Understanding Complex Adhesive Behaviour

Case Study U-type Bonding Geometry

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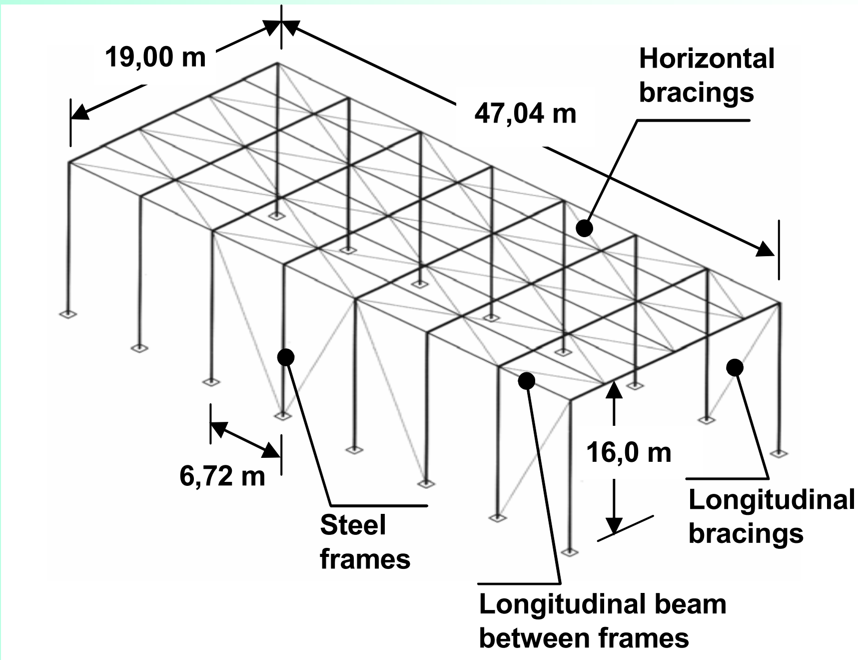
Contents

- **Glass Façade Herz Jesu Church, Munich**
- **Analysis of U-type Bonding**
- **Parameter Studies Bonding Geometry**
- **Conclusions and Outlook**

Glass Façade of the Herz Jesu Church



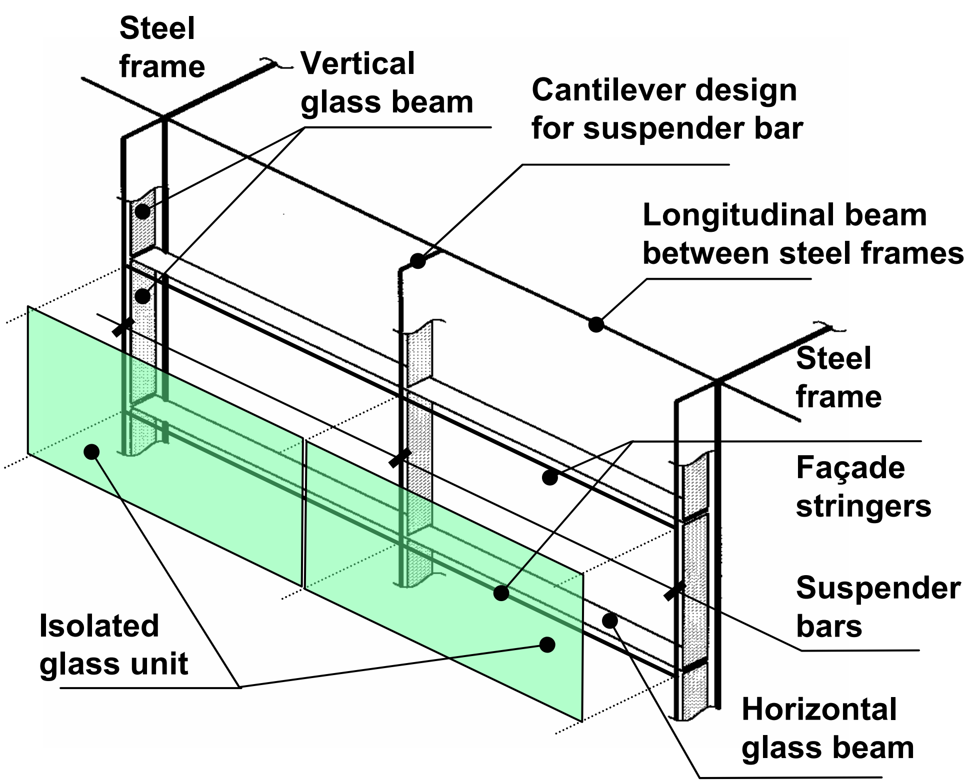
Architectural requirements: Minimum of visible load-carrying structures

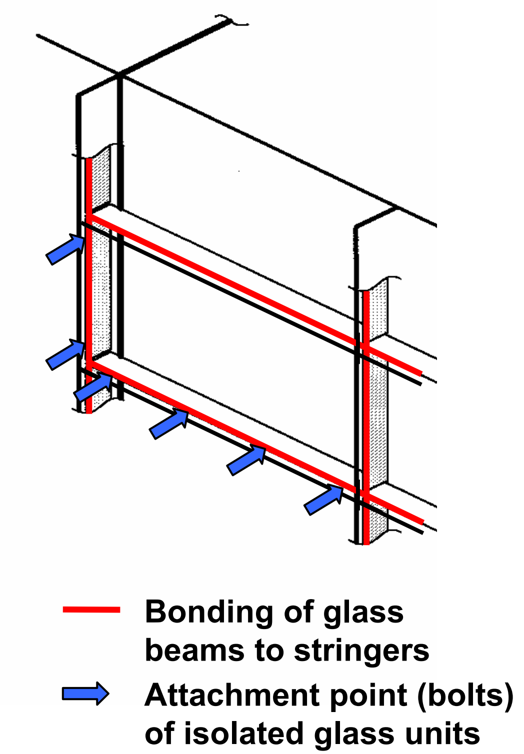
↳ **Sophisticated design solution**

- ➢ **Usage of glass beams as supporting members**
- ➢ **Load bearing line type bonding by Silicone adhesive**

The Design Philosophy – Bearing *and* Transparency

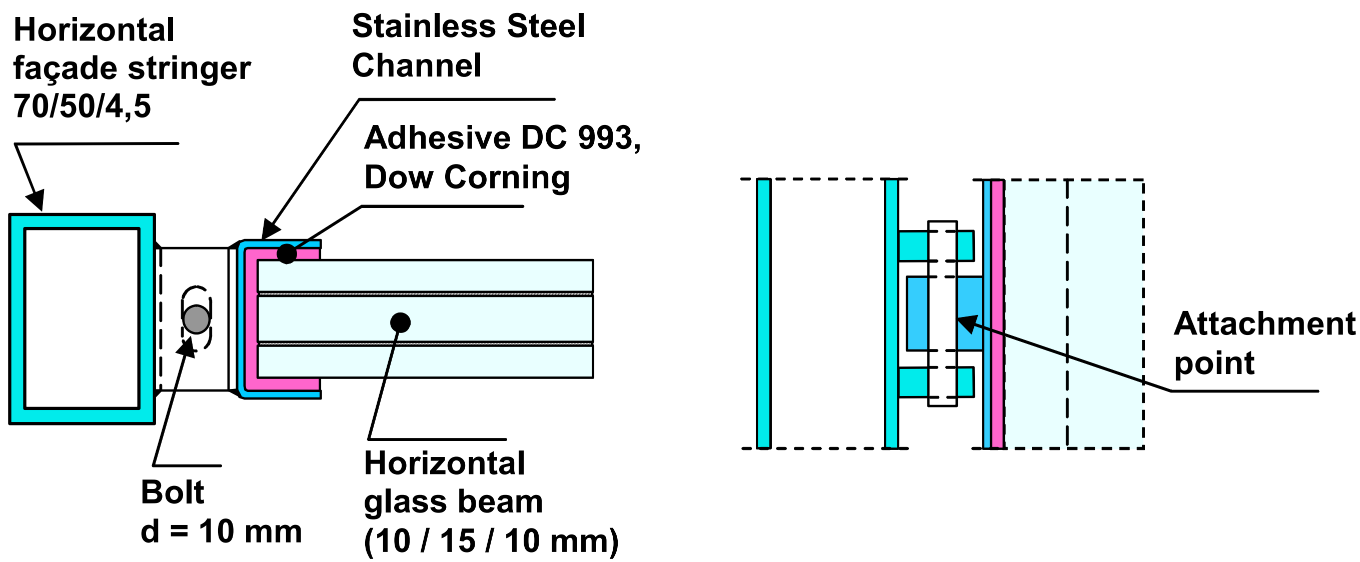
Detail of the Glass Façade





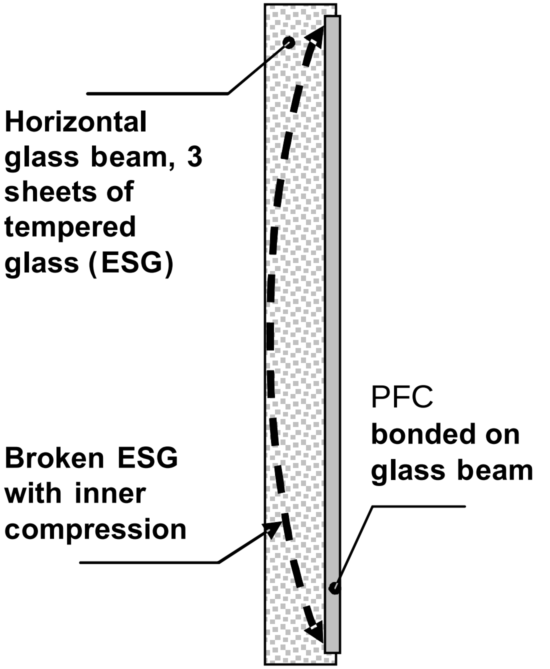
- Isolated glass units: width 3.35 m
- Horizontal glass beams: length 6.72 m
- Vertical glass beams: varying length (1.6 – 2.4 m)

Bonding Design



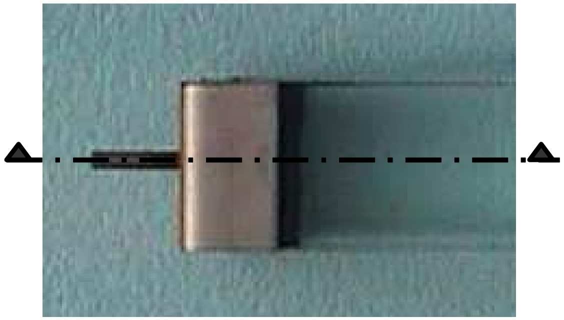
- **Three-sided bonding design of U-type geometry**
- **Selection of adequate channel type cross section for**
  - **tailoring joint regarding structural properties**
  - **protecting the adhesive against environmental influences**
- **Note: Design not covered by European guideline ETAG 002 !**

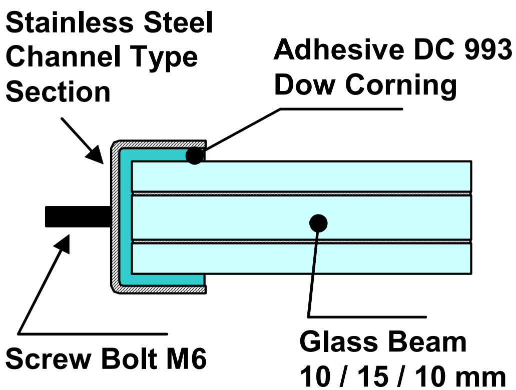
Testing of Bonded Glass Beam Structures

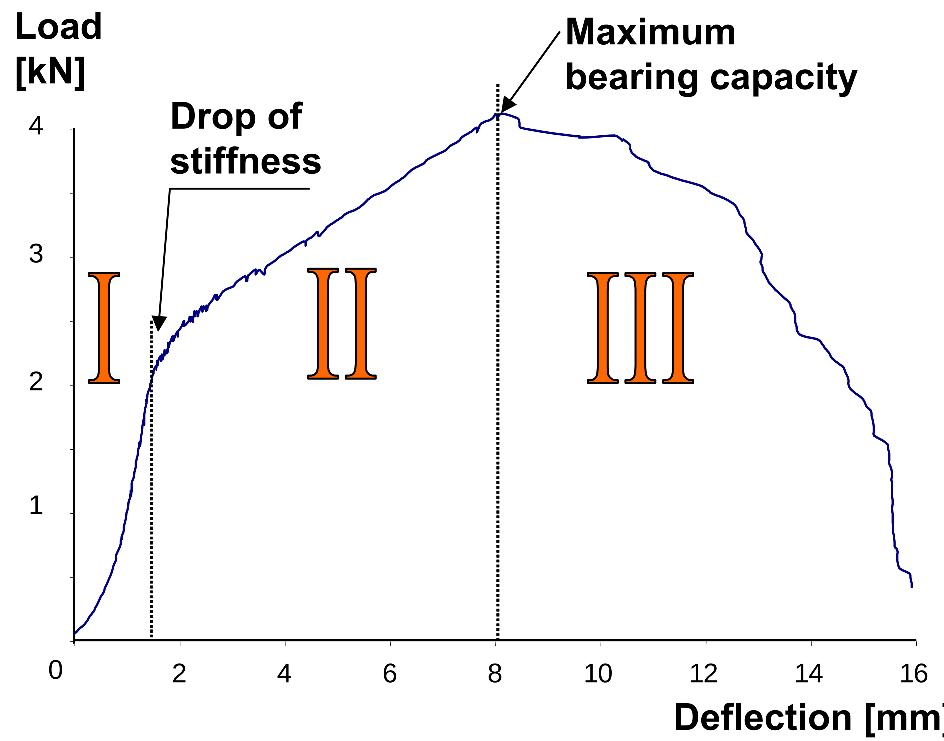


- **Favourable behaviour of glass beam elements in case of glass fracture**
  - **„Locking“ of broken parts of glass beams by inner compression**
  - **On-going provision of load bearing capabilites until repair of failed component**

Tension Testing of Bonded Glass Beam Specimens

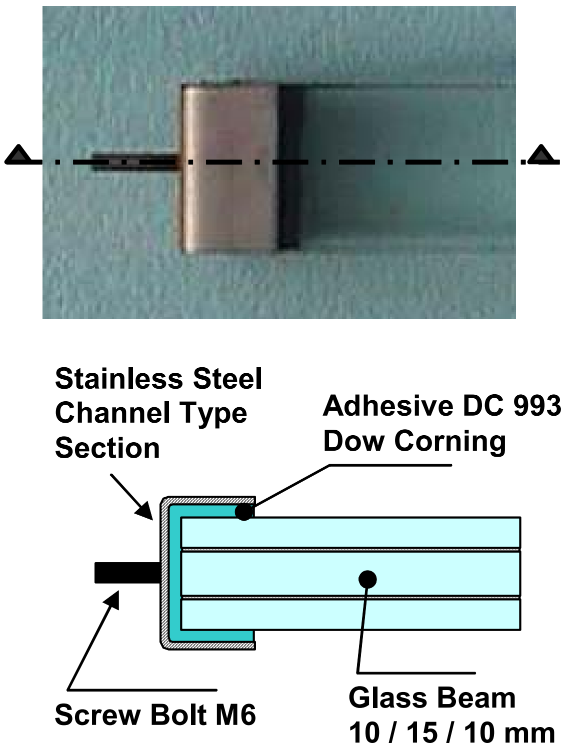


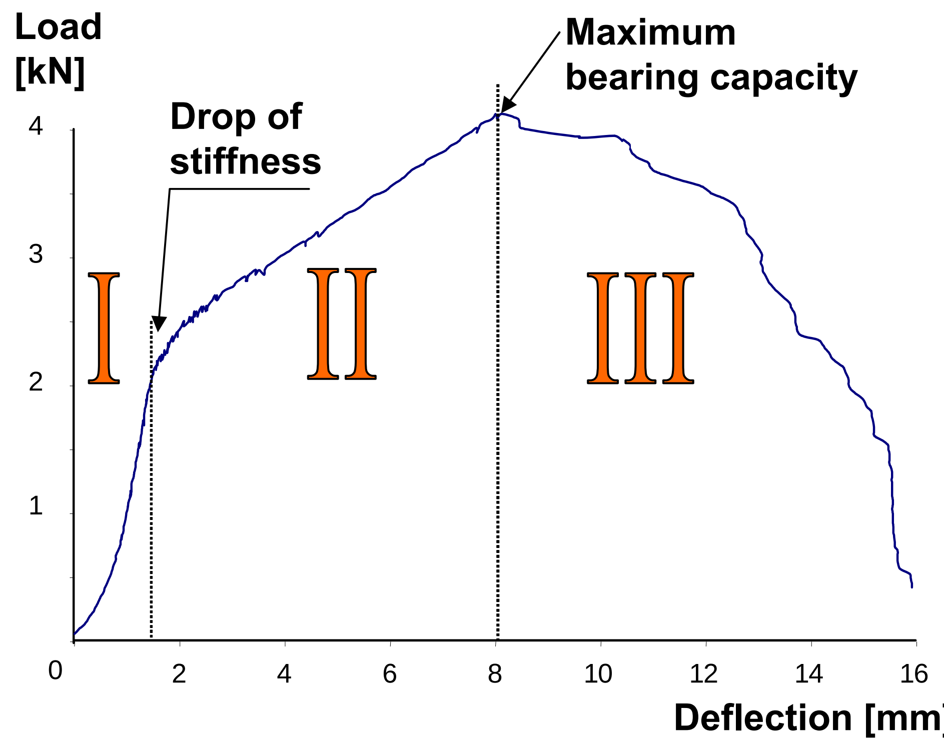




- Three different phases of load-deflection behaviour
  - Below 1.5mm (I) high stiffness of joint
  - Between 1.5mm and 8mm (II) significant drop of joint stiffness
  - Above 8mm (III) failure of the joint specimen

Tension Testing of Bonded Glass Beam Specimens

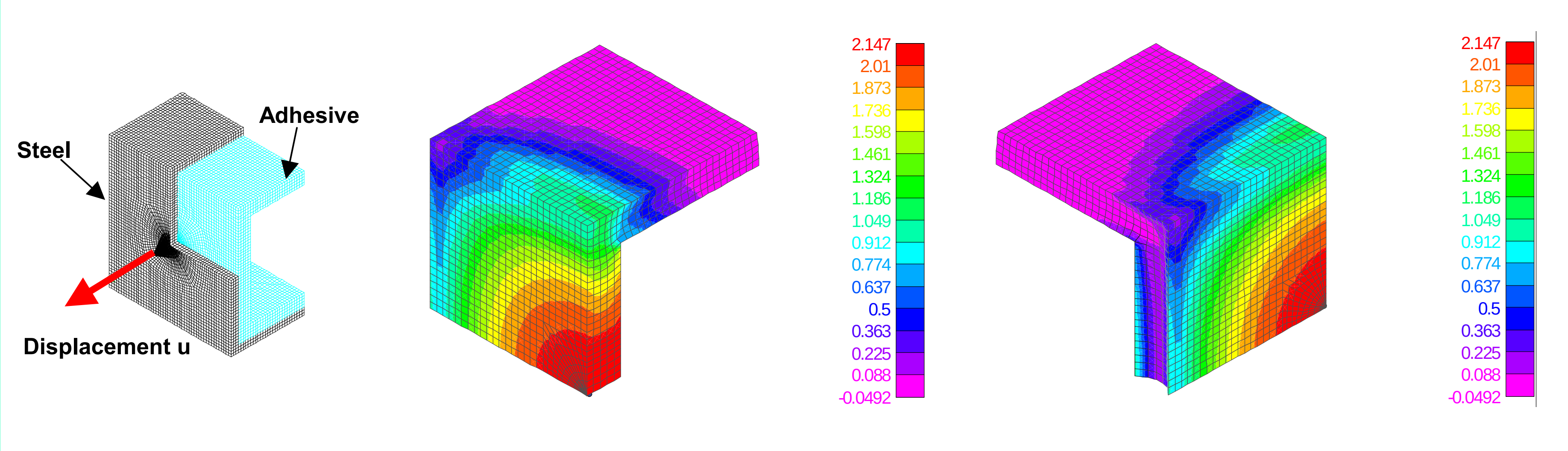




- **Full joint stiffness for phase I:** **Behaviour expected**
- **Failure by cracks in phase III:** **Behaviour expected**
- **What happens in phase II ???** **To be explained ...**

Contents

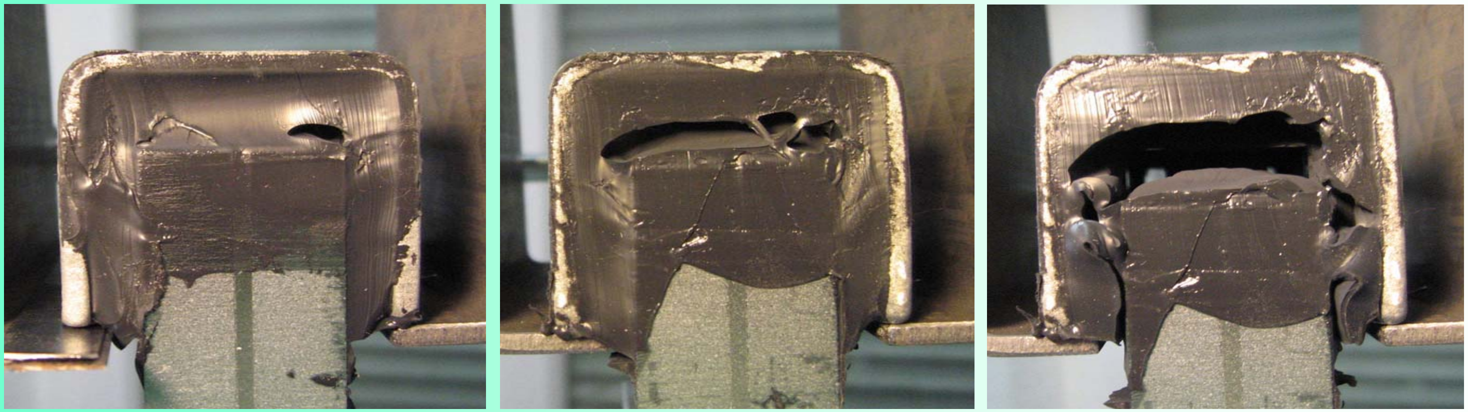
Finite Element Analysis of Bonding Specimen



- **Maximum principal stress distribution of top left quarter**
- **Load level corresponding to boundary I-II**
- **High stress levels in front region**
  - **≈ 90% load transfer by tension stress in front region**
  - **≈ 10% load transfer by shear stress in side region**
- **Load distribution due to**
  - **almost perfect incompressibility of Silicone adhesive**
  - **significant suppression of lateral contraction of Silicone in front region**

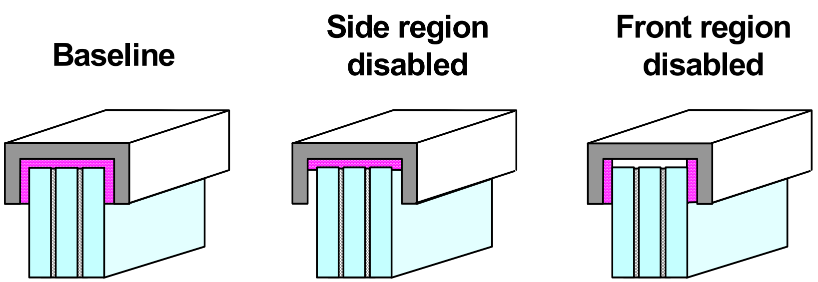
Failure Mechanism: What happens in Phase II ?

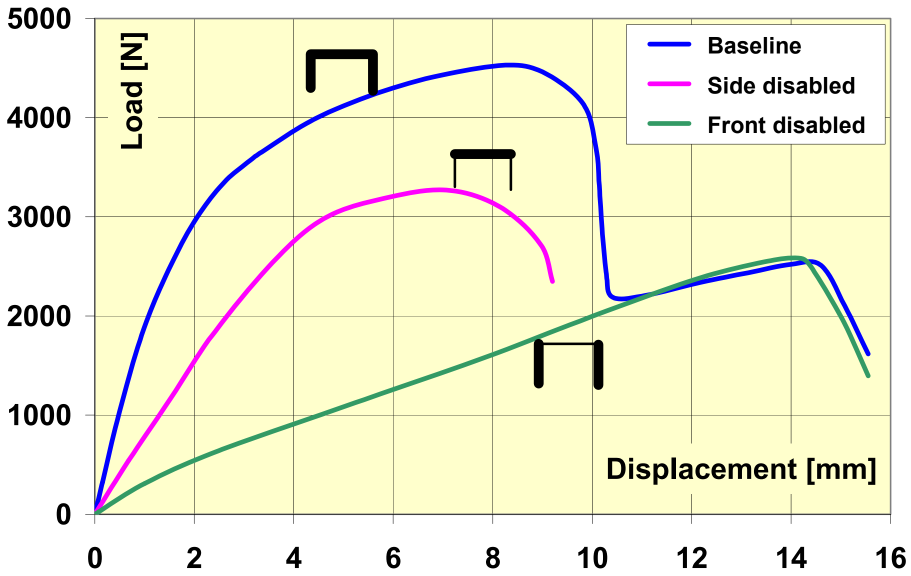
Images by GLASCONSULT, Uitikon, Swizzerland



- **Hypothesis for overloading behaviour of U-type bondings**
  - **Partial - and at the end total - failure of front region due to high stresses**
  - **Drop of total joint stiffness due to increased flexibility in front region**
  - **Load transfer shifted to undamaged side regions in terms of shear stresses**
  - **Boundary II-III in accordance to maximum shear strains experienced by ETAG specimens**
- **Final confirmation of hypothesis by experimental and numerical analysis of degraded U-type bonding geometries**

Degraded U-type Bonding Geometries



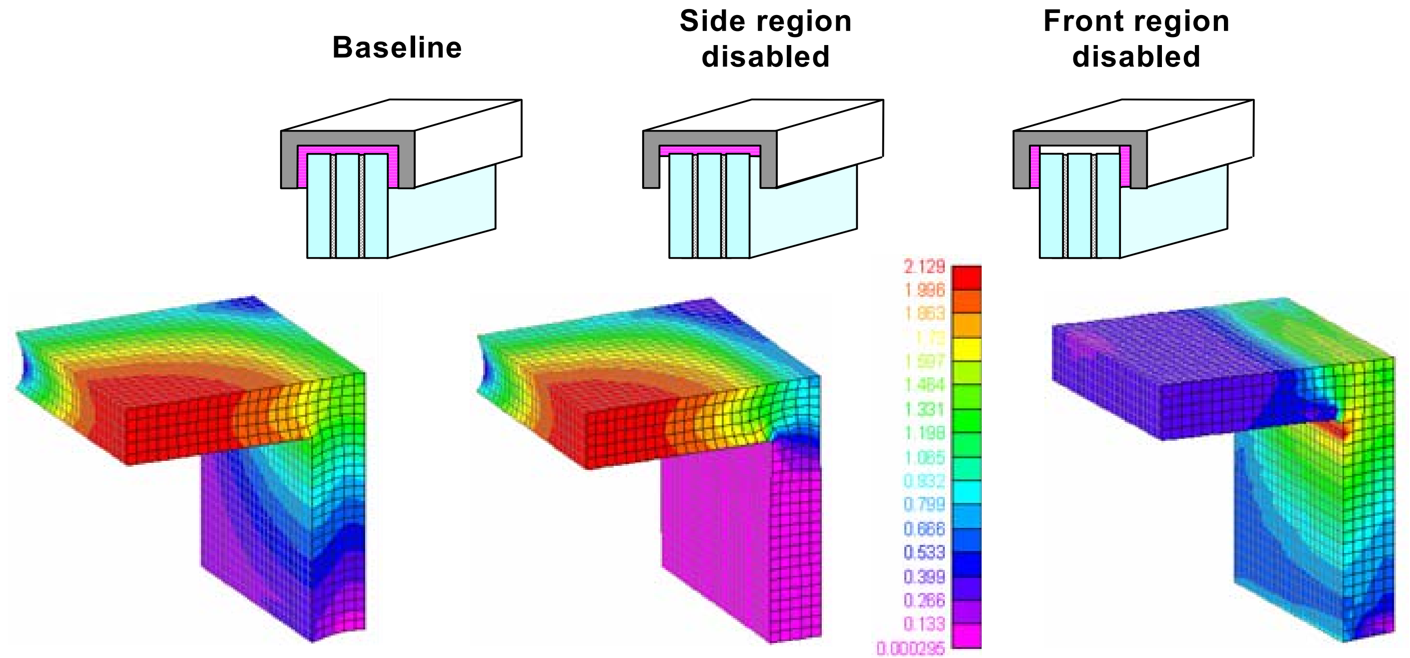


Results:

- **High initial stiffness for bondings with operative front region**
  - Initial load transfer mainly by tension in front region
- **Low stiffness for bondings with operative side region only**
  - Load transfer for large displacements mainly by shear

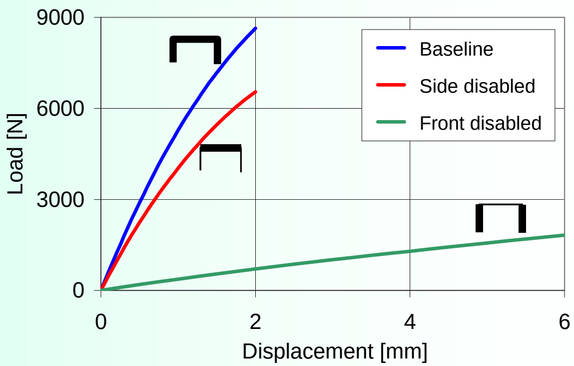
Conclusion: Failure hypothesis for U-type bonding geometries confirmed

Degraded U-type Bonding Geometries: FE Results



Maximum principal stress distributions

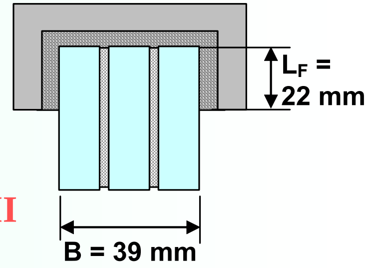
- **High stiffness for front region operative**
- **Low stiffness for operative side region only**
- **Qualitative agreement with experimental results**



Contents

U-type Bonding Geometry Parameter Variations

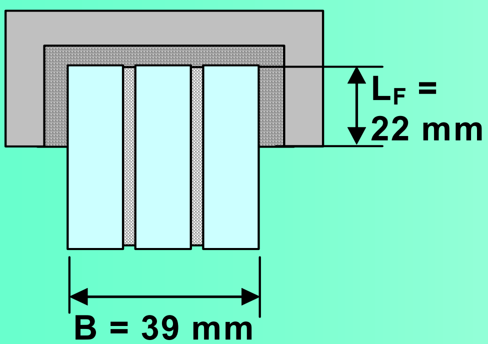
- **Three main parameters for U-type bonding geometries (cross sections)**
  - **Adhesive thickness of front and side region**
    - **Adhesive thickness typically between 5mm and 8mm for Silicone in structural glazing**
  - **Front region area defined by thickness of glass body**
    - **Glass thickness depending on sizing due to load requirements**
  - **Side region area defined by size of PFC (parallel flange channel)**
    - **Parameter for sizing of bonding geometry, determinede at end of phase II**



- **Expected impact on load bearing capacities according to previous findings**
  - **Increase of front area → Higher loads before drop of stiffness (phase I)**
  - **Increase of side area → Higher loads via shear load path (significant for phase II)**

➡ **Overall failure of the bonding affected by these design parameters**

Behaviour of Different U-type Geometries



Bonding status	Initial specimen stiffness [N/mm]	Beginning fracture		Maximum load	
		Load [N]	Displacement [mm]	Load [N]	Displacement [mm]
Baseline, 3x12 lf=22	2080	3400	2.6	4500	8.2
3x12 lf=15	1530	3200	3,0	3650	5,1
2x12 lf=15	760	3100	2,2	3400	2,7

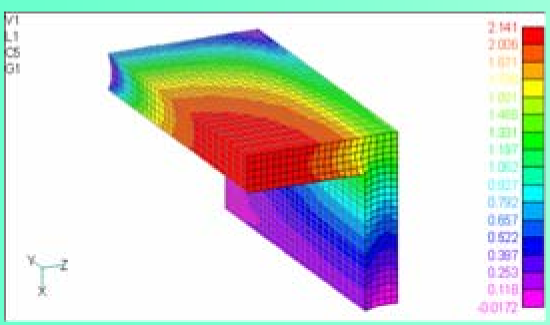
- **Expected trends qualitatively confirmed by results**

Note: **Beginning fracture corresponding to boundary I-II**

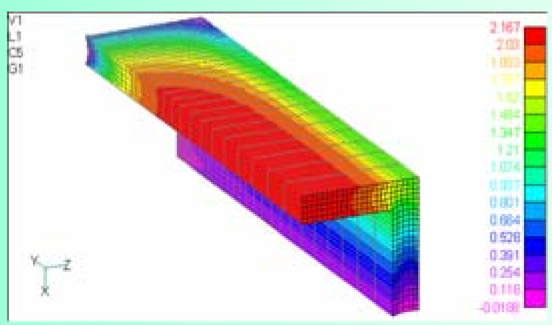
Maximum load is corresponding to boundary II-III

Role of Bonding Length / Width

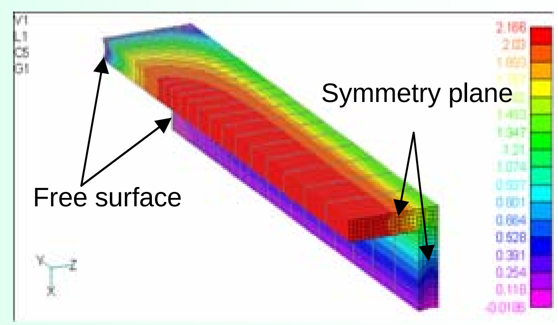
- **Significant impact of suppression of lateral contraction on mechanical behaviour for U-type bondings**
- **Level of suppression of lateral contraction is a function of bonding length**
  - **Very long bondings**
    - **Assumption of plain strain states: no strains in bonding main axis**
    - **Almost perfect suppression of lateral contraction**
  - **Very small bondings**
    - **Assumption of plain stress states**
    - **Free lateral contraction in bonding main axis**
  - **For investigated bonding geometry below (FE quarter models !)**
    - **Outer 50mm affected by free surface effects -> 3D states**
    - **For lengths larger 50mm, plain strain states can be assumed inside**



Total length 100mm



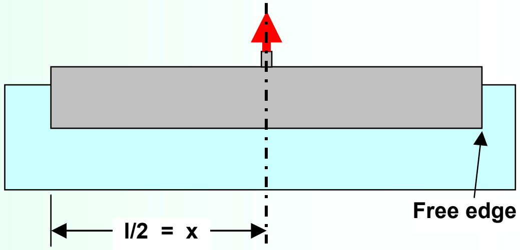
Total length 200mm

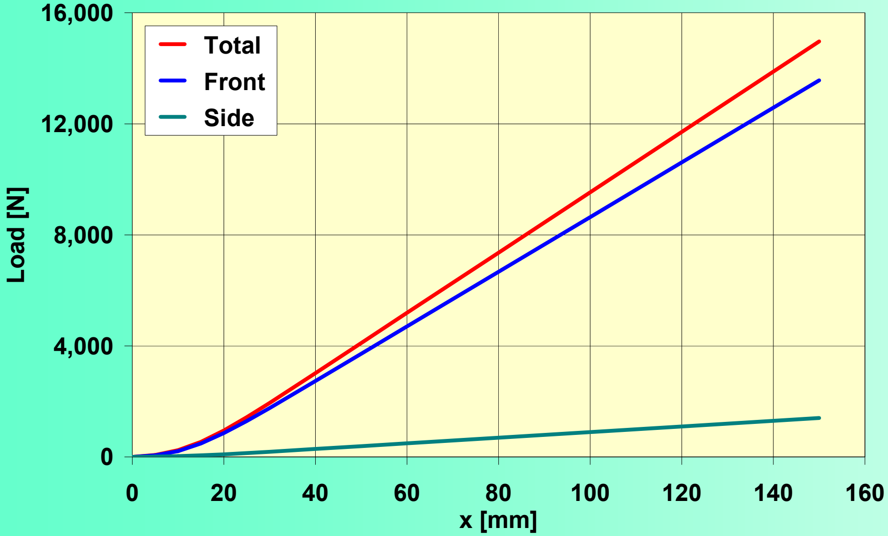


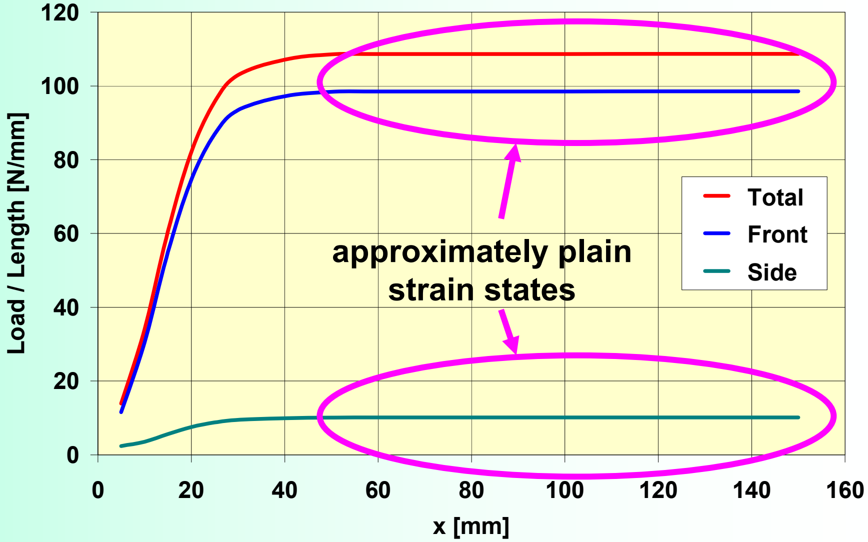
Total length 300mm

Variation of U-type Bonding Length

- **Parameter variation of U-type bonding length**
  - **Parameter x: Half bonding length due to FE model symmetry**
  - **Left figure: Total load and shares for front and side regions for half model**
  - **Right figure: Load per length for half model**







- **Results**
  - **Experimental testing with small specimen e.g. in case of Herz Jesu church is conservative !**
  - **Assumption of pure plain strain states for entire bonding is not conservative !**

Contents

Conclusions and Outlook

- **Successful application of load bearing U-type bonding to glass façade of Herz Jesu church, Munich**
- **Detailed analysis of load transfer and failure mechanism of U-type bonding geometries by experimental and numerical means**
  - **Very high loading of front region due to**
    - **almost perfect incompressibility of Silicone**
    - **suppression of lateral contraction by bonding geometry**
- **Impact of front and side regions on mechanical bonding properties identified by**
  - **Investigation of configurations with different degradations**
    - **Baseline**
    - **Side regions disabled**
    - **Front region disabled**
  - **Investigation of configurations with different geometries**
    - **Different glass thickness**
    - **Varying side regions**
- **Set-up of related design rules and analysis of 3D effects on the free surface allowing the estimation of efficiency loss**

End