Survey and Realistic Modelling of Ancient Austrian Roof Structures

Part I

CSHM-3 2010
Civil Structural Health Monitoring

Andreas Meisel
Institute for Timber Engineering and Wood Technology, Graz University of Technology

GRAZ UNIVERSITY OF TECHNOLOGY
Austria / Europe
7 faculties | 11,264 students | staff 2,222
budget: € 150 Mill. (1/3 3rd party budget)

Faculty of Civil Engineering Sciences
17 institutes | about 1,140 students
[207 “diploma”, 693 “Bachelor”, 146 “Master”, 93 “PhD”]

Institute for Timber Engineering and Wood Technology
1991: Chair for Timber Engineering
10|2004: Institute Timber Engineering and Wood Technology
Scientific staff: 7.0 FTE | third-party-budget: € 220,000 (2009)

Competence Centre holz.bau forschungs gmbh
09|2002 Acceptance of 4-year-fundings: Competence Center Timber Engineering and Wood Technology
12|2002 Competence Centre holz.bau forschungs gmbh
09|2007 Acceptance of 5-year-fundings: K-Project “timber.engineering” | COMET-Programme
Scientific staff: 7.1 FTE | budget: € 905,000 (2009)
CONTENT

- Introduction
- Challenges of the structural analysis
  - High variations in dimensions of the system and beams
  - Determination of material characteristics
  - Definition of support conditions
  - Consideration of the mechanical behaviour of carpentry joints
  - Three-dimensional load bearing behaviour
- Summary
INTRODUCTION

Central Europe:

Long tradition of roof structures

- Church of the “Franziskaner” in Graz
- Erected in the 13th century
- Erection of the vaults: 1515-1519

1st collar beam floor

2nd collar beam floor

3rd collar beam floor

17 m

Tie member floor
BUT in the case of ...

1. Damages
2. Poor reinforcements
3. Conversions

⇒ Knowledge of the load-bearing behaviour is the basis for repair concepts

⇒ Realistic models

CONTENT

- Introduction
- Challenges of the structural analysis
  - High variations in dimensions of the system and beams
  - Determination of material characteristics
  - Definition of support conditions
CONTENT

- Introduction
- Challenges of the structural analysis
  - High variations in dimensions of the system and beams
  - Determination of material characteristics
  - Definition of support conditions
  - Consideration of the mechanical behaviour of carpentry joints
  - Three-dimensional load bearing behaviour
- Summary

MECHANICAL BEHAVIOUR OF THE CARPENTRY JOINTS

Mechanical behaviour of the carpentry joints

- Joints considerably influence the internal forces
- Requirements in the standard
  - (EN 1995-1-1 in 5.1 (4) “The structural model … has to consider the influences of the flexibilities of joints”)
  - But the derivation of the stiffness values, eccentricities and design values according to standard is often impossible
- Large gaps in scientific activities

Dovetail scraf joint
Main Problems

- Load transfer
due to contact pressure and friction (sometimes shear)
NON-LINEAR (type of loading)

- Geometry causes
local compression and tensile stresses perpendicular to the grain

- Timber
inhomogeneous, anisotropic

- Interaction of connectors, long term effects …

Mechanical behaviour of a skew frontal tenon (loaded in compression)

Joint $N_{R,d} = 21 \text{ kN}$
### Determination of the spring stiffness $C_{VB}$

(neglecting friction and the treenail)

\[
C_H = \frac{E_{90,\text{mean}} \cdot A_{(2)}}{L} \quad \text{and} \quad C_V = \frac{E_{\alpha,\text{mean}} \cdot A_{(1)}}{H/2} \quad \Rightarrow \quad C_{VB} \approx 300 \text{ kN/cm}
\]

#### Structural tests

After the test

1st failure due to rolling shear between the tenon and the outer zones of the strut
Results: load-displacement diagramm (incl. comparison with calculated result)

\[
F_{\text{max}} = \frac{F'}{2 \cdot \cos \alpha}
\]

Cut through tenon

Influence on the internal forces

- Example: “Grazer Dachstuhl” (spatial models)

M1

Including the mechanical behaviour of joints

M2

Linear analysis
**Results for frame wall E**

<table>
<thead>
<tr>
<th>Joint: $N_{R,d}$</th>
<th>Struts: $N_{E,d}$</th>
<th>Purlin: $M_{yE,d}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-21 kN</td>
<td>-47 kN (100 %)</td>
<td>15 kNm (100 %)</td>
</tr>
<tr>
<td></td>
<td>-78 kN (166 %)</td>
<td>10 kNm (67 %)</td>
</tr>
</tbody>
</table>

**M1:**
- Load redistributions from the joints to the beams
- Lower utilization ratios
- Load-bearing capacity is plausible (except dormer), but safety level is lower than required by standards

**M2:**

**CONTENT**

- **Introduction**
- **Challenges of the structural analysis**
  - High variations in dimensions of the system and beams
  - Determination of material characteristics
  - Definition of support conditions
  - Consideration of the mechanical behaviour of carpentry joints
  - Three-dimensional load bearing behaviour
- **Summary**
**Basics: Purlin roof / rafter roof**

Frame wall or principal frame = “desk”

Rafter: inclined bending beam  
Three-hinged frame…

---

**Three-dimensional load bearing behaviour**

<table>
<thead>
<tr>
<th>Rafter</th>
<th>Purlin</th>
<th>Collar beam</th>
<th>Trimmer beam</th>
</tr>
</thead>
</table>

… as purlin roof: 56/2 %

=> Hybrid structure (rafter and purlin roof)

=> Spatial analysis is often needed
CONTENT

- Introduction
- Challenges of the structural analysis
  - High variations in dimensions of the system and beams
  - Determination of material characteristics
  - Definition of support conditions
  - Consideration of the mechanical behaviour of carpentry joints
  - Three-dimensional load bearing behaviour
- Summary

SUMMARY

Summary

- Realistic simulation of the load-bearing behaviour is difficult and time-consuming. A spatial, non-linear structural analysis (supports, behaviour of joints) is recommended.

- The parameters of the structural analysis of ancient roof structures include many uncertainties.

=> Further investigations of the mechanical behaviour of the carpentry joints are scheduled.

- Despite of serious damages: capacity of these structures is kept up by load-redistributions (redundant and therefore robust).
Practice is when everything works, but nobody knows why.

Many Thanks!

Contact:
Dipl. Dipl.-Ing. Andreas Meisel
Institute for Timber Engineering and Wood Technology,
Graz University of Technology | AT
Inffeldgasse 24/I, 8010 Graz, AUSTRIA
andreas.meisel@tugraz.at, phone.: +43 316 873 4612