EUROCODE 6

Design of masonry structures

Unreinforced masonry
Shear loading

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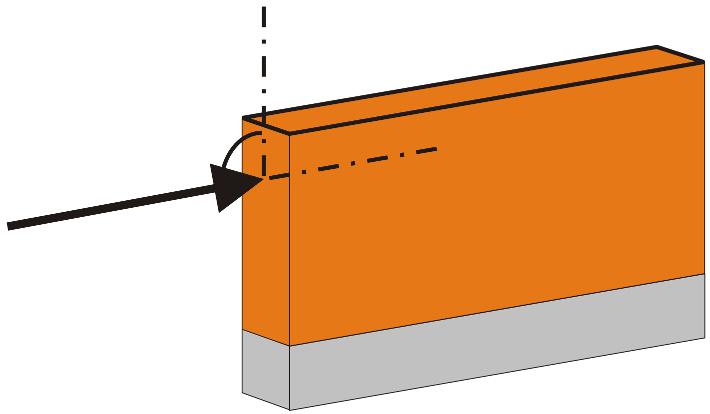
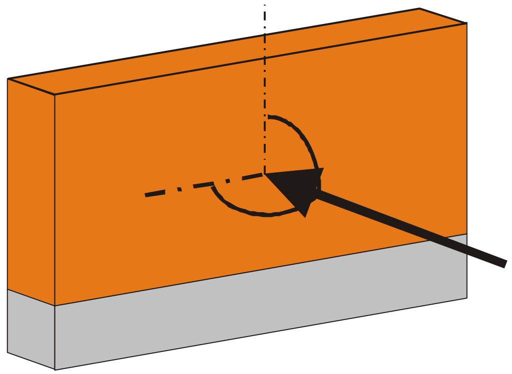
Types of actions for verification against shear





In plane

- transmission of wind loads
- stiffening forces

Out of plane

- wind action perpendicular to the wall
- pressure of earth.

Bracing of buildings

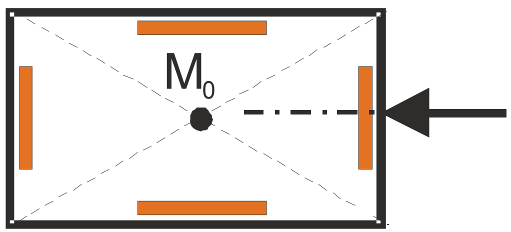
The layout of the walls in the ground plan of the building should be foreseen in such a way that the sufficient bracing of a building should be guaranteed.

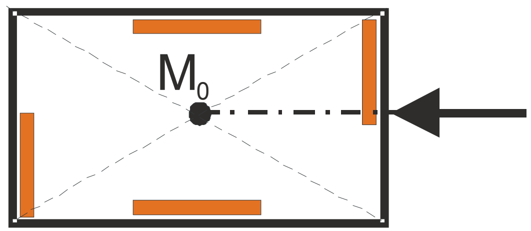
The principles of bracing are:

- concrete ceiling or ring beam
- more than 3 walls
- the axes should not intersect in one point

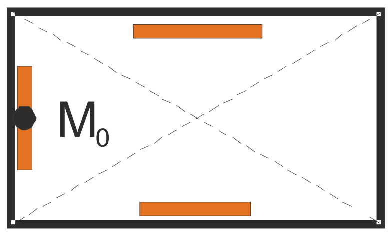
Bracing of buildings

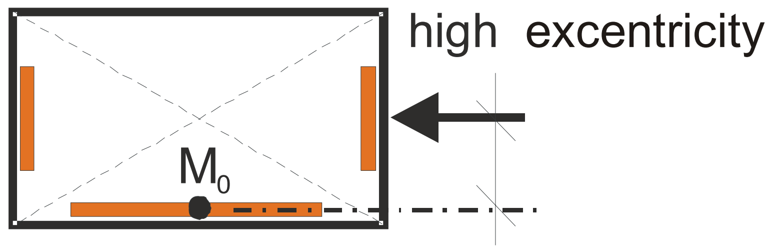
- favourable



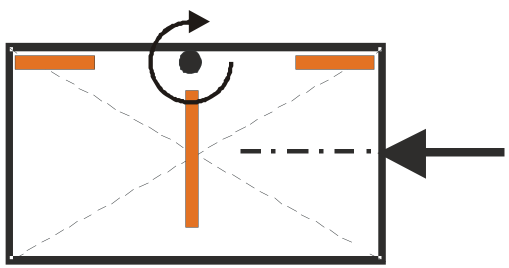


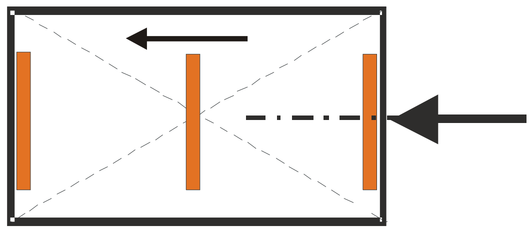
- unfavourable





- instable



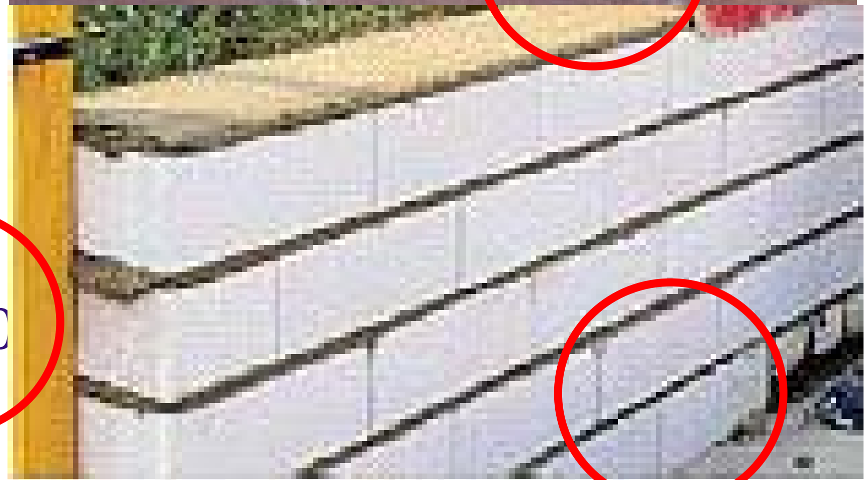


Verification format EN 1996-1-1

NDP - 2

$$V_{Rd} = f_{vd} \cdot t \cdot l_c$$

filled head joints $f_{vk} = f_{vk0} +$

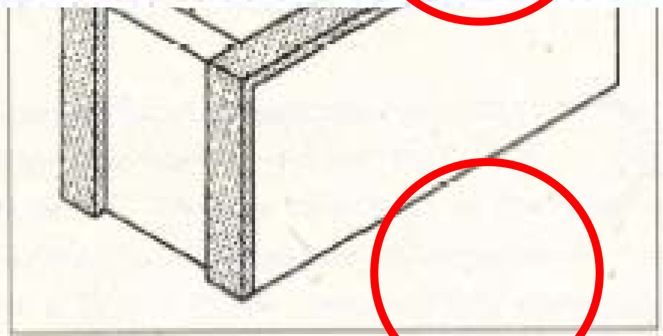


unfilled head joints

$$f_{vk} = 0,5 \cdot f_{vk0}$$

shell bedded masonry

$$f_{vk} = \frac{g}{t} \cdot f_{vk0} + 0,$$



NDP - 1

Verification format

Variables:

f_{vk0}: initial shear strength without load

σ_d: compressive stress, perpendicular with shear load

f_b: normalized compressive strength of masonry

f_{vlt}: limit of shear strength

g: overall with of mortar strips

t: thickness of the wall

Verification format EN 1996-3

Simplified calculation methods

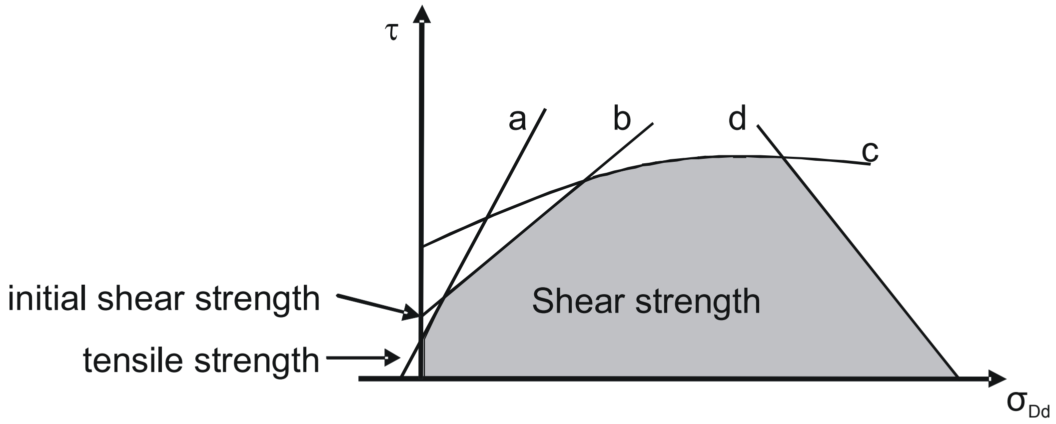
$$V_{Rd} = c_v \cdot \left[\frac{l}{2} - e_{Ed}\right] \cdot t \cdot f_{vdo} + 0{,}4 \cdot \frac{N_{Ed}}{\gamma_M} \leq 3\left[\frac{l}{2} - e_{Ed}\right] \cdot t \cdot f_{vdu}$$

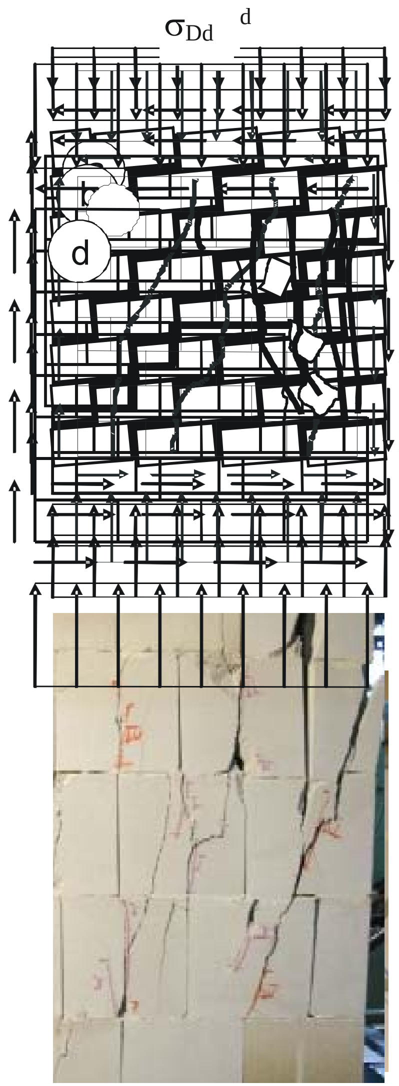
with:

c_v = 3 filled head joints
c_v = 1,5 unfilled head joints
e_{Ed}: excentricity of load
t: thickness of the wall
$f_{vd0} = f_{vk0}/\gamma_M$
N_{Ed}: vertical load
l: length of the wall
f_{vdu}: ultimate shear strength (0,065 f_b or f_{vlt}/γ_M)

Verification model

Background – theory





Failure due to

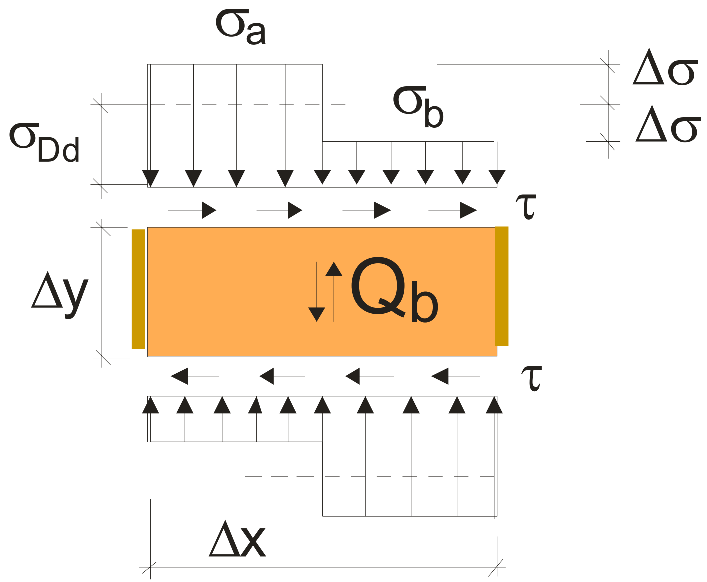
a) **gaping** of bed joint

b) **friction** of bed joint

c) **tensile failure** of the units

d) **crushing**

Verification model
Background – theory



result:
friction failure

$$f_{vk} = f_{vk0} + \bar{\mu} \cdot \sigma_{Dd}$$

equilibrium of forces at a masonry unit

$$2\left(2 \cdot \Delta\sigma\right) \cdot \frac{\Delta x}{2} \cdot \frac{\Delta x}{4} = \tau \cdot \Delta x \cdot \Delta y$$

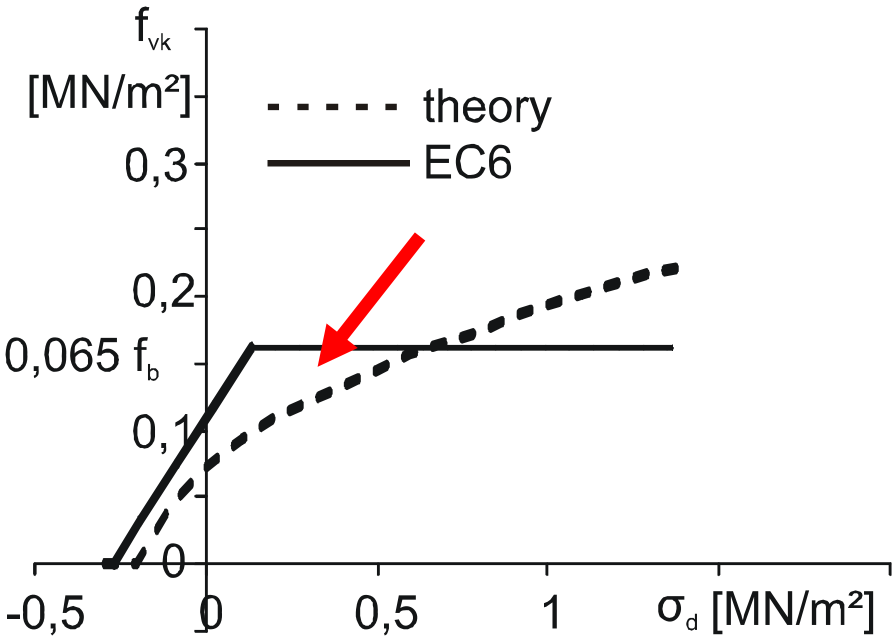
theory of principle stresses

$$f_{vb} = \frac{\sigma_{Dd}}{2} \pm \sqrt{\frac{\sigma_{Dd}{}^2}{4} + \left(2{,}3 \cdot \tau\right)^2}$$

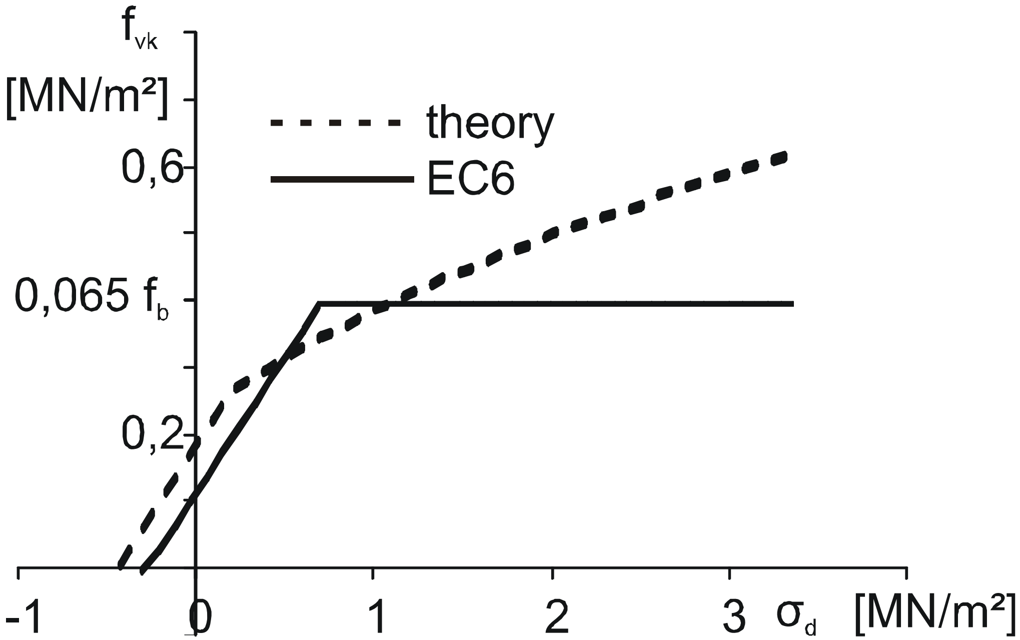
tensile failure (anisotrophy)

$$f_{vk} = 0{,}45\, f_{bt} \sqrt{1 + \frac{\sigma_{Dd}}{f_{bt}}}$$

Comparison to theory



AAC



Brick with vertical holes

Procedure in plane shear loading

A) Actions

- wind action
- bracing forces
- normal stresses/forces and compressed area
  - Bending action due to in plane lateral forces
  - Determination of the compressed area
  - Bending due to deflection of the ceilin

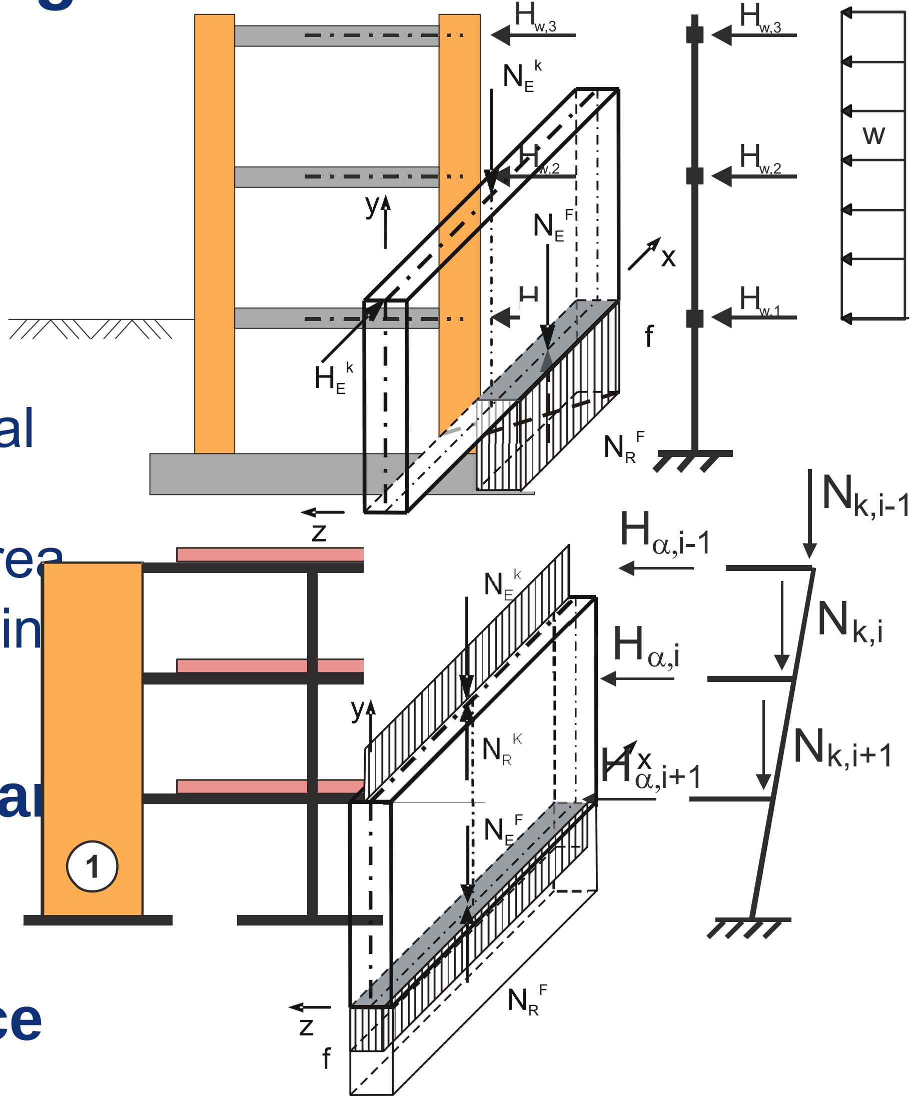
B) Resistance

- Determination of shear strength a shear resistance

C) Verification

- Design action ≤ Design resistance

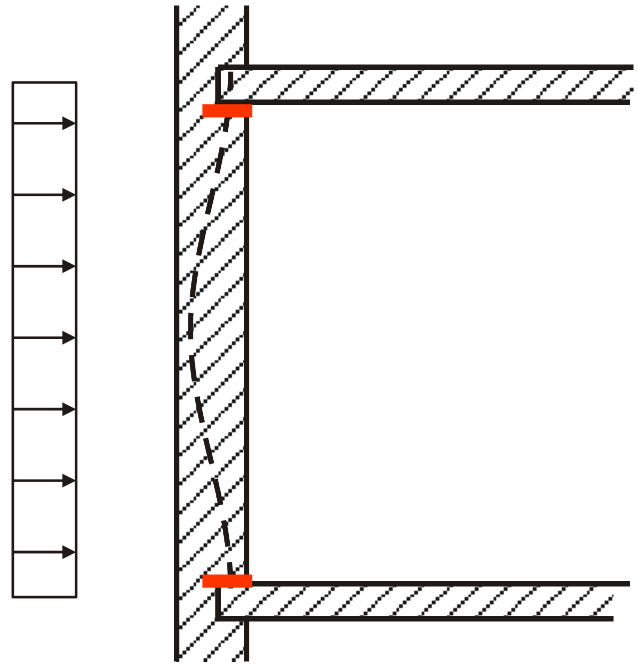
$V_{Ed} \leq V_{Rd}$



Procedure out of plane shear loading

A) Actions

- **Determination of wind action**
- **Determination of normal stresses/forces and compressed area**
  - Bending action due to out of plane lateral forces
  - Determination of the compressed area



B) Resistance

- **Determination of shear strength and shear resistance**

C) Verification

- **Design action ≤ Design resistance**

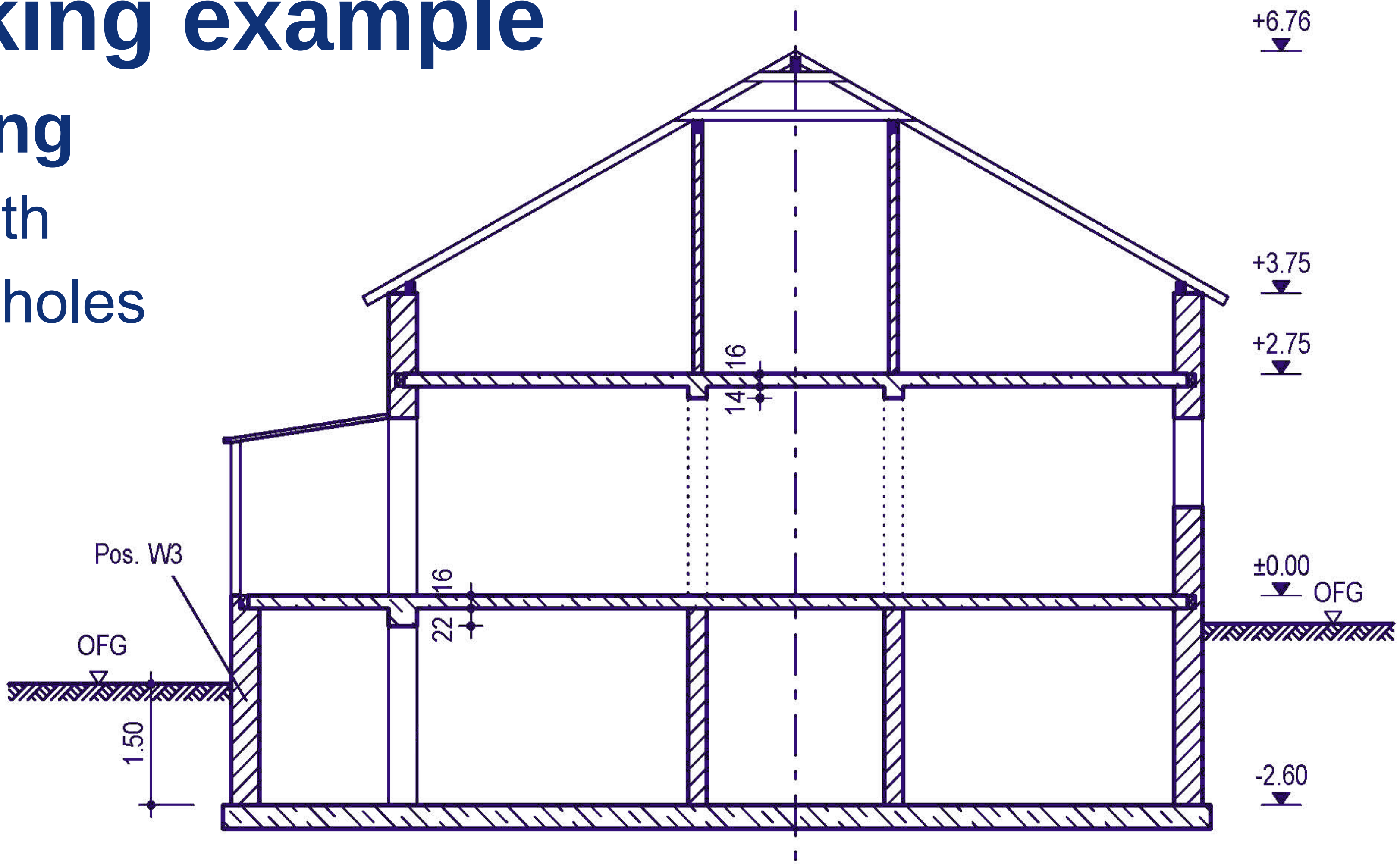
$$V_{Ed} \leq V_{Rd}$$

Working example

Building

Brick with

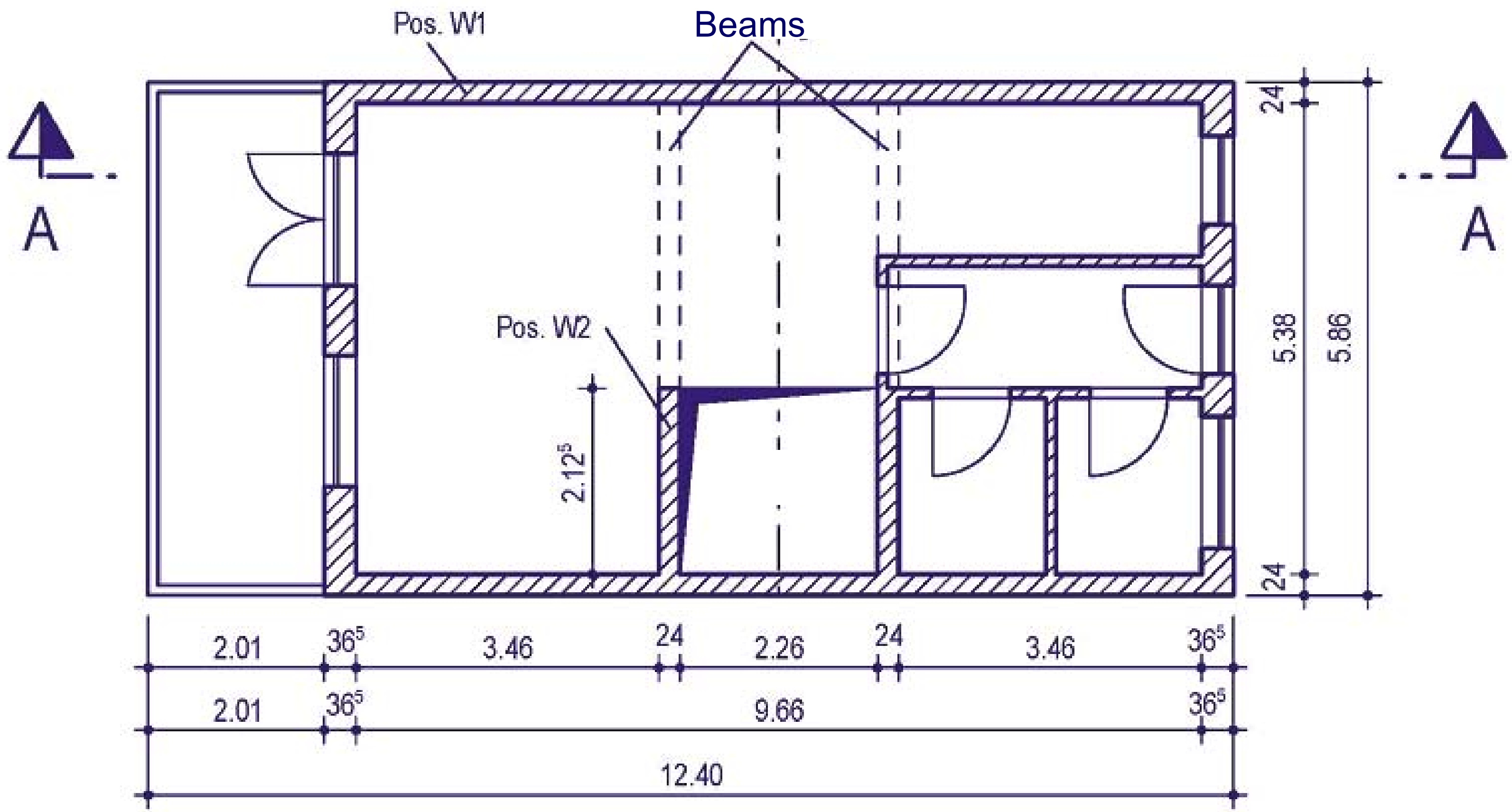
vertical holes



longitudinal section A-A

Working example

Building



first floor plan

Pos. W2 interior wall

Geometry

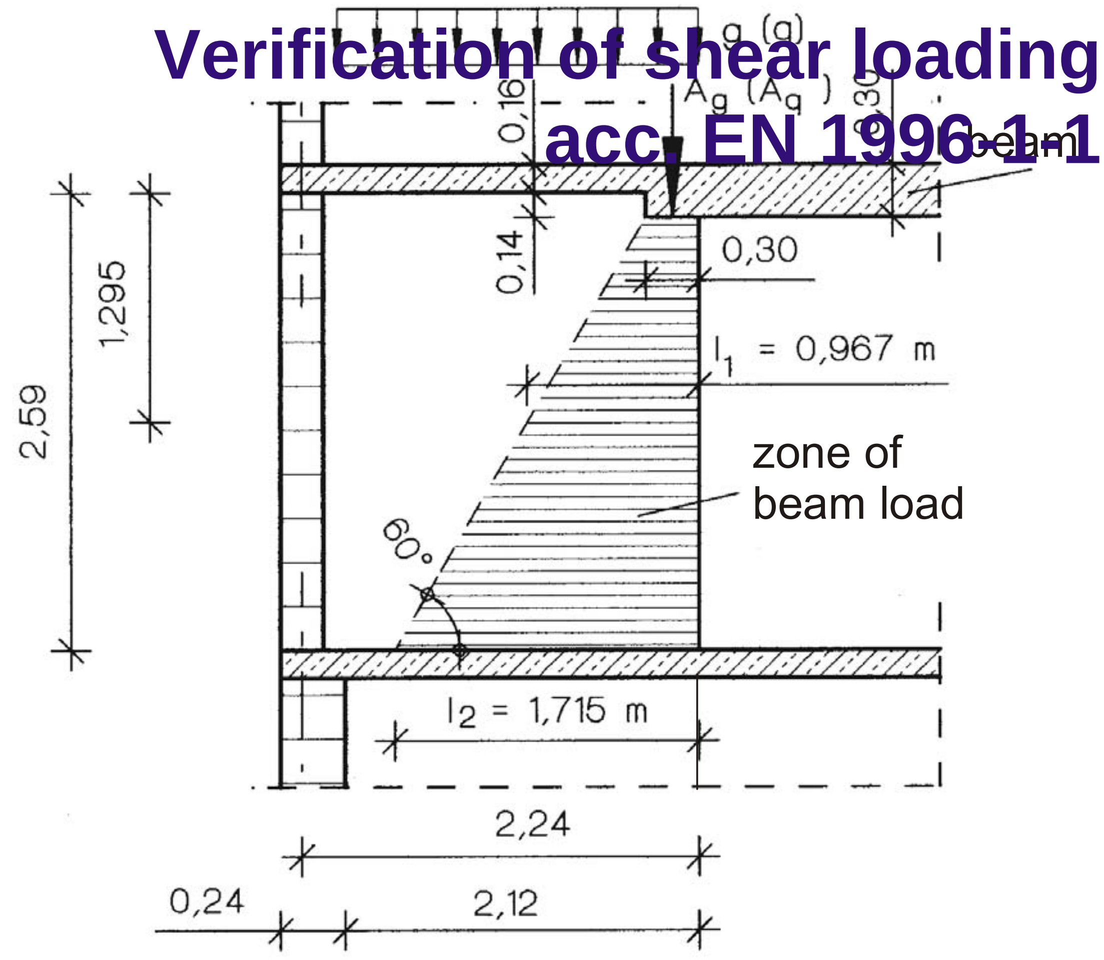
t = 0,24m
l = 2,24m
l_1 = 3,60m

Material parameters

clay bricks, group 2
f_b = 15 N/mm²
mortar M 2,5,
f_m = 2,5 N/mm²

g = 5,5 kN/m²; q = 1,5 kN/m²
A_g= 56,6 kN; A_p= 16,9 kN

Verification of shear loading acc. EN 1996-1-1



l = (1,295-0.14)/tan 60°+0,30 = 0,967m
l = (2,59-0,14)/tan 60°+0,30 = 1,715m

Vertical loads

beam

A_g=56,6 kN; A_q=16,9 kN

angle of load distribution 60°

line force from dead load of the wall

g_{wall}=4,67 kN/m²

line supporting force from dead load of the ceiling

g = 5,5 kN/m²; q = 1,5 kN/m²

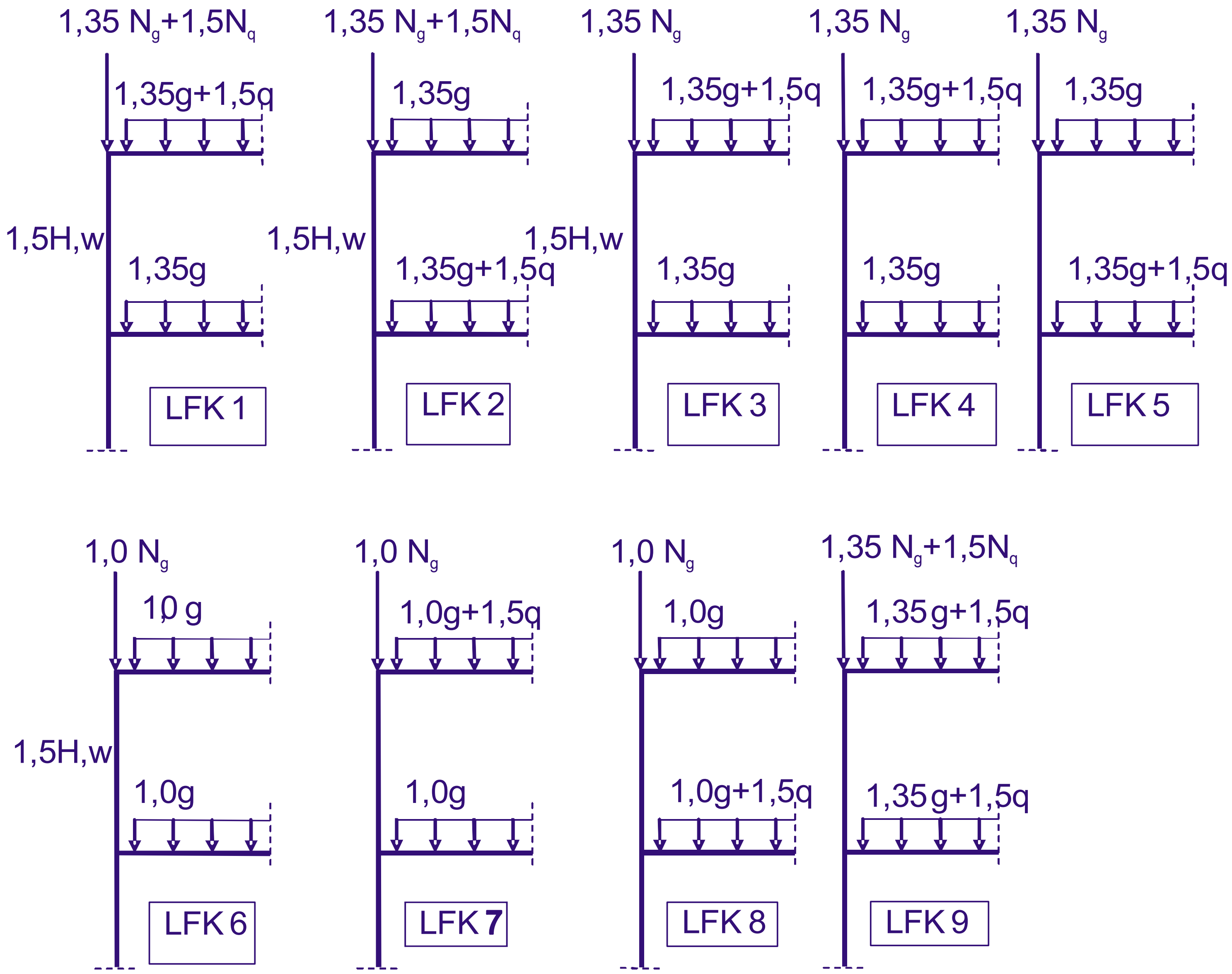
verification of bending in plane: see **3_am_6_Jäger.pdf** on the stick

determination of input data for shear check from bending in plane

l_c = l = 2,24 m (linear stress distribution)

min N = 22,96 kN

Load case combinations



Verification to shear loading

Design value of the shear resistance (load case 1)

$$V_{Rd} = \frac{f_{vk} \cdot t \cdot l_c}{\gamma_M}$$

γ_M =1,7 from NA
(see table 1 DIN EN 1996-1-1)

with

$$f_{vk} = f_{vko} + 0{,}4 \cdot \sigma_d$$

$$f_{vko} = 0{,}20 MN/m^2$$

unit group 2, mortar M2,5 from table NA

$$vorh\sigma_d = \frac{\min N}{t \cdot l_c} = \frac{0{,}23}{0{,}24 \cdot 2{,}24} = 0{,}427 MN/m^2$$

$$f_{vk} = 0{,}20 + 0{,}4 \cdot 0{,}427 = 0{,}371 MN/m^2$$

(filled head joints)

$$< 0{,}065 \cdot f_b = 0{,}065 \cdot 15 = 0{,}975 MN/m^2$$

Verification to shear loading

Design value of the shear resistance

$$f_{vk} = 0{,}5 \cdot 0{,}20 + 0{,}4 \cdot 0{,}427 = 0{,}271\,MN/m^2$$ **(unfilled head joints)**

$$< 0{,}045 \cdot f_b = 0{,}045 \cdot 15 = 0{,}675\,MN/m^2$$

$$f_{vk} = 0{,}5 \cdot 0{,}20 + 0{,}4 \cdot 0{,}427 = 0{,}271\,MN/m^2$$ **(shell bedded joints)**

$$< 0{,}045 \cdot f_b = 0{,}045 \cdot 15 = 0{,}675\,MN/m^2$$ **(g/t = 0,5)**

$$V_{Rd} = \frac{0{,}371 \cdot 0{,}24 \cdot 2{,}24}{1{,}7} = 117{,}3\,kN$$ **(filled head joints)**

$$V_{Rd} = \frac{0{,}271 \cdot 0{,}24 \cdot 2{,}24}{1{,}7} = 85{,}7\,kN$$ **(unfilled/shell bedded)**

$$V_{Ed} = 29{,}61\,kN < 117{,}3\,kN\ (85{,}7\,kN) = V_{Rd}$$

Verification to shear loading simplified method

Requirements

EN 1996-3

- stores above ground level ≤ 3;
- the walls are fixed either through the ceiling or through appropriate constructions, such as ring beams;
- load depth of the ceiling and the roof on the wall is at least 2 / 3 of wall thickness, but not less than 85 mm;
- floor height ≤ 3.0 m;
- the smallest dimensions in the building floor plan is at least 1 / 3 of building height;
- the characteristic values of the variable loads on the ceiling and the roof ≤ 5.0 kN / m²;
- span of the ceiling ≤ 6.0 m;

Verification to shear loading - simplified method

Design value of the shear resistance

$$V_{Rd} = c_v \cdot \left[\frac{l}{2} - e_{Ed}\right] \cdot t \cdot f_{vdo} + 0{,}4 \cdot \frac{N_{Ed}}{\gamma_M} \leq 3\left[\frac{l}{2} - e_{Ed}\right] \cdot t \cdot f_{vdu}$$

c_v = 3 (filled head joints)

$$V_{Rd} = 3 \cdot \left[\frac{2{,}24}{2} - 0{,}376\right] \cdot 0{,}24 \cdot \frac{0{,}2}{1{,}7} + 0{,}4 \cdot \frac{0{,}229}{1{,}7}$$

$$\leq 3\left[\frac{2{,}24}{2} - 0{,}376\right] \cdot 0{,}24 \cdot \frac{0{,}371}{1{,}7} \qquad e_{Ed} = \frac{M_{Ed}}{N_{Ed}} = \frac{77{,}031}{229{,}585} = 0{,}376\text{m}$$

$$V_{Rd} = 180\text{kN} \leq \underline{117\text{kN}}$$

$$V_{Ed} = 29{,}61\text{kN} < 117\text{kN} = V_{Rd}$$

Verification to shear loading - simplified method

Design value of the shear resistance

c_v = 1,5 (unfilled head joints)

$$V_{Rd} = 1{,}5 \cdot \left[\frac{2{,}24}{2} - 0{,}376\right] \cdot 0{,}24 \cdot \frac{0{,}2}{1{,}7} + 0{,}4 \cdot \frac{0{,}229}{1{,}7}$$

$$\leq 1{,}5\left[\frac{2{,}24}{2} - 0{,}376\right] \cdot 0{,}24 \cdot \frac{0{,}371}{1{,}7}$$

$$V_{Rd} = 90\text{kN} \leq \underline{58{,}5\text{kN}}$$

$$V_{Ed} = 29{,}61\text{kN} < 58{,}5\text{kN} = V_{Rd}$$

Applikation of f_{vlt}

tensile failure of the unit

$$f_{vklt} = 0{,}45\, f_{bt} \sqrt{1 + \frac{\sigma_{Dd}}{f_{bt}}}$$

f_{bt}: tensile strength of the unit

$f_{bt} = 0{,}025 \cdot f_b$ hollow blocks;

$f_{bt} = 0{,}033 \cdot f_b$ vertically perforated bricks and units with grip hole;

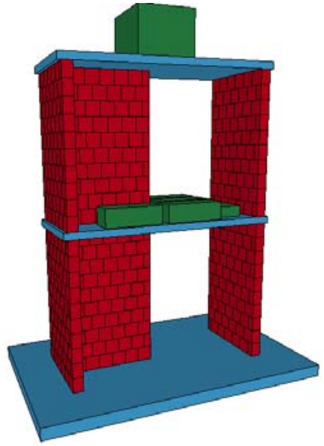
$f_{bt} = 0{,}040 \cdot f_b$ full blocks without grip hole;

simplified

$$f_{vklt} = 0{,}065\, f_b$$ (filled head joints)

$$f_{vklt} = 0{,}045\, f_b$$ (unfilled head joints)

Collapse analyses



Reason:

$1,5 \cdot H / 1.0 \cdot N = 1,5 \cdot e^{previous}$

Aim:

description of the shear failure closer to reality to use the reserves

Done:

a) Matrial tests/test methods
b) Static/cyclic shear tests
c) Pseudodynamic tests
d) Shaking tabel tests
e) Theoretical analyses
f) Engineering model
g) Recommandations for the practice

Test on shaking table in Athens (CS)

Eng.-Model: From stress level to force level

	Proposal from WP 4
Bending	$V_{bending} = \frac{1}{2 \cdot \lambda_v} \cdot \left(N - \frac{N^2}{t \cdot l \cdot f} \right)$
Gaping	$V_{gaping} = \frac{l_b \cdot N}{2} \left(\frac{1}{h_b} + \frac{1}{h} \right)$
Friction	$V_{friction} = \mu \cdot N$
Tensile failure of the unit	$V_{unit} = \frac{1}{c} \cdot f_{bt,cal} \cdot l \cdot t \cdot \left(F^*\right)^{-2} \left(\sqrt{1 + \left(F^*\right)^2 \left(1 + \frac{\sigma_d}{f_{bt,cal}}\right)} - 1 \right)$ $F^* = 1.2 + 0.85 f_{bt}$ **for AAC:** $V_{unit,AAC} = \frac{1}{c} \cdot f_{bt,cal} \cdot l \cdot t \cdot 2 \cdot \left(F^*\right)^{-2} \left(\sqrt{1 + \frac{\left(F^*\right)^2}{4} \left(1 + \frac{\sigma_d}{f_{bt,cal}}\right)} - 1 \right)$

TECHNISCHE UNIVERSITÄT DRESDEN

International Masonry Society

Faculty of Architecture Chair of Structural Design, Prof. Dr.-Ing. Wolfram Jäger

8^{th} International Masonry Conference (IMC) DRESDEN 2010

Wolfram Jäger & Bary Haseltine

Workshop on EC 6 Brussels, 2/3 April 2009

T:\Vorträge\2008\09-28-CIB-Ancona\03-Folien\01-shear

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Innovative Solutions for Sustainable Masonry Construction

Dresden 4th to 7th of July 2010

8IMC

4th to 7th of July 2010

From Sunday till Wednesday

Deadline of submission of abstracts

30th of May 2009