Combination of timber, CFRP and GFRP for the design and construction of a bowstring arch bridge

Robert Widmann
Urs Meier

Rolf Brönnimann, Empa
Philip Irniger, Dr. Deuring + Oehninger AG
Andreas Winistoerfer, Carbo-Link AG
Basic Parameters

### Material

<table>
<thead>
<tr>
<th>Material</th>
<th>$E$</th>
<th>$\rho$</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glulam GL24h (EN 1194)</td>
<td>11.5</td>
<td>455</td>
<td>$f_m,g,k = 24$ at $u = 12%$ (measured) $f_{c,0,k} = 24$</td>
</tr>
<tr>
<td>CFRP</td>
<td>150</td>
<td>1500</td>
<td>$f_t = 2000$</td>
</tr>
<tr>
<td>GFRP</td>
<td>44.5</td>
<td>2000</td>
<td>$f_c = 900$</td>
</tr>
</tbody>
</table>
Pin-loaded CFRP Straps as tendons

Continuous, thermoplastic CFRP tapes

Thickness \( t \approx 0.12 \text{mm} \)

Min. radius \( r \approx 25 \text{mm} \)
Lateral Prestressing

Principle
Tensioning of the bow
Tensioning of the bow
Tensioning of the bow
Load Tests
Load Tests
Load Tests

65 Hz
Fundamental Frequency of a vibrating string

\[ f = \frac{1}{2 \cdot \ell} \cdot \sqrt{\frac{F}{\rho \cdot A}} \]

\[ F = 4 \cdot \ell^2 \cdot f^2 \cdot \rho \cdot A \]

\[ F = 4 \cdot 3.00^2 \cdot 65^2 \cdot 1500 \cdot (0.03 \cdot 0.004) = 27.4 \text{kN} \]

<table>
<thead>
<tr>
<th>Step</th>
<th>Load</th>
<th>Mean deflection</th>
<th>Mean tension force</th>
<th>Accumulated tension force</th>
<th>Tension from static calculation</th>
<th>Deflection from static calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kN</td>
<td>mm</td>
<td>kN</td>
<td>kN</td>
<td>kN</td>
<td>mm</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>149</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>8.5</td>
<td>6.54</td>
<td>23.8</td>
<td>143</td>
<td>208</td>
<td>18.7</td>
</tr>
<tr>
<td>2</td>
<td>17.2</td>
<td>14.1</td>
<td>26.6</td>
<td>160</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>25.6</td>
<td>20.8</td>
<td>29.4</td>
<td>176</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design load</td>
<td>4/m²</td>
<td></td>
<td></td>
<td>405</td>
<td>83.1</td>
</tr>
</tbody>
</table>
Side-Topic: Monitoring while passing by....
Monitoring with iphone or….

- iAnalyzer or similar App
- Indicates peaks in spectrum
- Has to be corrected for mic-response

- e.g. here for 65.1Hz: 88.7dB + 25dB ≈ 114dB
Monitoring with iphone or....(continued)

- Context Log, AccelPro or similar App
- Indicates and records x,y,z accelerations
- Data can be exported to a PC
- Analysis e.g. with MS-Excel

- e.g. here: $f_0 \approx 4.5\text{Hz}$, $\zeta \approx 1.2\%$
More Monitoring

For details: see e.g. Brönnimann et al: ICTB 2010 publication
Weak points / Potential for improvements

- Anchorage of railing posts
  - Not tight
  - Lokaly and temporarily increased MC of timber

- Decking
  - Slippery when wet and/or frozen
  - Sanding not sufficient

- Timber bridge deck
  - Cup deformations due to MC gradient
  - T > 80°C under decking in summer
Conclusions

- Pedestrian bridge made exclusively of glulam structural timber, CFRP and GFRP at the Empa site in Duebendorf, Switzerland.

- Lateral and longitudinal prestressing of the bridge with CFRP loop straps

- Load tests confirmed a superior stiffness of the system.

- Bridge in place since 2007 and since then continuously monitored

- From the advantages of the construction like lightweight structure, high stiffness, prevention of corrosion problems, easy installation, good value and an expected long service life, a good market potential for such structures can be expected.
Thank you

- Urs Meier, Empa
- Rolf Brönnimann, Empa
- Philip Irniger, Dr. Deuring + Oehninger AG
- Andreas Winistoerfer, Carbo-Link AG
- Bafa

and YOU for your attention