New applications for sandwich panels: stabilization and load transfer

Dipl.-Ing. Saskia Käpplein, Dr.-Ing. Thomas Misiek
Applications of sandwich panels

• Common application of sandwich panels
  – Transfer of transverse loads (wind, snow) to the substructure

• Additional possibilities to use sandwich panels
  – Stabilisation of beams and columns against buckling and lateral torsional buckling
  – Transfer of horizontal (wind) loads = stabilisation of structures and buildings
  – Buildings without substructure
    Transfer of axial loads
    Transfer of horizontal wind loads and stabilisation of building
Overview

Torsional restraint
Diaphragm action
Axial loads
Horizontal loads and stabilisation of buildings
Introduction of tensile forces
Stabilisation of beams by torsional restraint

Lateral torsional buckling

\[ \text{q} \]
Torsional restraint

- Sandwich panels can restrain rotation $\vartheta$
  
  - Increase of critical buckling moment $M_{cr}$

- Restraining effects are considered by springs
  
  - Rotational spring with stiffness $C_{\vartheta}$

- Stiffness of springs depends on stiffness of panels and connections
Stabilisation of beams by torsional restraint

Stiffness $C_\theta$ consists of three components

\[
\frac{1}{C_\theta} = \frac{1}{C_{\theta A}} + \frac{1}{C_{\theta B}} + \frac{1}{C_{\theta C}}
\]

- $C_{\theta B}$: distortional stiffness of the beam
- $C_{\theta C}$: bending stiffness of the attached panel
- $C_{\theta A}$: stiffness of the connection

Easy to calculate

Object of investigations of EASIE project
Stabilisation of beams by torsional restraint

Moment-rotation-relation

Downward loading

Uplift loading

\[ \theta = \frac{2}{C_{\theta 4}} \]

22/09/2011
Stabilisation of beams by torsional restraint

- Moment-rotation-relation – downward loading

\[ m = \frac{2}{3} m_k \]

\[ m_k = q_d \cdot \frac{b}{2} \]

\[ C_{\varphi A} = \frac{m_K}{\varphi(m_K)} \]

\[ C_{\varphi A} = f(q_d) \]
Overview

Torsional restraint
Diaphragm action
Axial loads
Horizontal loads and stabilisation of buildings
Introduction of tensile forces
Diaphragm action – load transfer

- Transfer of horizontal (wind) loads by diaphragm action

sandwich panels can replace wind bracings
Diaphragm action – load transfer

• Example
Diaphragm action – Stabilisation of beams and columns

Stability failure modes

- **Buckling**

- **Lateral torsional buckling**
Lateral restraint

• Sandwich panels can restrain displacement $v$
  - Increase of critical buckling moment $M_{cr}$
  - and critical buckling force $N_{cr}$

• Restraining effects are considered by springs
  - Longitudinal spring with stiffness $K$

• Stiffness $K$ depends on shear stiffness $S$ of the diaphragm
  - For sinusoidal deflection $K = S_i \cdot \left( \frac{\pi}{l} \right)^2$
Definition: Stiffness $S$ of a shear diaphragm

$$S = \frac{F}{\gamma}$$
Diaphragm action

General assumptions

- Stiff panels with flexible connections
- Panel rotates around a reference point P
- Panels are parallel to each other
- Panels remain parallel to the longitudinal edges
- At all fastenings only forces and displacements in longitudinal direction
Stiffness of fastenings

Mechanical model of a connection to the substructure

\[ k_v = \frac{1}{x_F} + \frac{t_{\text{sup}}^2}{k_{F_2}} + \frac{3 \cdot (1 - x_F) \cdot D \cdot t_{\text{sup}}^2 + t_{\text{sup}}^3}{24 \cdot EI} \]

\[ x_F = 1 - \frac{1}{k_{F_2}} - \frac{D \cdot t_{\text{sup}}}{2 \cdot C} - \frac{D^2 \cdot t_{\text{sup}}^2}{8 \cdot EI} \]

\[ + \frac{1}{k_{F_2}} + \frac{D^2}{C} + \frac{D^2 \cdot (2 \cdot D + 3 \cdot t_{\text{sup}})}{6 \cdot EI} \]
Stiffness of fastenings

Three components

- Bending stiffness of the fastener
  \[ EI = 200.000 \frac{N}{mm^2} \cdot \frac{\pi \cdot d_s^4}{64} \]

- Rotational stiffness of clamping in the substructure
  \[ C = 2400 \frac{N}{mm^2} \cdot \sqrt{t_{sup} \cdot d_1^5} \]

- Stiffness of internal face sheet (hole elongation)
  \[ k_{F2} = 6,93 \cdot \frac{f_{u,F2} \cdot \sqrt{t_{F2}^3 \cdot d_1}}{0,26mm + 0,8 \cdot t_{F2}} \]

Fastenings at longitudinal joints

\[ k_v = 1900 \frac{N}{mm^3} \cdot t_{F1} \cdot d \]
Overview

Torsional restraint
Diaphragm action
Axial loads
Horizontal loads and stabilisation of buildings
Introduction of tensile forces
New application:
Buildings made of sandwich panels but without substructure
- Wall panels transfer normal forces
- New questions:
  - Global load bearing capacity of axially loaded sandwich panels
  - Local load bearing capacity of load application area
Elastic buckling load

\[ N_{cr} = \frac{N_{ki}}{1 + \frac{N_{ki}}{GA}} \]

- Elastic buckling load of the faces: \( N_{ki} \)
- Elastic buckling load of the core: \( GA \)

Axial load, at which wrinkling of both faces occurs

\[ N_w = 2 \cdot A_F \cdot \sigma_w \]

Slenderness of a sandwich panel

\[ \lambda = \sqrt{\frac{N_w}{N_{cr}}} = \sqrt{\lambda_{ki}^2 + \lambda_{GA}^2} \]
Axial loads - global load bearing capacity

Design model based upon the existing model of EN 14509

Consideration of
- 2nd order effects
- creep effects
Axial loads - global load bearing capacity

Buckling tests

Long-term tests
Axial loads - global load bearing capacity

Ultimate stress of axially loaded panels
  → Wrinkling stress according to EN 14509

Consideration of creeping
  → Creep coefficients determined according to EN 14509

Advantage:
  • Determination by bending tests
  • For most sandwich panels already known
Axial loads - global load bearing capacity

2\textsuperscript{nd} Order Effects

amplification factor $\alpha = \frac{1}{1 - \frac{N}{N_{cr}}}$

Creep effects

sandwich creep coefficient

$\varphi_{St} = \frac{k}{1 + k} \cdot \varphi_{t}$

$k = \frac{w_v}{w_b} = \frac{B_s}{G A} \cdot \frac{\int V V dx}{\int M M dx}$
Axial loads - global load bearing capacity

Bending Moment

\[ M_{i}^{II} = \left( M_{W}^{I} + M_{\Delta T}^{I} + M_{S}^{I} \cdot \left( 1 + \varphi_{S2000} \right) + M_{G}^{I} \cdot \left( 1 + \varphi_{S100.000} \right) \right) \cdot \alpha \]

- wind temperature difference
- snow
- permanent load

Stress of the face sheet

\[ \sigma = \frac{M_{i}^{II}}{A_{F} \cdot D} + \frac{N}{2 \cdot A_{F}} \leq \sigma_{w} \]
Alternative: Design by buckling curves

• Equation following EC3

\[ \frac{N}{\kappa \cdot N_w} + k_{yy} \frac{M}{M_w} \leq 1 \]

• Reduction factor

\[ \kappa = \frac{1}{\phi + \sqrt{\phi^2 + \lambda^2}} \quad \phi = 0.5 + \left[ 1 + \alpha \sqrt{\lambda^2 - \lambda_{GA}^2} + \lambda^2 \right] \]

• Imperfection coefficient for sandwich panels

\[ \alpha = \frac{2e_0}{D} \cdot \pi \cdot \sqrt{\frac{B_S}{N_w}} \]
Alternative: Design by buckling curves
Axial loads – local load bearing capacity

Load application area:
Connection between wall and roof
- Load is introduced in the cut edge by contact
- Failure mode: Crippling of the free cut edge
Axial loads – local load bearing capacity

Load application area:
Failure mode is related to wrinkling of a compressed face

Load application area: elastically supported beam with a free end
Imperfections at load application area

- Uneven cut edge → contact imperfections
- Cracks between core and face
- Deflection of roof panel → Introduction of load not exactly vertical
Overview

- Torsional restraint
- Diaphragm action
- Axial loads
- Horizontal loads and stabilisation of buildings
- Introduction of tensile forces
Horizontal loads and stabilisation of buildings

New application:
Buildings made of sandwich panels but without substructure
- panels transfer horizontal wind loads
- panels stabilize the building

Transfer of forces:
- directly loaded walls
- roof (circumferential shear force)
- walls
- foundation

22/09/2011
Horizontal loads and stabilisation of buildings

Panels are loaded by in-plane shear forces
High in-plane shear stiffness and capacity of the panels
  ➡ fastenings are decisive
  ➡ fastenings have to be designed for the horizontal wind load

Determination of forces at fastenings
  ➡ by numerical calculation with a simple model
    – rigid panels and flexible fastenings
    – fastenings are considered by springs
  ➡ for simple applications also analytical determination possible
Overview

Torsional restraint
Diaphragm action
Axial loads
Horizontal loads and stabilisation of buildings
Introduction of tensile forces
Introduction of tensile forces in only one face

- tensile stresses in the bonding between core and face
- possible failure mode:
  - delamination of the face from the core material
  - tensile failure of the core
Introduction of tensile forces

Tensile forces:
- Minimum edge distance: Pull-out failure
- Smaller edge distances: Delamination of the face from the core material / tensile failure of the core material
Introduction of forces

Tensile forces:
For sufficient edge distances
- Face is elastically supported by the core material
- Stiffness of the elastic foundation is influenced by material parameters of the core
- Stiffness of the face is influenced by thickness and elastic modulus
- Concentrated tensile force
For further information

www.easie.eu

Deliverables of Workpackage 3 (examples)

- D3.3 – part 1: Torsional restraint
- D3.3 – part 2: Shear diaphragms
- D3.3 – part 3: Stiffness of fastenings
- D3.3 – part 4: Axially loaded sandwich panels
Thank you for your attention