Connective opportunities of reinforced glass segments

Design and validation of an edge-integrated connection for beam segments

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- Structural glass
- Research focus

Design
- Segmented reinforced beam
- Transfer of compressive and shear force
- Transfer of tensile force
- Performance

Validation
- Prototypes
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Structural glass:

Using glass as a structural material, for beams, columns and shear walls for example.

- Why would you use glass?
- What about safety?
Why would you use glass?

Apple cube 1, 2006

Apple cube 2, 2011
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Apple cube 1, 2006
Apple cube 2, 2011
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What about safety?

Risk = Chance \times Consequences

Glass is brittle, so the consequences of failure are large.

To compensate, the chance has to be very small.

It would be better to focus on decreasing the consequences.
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By bonding a steel section in the edge of the beam, safe failure behavior can be achieved.
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3 options for 6+ meter beams:

- Segmented beam

- Splice laminated beam

- Continuous beam
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Segmented beams have many advantages

- Easy to produce
  - Standard size glass panes
  - Standard size equipment
  - Standard size autoclave

- Easy to transport
  - Standard size truck

- Not bound to linear geometries
Despite these advantages, architects avoid the use of segments.

The key reason to use glass beams is transparency, but the connection between beam segments reduces the transparency.
Opportunity

Reinforcement seems to offer the opportunity for a highly transparent, edge-integrated, connection for beam segments.
A metal section is not transparent, but by integrating it in the opaque looking edge, it hardly reduces the transparency.

<table>
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<td>36%</td>
<td>18%</td>
<td>0%</td>
<td>0%</td>
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</tbody>
</table>
Research question:
• How to connect reinforced glass beam segments, in an edge-integrated way, in order to obtain a highly transparent connection?

Sub questions:
• What kind of glass beam segments need to be connected?
• How are glass beam segments currently connected?
• How to transfer compressive, tensile and shear force, between the edges of the segments?
• How does the designed connection performs?
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Design

• Segmented reinforced beam

• Transfer of compressive and shear force

• Transfer of tensile force

• Performance
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Research on reinforced glass beams

Result: Beam of 18 meters, consisting of 3 segments of 6 meters
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Transfer of compressive and shear force
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Design

To transfer the compressive and shear force, there is chosen for an edge integrated profile.

Frontview

Topview

Section A A’
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How to deal with large dimensional tolerances of glass?

Ideal connection

Result of tolerances
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Design

- Splitting the profile

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Compressive & shear

- Leveling after lamination
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Design

Material for profile

- Aluminum & polycarbonate
- Young’s modulus of glass is 70 GPa

Aluminum  $E = 70$ GPa

Polycarbonate  $E = 2.5$ GPa
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Design

Autoclave lamination

- Cooling down from 130 °C to about 20 °C
- Thermal expansion of glass is 9 μstrain/°C

Compressive & shear

Aluminum  CTE = 23 μstrain/°C

Polycarbonate  CTE = 65 μstrain/°C
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Transfer of tensile force
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Concept

Internal pin, bolted to the bottom of the square hollow section
The tensile force has to be transferred over a large length and by many bolts, to transfer it very gradually.

But, due to the effect of unequal strain, the first bolts will transfer most of the force.

To equally divide the force over the bolts, the bolts are loaded at their yield strength. It limits the amount of force they transfer.
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Design

Tensile force

- 50 x stainless steel M6 bolts

Coupling pin, made of tungsten heavy alloy
Performance of the total connection

The performance is based on three criteria:

- Transparency
- Strength
- Stiffness
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Design

Performance

Strength

Continuous beam

Segmented beam

**Strength**

![Graph showing stress in glass](image)

Legend:
- Segmented
- Continuous

**Strength**

**Continuous beam**

**Segmented beam**
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Design Performance

Stiffness

Continuous beam

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Validation Prototypes

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<thead>
<tr>
<th>Original</th>
<th>Prototype 1</th>
<th>Prototype 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 - 10 - 5 mm glass</td>
<td>10 - 10 mm glass</td>
<td>8 - 8 mm glass</td>
</tr>
<tr>
<td>10x10x1.0 mm steel</td>
<td>15x15x1.5 mm steel</td>
<td>20x20x2.0 mm steel</td>
</tr>
</tbody>
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**Performance**

Unfortunately, safe failure behavior was not achieved.

Partly because the glass did not fail at the expected load, probably due to the small scale and the reproduction.

Partly because the strength of the connection is limited by the used approach of loading the bolts at their yield strength.

To reach safe failure behavior with the used approach, the difference between the design and actual strength should be as low as possible. The difference between the yield and ultimate shear strength should be as high as possible.
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Research question:
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Compressive & shear force

Aluminum strips

Tensile force

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Based on the results, the connection performs quite well, and further improvement seems to be possible.

More research and testing is necessary, but for now the concept of an edge integrated connection seems to be feasible.

Transparency is quite a subjective criteria, but it is likely this connection is more transparent than the existing connections.

It is expected a connection like this makes the use of segmented beams more attractive for architects.
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