HISTORICAL REVIEW OF MEASUREMENTS USING INVAR WIRES IN SERBIA

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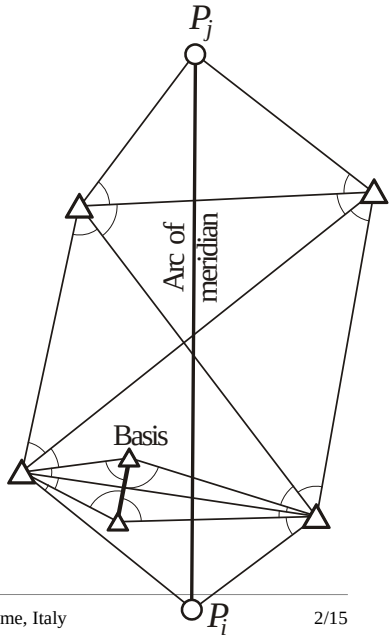
The idea

- 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***

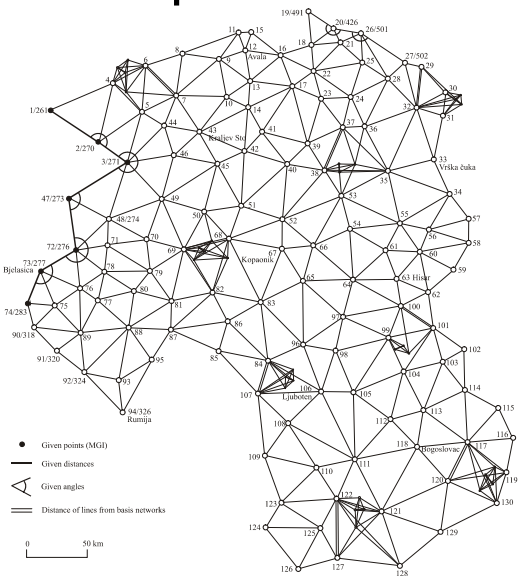
Invention of invar (1896)

- René Benoit & Charles Edouard Guillaume
- ***FeNI36 – alloy of:***
  - ***Steel: 63.3%***
  - ***Nickel: 36%,***
  - ***Traces of Manganese and Carbon***
- ***Thermal expansion coefficient: $1.2*10^{-6}$ K^{-1} (1.2 ppm/°C)***

Serbian 1st order trigonometric network (TNS)

- Militar Geogräphishen 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 Paraćin baseline measured in 4 days

Basis networks in numbers

Name of network	D b--line. [km]	D exit b.line [km]	Year	# of wires	# of mea.	Rel. b-line err 1:	# of pts.	# of dirs.	# of
Paraćin	5,60	36,61	1904.	1(1)	2	938 000	8	40	22
Negotin	4,66	33,99	1904.	1(1)	2	910 000	7	38	23
Vranje	4,97	32,03	1904.	1(1)	2	1 076 000	6	22	8
Loznica	5,03	35,21	1904.	1(1)	2	1 034 000	8	42	26
Prizren	5,38	27,67	1922.	1(5)	2	1 037 000	6	30	16
Strumica	6,62	34,27	1922.	1(5)	2	1 106 000	8	42	24
Prilep	5,98	48,14	1922.	1(5)	2	1 316 000	8	44	28
Sjenica	5,57	36,62	1924.	1(5)	2	798 000	9	48	27

Early days of metrology

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

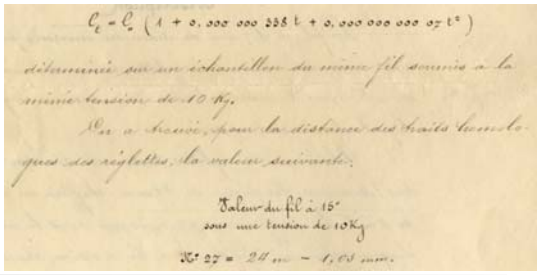

BUREAU INTERNATIONAL DES POIDS ET MESURES

CERTIFICAT

d'un fil en invar

appartenant

au Service Géographique de l'Armée Serbe


$l_t = l_0 \left(1 + 0,000\,000\,538\, t + 0,000\,000\,000\,07\, t^2\right)$

déterminé sur un échantillon du même fil soumis à la même tension de 10 Kg.

Pour la distance des traits terminaux des règlettes, la valeur suivante:

Valeur du fil à 15°
sous une tension de 10 Kg

$15°,27 = 24\,m. - 1,65\,mm.$

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-summetry 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

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