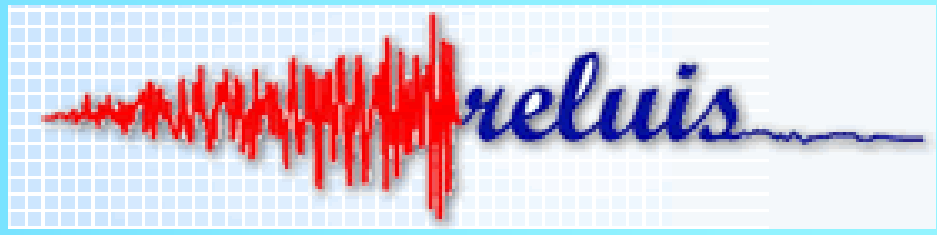

Materiali ed Approcci Innovativi per il Progetto in Zona Sismica e la Mitigazione della Vulnerabilità delle Strutture
Università degli Studi di Salerno – Consorzio ReLUIS, 12-13 Febbraio 2007

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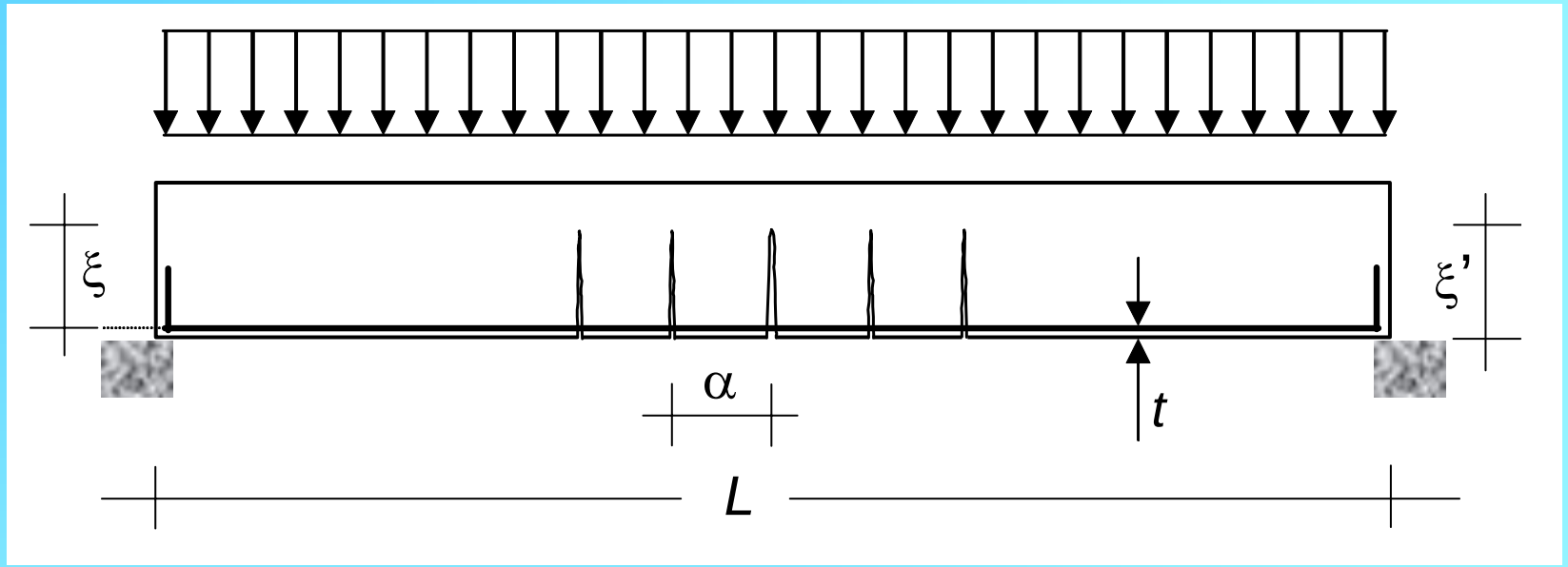
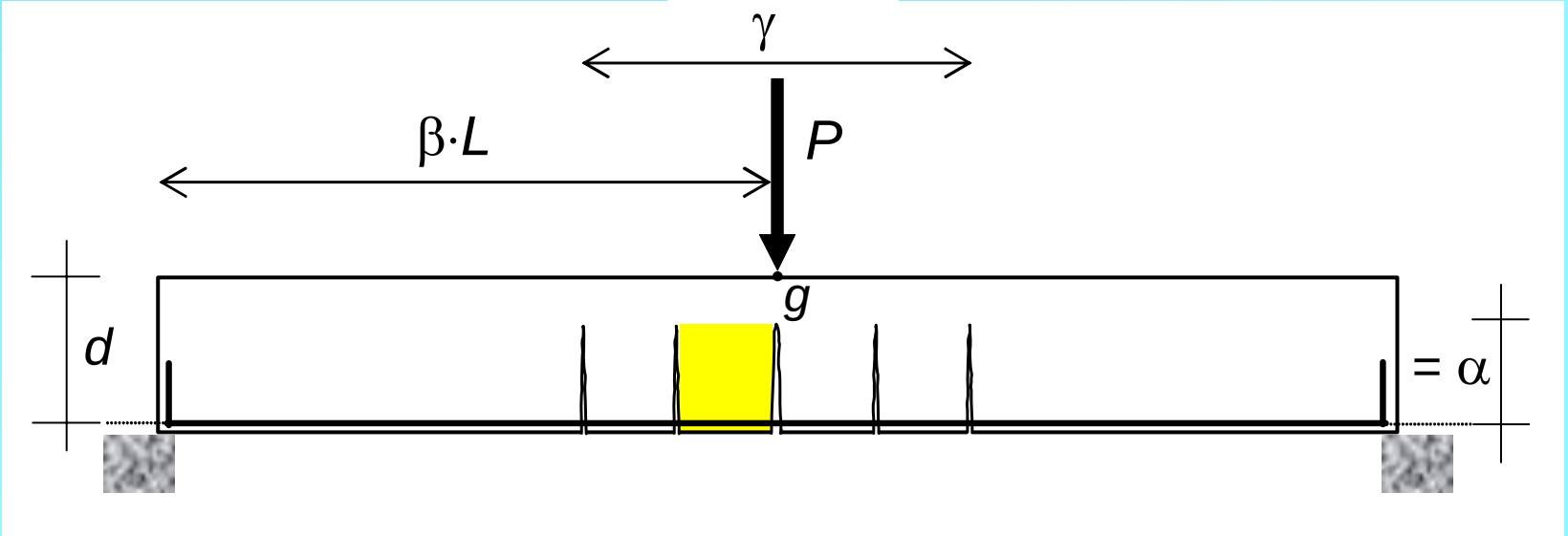
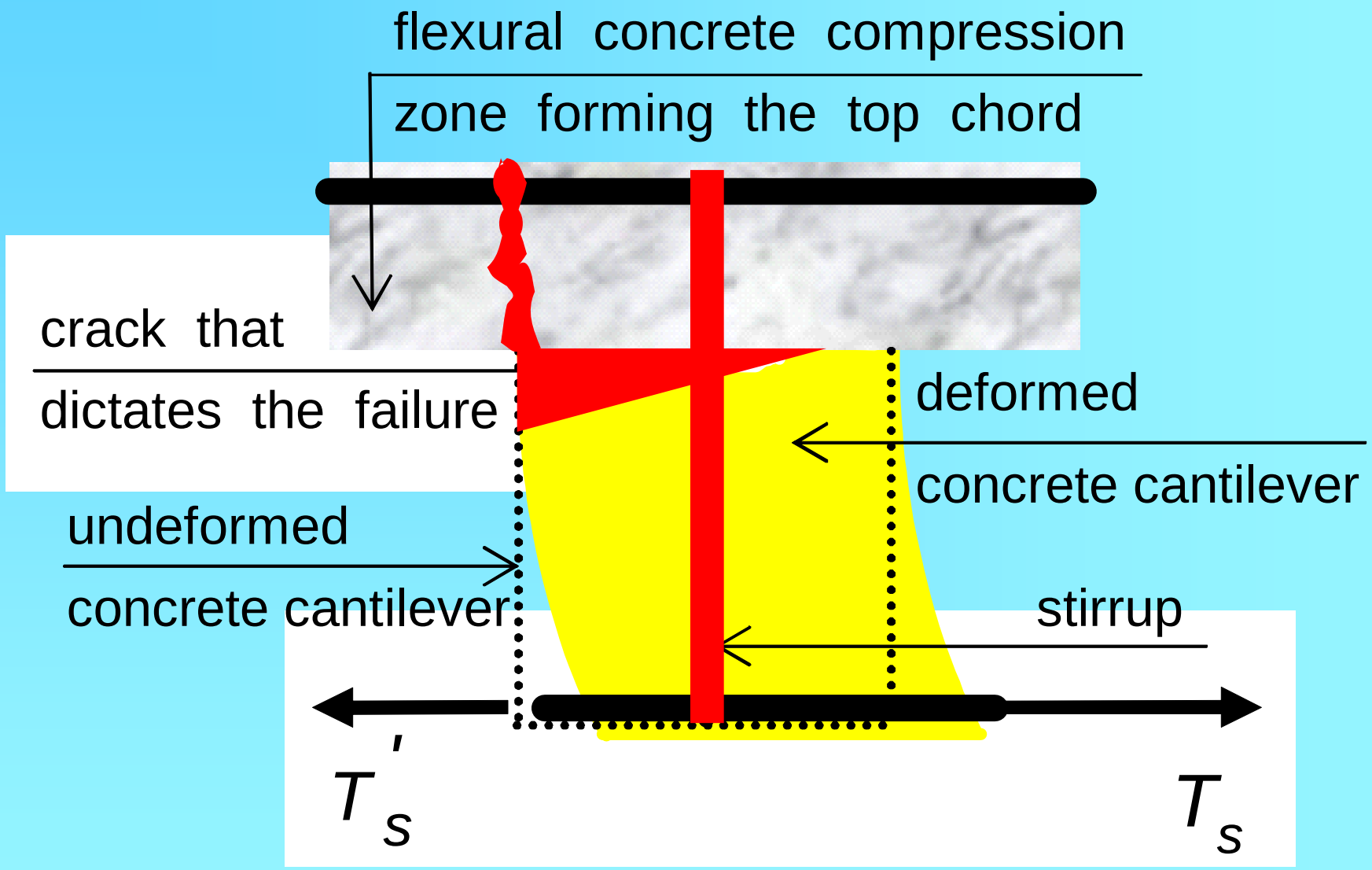
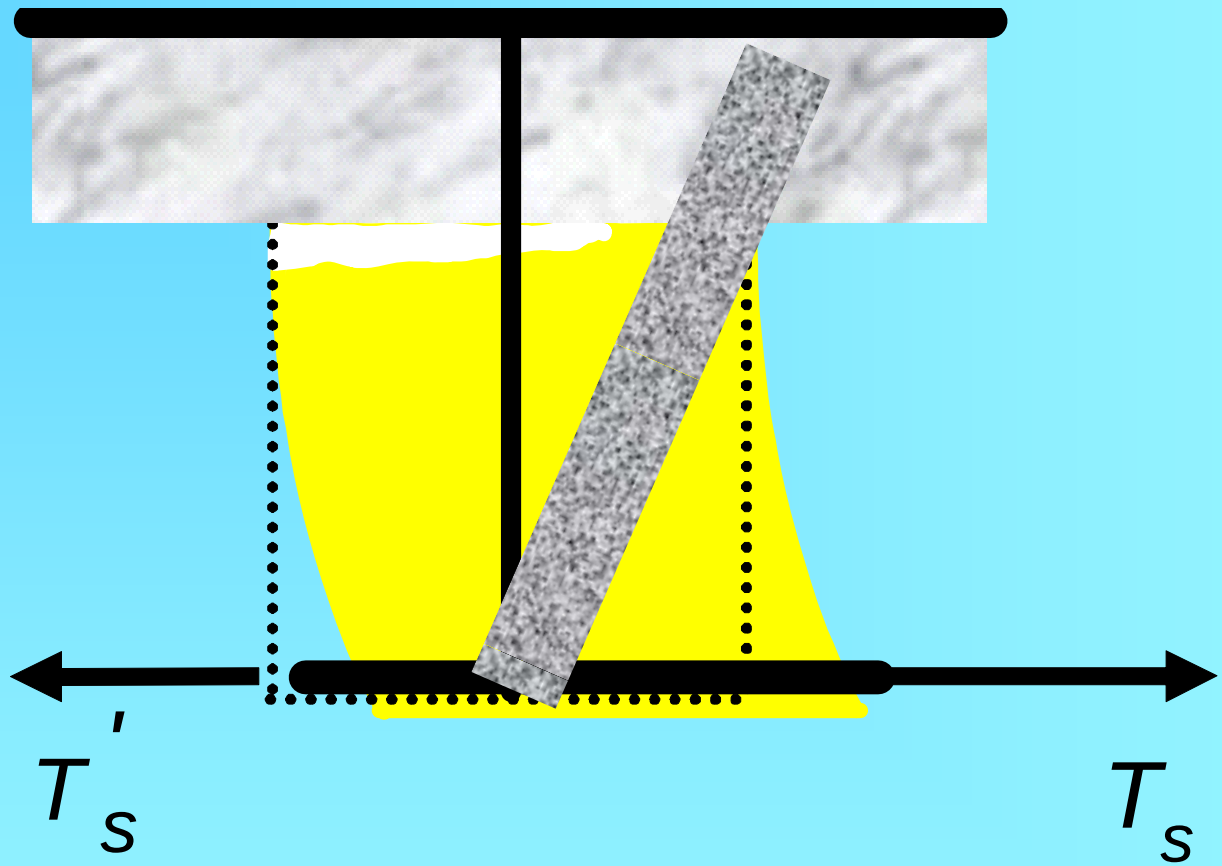
Università **IUAV** di **V**enezia
Dipartimento di **C**ostruzione dell'**A**rchitettura
E-Mail: paofor@iuav.it

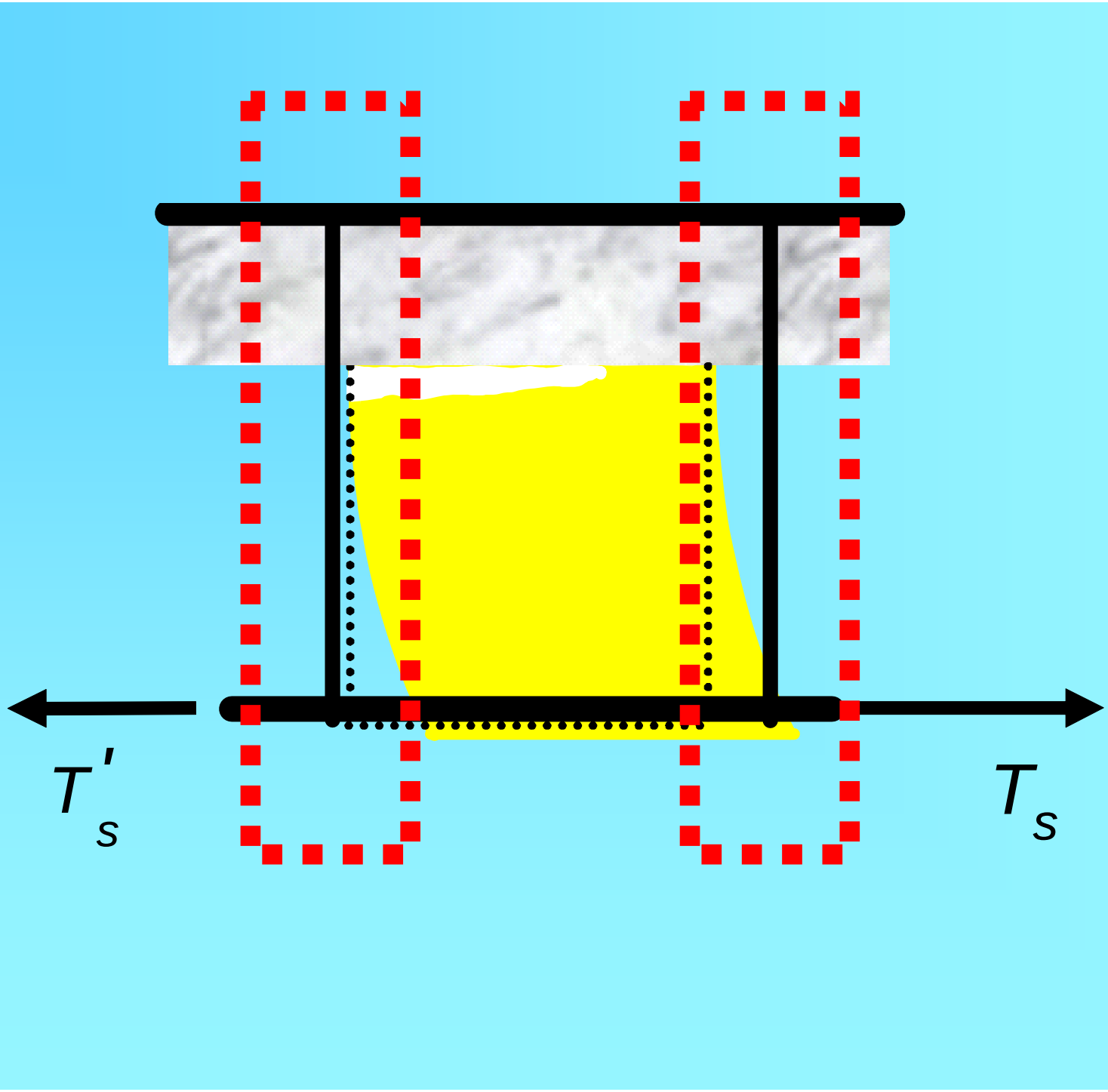
Strengthening of RC Beams with Vertical Cracks

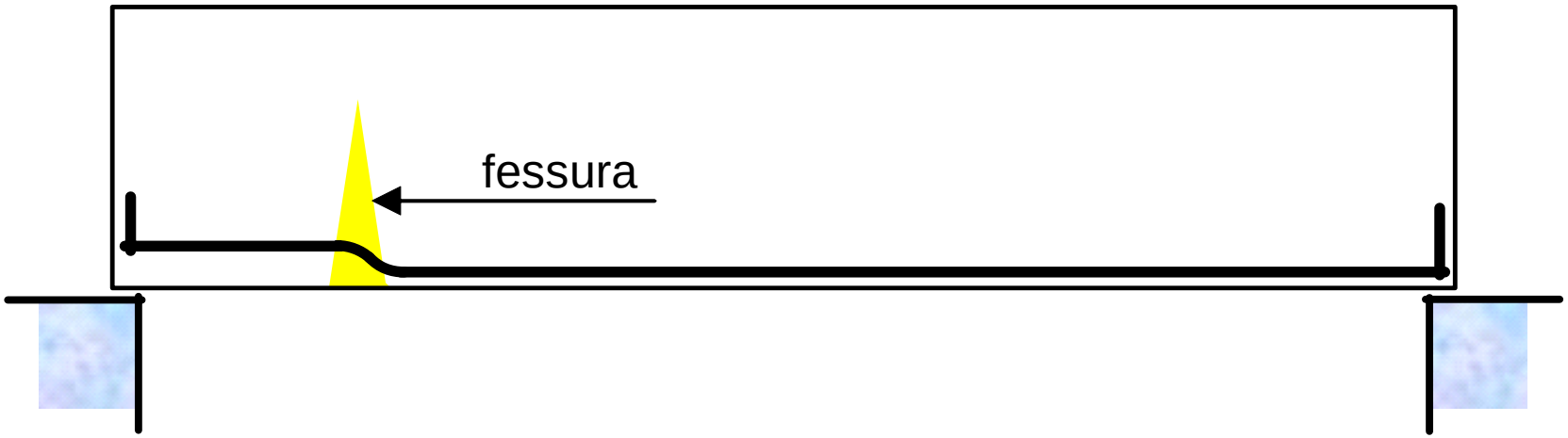

ξ
ξ'
α
t
L

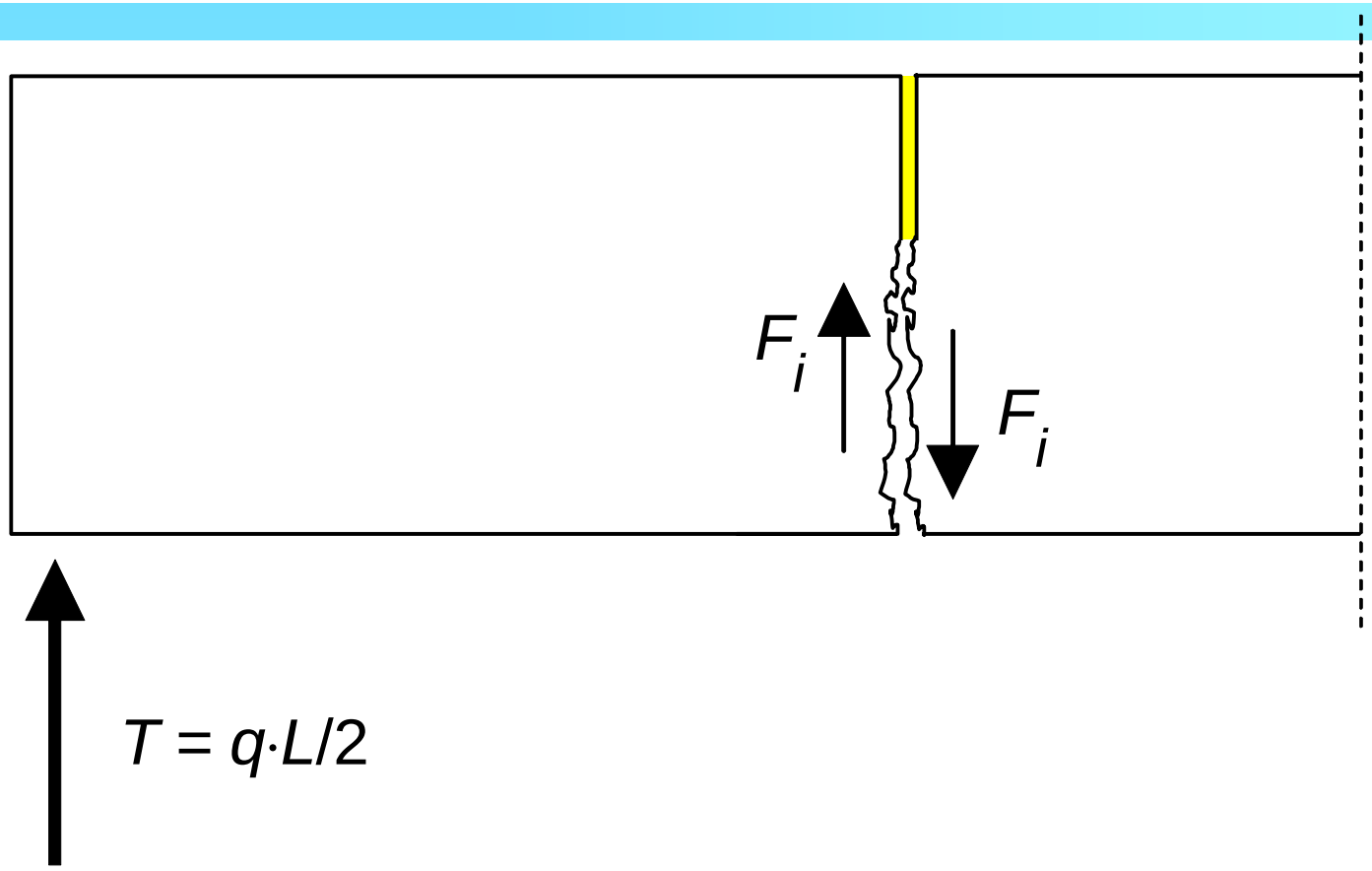

γ
β·L
P
g
d
= α

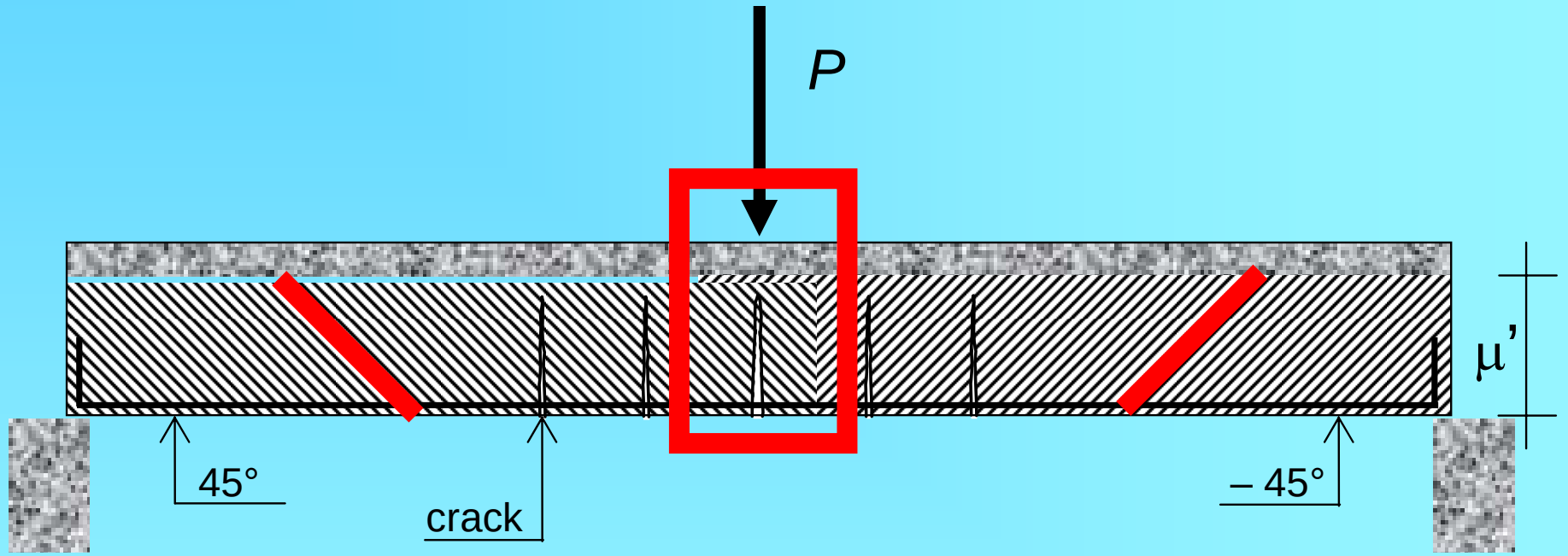

flexural concrete compression
zone forming the top chord
crack that
dictates the failure
deformed
concrete cantilever
undeformed
concrete cantilever
stirrup
T_s'
T_s


T_s'
T_s

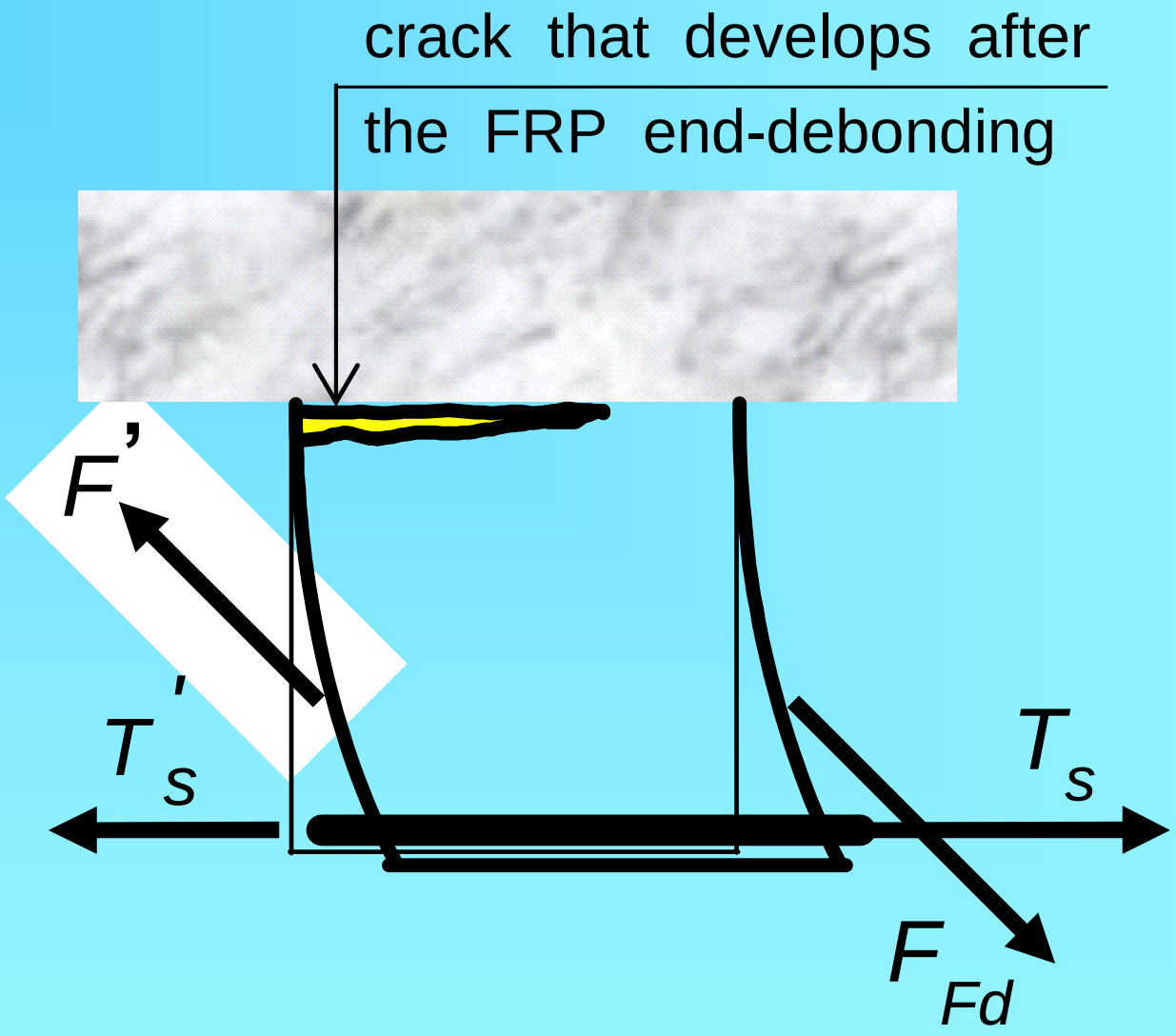

T'_s
T_s

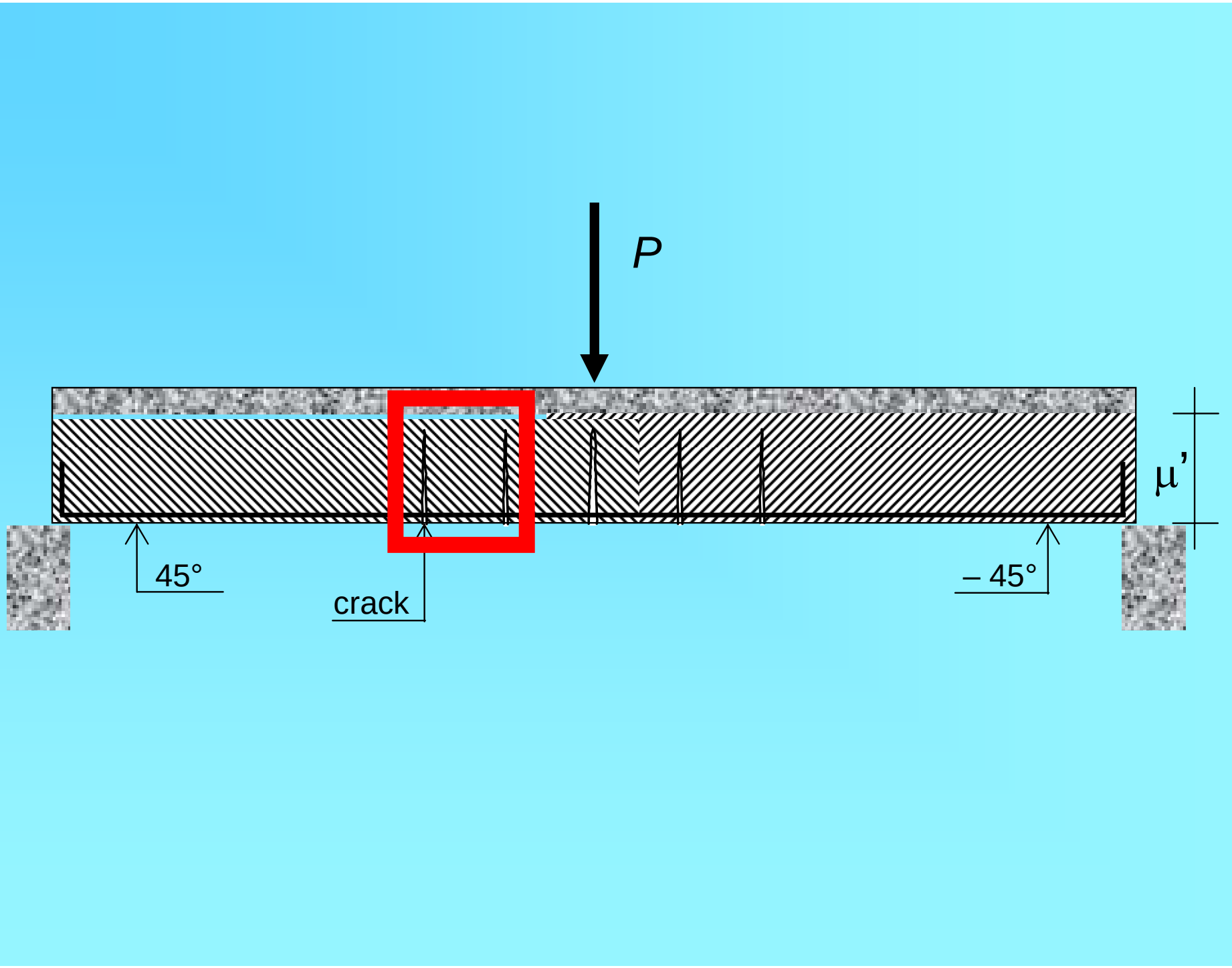

fessura

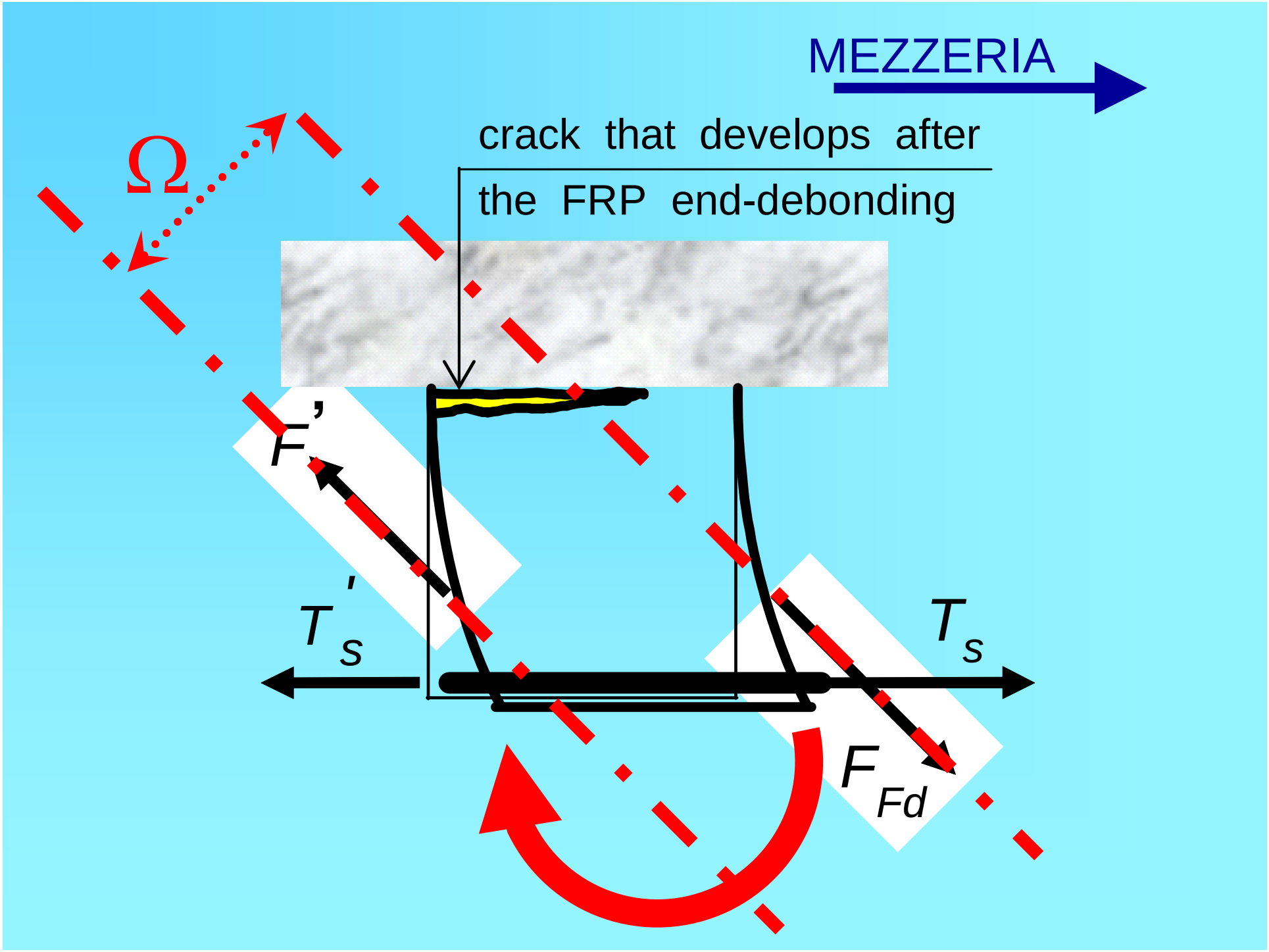

F_i
F_i
$T = q \cdot L/2$

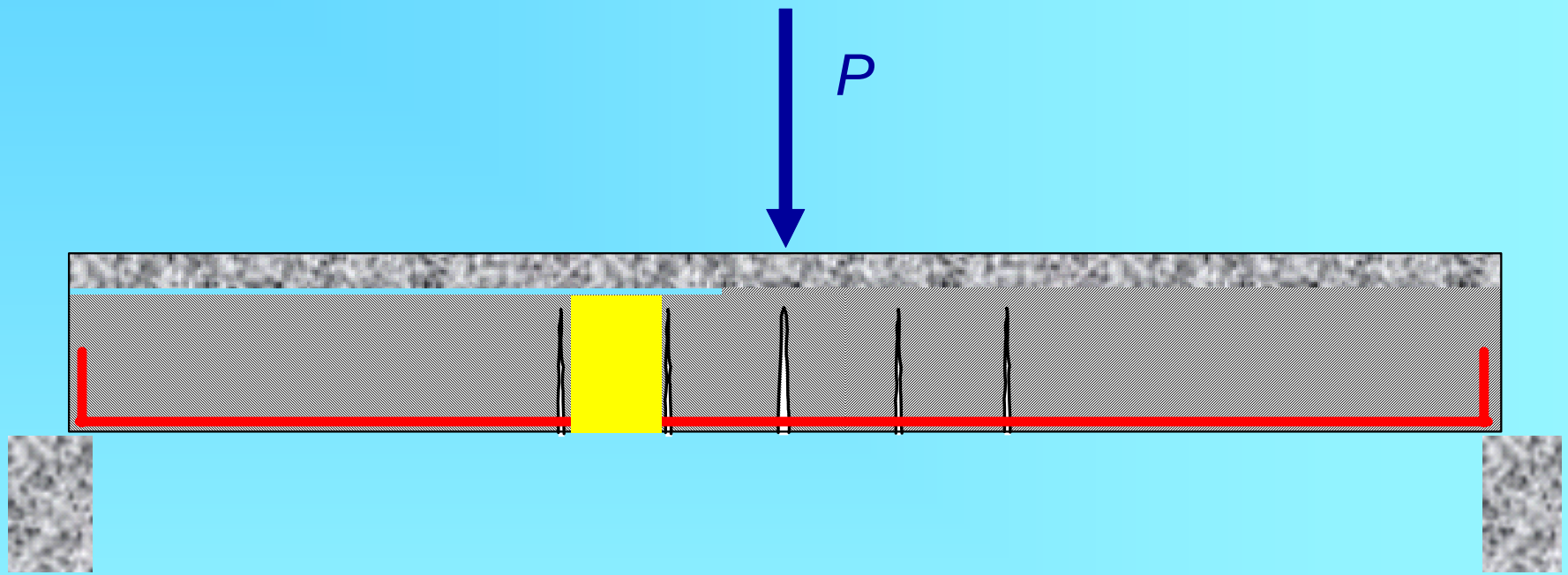


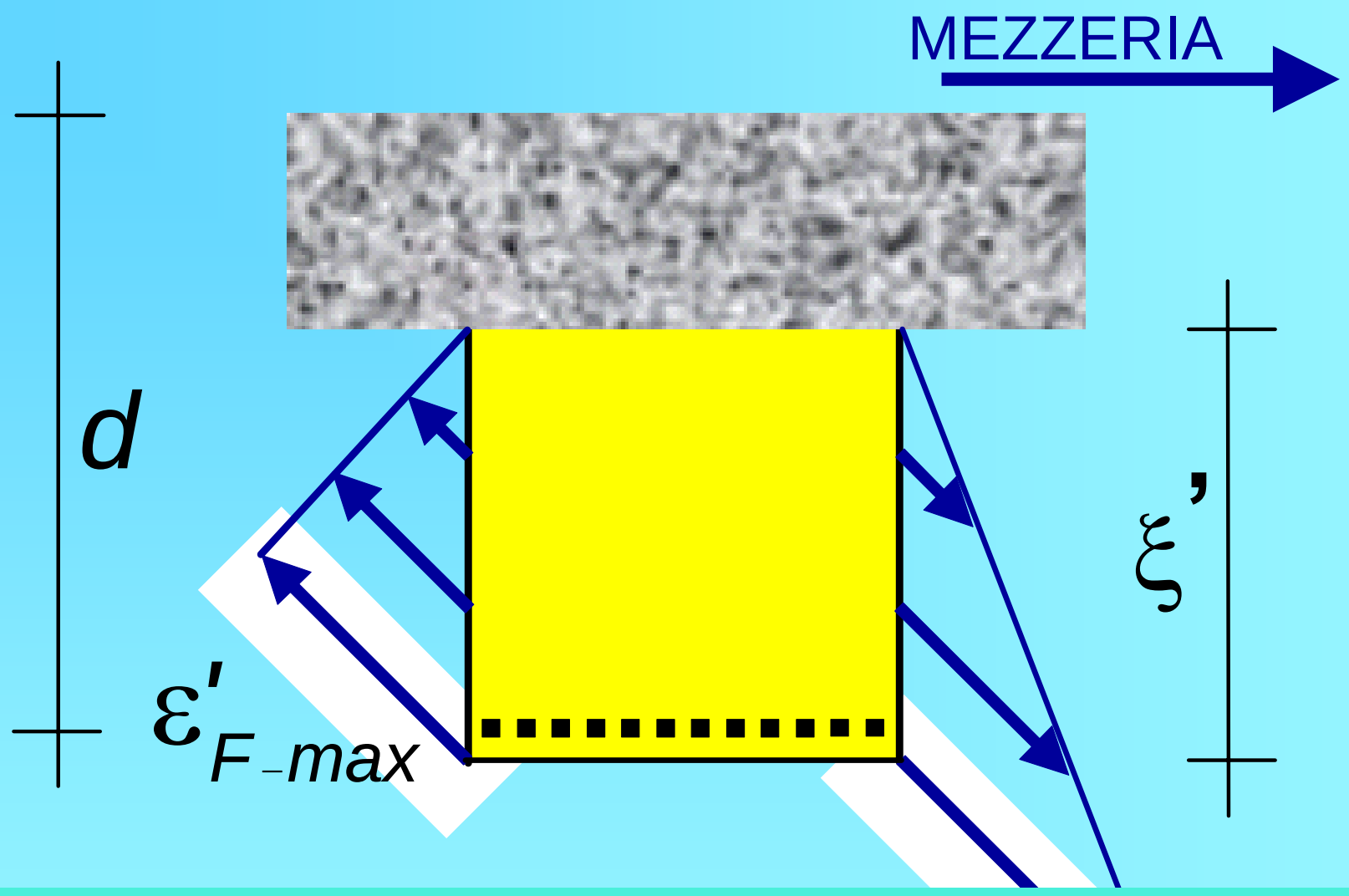
TESSUTO UNI-DIREZIONALE CON FIBRE OBLIQUE


crack that develops after
the FRP end-debonding
F'
T's
Ts
FFd


P
μ'
45°
crack
– 45°


MEZZERIA
crack that develops after
the FRP end-debonding
Ω
F'
T's
Ts
FFd


P



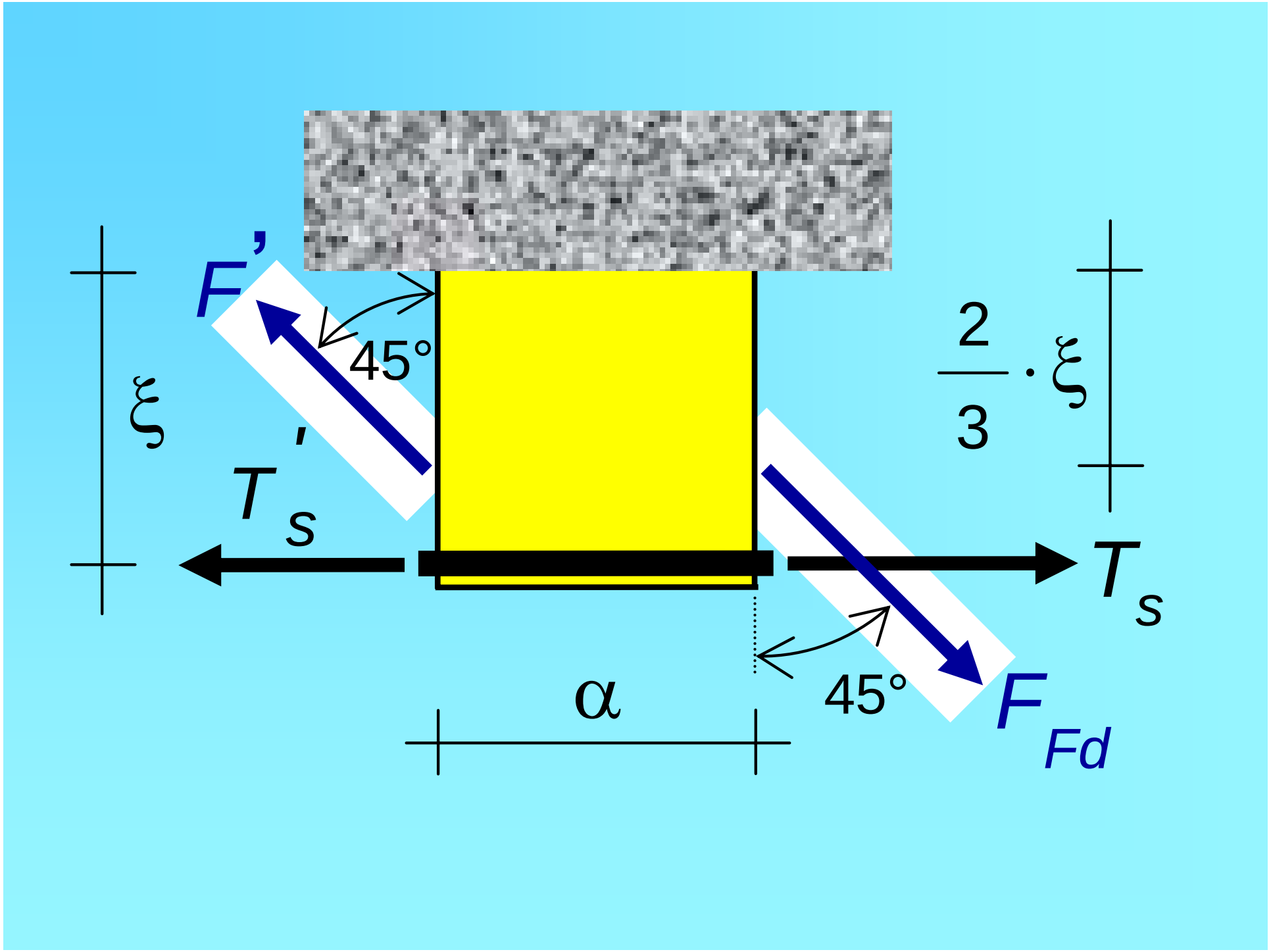
Se l'aderenza del tessuto fosse perfetta si avrebbero due profili triangolari completi. Le reali condizioni di aderenza implicano profili trapezoidali incompleti.

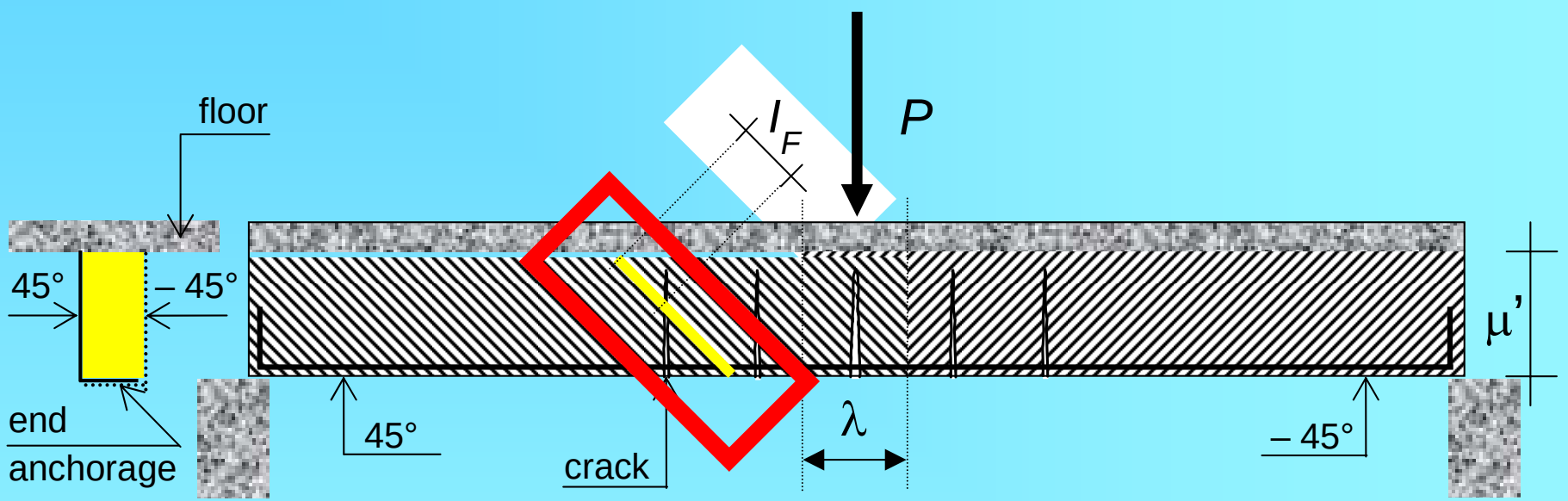
IPOTESI DEL MODELLO

$$\alpha = \xi$$

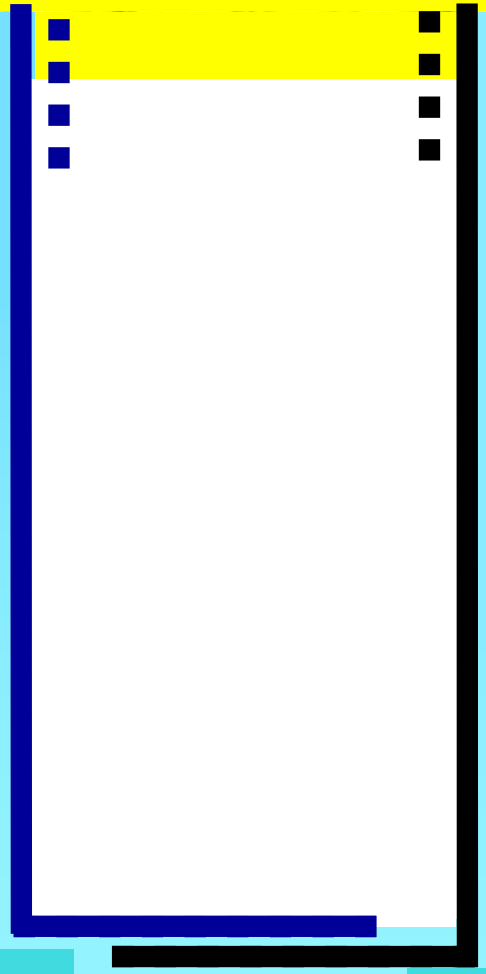
ossia:

$$\alpha = \xi' - t$$


F'
45°
ξ
T's
Ts
2/3 · ξ
α
45°
FFd


floor
l_F
P
45°
– 45°
μ'
end
anchorage
45°
crack
λ
– 45°

TRAVE A "T"

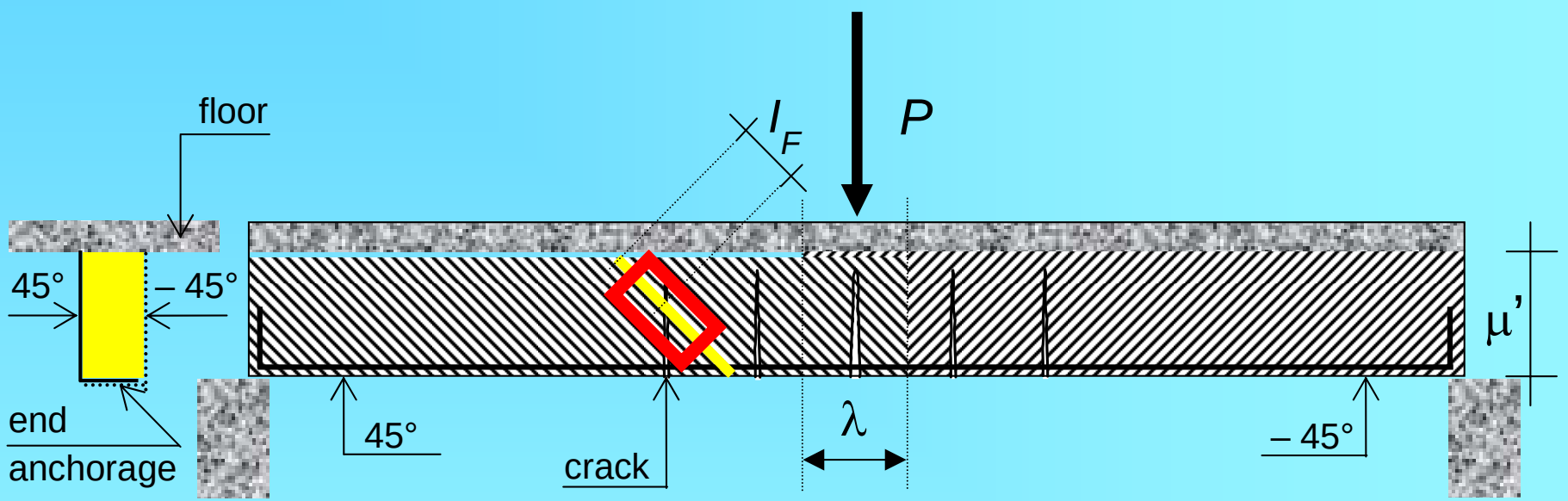


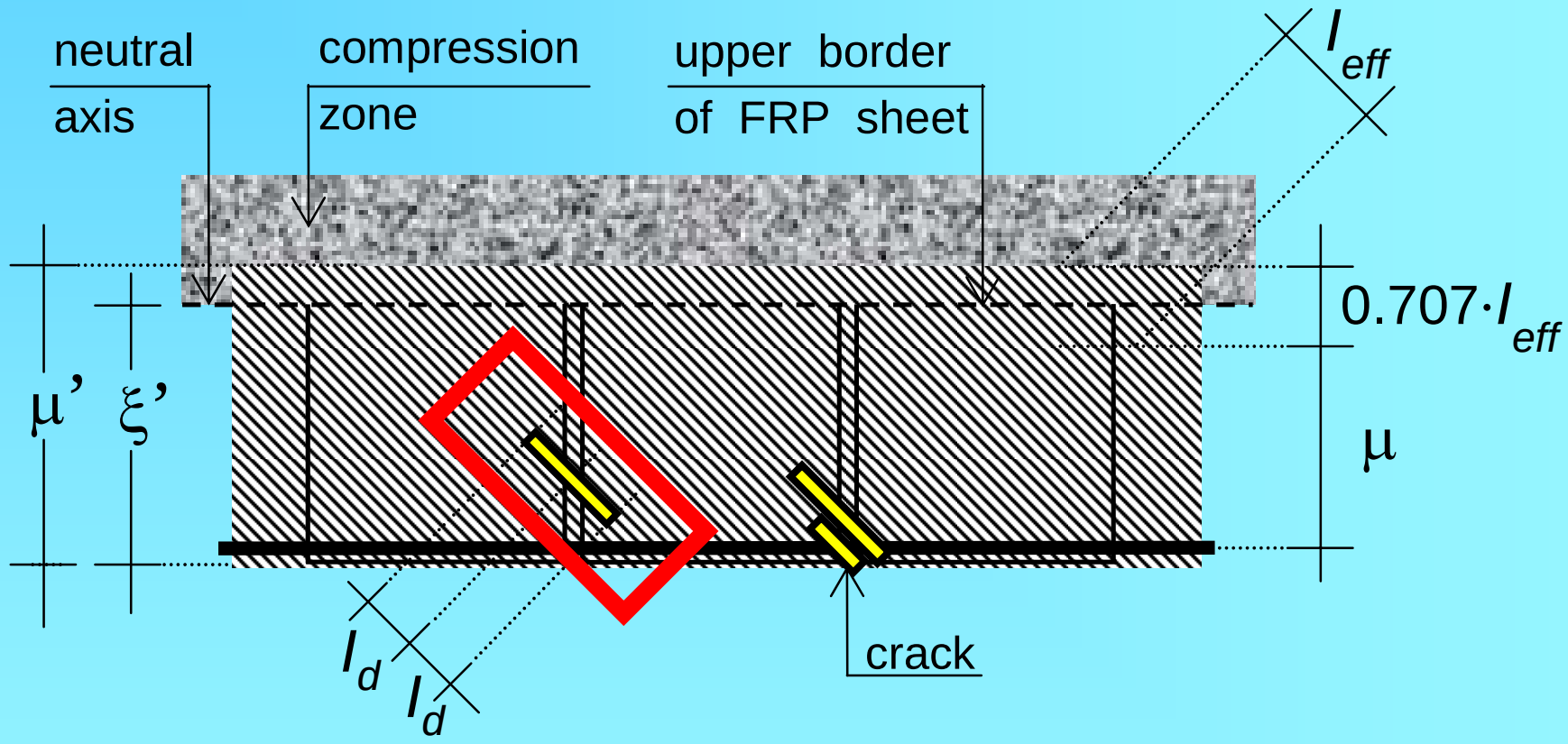
+ 45°

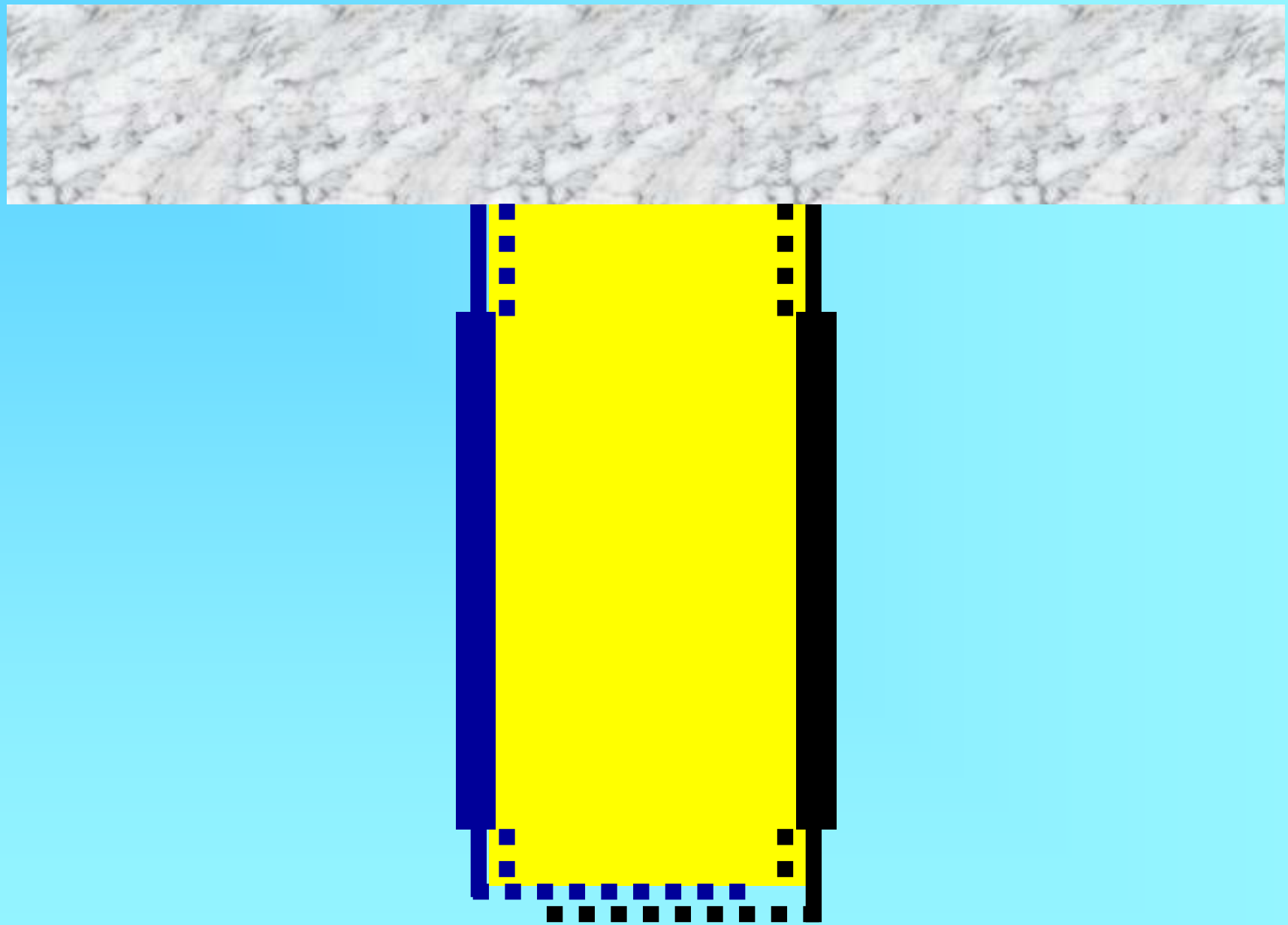
— 45°

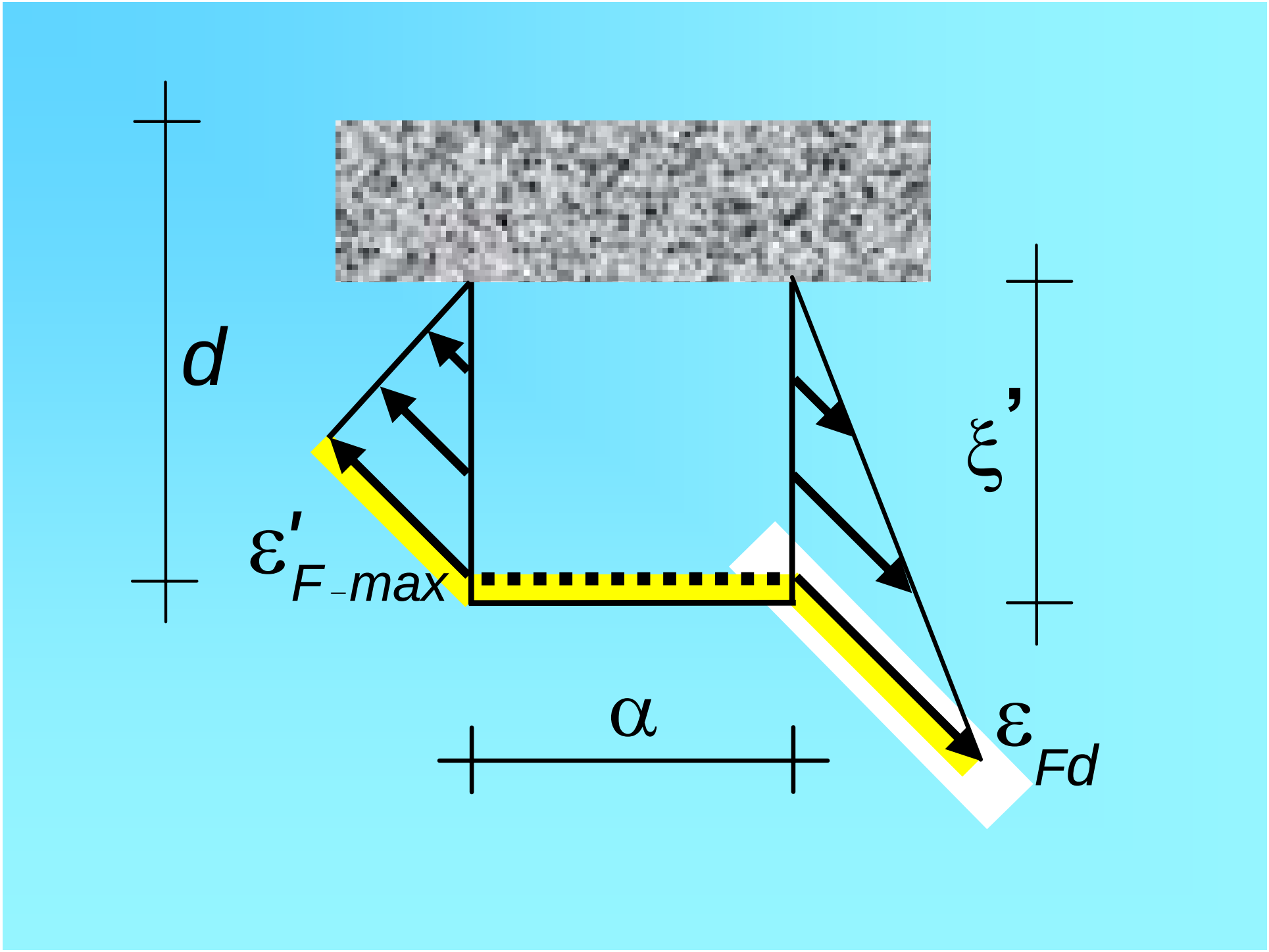
+ 45°

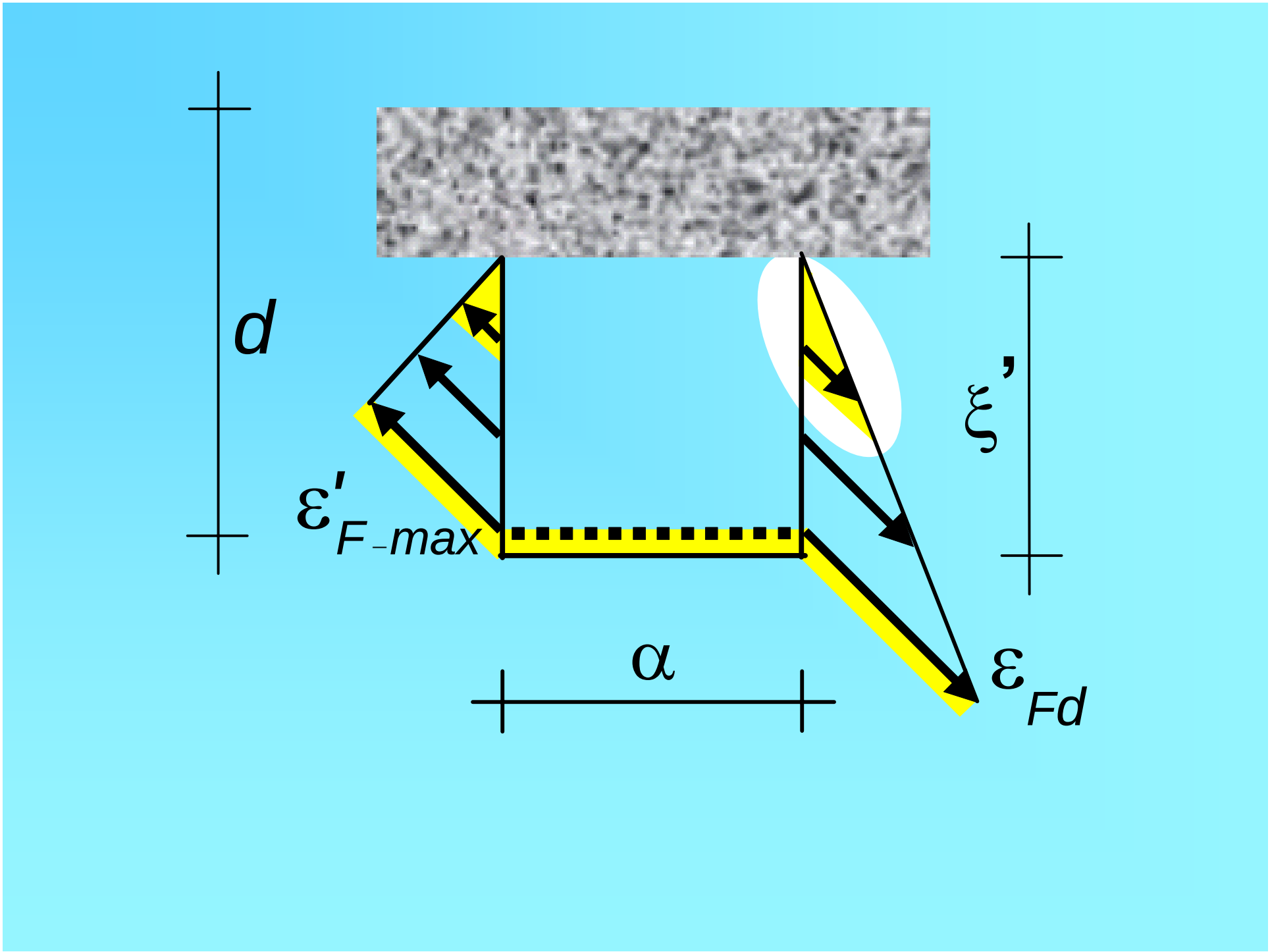
— 45°

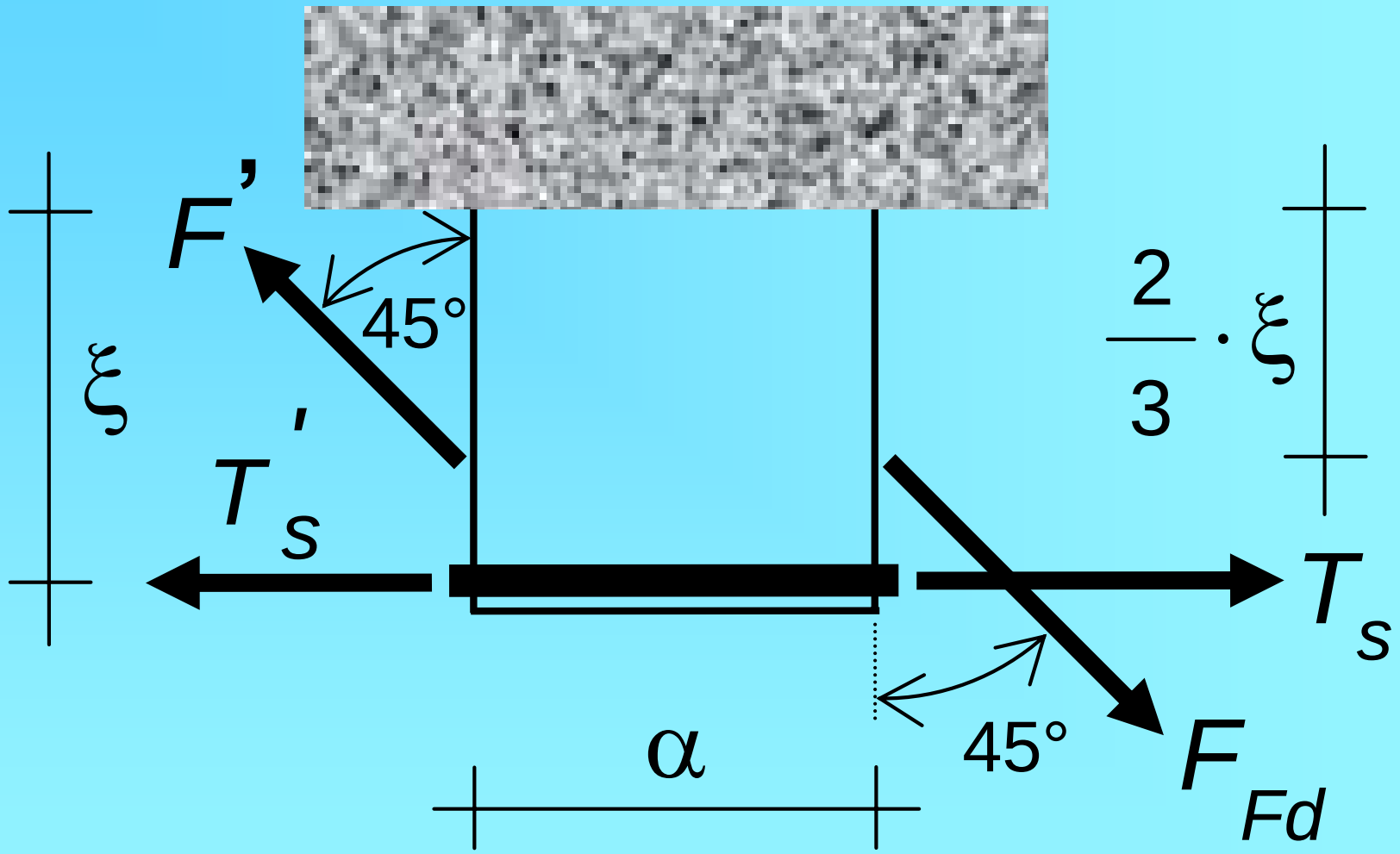

floor
l_F
P
45°
– 45°
μ'
end
anchorage
45°
crack
λ
– 45°


neutral
axis
compression
zone
upper border
of FRP sheet
l_{eff}
$0.707 \cdot l_{eff}$
μ'
ξ'
μ
l_d
l_d
crack



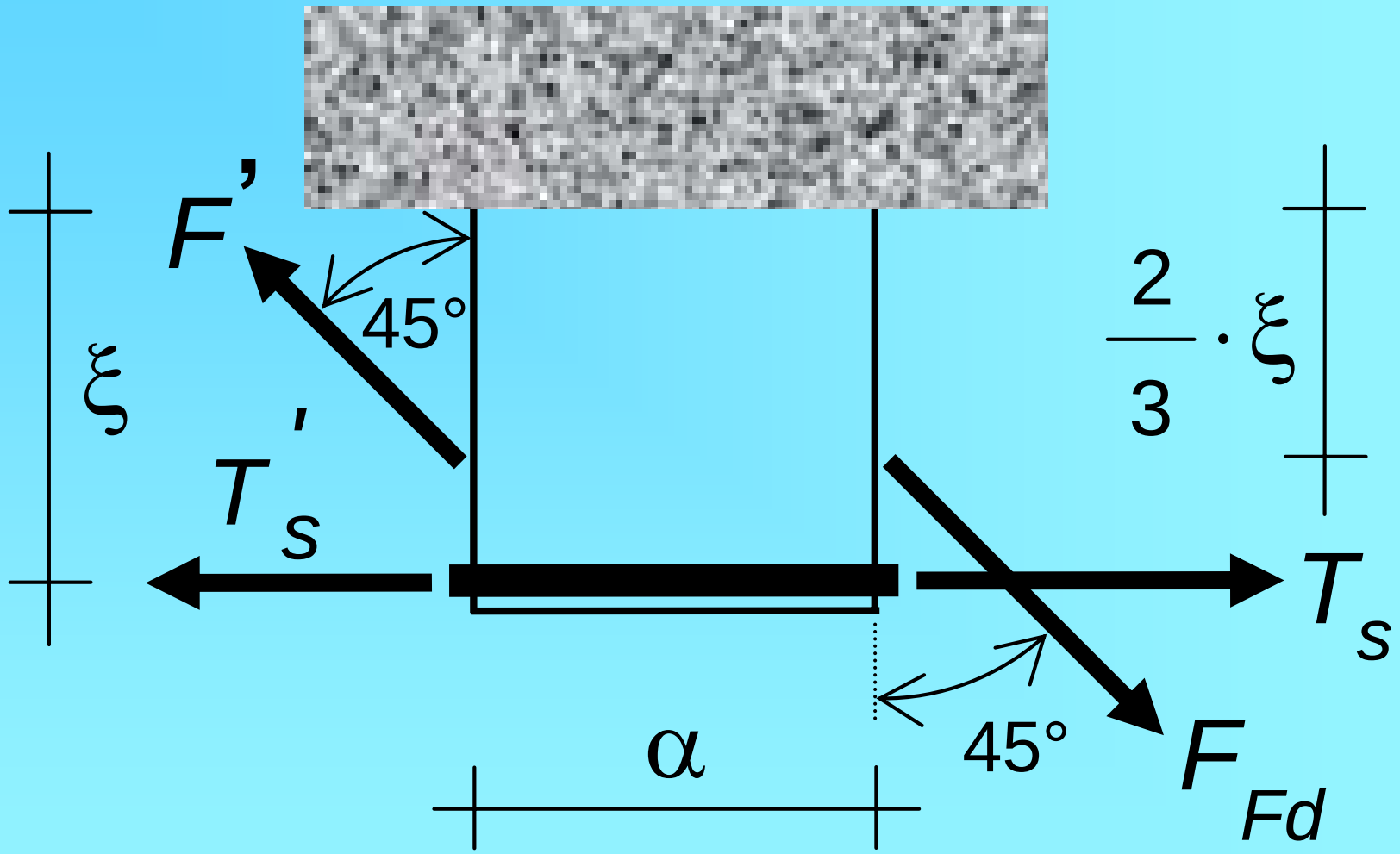

d
ε'F-max
ξ'
α
εFd

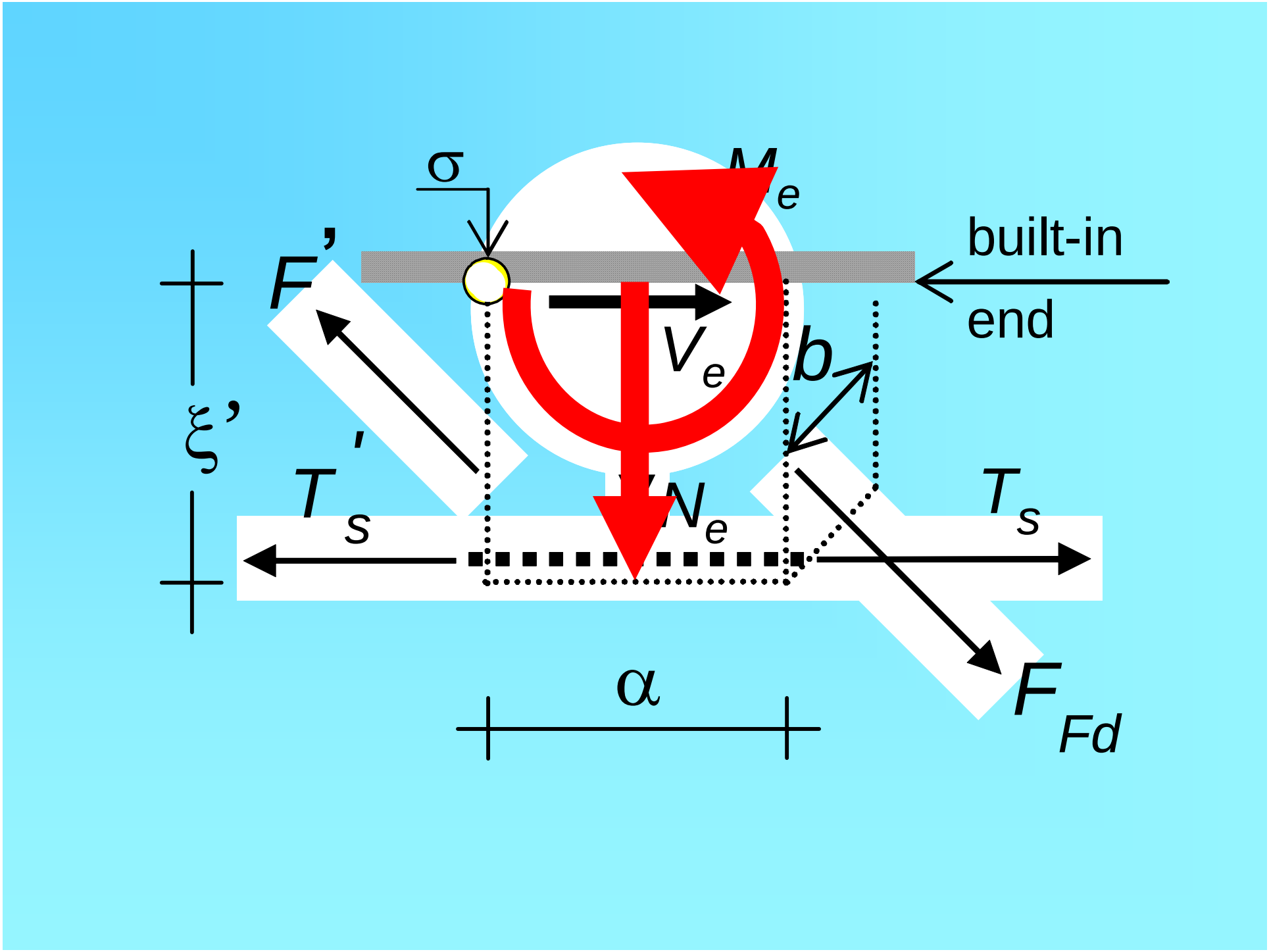

d
ε'F-max
ξ'
α
εFd


F'
45°
ξ
T's
2/3 · ξ
Ts
45°
α
FFd

$$\xi' = \frac{d}{1.5} + t$$

μ/ξ' > 0.80	0.80 > μ/ξ' > 0.65	0.65 > μ/ξ' > 0.50	0.50 > μ/ξ' > 0.35	0.35 > μ/ξ' > 0.20
$\eta = 1$	**$\eta = 0.87$**	**$\eta = 0.77$**	**$\eta = 0.65$**	**$\eta = 0.45$**

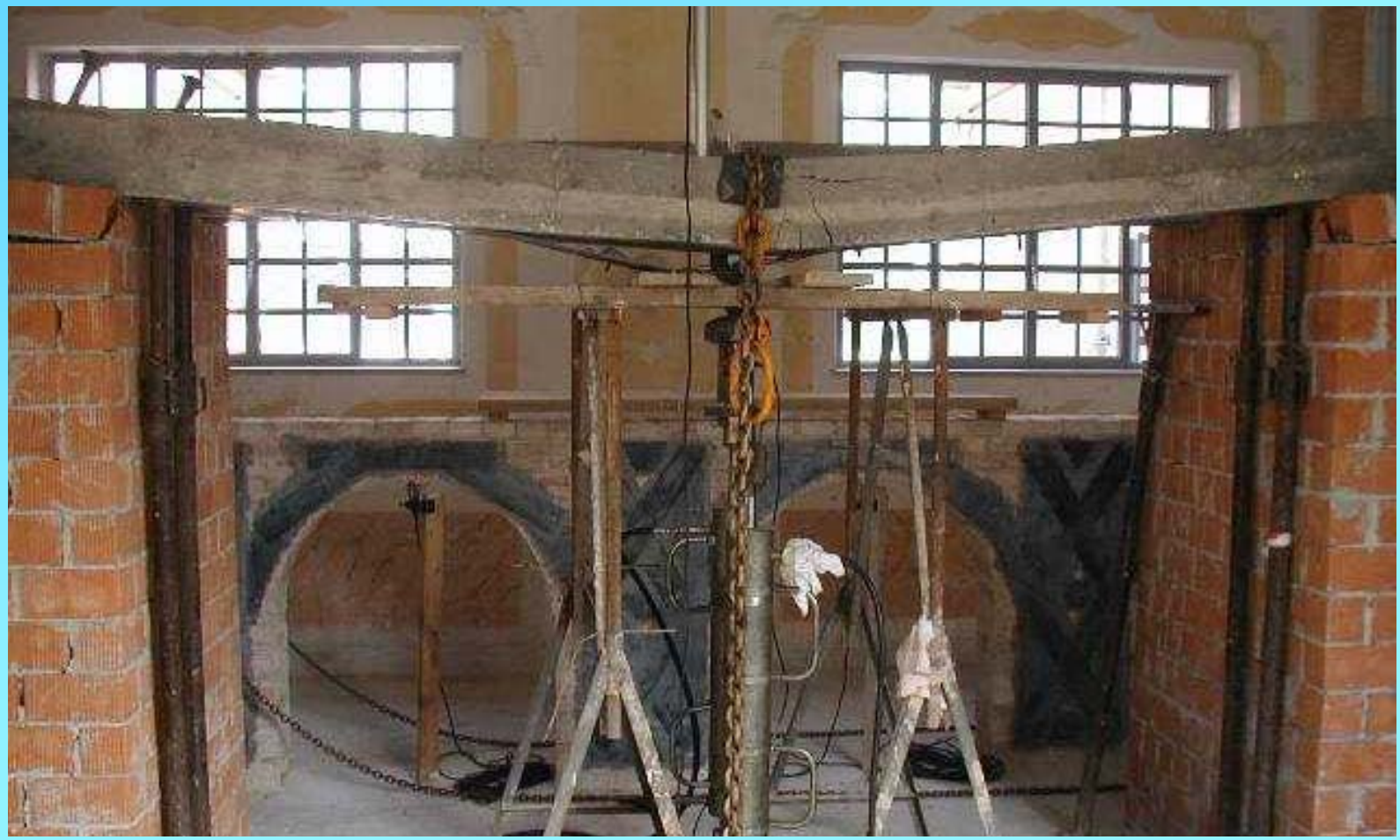

F'
45°
ξ
T's
2/3 · ξ
Ts
45°
α
FFd


σ
M_e
built-in
end
F'
V_e
b
ξ'
T's
N_e
T_s
α
F_{Fd}

$$V_{ud} = 0.148 \cdot b \cdot d \cdot f_{ctd} +$$

$$+ 0.314 \cdot \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot \eta \cdot N \cdot d - 0.280 \cdot \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot \eta \cdot N \cdot \frac{d^2}{\beta \cdot L}$$

$$P_{ud} = \frac{0.148 \cdot b \cdot d \cdot f_{ctd} + 0.314 \cdot \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot \eta \cdot N \cdot d - 0.280 \cdot \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot \eta \cdot N \cdot \frac{d^2}{\beta \cdot L}}{1 - \beta}$$



H mm	d mm	b mm	S mm	f_{cd} N/mm^2	f_{ctd} N/mm^2	E_F N/mm^2	t_F mm	N
450	410	150	200	13.2	1.14	244000	0.177	3 + 3
700	650	200	240	11.0	1.01	390000	0.222	2 + 2

$$V_{ud} = 10376.3 + 36006.6 = 46382.9 \text{ N}$$

$$P_{ud} = 92765.8 \text{ N}$$

H mm	d mm	b mm	S mm	f_{cd} N/mm^2	f_{ctd} N/mm^2	E_F N/mm^2	t_F mm	N
450	410	150	200	13.2	1.14	244000	0.177	3 + 3
700	650	200	240	11.0	1.01	390000	0.222	2 + 2

$$V_{ud} = 19432.4 + 74527.4 = 93959.8 \text{ N}$$

$$P_{ud} = 187919.7 \text{ N}$$

$$V_{ud} = (1-\beta)\cdot P_{ud}$$

$$M_{max} = \beta\cdot L\cdot V_{ud} = \beta\cdot L\cdot(1-\beta)\cdot P_{ud}$$

$$\alpha = \xi \qquad \alpha = \xi' - t$$

$$\xi = 0.67\cdot d \qquad \frac{d}{\xi} = 1.5 \qquad \frac{d}{\alpha} = 1.5$$

$$l_{eff} = 0.47 \cdot \sqrt[2]{\frac{E_F \cdot t_{F\text{-}tot}}{f_{ctd}}} \quad [\text{mm}]$$

$$\varepsilon_{Fd} = 0.35 \cdot \frac{\sqrt[4]{f_{cd} \cdot f_{ctd}}}{\sqrt[2]{E_F \cdot t_{F\text{-}tot}}}$$

$$F = \frac{\varepsilon_F^{max} \cdot E_F \cdot t_F}{2} \cdot \xi' \cdot N \quad \Rightarrow \quad F = \frac{\varepsilon_F^{max} \cdot E_F \cdot t_F}{2} \cdot (\xi + t) \cdot N$$

$$F = \frac{\varepsilon_F^{max} \cdot E_F \cdot t_F}{2} \cdot \xi' \cdot N \cdot \eta = \frac{\varepsilon_F^{max} \cdot E_F \cdot t_F}{2} \cdot (\xi + t) \cdot N \cdot \eta$$

$$F = \frac{\varepsilon_F^{max} \cdot E_F \cdot t_F}{2} \cdot \left(\xi + t - 0.707 \cdot l_d\right) \cdot N \cdot \eta$$

$$F = \frac{\varepsilon_F^{max} \cdot E_F \cdot t_F}{2} \cdot \xi \cdot N \cdot \eta = 0.333 \cdot E_F \cdot t_F \cdot d \cdot N \cdot \eta \cdot \varepsilon_F^{max}$$

$$F_{Fd} = \frac{\varepsilon_{Fd} \cdot E_F \cdot t_F}{2} \cdot \xi \cdot \eta \cdot N = 0.333 \cdot d \cdot \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot d \cdot \eta \cdot N$$

$$0.89 \cdot d \cdot \Delta T_s = V \cdot \alpha \quad \rightarrow \quad \Delta T_s = \frac{V \cdot \alpha}{0.89 \cdot d}$$

$$N_c = V_c = \frac{\sqrt[2]{2}}{2} \cdot \left(F_{Fd} - F' \right)$$

$$M_c = \frac{\sqrt[2]{2}}{3} \cdot \left(F_{Fd} - F' \right) \cdot \xi - \frac{\sqrt[2]{2}}{4} \cdot \left(F_{Fd} + F' \right) \cdot \alpha$$

$$M_{uf} = \frac{f_{ct} \cdot b \cdot \alpha^2}{6}$$

$$\sigma = \frac{\xi \cdot \Delta T_s}{W} + \frac{\sqrt[2]{2}}{3 \cdot W} \cdot \left(F_{Fd} - F' \right) \cdot \xi + \frac{\sqrt[2]{2}}{2 \cdot b \cdot \alpha} \cdot \left(F_{Fd} - F' \right) - \frac{\sqrt[2]{2}}{4} \cdot \left(F_{Fd} + F' \right) \cdot \frac{\alpha}{W}$$

$$\sigma = \frac{V \cdot \alpha \cdot \xi}{0.89 \cdot d \cdot W} + \frac{\sqrt[2]{2}}{3 \cdot W} \cdot \left(F_{Fd} - F' \right) \cdot \xi + \frac{\sqrt[2]{2}}{2 \cdot b \cdot \alpha} \cdot \left(F_{Fd} - F \right) - \frac{\sqrt[2]{2}}{4} \cdot \left(F_{Fd} + F' \right) \cdot \frac{\alpha}{W}$$

$$\sigma = \frac{0.44 \cdot V \cdot d^2}{0.89 \cdot d \cdot W} + \frac{\sqrt[2]{2} \cdot 0.67}{3 \cdot W} \cdot \left(F_{Fd} - F' \right) \cdot d + \frac{\sqrt[2]{2} \cdot 1.5}{2 \cdot b \cdot d} \cdot \left(F_{Fd} - F \right) - \frac{\sqrt[2]{2} \cdot 0.67}{4} \cdot \left(F_{Fd} + F' \right) \cdot \frac{d}{W}$$

$$\sigma = \frac{0.499 \cdot V \cdot d}{W} + \frac{0.314}{W} \cdot \left(F_{Fd} - F' \right) \cdot d + \frac{1.061}{b \cdot d} \cdot \left(F_{Fd} - F \right) - 0.236 \cdot \left(F_{Fd} + F' \right) \cdot \frac{d}{W}$$

$$\varepsilon'_{\text{F-max}} = \varepsilon_{\text{Fd}} \cdot \frac{M'}{M_{max}}$$

$$\varepsilon'_{\text{F-max}} = \varepsilon_{\text{Fd}} \cdot \frac{M_{max} - \alpha \cdot V_{ud}}{M_{max}} = \varepsilon_{\text{Fd}} \cdot \left(1 - \frac{\alpha \cdot V_{ud}}{M_{max}}\right) = \varepsilon_{\text{Fd}} \cdot \left(1 - \frac{0.667 \cdot d \cdot V_{ud}}{M_{max}}\right)$$

$$\varepsilon'_{\text{F-max}} = \varepsilon_{\text{Fd}} \cdot \left(1 - \frac{0.667 \cdot d \cdot V_{ud}}{\beta \cdot L \cdot V_{ud}} \right) = \varepsilon_{\text{Fd}} \cdot \left(1 - \frac{0.667 \cdot d}{\beta \cdot L} \right)$$

$$F' = \frac{\varepsilon'_{\text{F-max}} \cdot E_F \cdot t_F}{2} \cdot \xi \cdot \eta \cdot N = \varepsilon_{\text{Fd}} \cdot E_F \cdot t_F \cdot d \cdot \eta \cdot N \cdot \left(0.333 - \frac{0.222 \cdot d}{\beta \cdot L} \right)$$

$$f_{ctd} = \frac{0.499 \cdot d \cdot V_{ud}}{W} + \frac{0.314}{W} \cdot \left(F_{Fd} - F' \right) \cdot d + \frac{1.061}{b \cdot d} \cdot \left(F_{Fd} - F \right) - 0.236 \cdot \left(F_{Fd} + F' \right) \cdot \frac{d}{W}$$

$$V_{ud} = \frac{2 \cdot W}{d} \cdot \left[f_{ctd} - \frac{0.314}{W} \cdot \left(F_{Fd} - F' \right) \cdot d + 0.236 \cdot \left(F_{Fd} + F' \right) \cdot \frac{d}{W} - \frac{1.061}{b \cdot d} \cdot \left(F_{Fd} - F \right) \right]$$

$$V_{ud} = \frac{2 \cdot W \cdot f_{ctd}}{d} - 0.629 \cdot \left(F_{Fd} - F' \right) + 0.471 \cdot \left(F_{Fd} + F' \right) - \frac{2.121 \cdot W}{b \cdot d^2} \cdot \left(F_{Fd} - F \right)$$

$$V_{ud} = \frac{0.148 \cdot b \cdot d^2 \cdot f_{ctd}}{d} - 0.629 \cdot \left(F_{Fd} - F' \right) + 0.471 \cdot \left(F_{Fd} + F' \right) - \frac{0.157 \cdot b \cdot d^2}{b \cdot d^2} \cdot \left(F_{Fd} - F \right)$$

$$V_{ud} = 0.148 \cdot b \cdot d \cdot f_{ctd} - 0.629 \cdot \left(F_{Fd} - F' \right) + 0.474 \cdot \left(F_{Fd} + F' \right) - 0.157 \cdot \left(F_{Fd} - F \right)$$

$$F_{Fd} - F' = 0.33 \cdot d \cdot \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot d \cdot \eta \cdot N - \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot d \cdot \eta \cdot N \cdot \left(0.333 - \frac{0.222 \cdot d}{\beta \cdot L} \right)$$

$$F_{Fd} - F' = 0.222 \cdot \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot \eta \cdot N \cdot \frac{d^2}{\beta \cdot L}$$

$$F_{Fd} + F' = 0.333 \cdot d \cdot \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot d \cdot \eta \cdot N + \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot d \cdot \eta \cdot N \cdot \left(0.333 - \frac{0.222 \cdot d}{\beta \cdot L} \right)$$

$$F_{Fd} + F' = \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot \eta \cdot N \cdot \left(0.666 \cdot d - \frac{0.222 \cdot d^2}{\beta \cdot L} \right)$$

$$V_{ud} = 0.148 \cdot b \cdot d \cdot f_{ctd} - 0.140 \cdot \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot \eta \cdot N \cdot \frac{d^2}{\beta \cdot L} +$$

$$+ \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot \eta \cdot N \cdot \left(0.314 \cdot d - \frac{0.105 \cdot d^2}{\beta \cdot L} \right) - 0.035 \cdot \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot \eta \cdot N \cdot \frac{d^2}{\beta \cdot L}$$

$$_{ud} = 0.148 \cdot b \cdot d \cdot f_{ctd} + 0.314 \cdot \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot \eta \cdot N \cdot d - 0.280 \cdot \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot \eta \cdot N \cdot \frac{d}{\beta}.$$

$$P_{ud} = \frac{0.148 \cdot b \cdot d \cdot f_{ctd} + 0.314 \cdot \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot \eta \cdot N \cdot d - 0.280 \cdot \varepsilon_{Fd} \cdot E_F \cdot t_F \cdot \eta \cdot N \cdot \frac{d^2}{\beta \cdot L}}{1 - \beta}$$