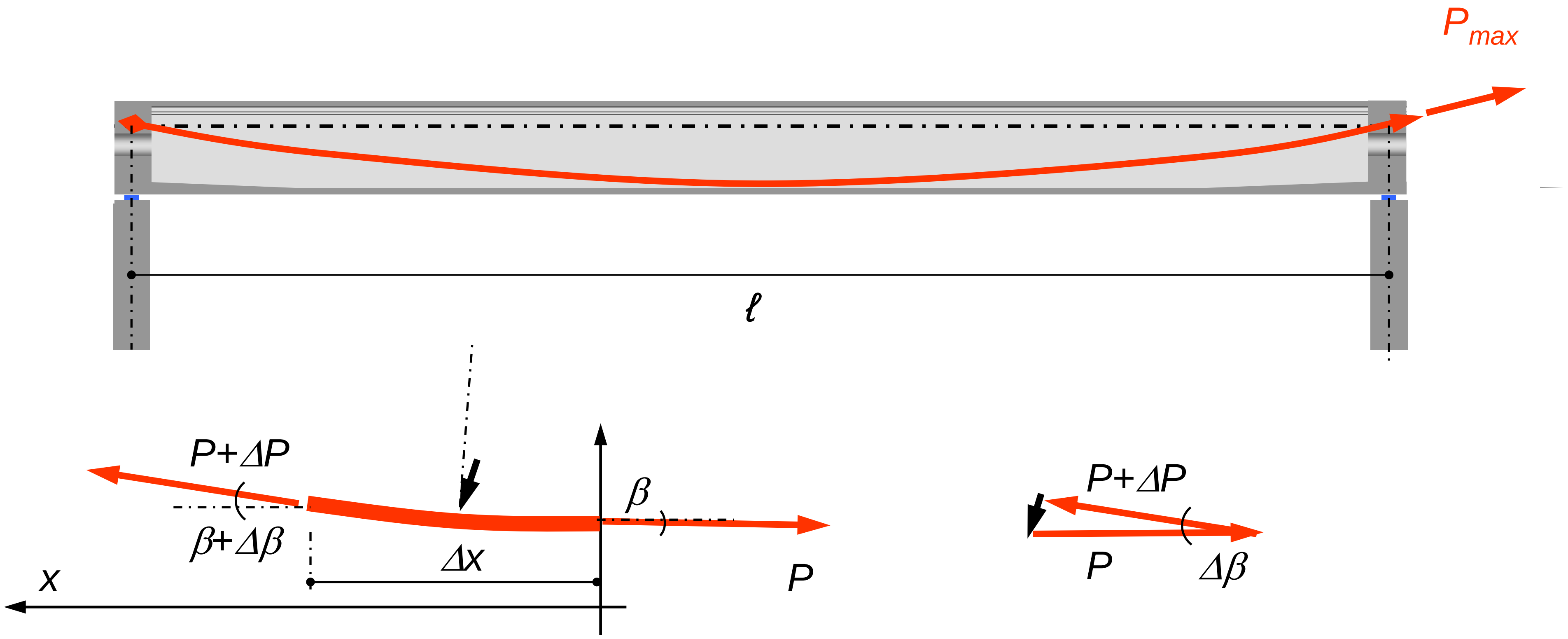
Prestressing tendon geometry

Post-tensioning





Immediate losses of prestress : due to friction

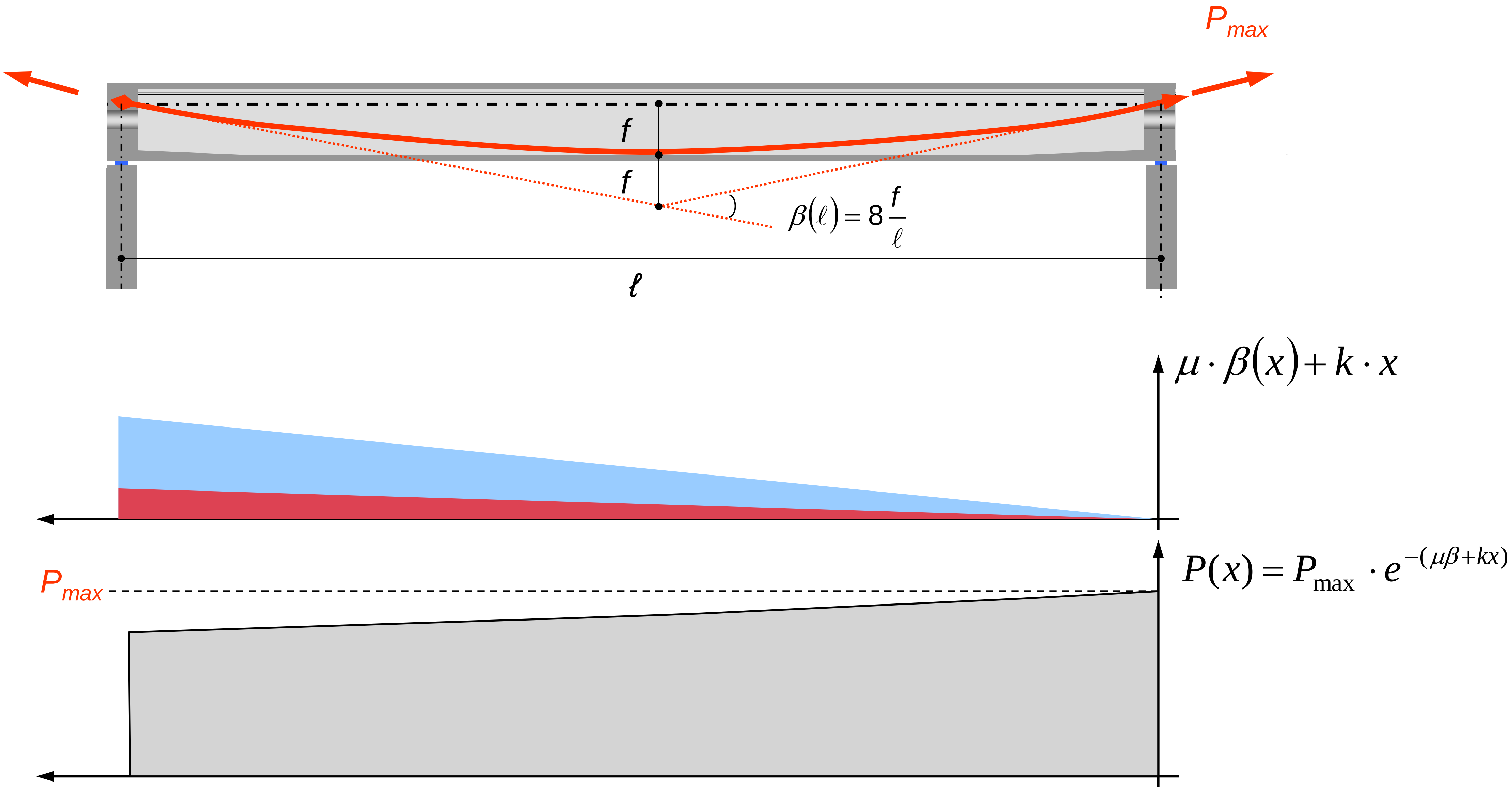


$$\Delta P = -P \cdot (\mu \cdot \Delta\beta + k \cdot \Delta x) \quad \longrightarrow \quad P(x) = P_{\max} \cdot e^{-(\mu\beta + kx)}$$

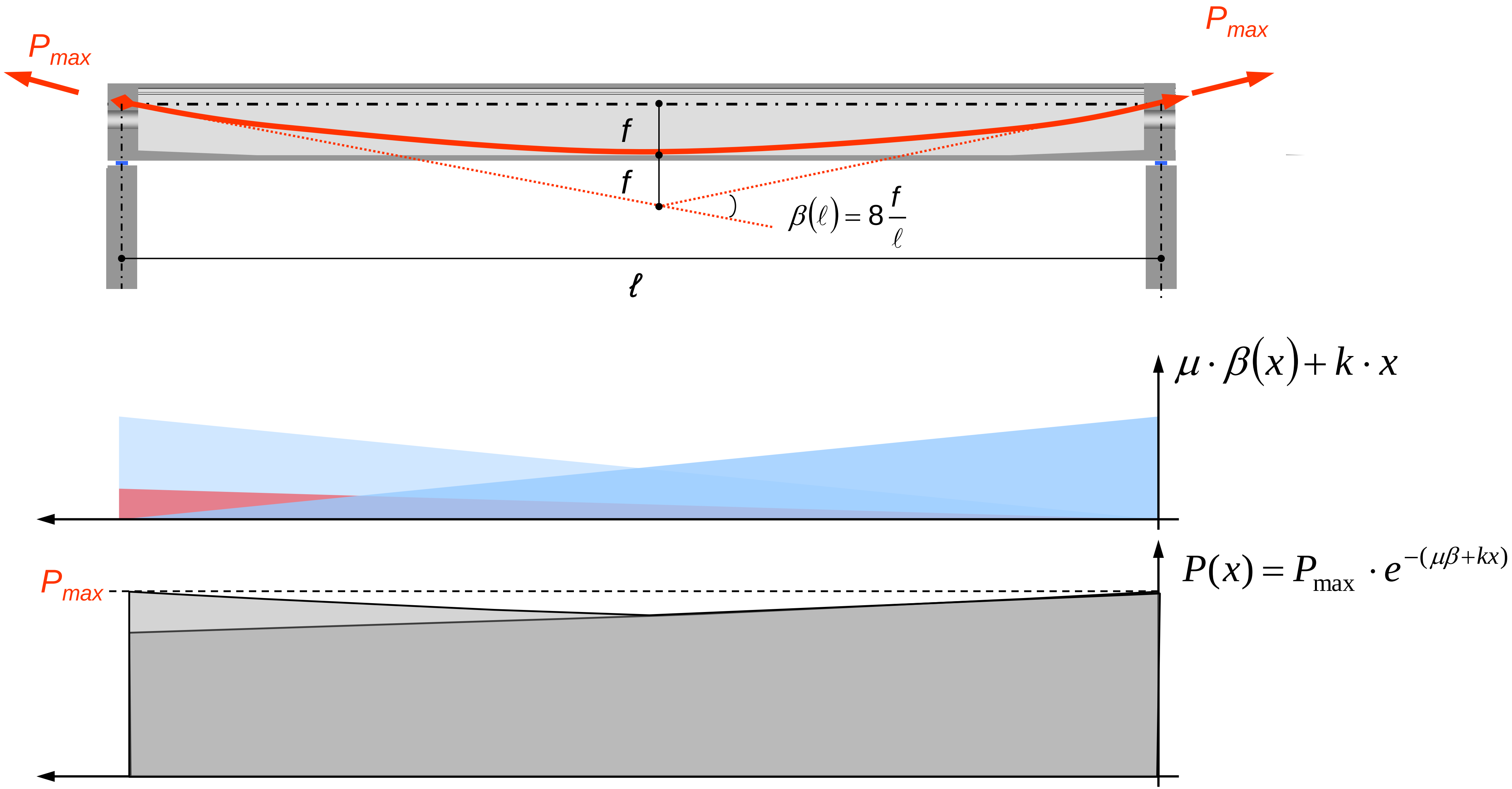
For example for strands

Duct type		
Metal	$\mu \approx 0.20$	$k \approx 0.0008\ \mathrm{m}^{-1}$
Polymer (plastic)	$\mu \approx 0.14$	$k \approx 0.0010\ \mathrm{m}^{-1}$

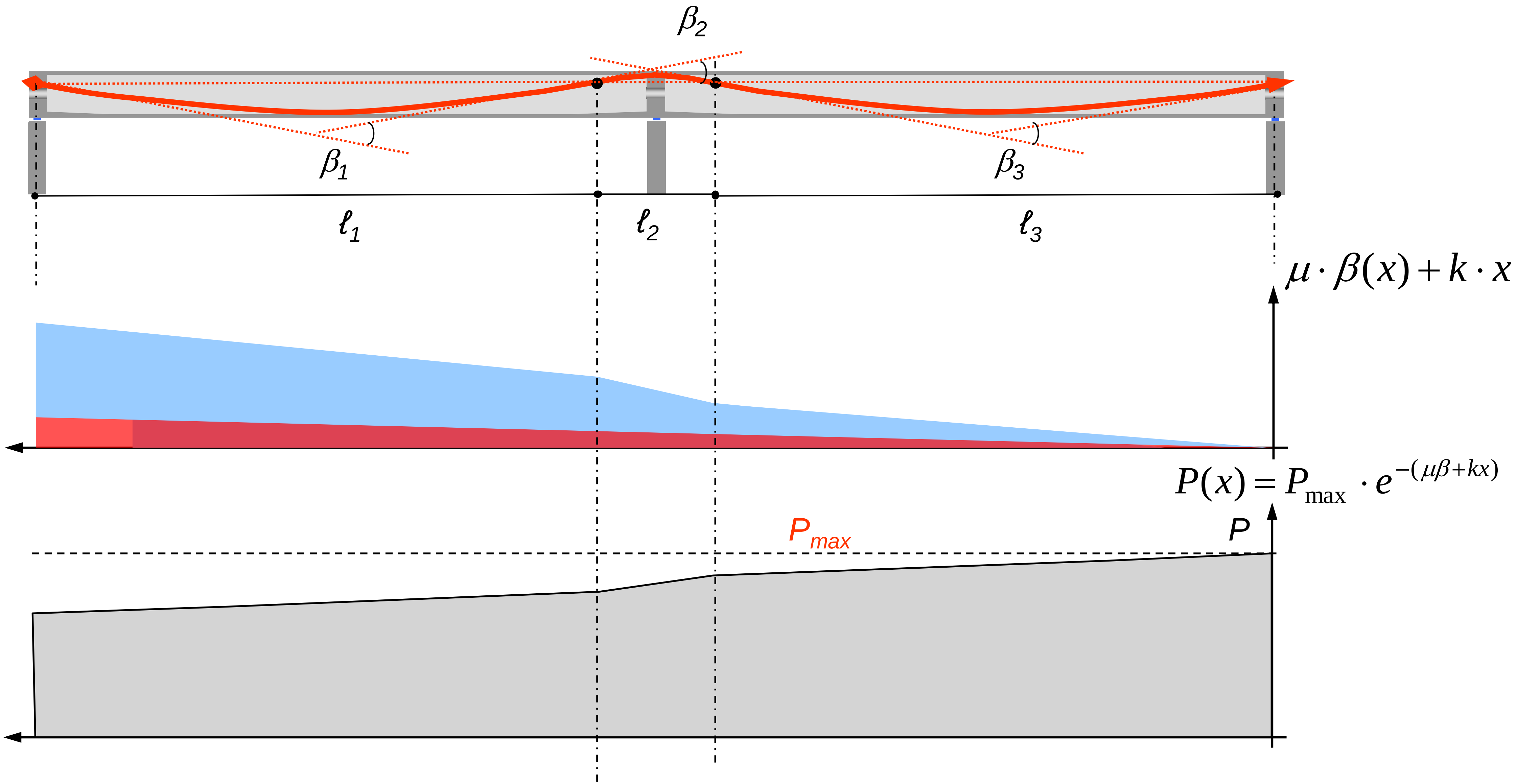
Immediate losses of prestress : due to friction



Immediate losses of prestress : due to friction



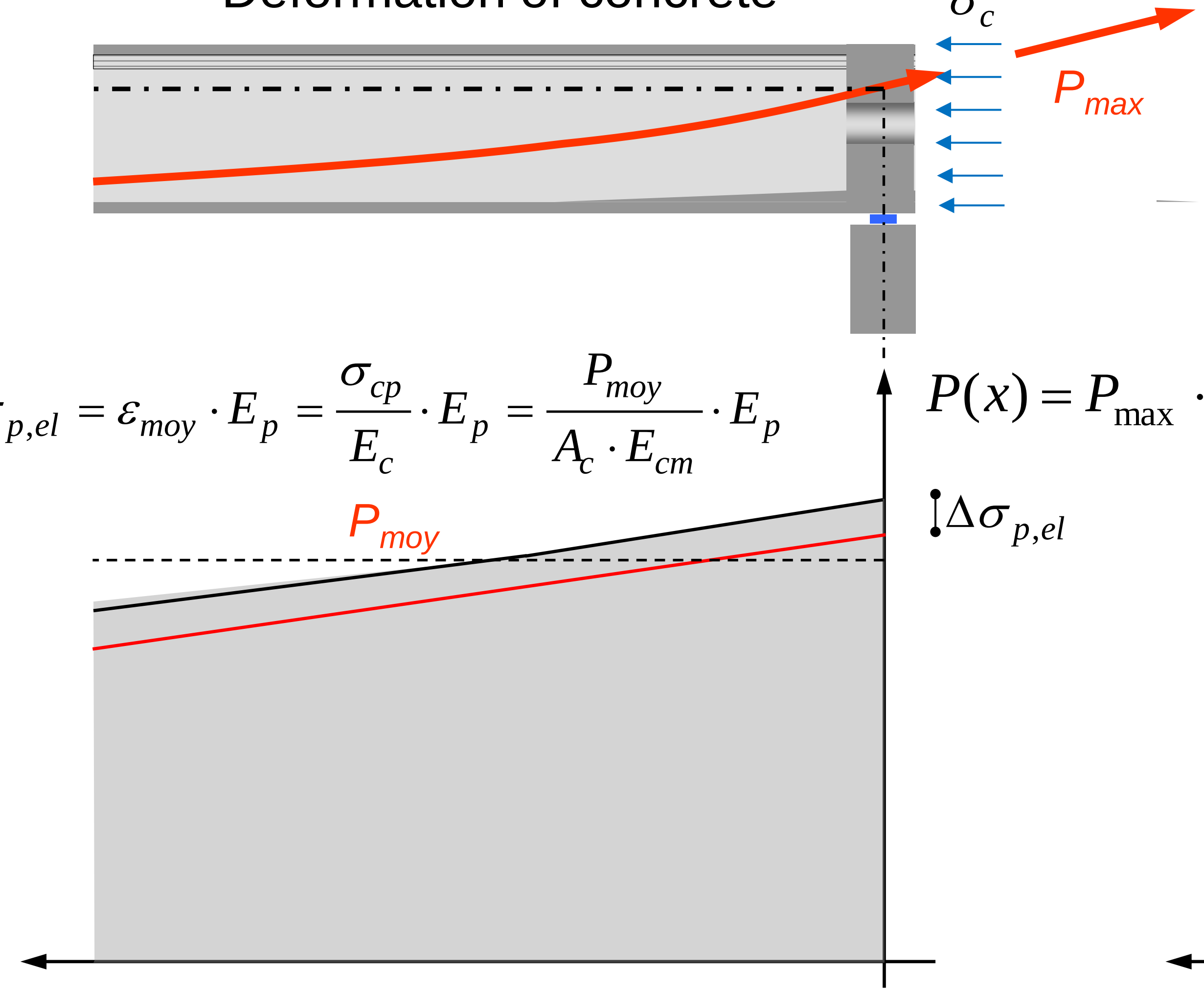
Immediate losses of prestress : due to friction



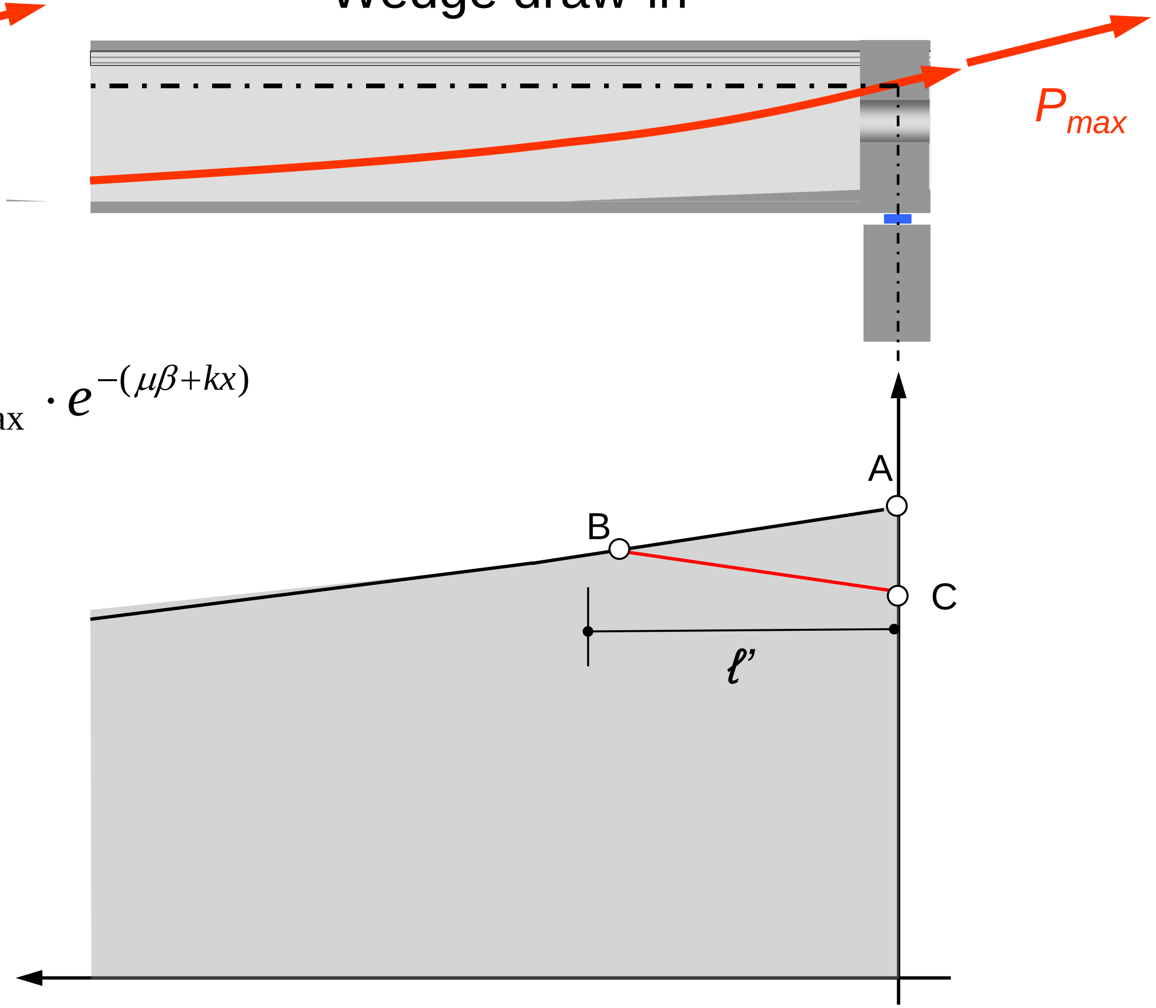
Immediate losses of prestress : others

Deformation of concrete

Wedge draw-in



$$\Delta\sigma_{p,el} = \varepsilon_{moy} \cdot E_p = \frac{\sigma_{cp}}{E_c} \cdot E_p = \frac{P_{moy}}{A_c \cdot E_{cm}} \cdot E_p$$



$$P(x) = P_{\max} \cdot e^{-(\mu\beta + kx)}$$

This losse can be negleted by

- Sequence of prestressing
- Larger prestressing stresses

A_c : Cross sectional area of concrete

E_c : modulus of elasticity of concrete

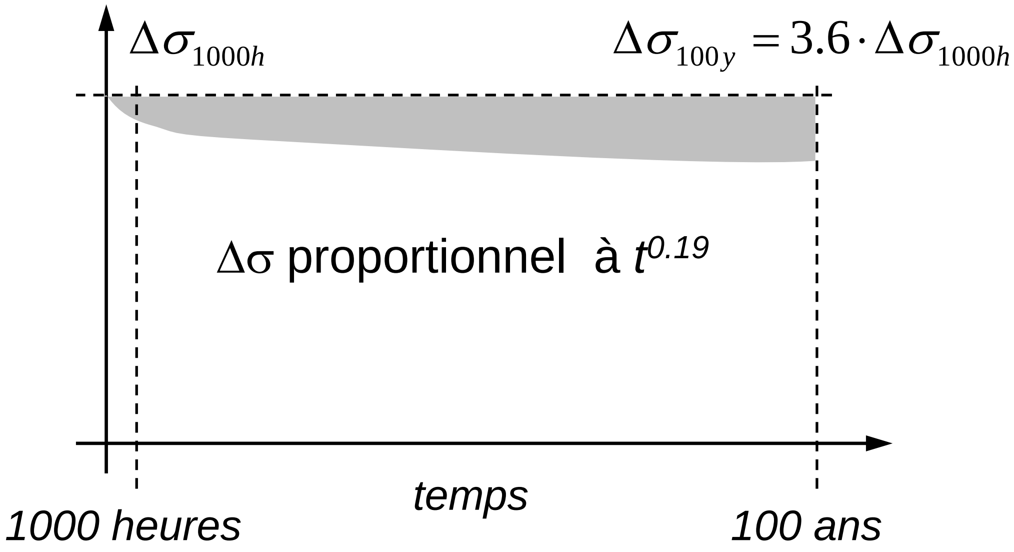
Time dependant losses of prestress

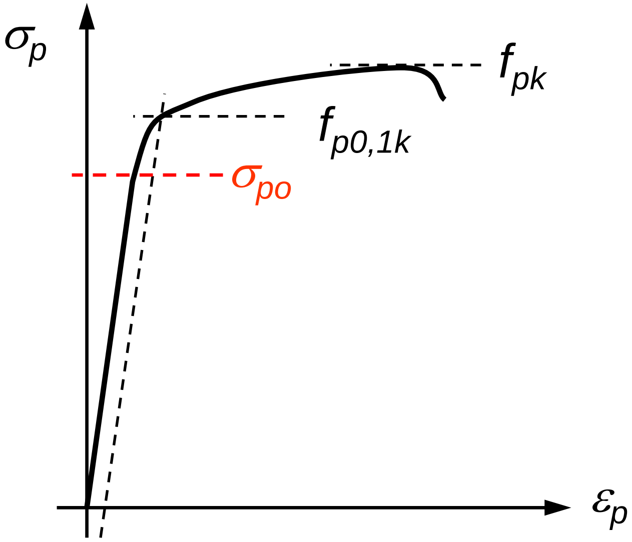
Losses of prestress due to

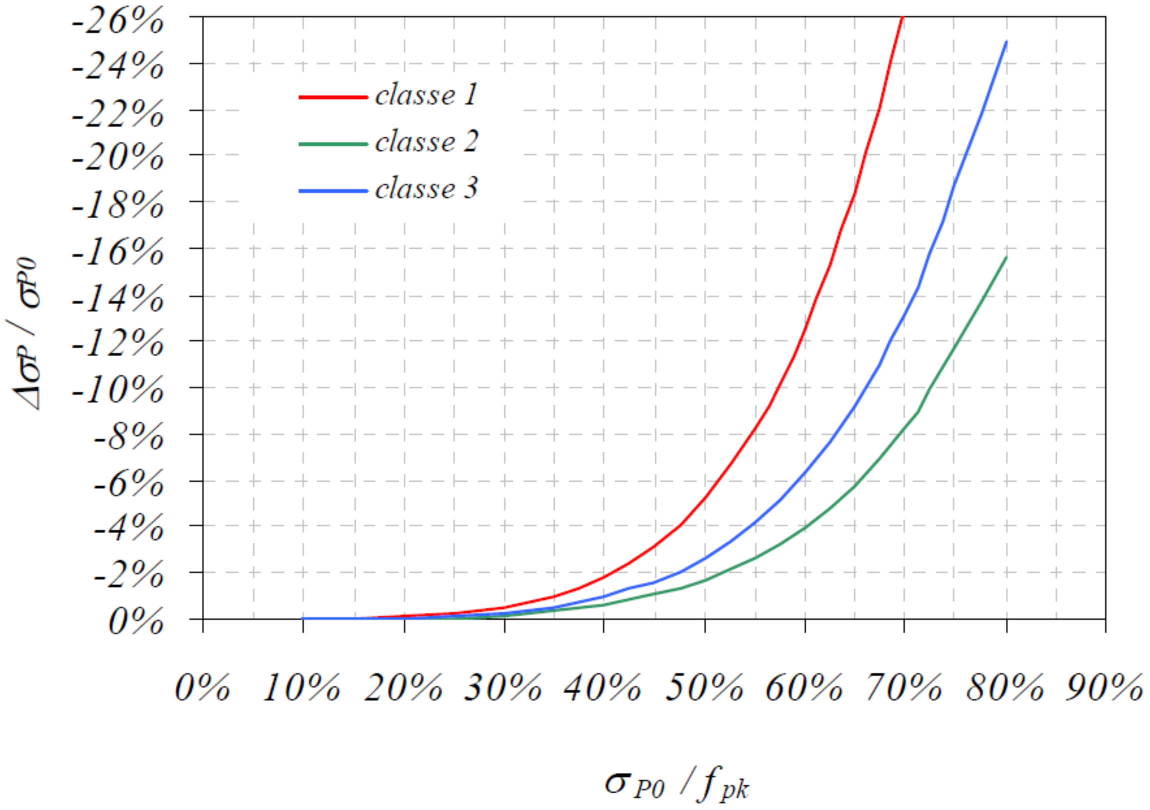
1. **relaxation** : reduction of stress at constant strain
2. **shrinkage** : concrete shortening over time
3. **creep** : concrete compressive stress in concrete causes elastic strain and an strain increment over time due to creep

Time dependant losses of prestress

Relaxation







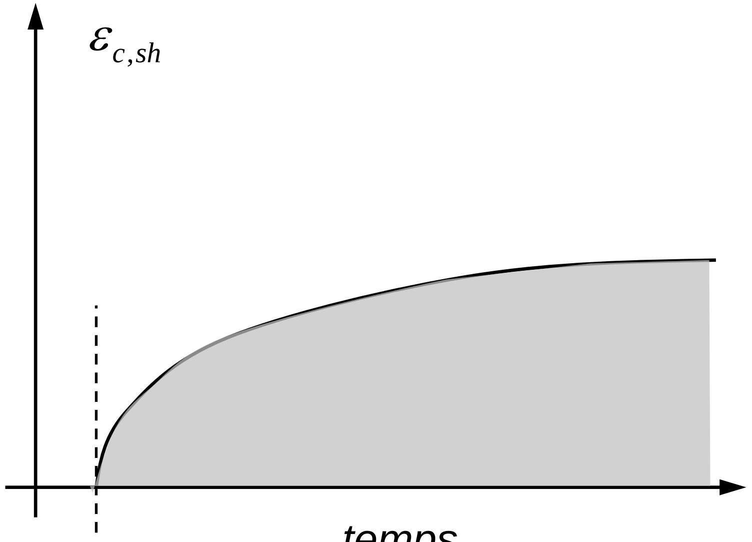
$\sigma_{p0} \leq 0.70 \cdot f_{pk}$ After the intinal prestressing force

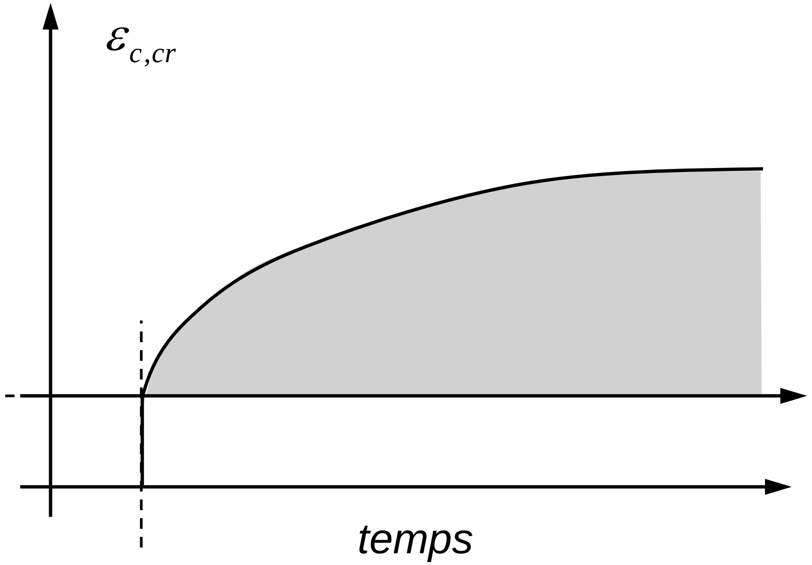
$\sigma_{p0} \leq 0.75 \cdot f_{pk}$ During the initial prestressing force

$\sigma_{p\infty} \geq 0.45 \cdot f_{pk}$ at $t = \infty$

Time dependant losses of prestress

Shrinkage and creep





$$\Delta P = -A_p \cdot E_p \cdot \left(\varepsilon_{c,sh} + \varepsilon_{c,cr}\right)$$

Time dependant losses of prestress

Interaction between relaxation, shrinkage and creep

Without interaction

With interaction

Simplified

$$\Delta P = -\rho(t,\sigma_{P0})\cdot P_0 + A_p \cdot E_p \cdot \left(\varepsilon_{cs}(t) + \varepsilon_{cc}(t,t_0,\sigma_c)\right)$$

$$= -\rho(t,\sigma_{P0})\cdot P_0 + A_p \cdot E_p \cdot \left(\varepsilon_{cs}(t) + \frac{\sigma_c}{E_c}\cdot\varphi(t,t_0)\right)$$

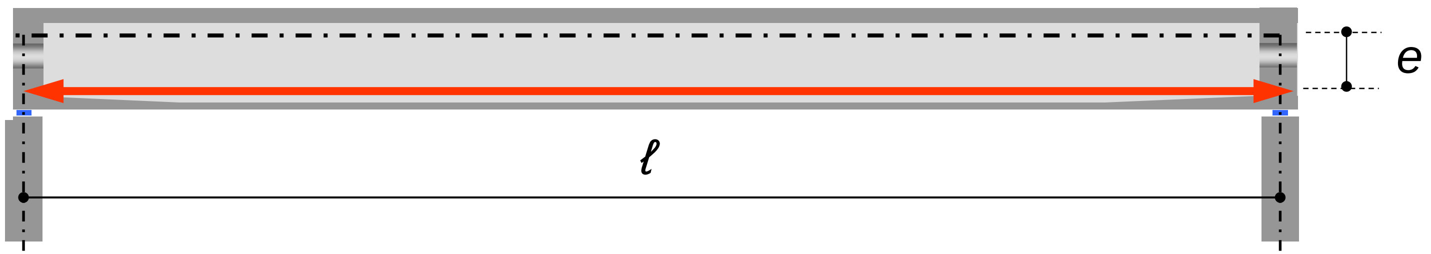
$$\Delta P = -0.8\cdot\rho(t,\sigma_{P0})\cdot P_0 + A_p \cdot E_p \cdot \left(\varepsilon_{cs}(t) + \frac{\sigma_c}{E_c}\cdot\phi(t,t_0)\right)$$

EC 2004 Approached

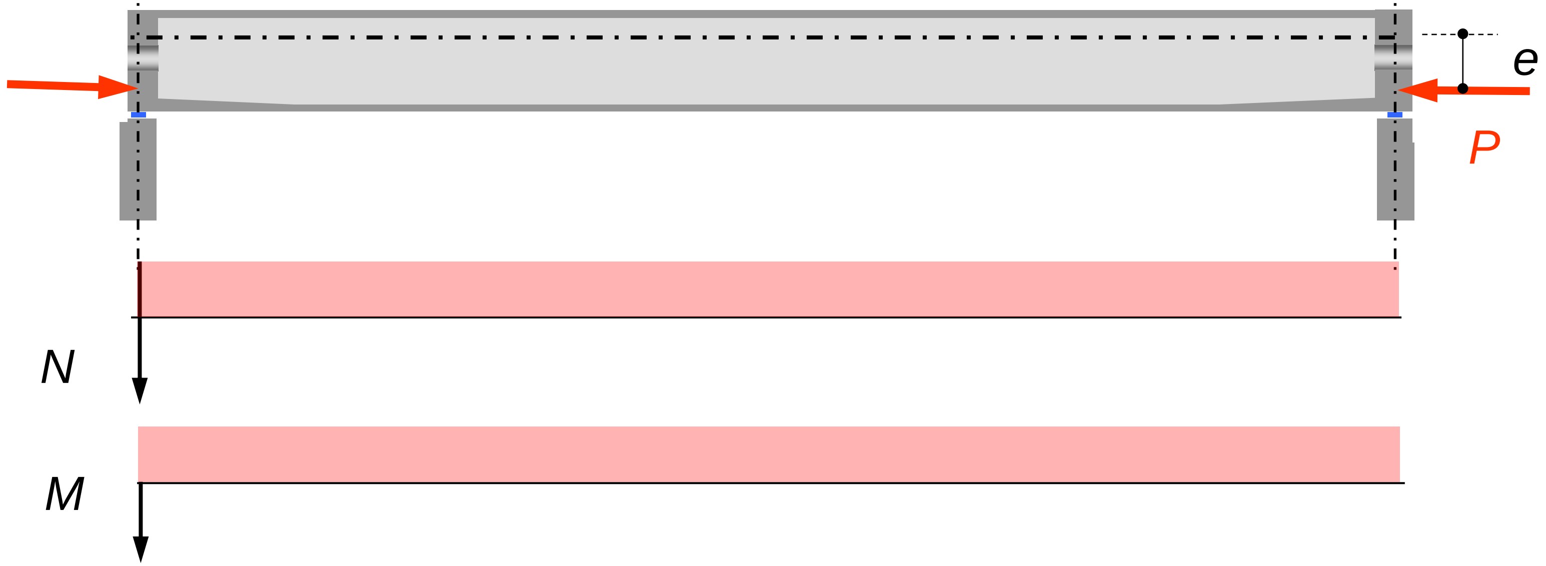
$$\Delta P = \frac{-0.8\cdot\rho(t,\sigma_{P0})\cdot P_0 + A_p \cdot E_p \cdot \left(\varepsilon_{cs}(t) + \frac{\sigma_c}{E_c}\cdot\phi(t,t_0)\right)}{1 + \frac{E_p}{E_c}\frac{A_p}{A_c}\left(1 + \left(\frac{e}{i_c}\right)^2\right)\cdot\left(1 + 0.8\cdot\phi(t,t_0)\right)}$$

Isostatic example

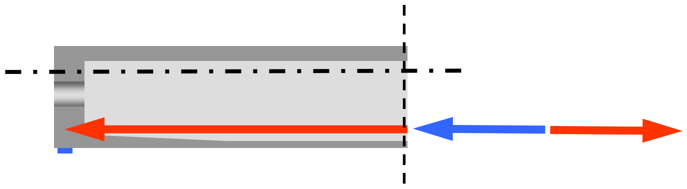
Simple supported beam with straight excentric tendon



Approach :
system of Forces



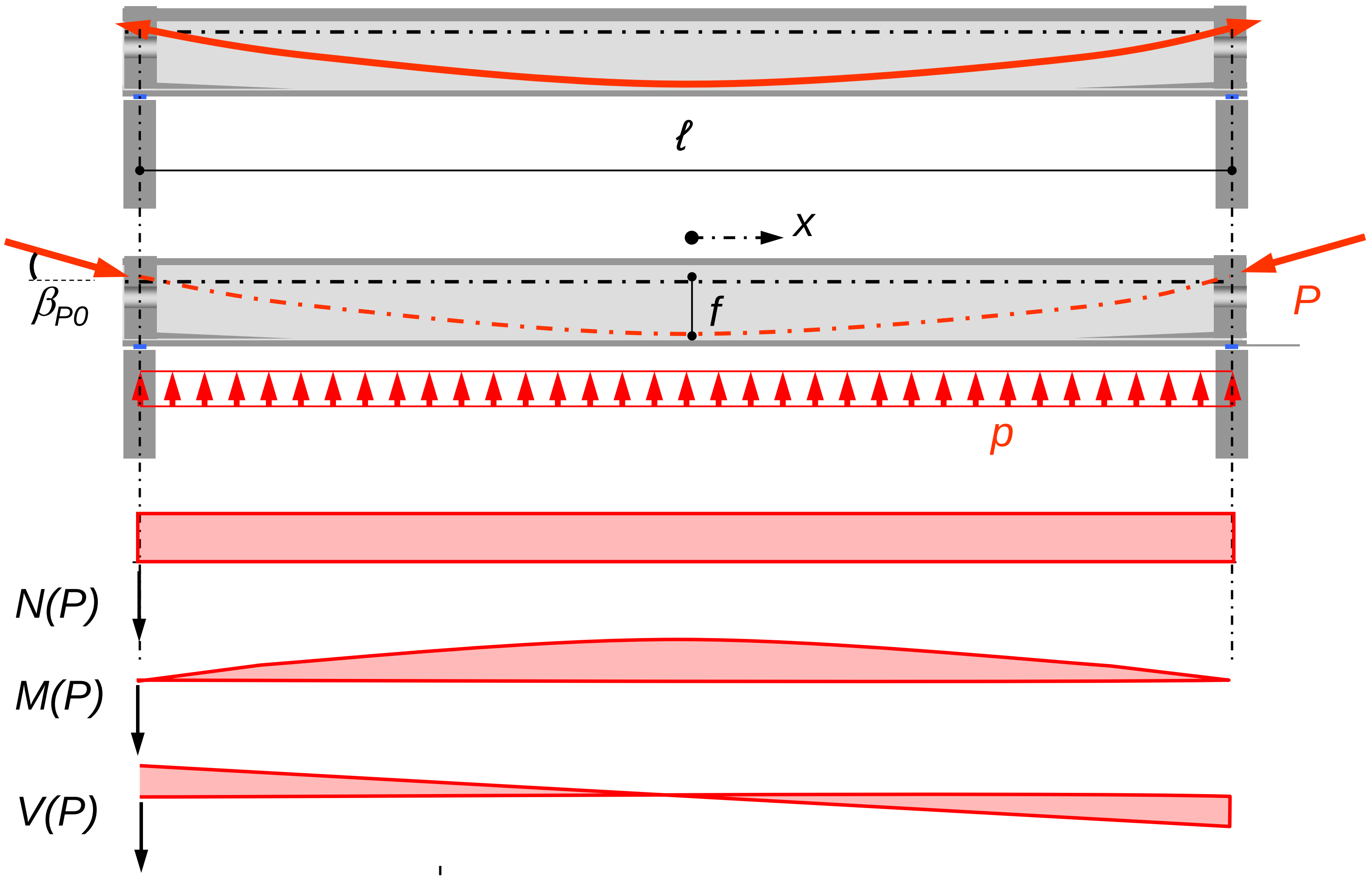
Approach :
state of stresses



Isostatic example

Simple supported beam with parabolic tendon

Approach : system of Forces



Approach : state of stresses