The bearing strength perpendicular to the grain of locally loaded blocks and dowel-type fasteners

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Supported by the Dutch

Technology Foundation STW

Building European Science

Action E55:
Modelling of the Performance of Timber Structures

Presentation

October 4th 2006, 14:00

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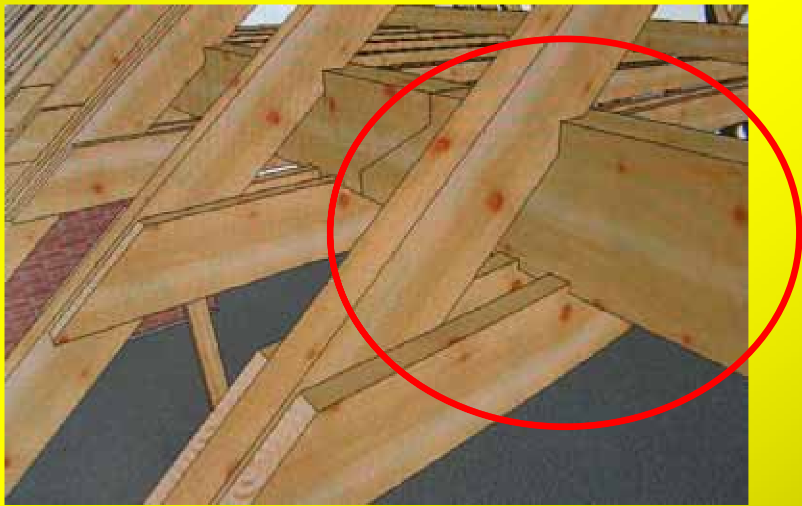
- **Working group 2 -** *"Vulnerability of Timber Components"*
- Failure due to stresses perpendicular to the grain
    - **Compression (e.g. supports)**



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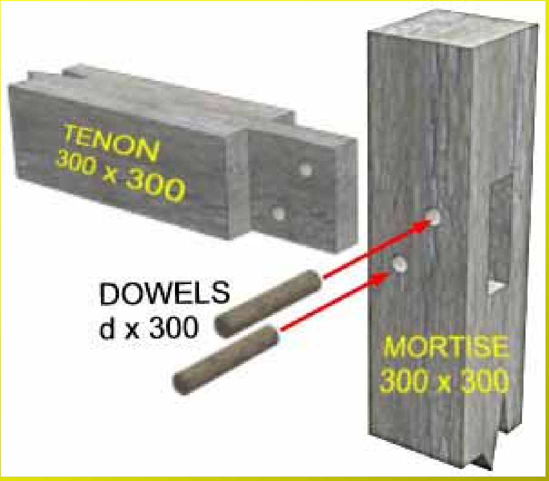
  - **Embedding (dowel-type joints)**



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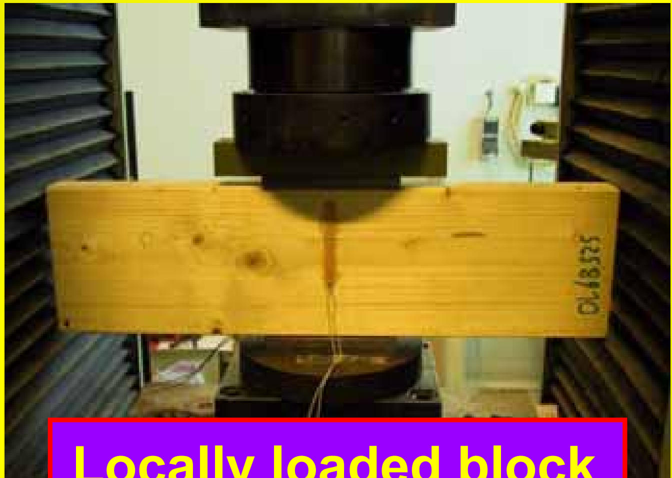
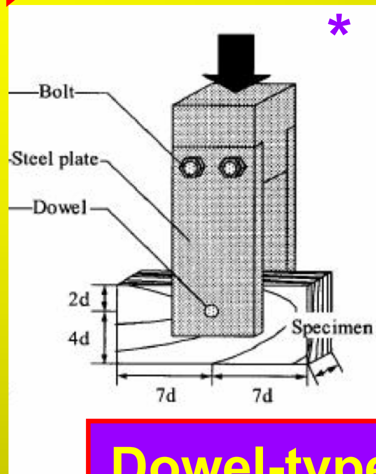
Bearing strength



Locally loaded block



Dowel-type joints

*: Left: Sawata and Yasumura (2002)

**: Right: Vreeswijk (2003)

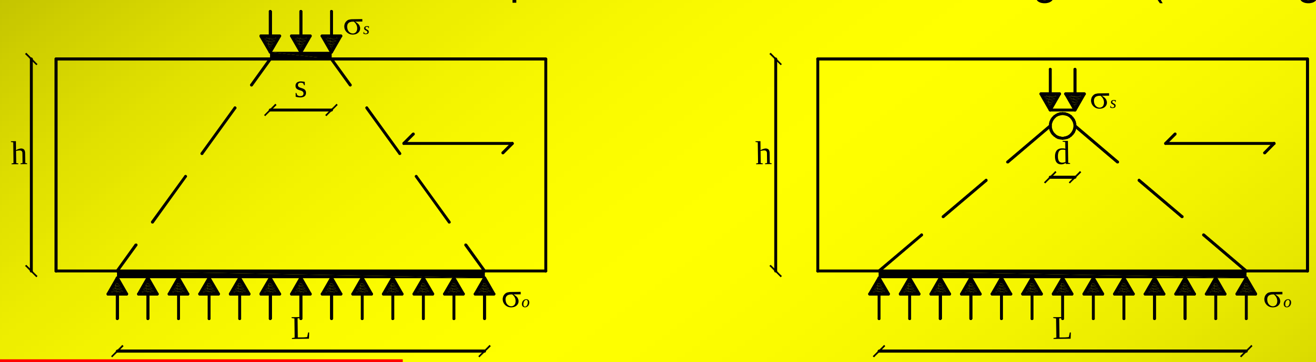
The bearing strength perpendicular to the grain of locally loaded blocks and dowel-type fasteners

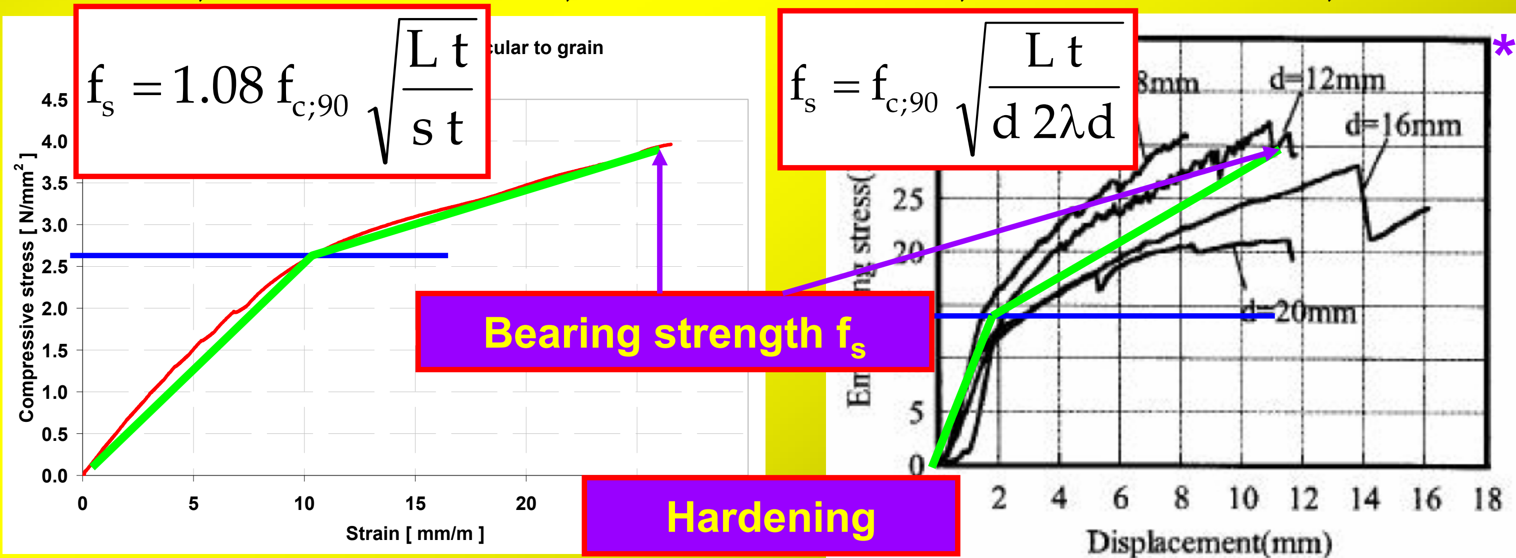
Contents

- General aspects / behaviour perpendicular to grain
- Derivation of the bearing strength perpendicular to grain
- Locally loaded blocks
- Dowel-type fasteners
- Discussion / remarks

General aspects / behaviour

- Similar behaviour compression test and embedding test (both ⊥ grain)

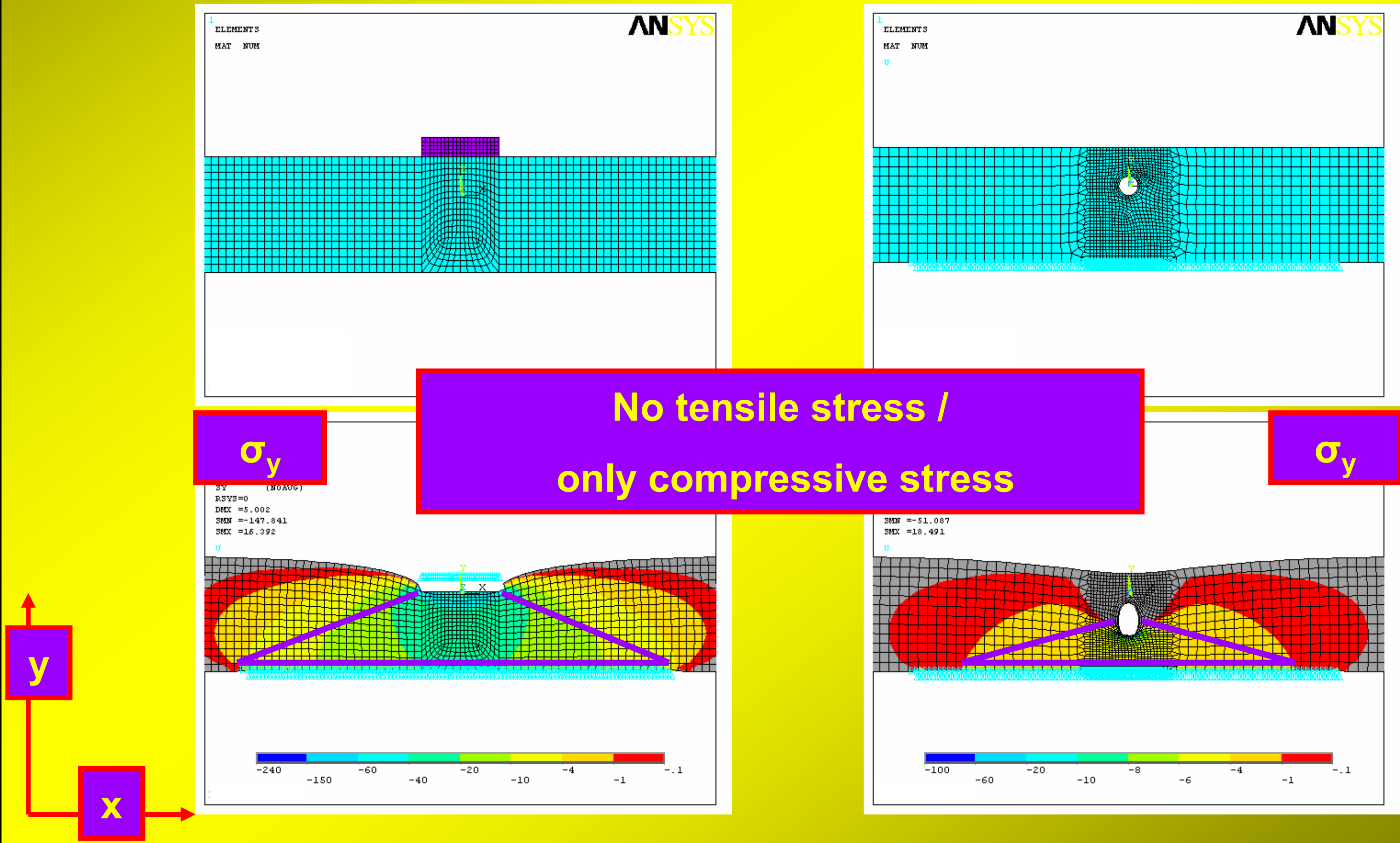




*: Sawata and Yasumura (2002)

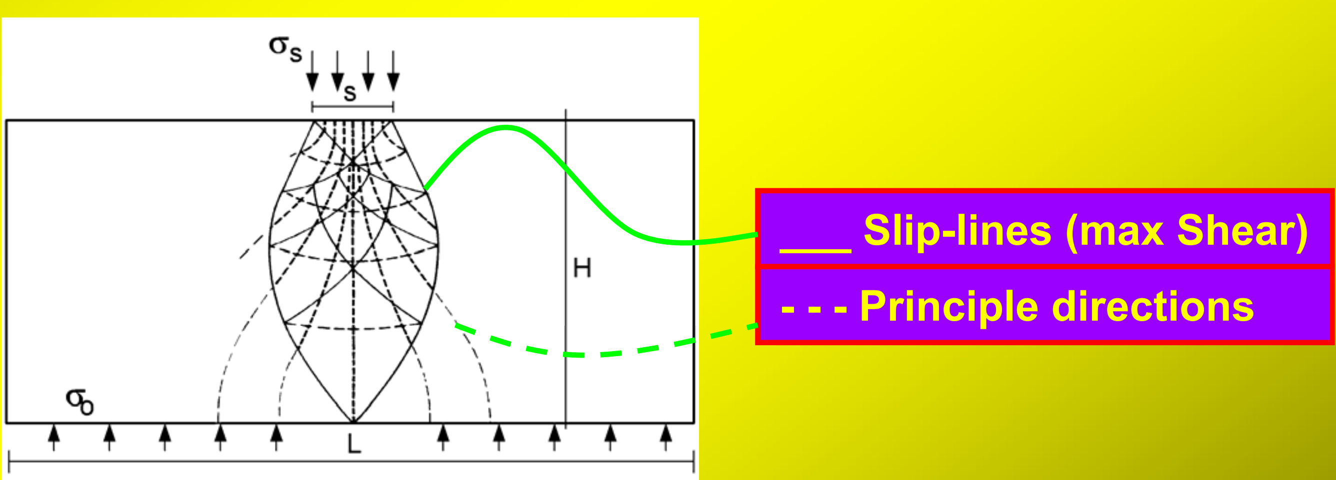
General aspects / behaviour

➢ Similar behaviour compression test and embedding test (both ⊥ grain)



Derivation of the bearing strength: general

- Theoretical / physical model (according to Van der Put (1988), (2000))
- Stress field according to slip-line field theory
  - Equilibrium
  - Boundary conditions
  - Failure / Strength criterion (Tresca)



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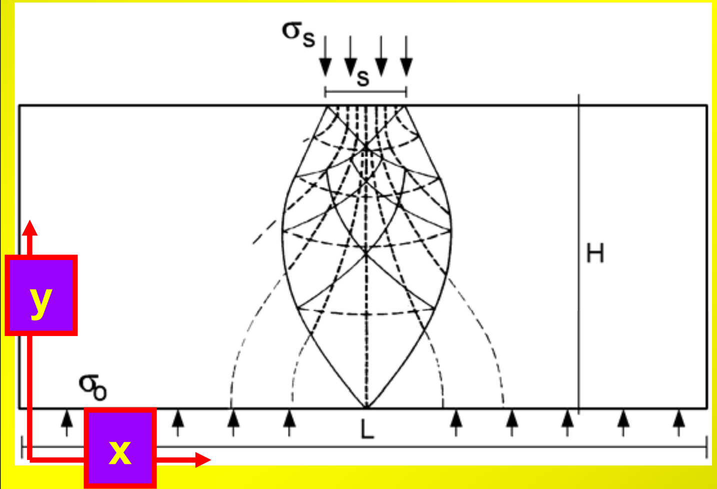

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau}{\partial y} = 0$$

$$\frac{\partial \sigma_y}{\partial y} + \frac{\partial \tau}{\partial x} = 0$$

Derivation of the bearing strength: general

- Theoretical / physical model (according to Van der Put (1988), (2000))
- Stress field according to slip-line field theory
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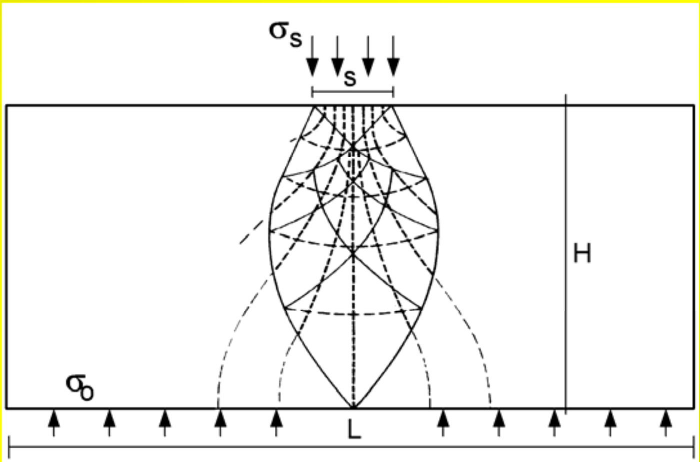
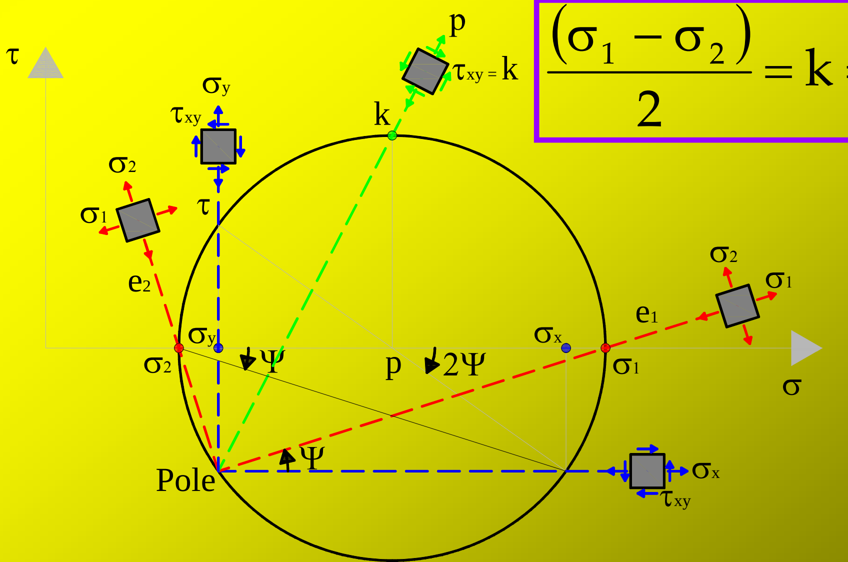
  - **Failure / Strength criterion (Tresca)**

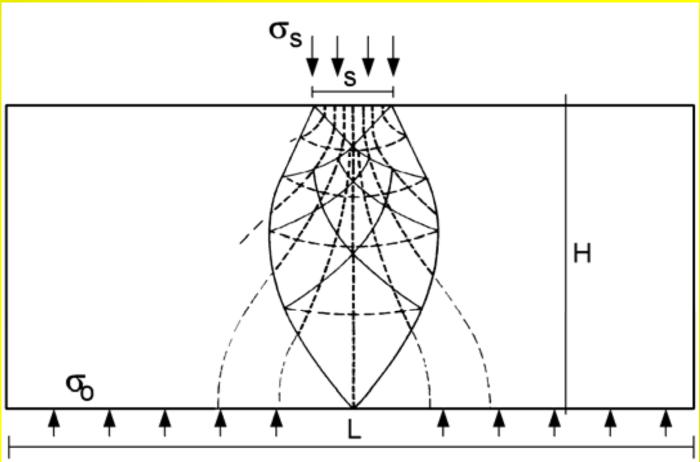
$$\frac{(\sigma_1 - \sigma_2)}{2} = k = f_v$$

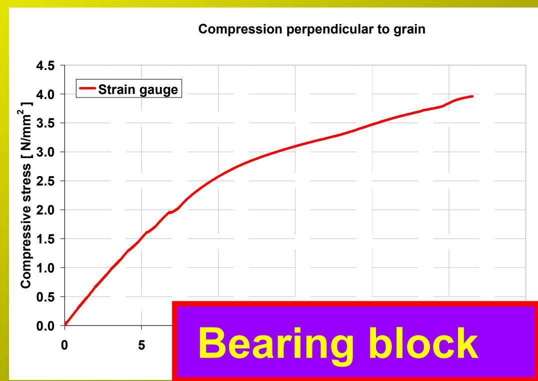




Derivation of the bearing strength: general

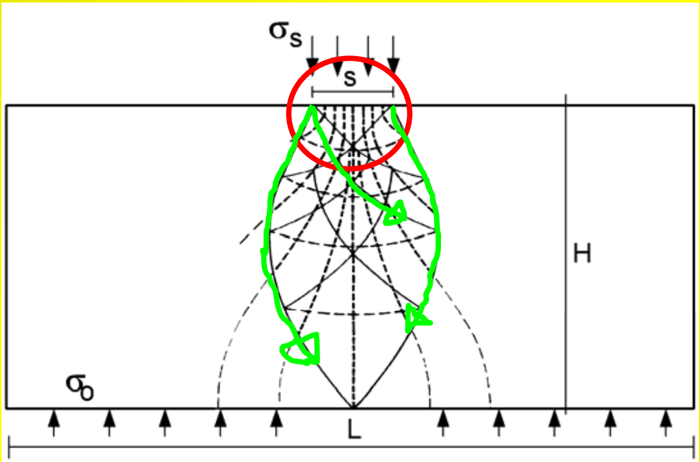
- Theoretical / physical model
- Stress field according to slip-line field theory
  - Equilibrium
  - Boundary conditions
  - Failure / Strength criterion (Tresca)
- Little plasticity needed (hardening behaviour) → stress redistribution

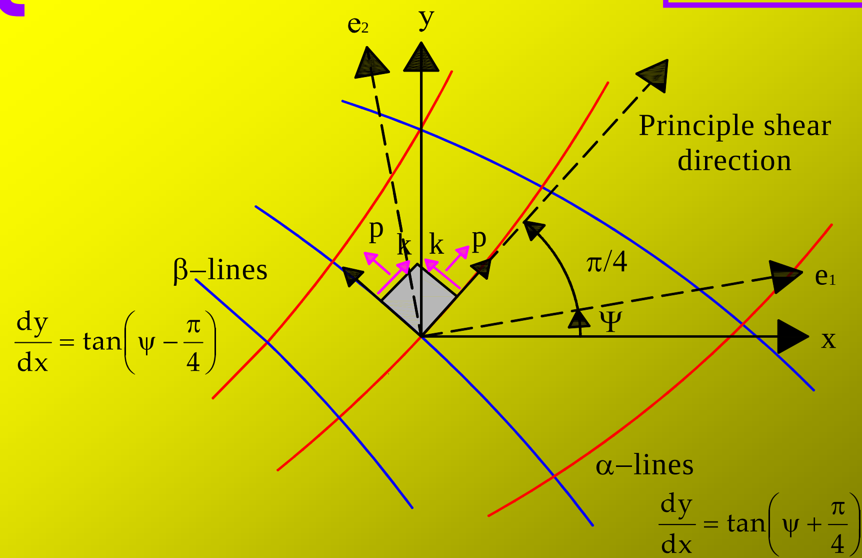




Derivation of the bearing strength: general

- Stress field according to slip-line field theory
  - 1) In "wedge region" due to symmetry: $\left\{ \begin{array}{ll} \frac{dy}{dx} = \tan\left(\frac{3\pi}{4}\right) = -1 & \alpha\text{-lines} \\ \frac{dy}{dx} = \tan\left(\frac{\pi}{4}\right) = 1 & \beta\text{-lines} \end{array} \right.$
  - 2) Along α- and β-lines: $\left\{ \begin{array}{ll} p - 2k\psi & \text{Constant along } \alpha\text{-lines} \\ p + 2k\psi & \text{Constant along } \beta\text{-lines} \end{array} \right.$ **Hencky-equations**



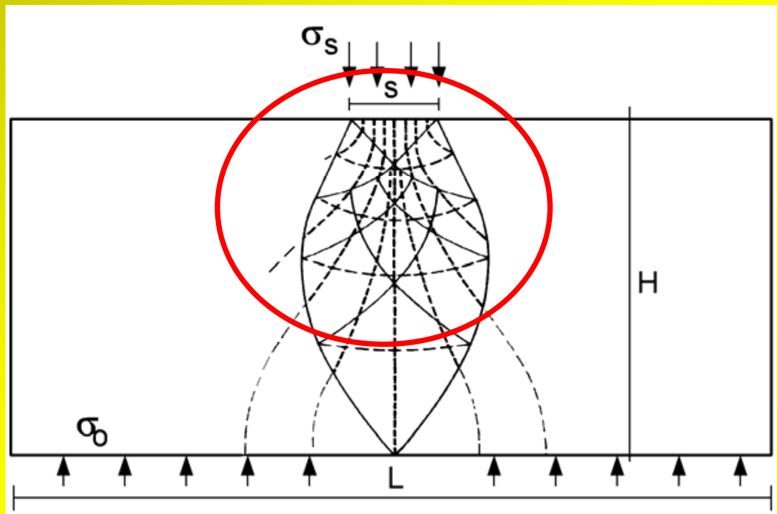


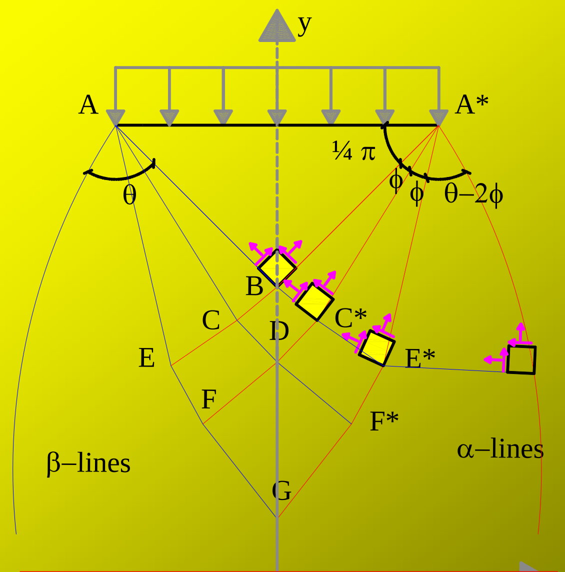
Derivation of the bearing strength: general

- Stress field according to slip-line field theory

- Hencky-equations

$$\begin{cases} p - 2k\psi & \text{Constant along } \alpha\text{-lines} \\ p + 2k\psi & \text{Constant along } \beta\text{-lines} \end{cases}$$



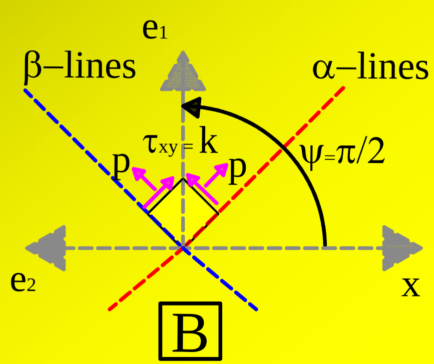


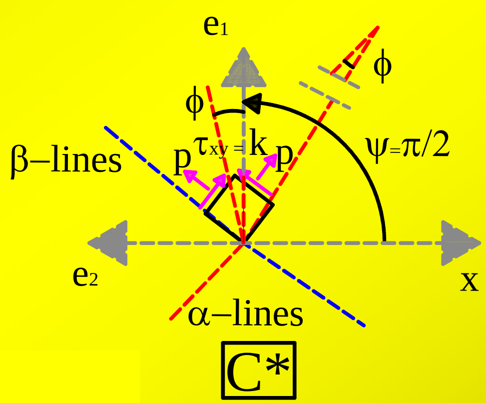
Sample (approximation)

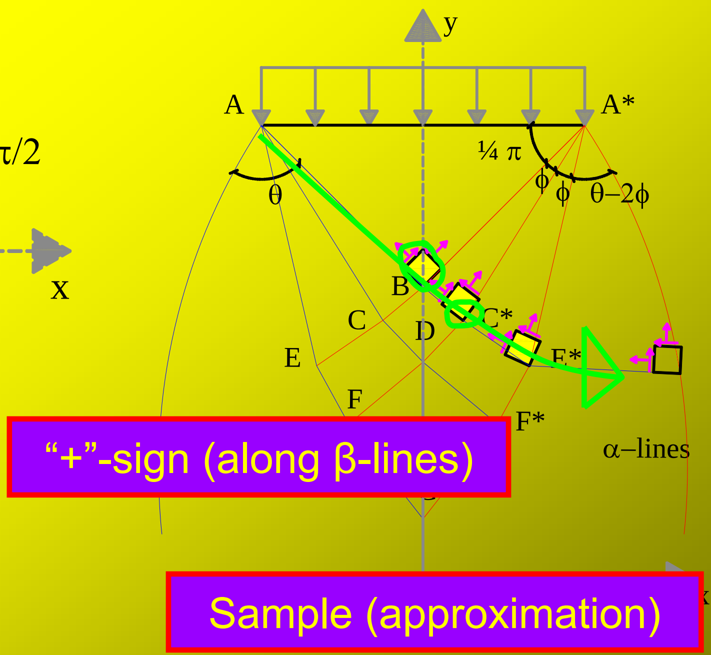
Derivation of the bearing strength: general

- Stress field according to slip-line field theory

- Hencky-equations $\begin{cases} p - 2k\psi & \text{Constant along } \alpha\text{-lines} \\ p + 2k\psi & \text{Constant along } \beta\text{-lines} \end{cases}$







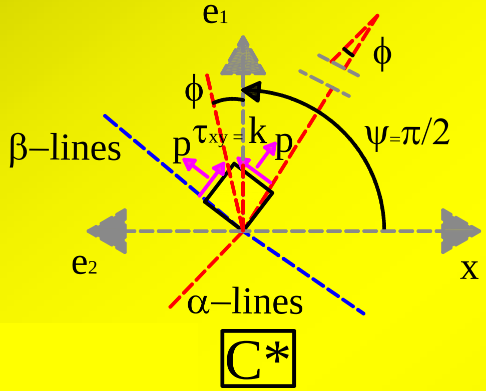
$$p_B + 2k\frac{\pi}{2} = p_{C^*} + 2k\left(\frac{\pi}{2} + \phi\right)$$

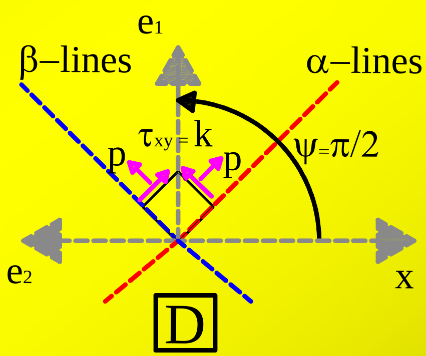
$$\Rightarrow \quad p_{C^*} = p_B - 2k\phi$$

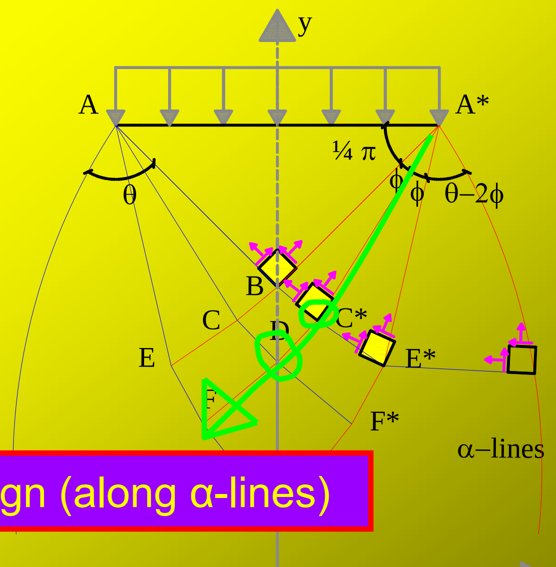
Derivation of the bearing strength: general

- Stress field according to slip-line field theory

- Hencky-equations
  - $p - 2k\psi$ Constant along α-lines
  - $p + 2k\psi$ Constant along β-lines







“-”-sign (along α-lines)

Sample (approximation)

$$p_{C^*} - 2k\left(\frac{\pi}{2} + \phi\right) = p_D - 2k\frac{\pi}{2}$$

$$\Rightarrow \quad p_D = p_{C^*} - 2k\phi$$

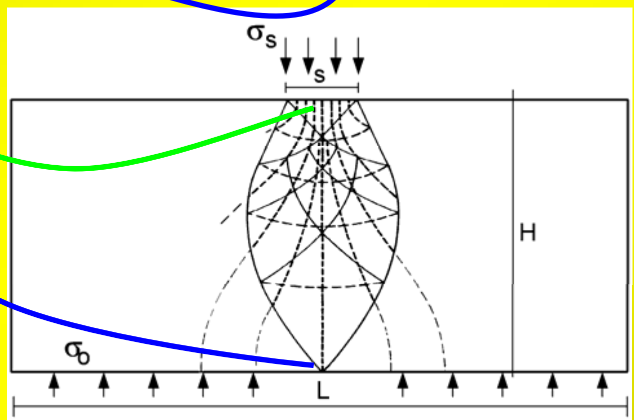
Derivation of the bearing strength: general

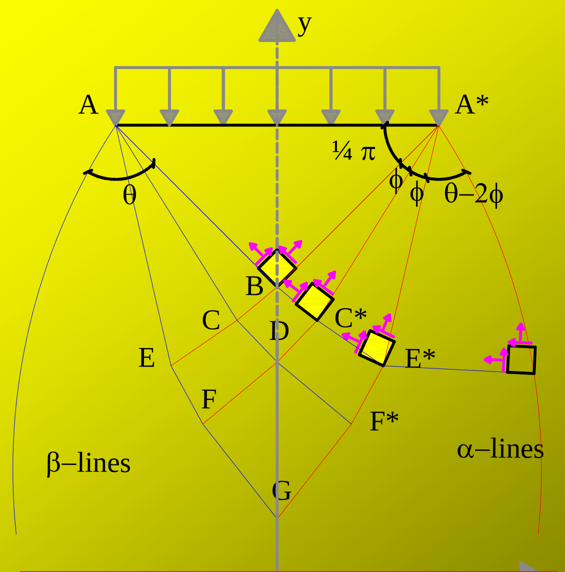
- Stress field according to slip-line field theory
  - Generally:

$$p_o = p_s - 4\,k\,n\phi = p_s - 4\,k\,\theta$$
$$\Rightarrow p_s = p_o + 4\,k\,\theta$$

p_s: hydrostatic pressure in B (=bearing strength)

p_0: hydrostatic pressure in lower point





Sample (approximation)

Derivation of the bearing strength: general

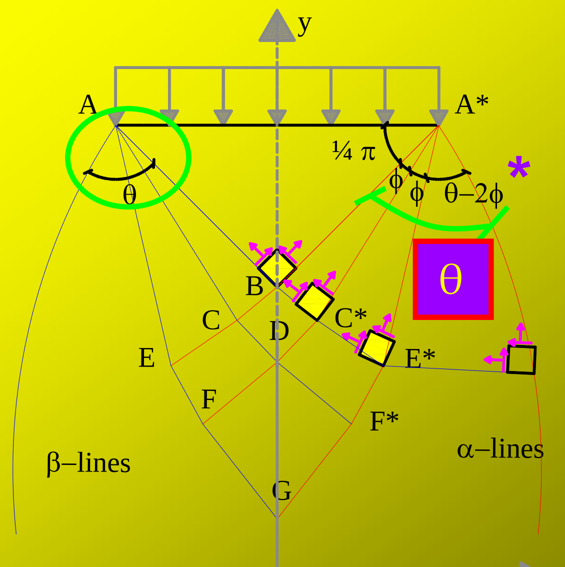
- Stress field according to slip-line field theory
  - Generally:

$$p_o = p_s - 4\,k\,n\phi = p_s - 4\,k\,\theta$$

$$\Rightarrow \quad p_s = p_o + 4\,k\,\theta$$

  - Angle θ can be approximated*:

$$\theta \approx 0.62\,\ln(2h/s)$$



Sample (approximation)

*: Schwarz (1969)

Derivation of the bearing strength: general

- Stress field according to slip-line field theory
  - Generally:

$$p_o = p_s - 4\,k\,n\phi = p_s - 4\,k\,\theta$$
$$\Rightarrow \quad p_s = p_o + 4\,k\,\theta$$

  - Angle θ can be approximated:

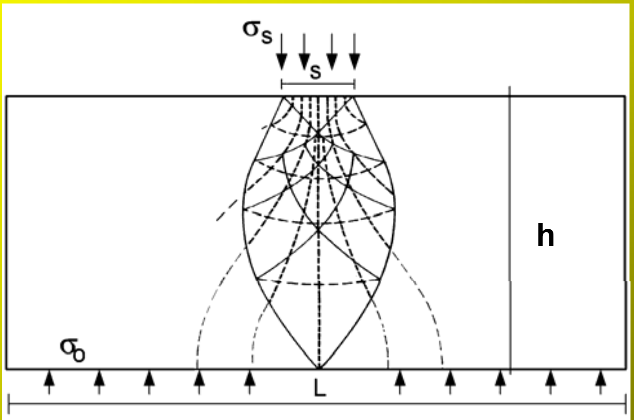
$$\theta \approx 0.62\,\ln(2h/s)$$

  - Equilibrium, and rearranging:

$$\sigma_s\,s = \sigma_o\,L \quad \Rightarrow \quad \sigma_o = \frac{\sigma_s\,s}{L}$$

$$p_s - p_o = 4\,k\,\theta$$

$$\sigma_s - \frac{\sigma_s\,s}{L} = \sigma_s\left(1 - \frac{s}{L}\right) = 2.48\,k\,\ln(2h/s)$$



Derivation of the bearing strength: general

- Stress field according to slip-line field theory
  - Elastic spreading (a first flow / plasticity) at 45˚ (if h>s):

$$h \approx \frac{(L-s)}{2}$$, and thus: $$\frac{L}{s} > 3$$

Lower bound approach

  - Substitution, and rearranging → **Solution**:

$$\sigma_s\left(1-\frac{s}{L}\right) = 2.48\,k\,\ln\left(\frac{L}{s}-1\right) \quad \Rightarrow \quad \sigma_s = \frac{2.48\,k\,\ln\left(\frac{L}{s}-1\right)}{\left(1-\frac{s}{L}\right)}$$

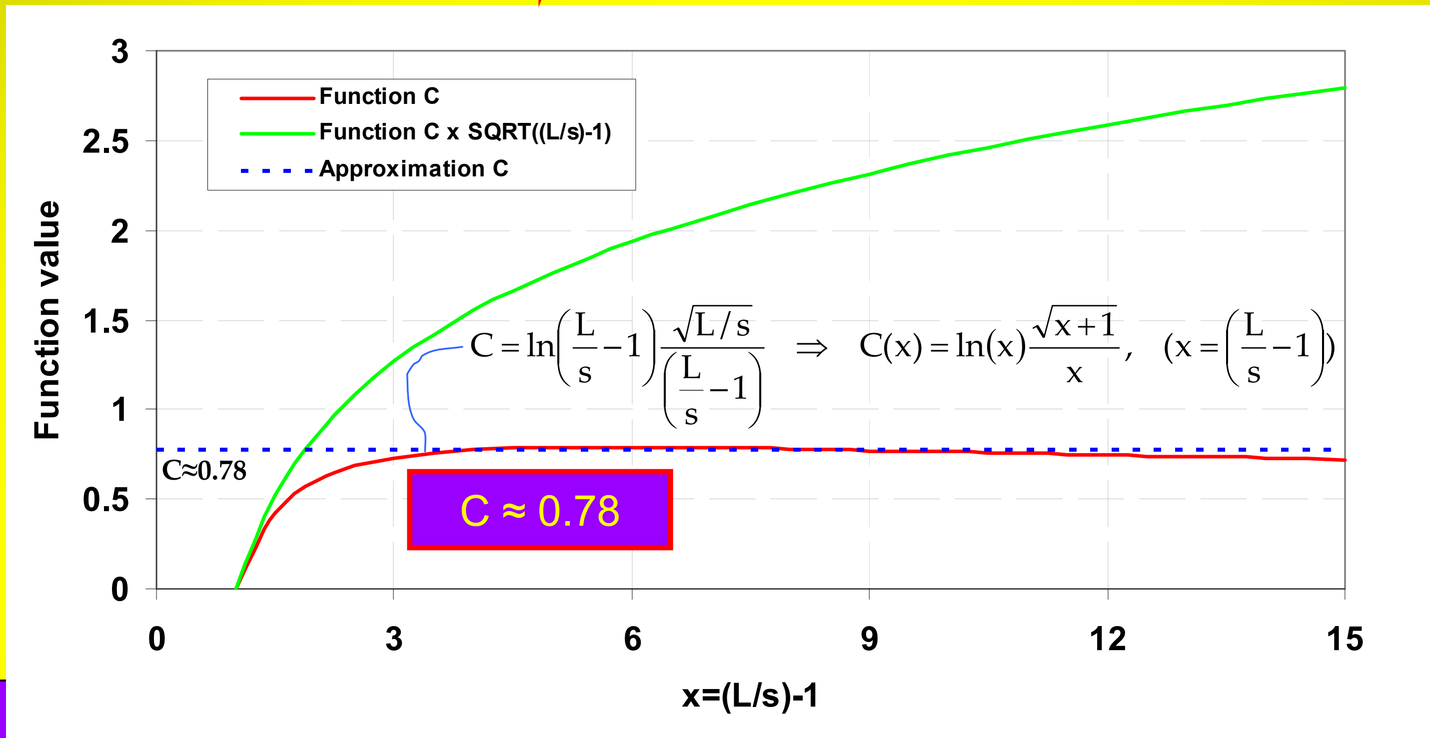
  - Define a “constant” C (proportional with √(L/s)):

$$C = \ln\left(\frac{L}{s}-1\right)\frac{\sqrt{L/s}}{L/s-1} \quad \Rightarrow \quad \sigma_s = 2.48\,k\,C\,\sqrt{L/s}$$

Derivation of the bearing strength: general

- Stress field according to slip-line field theory
  - Define a “constant” C (proportional with √(L/s)):

$$C = \ln\left(\frac{L}{s}-1\right)\frac{\sqrt{L/s}}{L/s-1} \quad \Rightarrow \quad \sigma_s = 2.48\,k\,\ln\left(\frac{L}{s}-1\right)\frac{L/s}{(L/s)-1} = 2.48\,k\,C\,\sqrt{L/s}$$



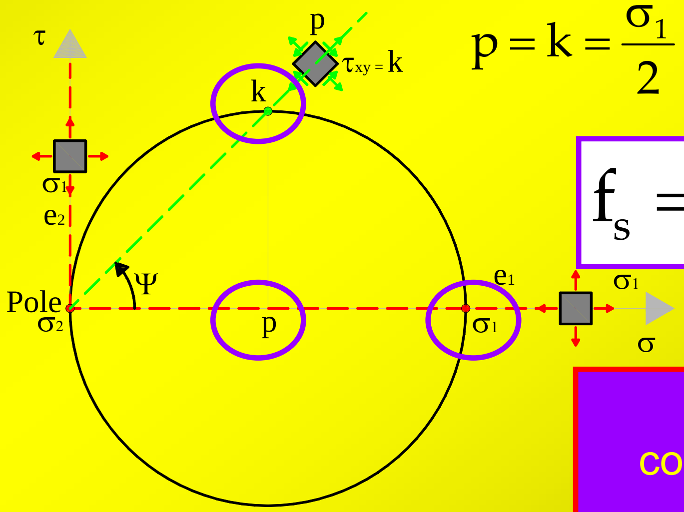
$$C = \ln\left(\frac{L}{s}-1\right)\frac{\sqrt{L/s}}{\left(\frac{L}{s}-1\right)} \Rightarrow C(x) = \ln(x)\frac{\sqrt{x+1}}{x}, \quad \left(x = \left(\frac{L}{s}-1\right)\right)$$

Derivation of the bearing strength: general

- Stress field according to slip-line field theory
  - Define a “constant” C (proportional with √(L/s)):

$$C = \ln\left(\frac{L}{s} - 1\right)\frac{\sqrt{L/s}}{L/s - 1} \quad \Rightarrow \quad \sigma_s = 2.48\, k\, C\, \sqrt{L/s}$$

  - Recall Mohr’s circle (Pole being at σ_2=0 ($\psi = \pi/4$)):



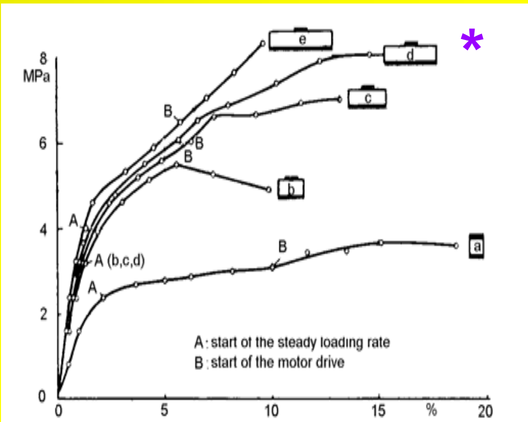
$$p = k = \frac{\sigma_1}{2} = \frac{f_{c;90}}{2}$$

$$f_s = 0.97\, f_{c;90}\sqrt{L/s} \approx \mu\, f_{c;90}\sqrt{L/s}$$

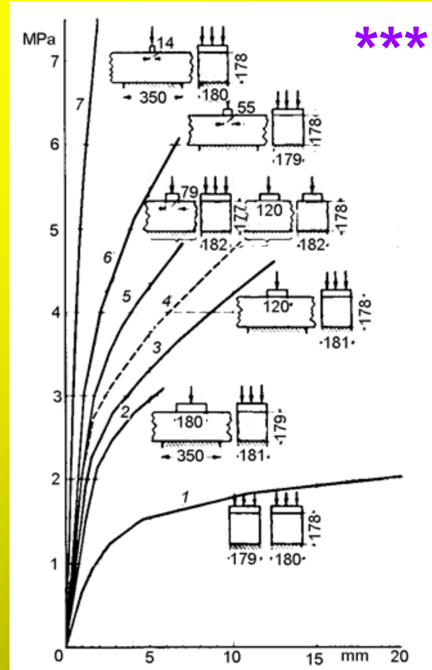
Material property: Equivalent compressive strength $f_{c;90}$ (cubic test) derive from tests

Bearing strength of locally loaded blocks

- Angle of stress distribution ≈ 34° (→ 1:1.5), or ≈ 45° (→ 1:1)
  (from bearing tests, and FEM)
- Evaluation of tests of different sources (see CIB-W18 / 40-6-1)



Bearing tests by Suensson



Bearing tests by Graf

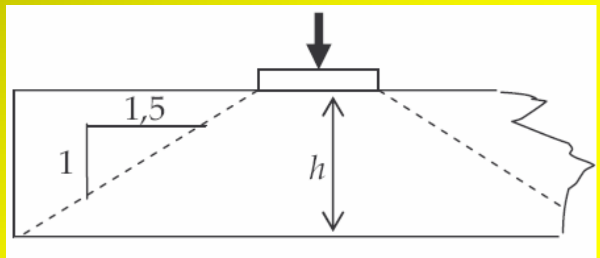
*: Suensson (From: Kollmann (1955))

**: Augustin and Schikhofer (2006)

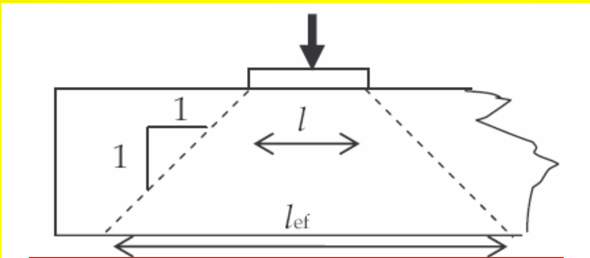
***: Graf (From: Kollmann (1955))

Bearing strength of locally loaded blocks

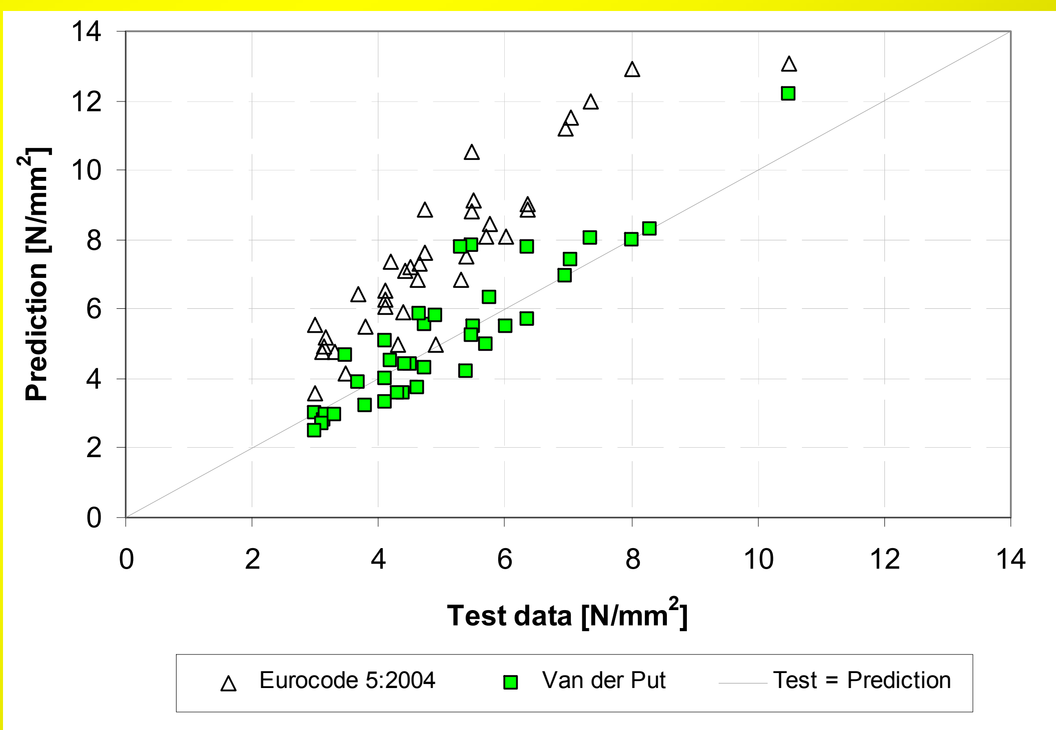
- Angle of stress distribution ≈ 34˚ (→ 1:1.5), or ≈ 45˚ (→ 1:1) (from bearing tests, and FEM)
- Comparison with prediction ability Eurocode 5: 2004



Plastic (large strains)

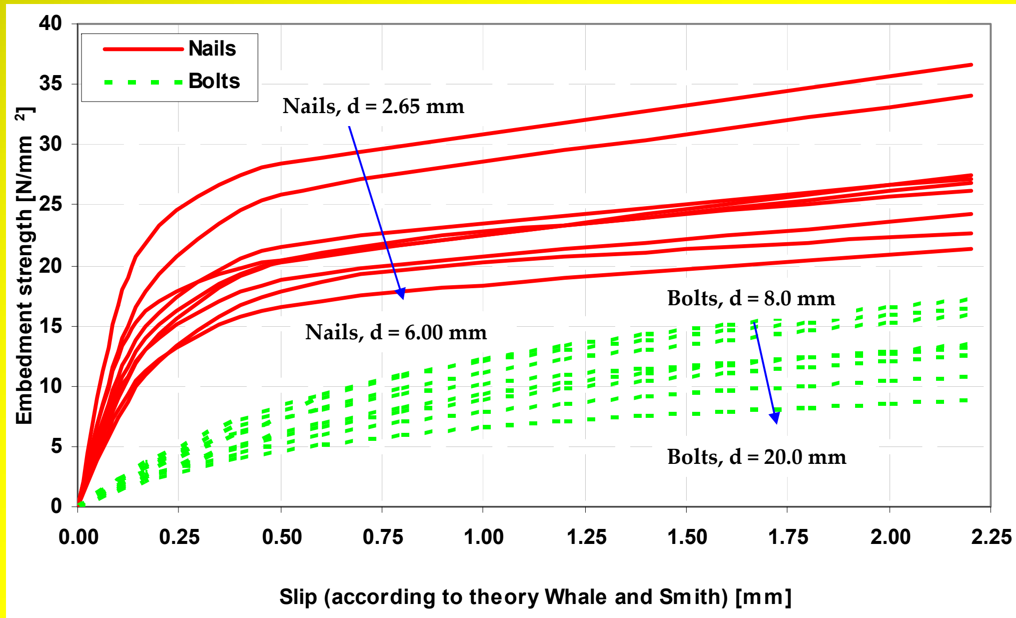


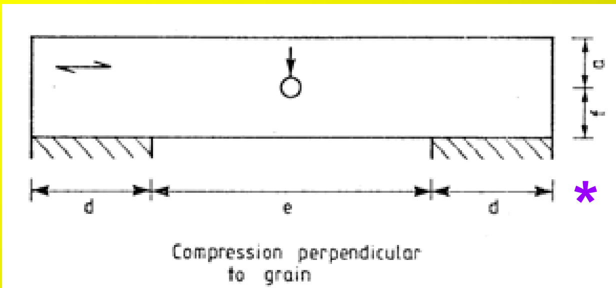
Elastic (small strains)



Bearing strength of dowel-type fasteners

- Angle of stress distribution ≈ 34˚ (→ 1:1.5) (from bearing tests, and FEM)
- Evaluation of embedding tests by Whale and Smith (CEC) (1986)
  - Nails and Bolts, Eur. Whitewood, -Redwood, Canadian Spruce
- Load-slip derived from stiffness parameters (sufficient plasticity)





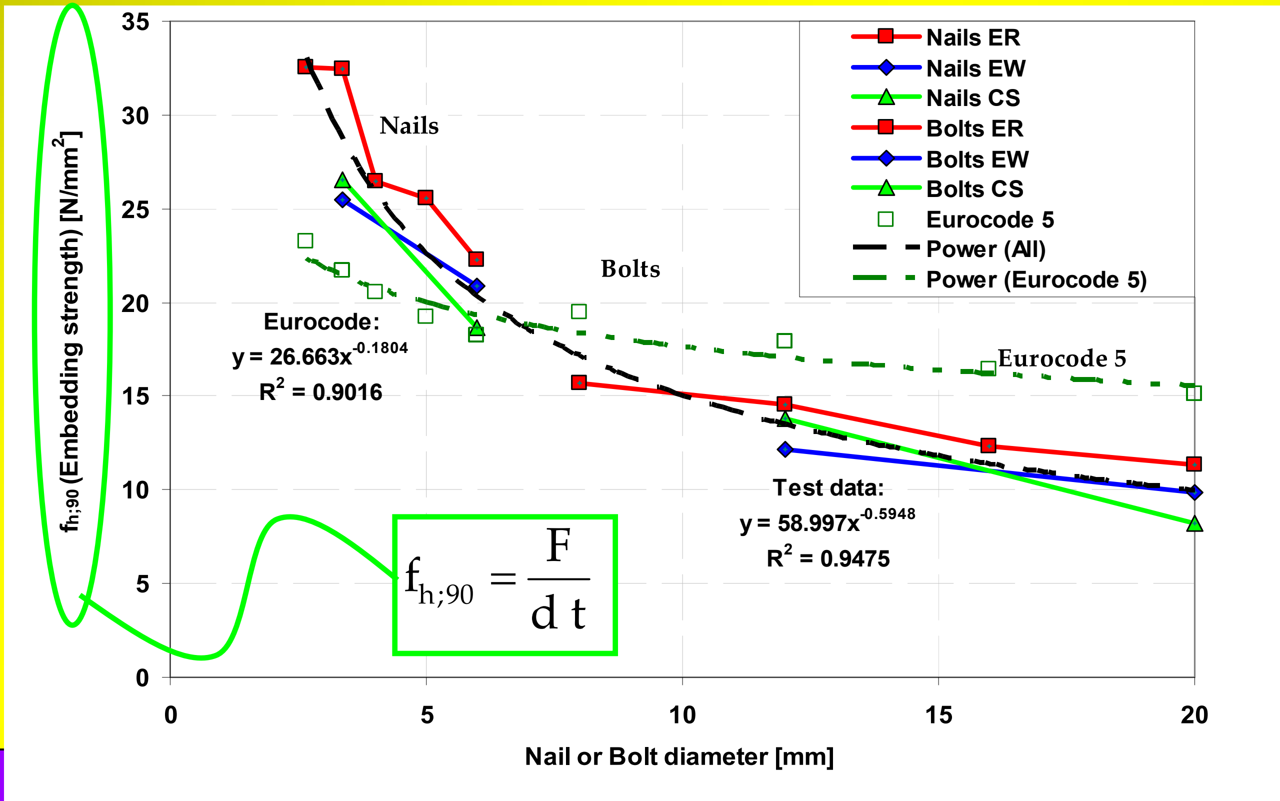
	Nails	Bolts
a	5 d	1.5 d
d	20 d	20 d
e	30 d	18 d
f	5 d	4 d
Thickness	2 d	2 d

Total: 340 experiments

**: Whale and Smith (1986)*

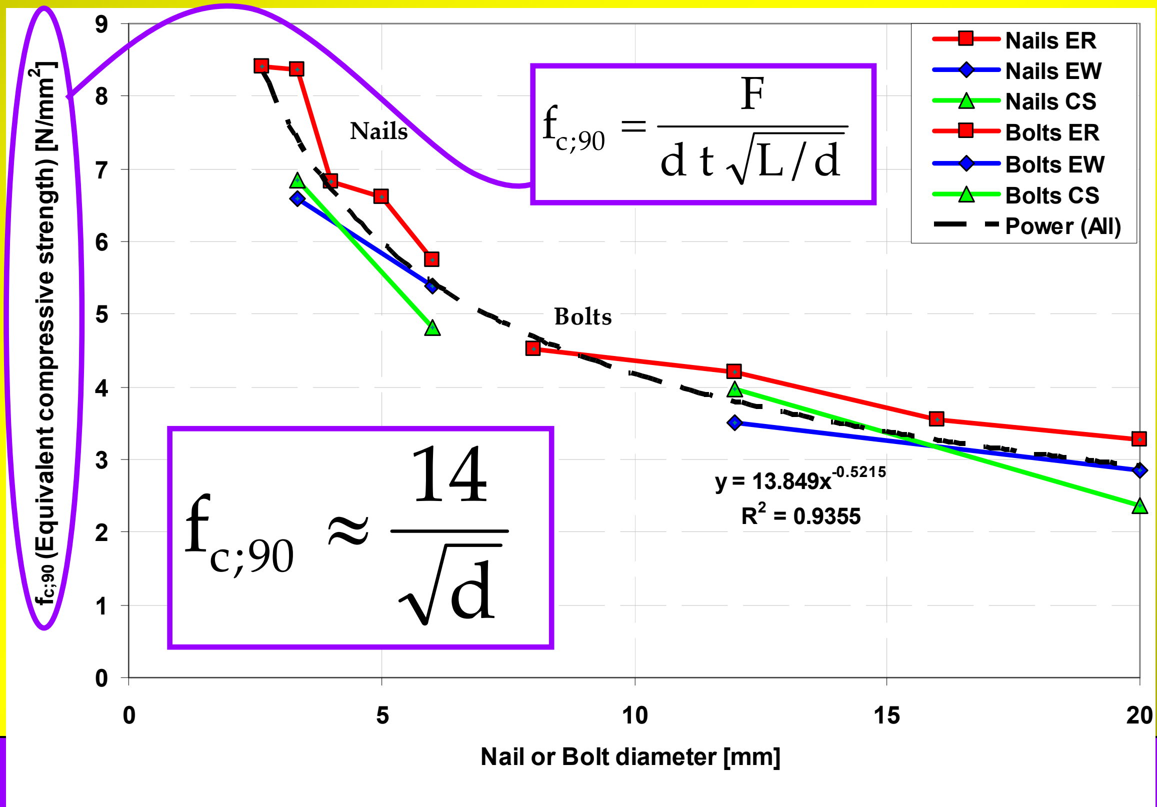
Bearing strength of dowel-type fasteners

- Embedding strength, being F/dt [Failure load/ (diameter x thickness)]
- Embedding strength according to Eurocode 5: 2004
  - Nails and bolts approximated with one line (power fit)



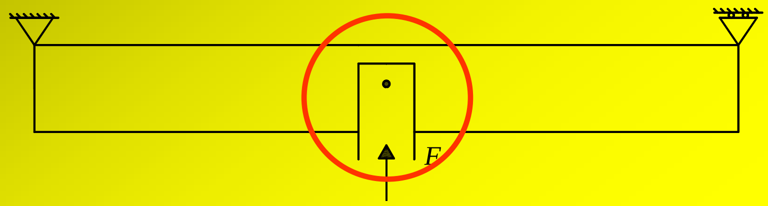
Bearing strength of dowel-type fasteners

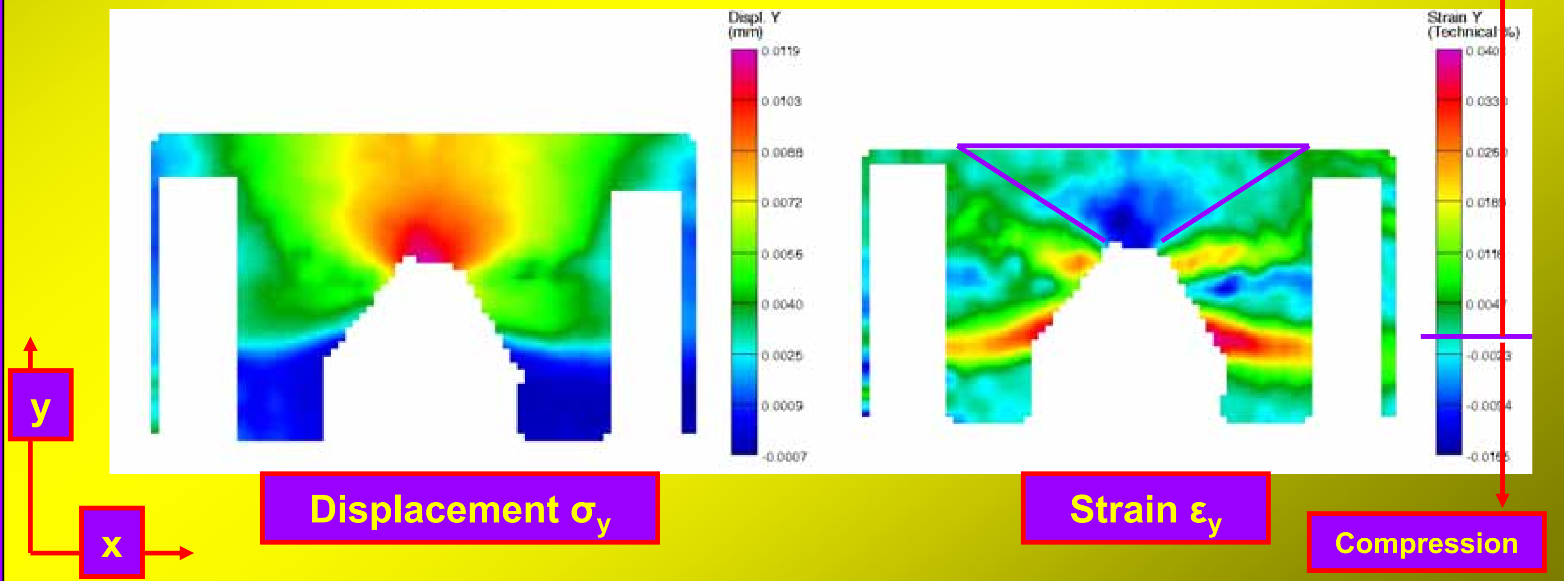
- Equivalent compression strength $f_{c;90}$ derived from tests
  - Nails and bolts approximated with one line (power fit)
- Strongly diameter dependant (size effect)



Bearing strength of dowel-type fasteners

- ESPI-measurement (simply supported beam, loaded at mid span)





Conclusions / remarks

- Theoretical model to explain the bearing strength of locally loaded blocks and dowel-type fastener joints (according to Van der Put (1988), (2000))
- Prediction ability is better than other existing models
- Further research shall lead to new results and knowledge

End of this presentation