HISTORICAL REVIEW OF MEASUREMENTS USING INVAR WIRES IN SERBIA

Siniša Delčev
Vukan Ogrizović
Jelena Gučević

University in Belgrade
Faculty of Civil Engineering
Department of Geodesy and Geoinformatics

The idea

- W. Snellius (1615)
- Piccard
- Triangulation
- Short, directly measured lengths
- How to achieve accuracy requested for 1st order triangulation networks?
How did it begin

- Measuring tapes
- Metal chains
- Wooden staffs

Huge step forward

- Jäderin basis apparatus (1880)
  - Advanced metal chain
  - Streching mechanism
  - Made of iron (24 m long with weights on both sides)
  - 60 cm high tripods
  - Rulers for reading on both sides
- Drawback:
  - Large temperature coefficient
Invention of invar (1896)

- René Benoit & Charles Edouard Guillaume

- FeNi36 – alloy of:
  - Steel: 63.3%
  - Nickel: 36%,
  - Traces of Manganese and Carbon

- Thermal expansion coefficient: $1.2 \times 10^{-6} \, K^{-1}$
  ($1.2 \, \text{ppm/°C}$)

Serbian 1st order trigonometric network (TNS)

- Militar Geographishen Institut (1872)
  - Chain of triangles, divided into parts
  - Each part → network datum

- Geodetic Institut of Serbian Kingdom (1887)
  - Paraćin basis

- Vojno-geografski institut - VGI (1899)
  - Horizontal angles
  - Baselines
  - Astro-geodetic determinations (30 points)
TNS – Epoch 1900-1927

General Stevan Bošković

- The head of VGI
- Well known of his astro-geodetic determinations
- He provided a Carpentier set with invar wires from France
- S/Ns: „0“, A26, and A30
Measurements

- Eight baselines in total
- The baselines fixed with stone pillars
- One „operational“ and two „testing“ wires
- Speed: 5.6 km of Paračin baseline measured in 4 days

<table>
<thead>
<tr>
<th>Name of network</th>
<th>D b-line. [km]</th>
<th>D exit b-line [km]</th>
<th>Year</th>
<th># of wires</th>
<th># of mea.</th>
<th>Rel. b-line err 1:</th>
<th># of pts.</th>
<th># of dirs.</th>
<th># of Paras in 5,60 36,61 1904. 1(1) 2</th>
<th>938 000</th>
<th>8</th>
<th>40</th>
<th>22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parācin</td>
<td>5.60</td>
<td>36.61</td>
<td>1904.</td>
<td>1(1)</td>
<td>2</td>
<td>938 000</td>
<td>8</td>
<td>40</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negotin</td>
<td>4.66</td>
<td>33.99</td>
<td>1904.</td>
<td>1(1)</td>
<td>2</td>
<td>910 000</td>
<td>7</td>
<td>38</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vranje</td>
<td>4.97</td>
<td>32.03</td>
<td>1904.</td>
<td>1(1)</td>
<td>2</td>
<td>1 076 000</td>
<td>6</td>
<td>22</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loznica</td>
<td>5.03</td>
<td>35.21</td>
<td>1904.</td>
<td>1(1)</td>
<td>2</td>
<td>1 034 000</td>
<td>8</td>
<td>42</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prizren</td>
<td>5.38</td>
<td>27.67</td>
<td>1922.</td>
<td>1(5)</td>
<td>2</td>
<td>1 037 000</td>
<td>6</td>
<td>30</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strumica</td>
<td>6.62</td>
<td>34.27</td>
<td>1922.</td>
<td>1(5)</td>
<td>2</td>
<td>1 106 000</td>
<td>8</td>
<td>42</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prilep</td>
<td>5.98</td>
<td>48.14</td>
<td>1922.</td>
<td>1(5)</td>
<td>2</td>
<td>1 316 000</td>
<td>8</td>
<td>44</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sjenica</td>
<td>5.57</td>
<td>36.62</td>
<td>1924.</td>
<td>1(5)</td>
<td>2</td>
<td>798 000</td>
<td>9</td>
<td>48</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Early days of metrology

- All wires calibrated in Paris
- Length and temperature expansion
- Certificates of calibration still exist

Institute of Geodesy measurements

- Suspicion in the results: possible gross errors in basis networks
- Reconstruction of Paraćin basis (81 instead of 3 pillars – 8 x 24 m, 3 x 192 m, 9 x 480 m & 1 x 504 m) and re-measurement
- Taken into account:
  - Deviation of the wire length from the nominal value
  - Change of the length due to temperature diff.
  - Non-symmetry of the catenary
  - Inclination of reading scales
  - Reduction to the horizon
Results

- 1 dm error in the first measurement found
- => 1 m error in the exit baseline
- The error confirmed later, by direct measurements

Conclusion & remarks

- The work of Jäderin and Snellius made the (indirect) measurement of lengths in trigonometric networks possible
- Thanks to Gen. Bošković’s efforts and connections, Kingdom of Serbia obtained the invar wires
- Applied principle sensitive to outliers, due to low reliability
Thank you for your attention

University in Belgrade
Faculty of Civil Engineering
Department of Geodesy and Geoinformatics

Dr Siniša Delčev, associate professor
delcev@grf.bg.ac.rs

Dr Vukan Ogrizović, assistant professor
vukan@grf.bg.ac.rs

Dr Jelena Gučević, associate professor
jgucevic@grf.bg.ac.rs