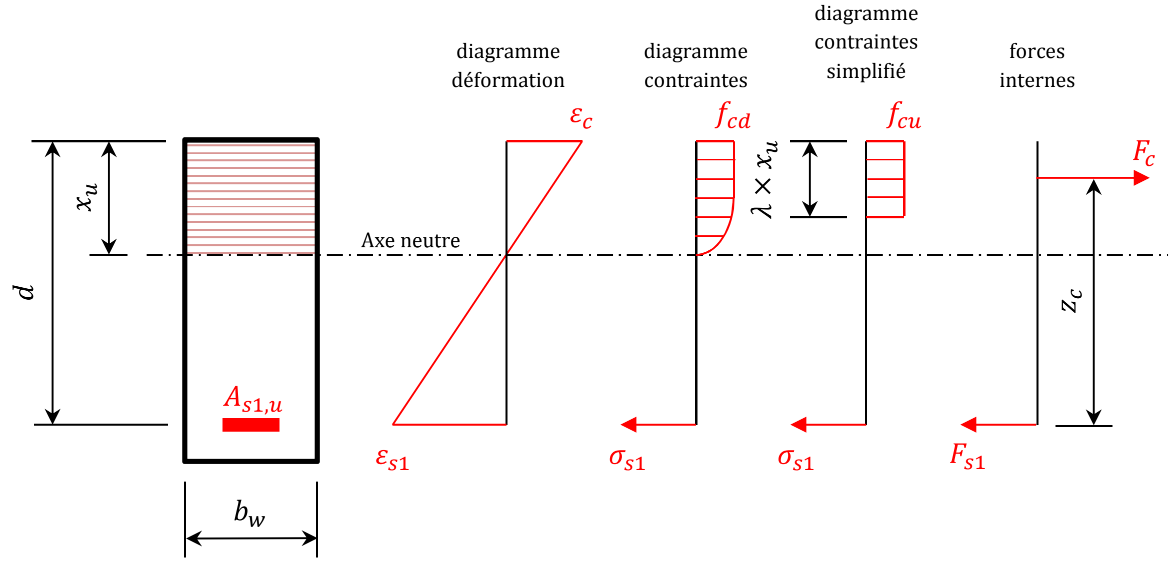
4.1 - FLEXION SIMPLE - ELU



$f_{cd} = \alpha_{cc} \times \frac{f_{ck}}{\gamma_c}$ avec $\alpha_{cc} = 1$ (valeur annexe nationale)

$f_{cu} = \eta \times f_{cd}$ avec $\eta = 1$ si $f_{ck} \leq 50\ MPa$

$\eta = 1 - \frac{f_{ck}-50}{200}$ si $50\ MPa < f_{ck} \leq 90\ MPa$

$\lambda = 0.8$ si $f_{ck} \leq 50\ MPa$

$\lambda = 0.8 - \frac{f_{ck}-50}{400}$ si $50\ MPa < f_{ck} \leq 90\ MPa$

$x_u = \alpha_u \times d$

$z_c = d - \frac{\lambda \times x_u}{2} = d \times \left(1 - \frac{\lambda \times \alpha_u}{2}\right)$

$F_c = b_w \times \lambda \times x_u \times f_{cu} = b_w \times \lambda \times \alpha_u \times d \times f_{cu}$

$F_{s1} = A_{s1,u} \times \sigma_{s1}$

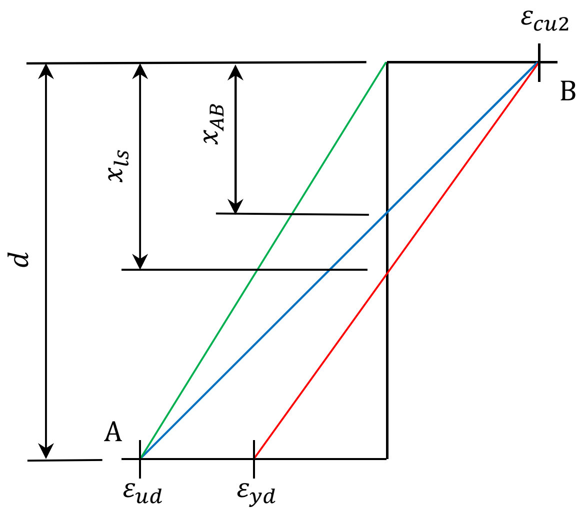
Equations d'équilibre :

$M_{Ed} = F_c \times z_c = b_w \times \lambda \times \alpha_u \times d \times f_{cu} \times d \times \left(1 - \frac{\lambda \times \alpha_u}{2}\right) = b_w \times d^2 \times f_{cu} \times \lambda \times \alpha_u \times \left(1 - \frac{\lambda \times \alpha_u}{2}\right)$

on pose : $\mu_{cu} = \frac{M_{Ed}}{b_w \times d^2 \times f_{cu}} = \lambda \times \alpha_u \times \left(1 - \frac{\lambda \times \alpha_u}{2}\right)$ (moment réduit)

$M_{Ed} = F_{s1} \times z_c = A_{s1,u} \times \sigma_{s1} \times z_c$

→ $A_{s1,u} = \frac{M_{Ed}}{\sigma_{s1} \times z_c}$



Calcul de μ_{AB} :

$\varepsilon_c = \varepsilon_{cu2}$

$\varepsilon_{s1} = \varepsilon_{ud}$

$\alpha_{AB} = \frac{x_{AB}}{d} = \frac{\varepsilon_{cu2}}{\varepsilon_{ud}+\varepsilon_{cu2}}$

$\mu_{AB} = \lambda \times \alpha_{AB} \times \left(1 - \frac{\lambda \times \alpha_{AB}}{2}\right)$

Calcul de μ_{ls} :

$\varepsilon_c = \varepsilon_{cu2}$

$\varepsilon_{s1} = \varepsilon_{yd}$

$\alpha_{ls} = \frac{x_{ls}}{d} = \frac{\varepsilon_{cu2}}{\varepsilon_{yd}+\varepsilon_{cu2}}$

$\mu_{ls} = \lambda \times \alpha_{ls} \times \left(1 - \frac{\lambda \times \alpha_{ls}}{2}\right)$

si $\mu_{cu} > \mu_{ls}$ → Aciers comprimés

si $\mu_{cu} \leq \mu_{ls}$ → Pas d'aciers comprimés
- si $\mu_{cu} \leq \mu_{AB}$ → Pivot A
- si $\mu_{cu} > \mu_{AB}$ → Pivot B

Cas sans aciers comprimés $\boldsymbol{\mu_{cu} \leq \mu_{ls}}$:

$\mu_{cu} = \lambda \times \alpha_u \times \left(1 - \frac{\lambda \times \alpha_u}{2}\right)$

→ Equation du 2nd degré en α_u

→ Solution : $\alpha_u = \frac{1}{\lambda}\left(1 - \sqrt{1 - 2 \times \mu_{cu}}\right)$

si $\boldsymbol{\mu_{cu} \leq \mu_{AB}}$ → Pivot A :

$\varepsilon_c < \varepsilon_{cu2}$

$\varepsilon_{s1} = \varepsilon_{ud}$

si $\boldsymbol{\mu_{cu} > \mu_{AB}}$ → Pivot B :

$\varepsilon_c = \varepsilon_{cu2}$

$\varepsilon_{yd} < \varepsilon_{s1} < \varepsilon_{ud}$ (ε_{s1} est sur le palier du diagramme contraintes/déformations)

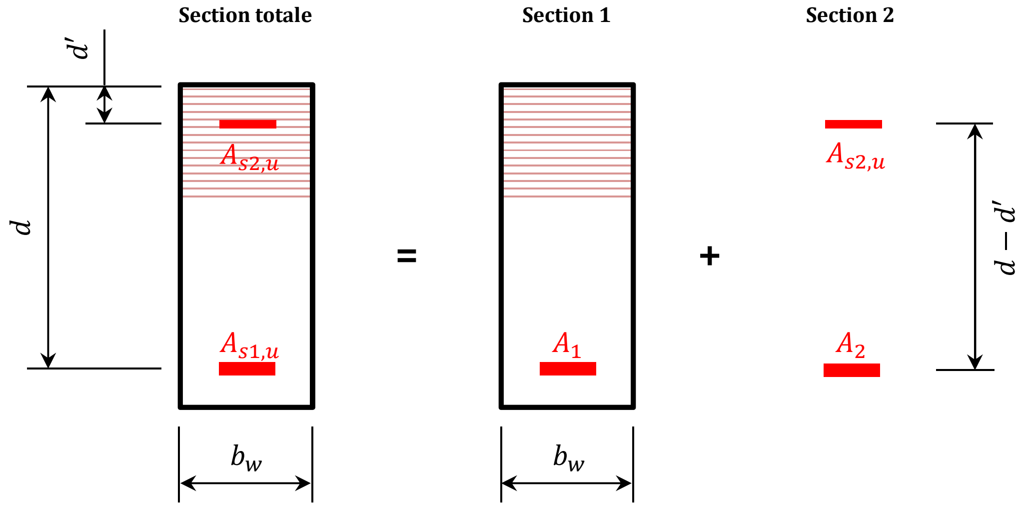
$\varepsilon_{s1} = \varepsilon_{cu2} \times \left(\frac{1 - \alpha_u}{\alpha_u}\right)$

$\sigma_{s1} = A + B \times \varepsilon_{s1}$ (Equation de la droite du palier incliné)

$z_c = d \times \left(1 - \frac{\lambda \times \alpha_u}{2}\right)$

$A_{s1,u} = \frac{M_{Ed}}{\sigma_{s1} \times z_c}$

Cas avec aciers comprimés $\mu_{cu} > \mu_{ls}$:

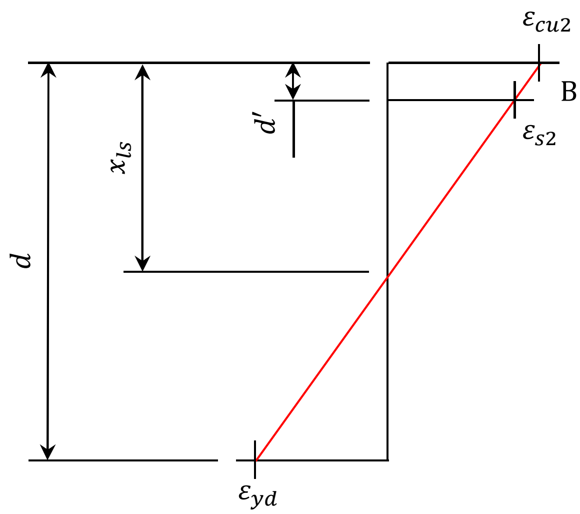


$$M_{Ed} \quad = \quad M_{ls} \quad + \quad M_{Ed} - M_{ls}$$

$$M_{ls} = \mu_{ls} \times b_w \times d^2 \times f_{cu}$$

Calcul de $A_{s2,u}$:

$$M_{Ed} - M_{ls} = A_{s2,u} \times \sigma_{s2} \times (d - d')$$



$$\varepsilon_{s2} = \varepsilon_{cu2} \times \frac{\alpha_{ls} - \frac{d'}{d}}{\alpha_{ls}}$$

si $\varepsilon_{s2} \leq \varepsilon_{yd}$: $\sigma_{s2} = E_s \times \varepsilon_{s2}$ (droite de Hooke)
si $\varepsilon_{s2} > \varepsilon_{yd}$: $\sigma_{s2} = A + B \times \varepsilon_{s2}$ (palier incliné)

$$A_{s2,u} = \frac{M_{Ed} - M_{ls}}{(d - d') \times \sigma_{s2}}$$

Calcul de $A_{s1,u}$:

$$A_{s1,u} = A_1 + A_2$$

$A_1 = \frac{M_{ls}}{\sigma_{s1} \times z_c}$ avec $\sigma_{s1} = f_{yd}$

$$z_c = d \times \left(1 - \frac{\lambda \times \alpha_{ls}}{2}\right)$$

$$M_{Ed} - M_{ls} = A_{s2,u} \times \sigma_{s2} \times (d - d') = A_2 \times \sigma_{s1} \times (d - d')$$

$$A_{s2,u} \times \sigma_{s2} = A_2 \times \sigma_{s1}$$

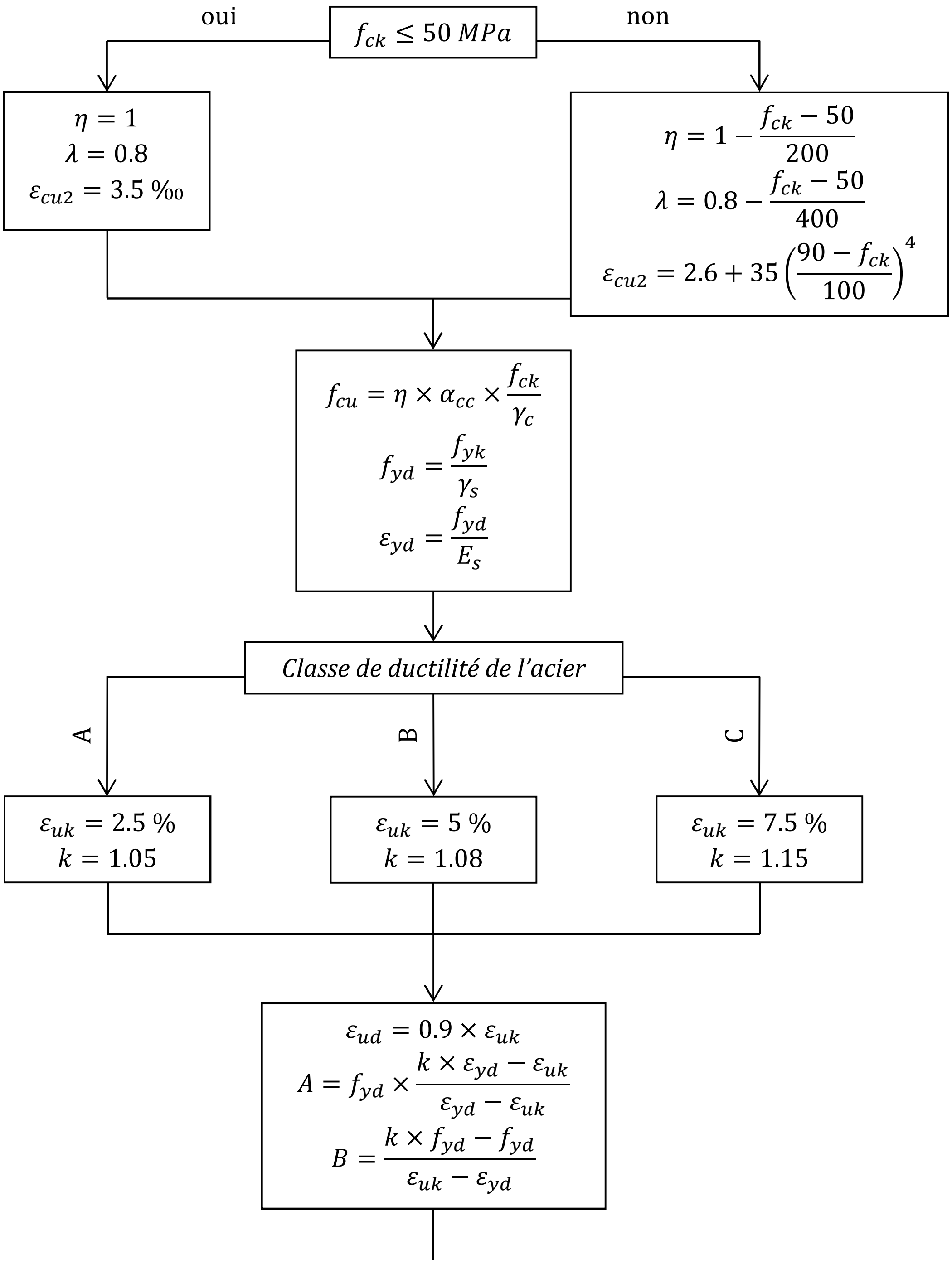
$$A_2 = A_{s2,u} \times \frac{\sigma_{s2}}{\sigma_{s1}}$$

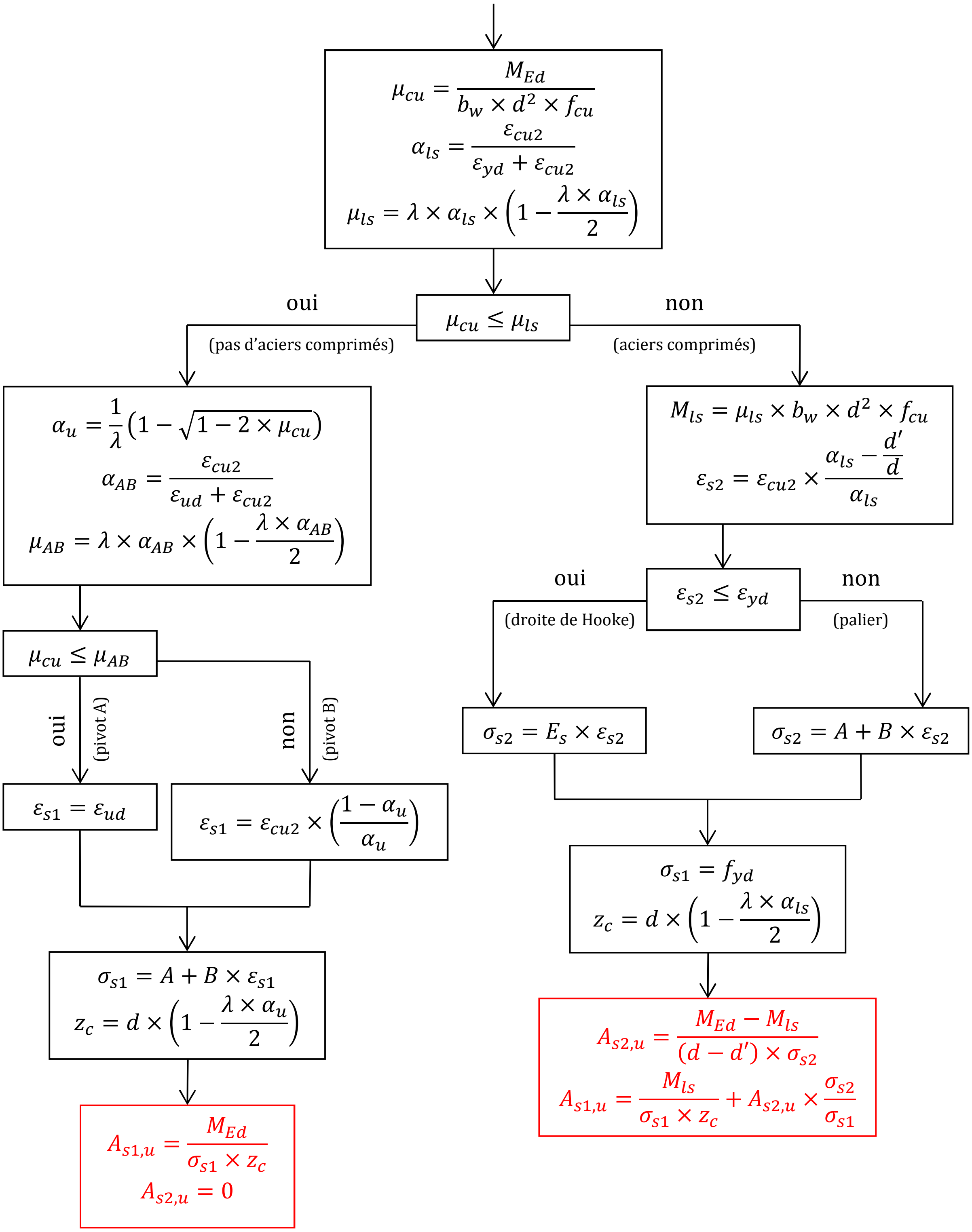
$$A_{s1,u} = \frac{M_{ls}}{\sigma_{s1} \times z_c} + A_{s2,u} \times \frac{\sigma_{s2}}{\sigma_{s1}}$$

Flexion simple - ELU
Section rectangulaire

(diagramme contraintes-déformations des aciers avec palier incliné)

Béton	**Acier**	**Dimensions**	**Sollicitations**
f_{ck}	f_{yk}	b_w	M_{Ed}
γ_c	γ_s	d	
α_{CC}	E_s	d'	
	Classe de ductilité		




$\mu_{cu} = \frac{M_{Ed}}{b_w \times d^2 \times f_{cu}}$
$\alpha_{ls} = \frac{\varepsilon_{cu2}}{\varepsilon_{yd} + \varepsilon_{cu2}}$
$\mu_{ls} = \lambda \times \alpha_{ls} \times \left(1 - \frac{\lambda \times \alpha_{ls}}{2}\right)$
$\mu_{cu} \leq \mu_{ls}$
oui
(pas d'aciers comprimés)
non
(aciers comprimés)
$\alpha_u = \frac{1}{\lambda}\left(1 - \sqrt{1 - 2 \times \mu_{cu}}\right)$
$\alpha_{AB} = \frac{\varepsilon_{cu2}}{\varepsilon_{ud} + \varepsilon_{cu2}}$
$\mu_{AB} = \lambda \times \alpha_{AB} \times \left(1 - \frac{\lambda \times \alpha_{AB}}{2}\right)$
$\mu_{cu} \leq \mu_{AB}$
oui
(pivot A)
non
(pivot B)
$\varepsilon_{s1} = \varepsilon_{ud}$
$\varepsilon_{s1} = \varepsilon_{cu2} \times \left(\frac{1 - \alpha_u}{\alpha_u}\right)$
$\sigma_{s1} = A + B \times \varepsilon_{s1}$
$z_c = d \times \left(1 - \frac{\lambda \times \alpha_u}{2}\right)$
$A_{s1,u} = \frac{M_{Ed}}{\sigma_{s1} \times z_c}$
$A_{s2,u} = 0$
$M_{ls} = \mu_{ls} \times b_w \times d^2 \times f_{cu}$
$\varepsilon_{s2} = \varepsilon_{cu2} \times \frac{\alpha_{ls} - \frac{d'}{d}}{\alpha_{ls}}$
$\varepsilon_{s2} \leq \varepsilon_{yd}$
oui
(droite de Hooke)
non
(palier)
$\sigma_{s2} = E_s \times \varepsilon_{s2}$
$\sigma_{s2} = A + B \times \varepsilon_{s2}$
$\sigma_{s1} = f_{yd}$
$z_c = d \times \left(1 - \frac{\lambda \times \alpha_{ls}}{2}\right)$
$A_{s2,u} = \frac{M_{Ed} - M_{ls}}{(d - d') \times \sigma_{s2}}$
$A_{s1,u} = \frac{M_{ls}}{\sigma_{s1} \times z_c} + A_{s2,u} \times \frac{\sigma_{s2}}{\sigma_{s1}}$