APPLICATION OF PRECISE DISTANCERS AND GPS RECEIVERS FOR LENGHT DETERMINATION AND KRAKOW-LOCATED „WISŁA" CALIBRATION BASELINE STABILITY CONTROL

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1. „WISŁA" CALIBRATION BASELINE

The baseline comprises rectilinear section of the right Vistula river flood embankment in Bodzów, which actually belongs to Podgórze district of Krakow city. Currently used baseline is a second one. The first was installed in the middle of the flood embankment crown. The baseline comprises 24 pillars located in line and one additional point located on the left river bank, on its elongation toward E direction. During the flood embankment renovation the baseline was destroyed and the new object has been built in this place. The new baseline was built in the period 1996-1999, according to building permission issued by the City Council. The new baseline is located on the flood embankment external side. The baseline is located in E-W direction and comprises 20 pillars (Fig. 1), and its total length amounts for 1230 m. The points are stabilized with steel pipes of 30 cm diameter and length amounting for 8 m, corresponding to the flood embankment height. The pipes are filled with concrete and they are equipped with thermal shield in form of a water supply system pipe.

Fig. 1. „Wisła" testing baseline – view from point „0" toward the E direction.

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Possibly best manner of forced instrument alignment, i.e. Kern's tower tribrach, have been applied. (Fig.2). Kern/Leica GDF21K indirect tribrach (connected with three pins) were used for alignment of Wild's system instruments. The tribrach is equipped only with two adjustment screws, what means that the instrument or reflector height in given point is not changed. On each pole, the tribrach is set in such manner that the adjustment screws are located along the baseline. Only two suitably marked tribrachs are applied: one for instrument and the second one to reflector. Alignment of the Zeiss system instruments is executed via additional intermediate ring.

Fig. 2. Head of the baseline pole with Kern forced alignment.

2. LENGTH MEASUREMENT

2.1. Measurement with use of Di/TC 2002 precise distancers

Two measurement cycles executed in 7 month intervals will be discussed in the present study; it is interesting that from this point of view that Vistula river reached high water table level resulting in flood within the region of Sandomierz and Opole Lubelskie. The first testing measurement of the baseline length was executed in the day 7.04.2010 in good atmospheric conditions (full cloud cover, temperature 8.5 – 10.4 C). Wild/Leica T2002 nr 346328 set was made with Di2002 attachments No. 180231 and 180650. Only one suitably marked GPH1AP precise reflector and one checked Wild/Leica GRZ3 plummet, and suitably prescribed to instrument and reflector Leica GDF21K tribrachs, have been applied in the measurement. GPH1AP reflector is applied only to Di2002 distancer attachment.

Second measurement cycle was executed in the day 22.11.2010 with use of TC2002 tachymeter No. 358534 with reflector GPH1P, in conditions similar as in case of the first cycle. On the basis of comparison of lengths measured with use of field distancers with laser interferometer HP 5529A and measurements executed in laboratory, cyclic errors occurring during the measurements have been proved (Szczutko 2007).

The temperature in the testing stand is measured with use of psychometer of the finest scale grade of 0.2 ºC. Theoretically the temperature can be red with accuracy

of 0.1 ºC. The temperature is red in shade, air circulation is forced with use of propeller with electric motor. Bertrand aneroid is used for pressure measurement with accuracy of 0.1 mmHg. Both instruments are checked with use of temperature and pressure sensor, which are components of the HP 5529A – HP 10751C laser interferometer system. Air humidity/water content was measured with use of electronic hygrometer LB-755. Stability of standard frequency was controlled during the measurement with use of precise frequency measuring instrument HP 53131A. In order to calculate current lengths of the baseline with reference to initial point, measurement from three points located at the beginning (0), and (19) and in the middle of the baseline (11) to all other points. It gives combination of 57 measured lengths. Each length is red five times. At the same time, horizontal directions and zenith angles are stored in the tachymeter memory in order to determine spatial position of the baseline points and then their stability assessment.

2.2. Measurement of chosen baseline lengths with use of GPS set

Measurement with use of static GPS method allows calculation of the length vector length with accuracy below 1 mm. Because of possible shift of the phase center of receivers, systematic errors, which are essential for the measurement result, can occur. The errors can be eliminated in two ways:

- **making two measurement sessions on the same points; after the first session receivers are turned over with 180 (Solarić et al., 2008),**
- **measuring the baseline sections in all combinations (from each point into the all others toward the front) at the same setting of the receivers shields with reference to the baseline (Fig. 3) and the same setting sequence.**

The first method can be used in flat networks (XY) or spatial networks (XYH), whereas the second one only for baseline measurement (points are distributed in line, single-dimension space X).

GPS measurement, which should assure baseline scale control, was executed with use of the second of mentioned methods, with use of five measuring points 0, 7, 11, 15 and 19. Number of sessions of length measurement in combination for five points is 10. Measurement of all points, taking into consideration elimination of antenna zero errors could not be economically and technically reasonable (too long measuring time). The measurement was made with use of pair of Topcon HiperPro receivers. The receiver marked as „Baza" was placed always in eastern point of the vector, whereas „Rover" was placed in western point. The session duration was set for 90 minutes. Vector length measurements were executed with use of Topcon Tools v. 7.2 program, taking advantage of GPS and GLONASS satellite observations, 15 over the horizon. The measurement was executed in the days 10-16.04 and 17-22.11.2010.

Fig. 3. Topcon HiperPro receiver on GDF21K tribrach – point „0”.

3. MEASURING RESULT CALCULATION – LENGTH EQUALIZATION

The present work is aimed at calculation of standard lengths via equalization of a set of lengths measured with elimination of systematic error, i.e. additive constant of a set distancer-reflector.
There are two possible procedures of this task realization:

- **Length measurement with calculation of additive constant of a set distancer-reflector, or pair of GPS receivers as unknown in equalization process with use of self-calibration method (Schwendener, 1972),**
- **Length measurement with use of distancer or GPS set, for which the additive constant and equalization of observations (as for angular-linear network) is determined in separate measurement.**

Finally, the baseline lengths were calculated with reference to initial point „0”, and Schwendener's method was used in calculations.

3.1. Mathematical calculation model in Schwendener's method

Equations of measured lengths have the following form:

$$D_{ij} + v_{ij} + c = X_j - X_i \qquad (3.1)$$

where:

D_{ij} **– length measured between points i,j**
v_{ij} **– length correction**
c – Additive constant of the set distancer-reflector
X_j, X_i **– point coordinates calculated from initial point along the base line**

Correction equations have following form:

$$v_{ij} = - c - D_{ij} + X_j - X_i$$

In order to reduce numerical error in the calculation process the following equations in modified form are used:

$$v_{ij} = - c - D_{ij} + X_{0j} + dX_j - X_{0i} - dX_i$$
$$v_{ij} = - c - dX_i + dX_{0j} - D_{ij} + X_{0j} - X_{0i} \qquad (3.2)$$
$$v_{ij} = - c - dX_i + dX_j - l_{ij}$$

where:

X_{0i}, X_{0j} – approximate lengths, for example lengths from previous baseline
dX_i, dX_j – coordinate increments (unknown)
l_{ij} – absolute term

Unknown c and dX are calculated in equalization process and then coordinates X i.e. current baseline lengths are calculated as standard values for testing low-precise distancers.

3.2. Results of measurements

Comparison of averaged results of measurements with use of two distancers Di2002 and GPS from April and TC2002 and GPS from November 2010 are shown in Table 1.

Tab. 1. Comparison of measurement results with use of distancers and GPS

Pillar number	April 2010				November 2010			
	Length measured with use of distancer Di2002	Measured length GPS	D Di2002-GPS	D reduced.	Length measured with use of distancer Di2002	Measured length GPS	D Tc2002-GPS	D reduced
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
0	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.04
1	25964.08				25964.33			
2	39264.02				39264.76			
3	51890.53				51890.81			
4	77846.12				77846.12			
5	155586.94				155587.22			
6	233299.38				233299.39			
7	311132.00	311132.04	-0.04	0.01	311132.19	311132.10	0.09	0.13
8	388882.21				388882.34			
9	466529.40				466529.42			
10	544334.14				544334.30			
11	622083.28	622083.29	-0.01	0.04	622083.25	622083.32	-0.07	-0.03
12	699849.20				699849.13			
13	777637.82				777637.78			
14	855349.46				855349.58			
15	933115.50	933115.55	-0.05	0.00	933115.86	933115.96	-0.10	-0.06
16	1010774.01				1010773.94			
17	1088575.31				1088575.40			
18	1166290.98				1166291.05			
19	1230046.93	1230047.07	-0.15	-0.10	1230047.05	1230047.16	-0.11	-0.07
		Average =	-0.05			Average =	-0.04	
Cons-tant c (mm)	Di2002 nr 180231 - 0.56 ± 0.04 Di2002 nr 180650 - 0.75 ± 0.05		GPS HiperPro - 0.56 ± 0.28		TC2002 nr 358534 + 0.80 ± 0.04		GPS HiperPro - 0.25 ± 0.08	

Current lengths from point „0” and differences between them for corresponding points, have been gathered. Assuming that point „0” could also change its position, reduced

shift was calculated subtracting average value D from each difference. Comparison of results of measurements executed in April and November 2010 proves similar compatibilities, both for measurement with use of distancer and GPS and in scope of the same methods.

Constants calculated in equalization process are gathered in the last line of Table 1. Difference in calculation of the set constant of two receivers Topcon HiperPro results from the fact that in November 2010 another type of plummet was used under receiver „Rover". It means that individual elements of the measuring accessories are different what is essential for measurements of the baseline. Averaged observation errors after equalization, which allow assessment of reliability of the obtained length differences between measuring methods and between the cycles, are gathered in Table 2. Scale error calculated on the basis of length differences distancer-GPS for measuring cycles are not bigger than 0.1 ppm.

Comparison of length calculated with use of distancers and GPS from both measurements are shown in Table 3 and Fig. 4. Compatibility of measurements made with use of distancers and GPS is evident. Difference ± 0.2 mm was assumed as a criterion of stability of individual points. It is seen from diagram and table, that essential length changes (0.69 and 0.31 mm) occurred only for two baseline points. The results should be verified in next baseline measurements.

Tab. 3. Comparison of lengths between measuring cycles

Pillar number	Measurement Di2002 IV.2010	Measurement TC2002 XI.2010	ΔD IV-XI	ΔD reduced IV-XI	GPS measurement IV.2010	GPS measurement XI.2010	ΔD GPS IV-XI	ΔD GPS reduced IV-XI
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
0	0.00	0.00	0.00	-0.05	0.00	0.00	0.00	-0.04
1	25964.08	25964.33	0.26	0.21				
2	39264.02	39264.76	0.74	0.69				
3	51890.53	51890.81	0.28	0.23				
4	77846.12	77846.12	0.00	-0.05				
5	155586.94	155587.22	0.29	0.24				
6	233299.38	233299.39	0.01	-0.04				
7	311132.00	311132.19	0.20	0.15	311132.04	311132.10	0.06	0.02
8	388882.21	388882.34	0.14	0.09				
9	466529.40	466529.42	0.02	-0.03				
10	544334.14	544334.30	0.16	0.11				
11	622083.28	622083.25	-0.03	-0.08	622083.29	622083.32	0.03	-0.01
12	699849.20	699849.13	-0.07	-0.12				
13	777637.82	777637.78	-0.04	-0.09				
14	855349.46	855349.58	0.12	0.07				
15	933115.50	933115.86	0.36	0.31	933115.55	933115.96	0.41	0.27
16	1010774.01	1010773.94	-0.07	-0.12				
17	1088575.31	1088575.40	0.09	0.04				
18	1166290.98	1166291.05	0.07	0.02				
19	1230046.93	1230047.05	0.13	0.08	1230047.07	1230047.16	0.09	0.05
		Average =	0.13			Average =	0.12	

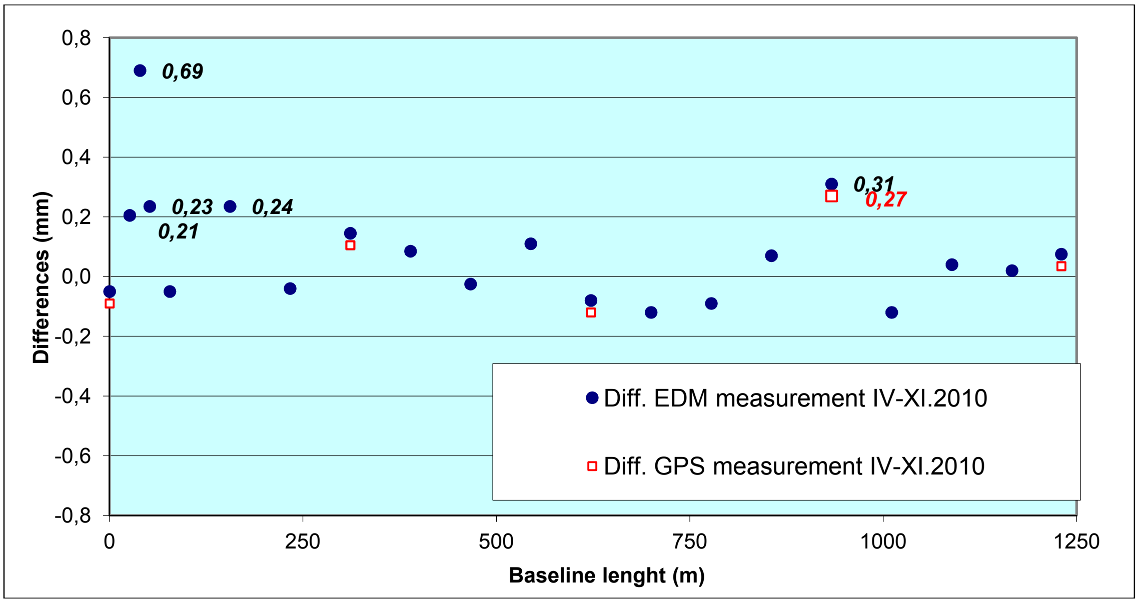

Fig. 4. Comparison of "Wisła" baseline length measurements executed with use of distancers Di2002 and TC2002 and GPS Topcon HiperPro – in the period IV.2010 - XI.2010.

4. SUMMARY

The presented manner of the baseline length calculation allows elimination of systematical errors in form of additive constant, including scale control. GPS measurement assures accuracies comparable with measurements executed with use of precise distancer, but the measurement duration is considerably longer. Length measurement from three measuring stands to 19 points takes about 5 hours, whereas execution of 10 GPS sessions, where only 5 points are determined, requires two full working days to be completed. In case of long measurement time we can expect that the GPS measurements can be influenced by the movement of points, which irrespectively on heavy stabilization and thermal cover, can reach values of several tens of millimeter. Precise baseline length calculation requires good enough weather and reliability that the ground base is stabilized. It results from the experiments that the measurement should be executed in April and November. Next cycle of measurements executed with use of two tachymeters Leica TC2002 and GPS Topcon HiperPro have been conducted in April 2011. The preliminary analysis of the results indicates that similar to those described above results were obtained. The obtained results prove high stability of the baseline points. Flood in the year 2010 did not change their position.

Described baseline can be used for testing low accuracy distarcers, and it can also be used as evaluation center for development of length measurement methods and assessment of the influence of external conditions onto their result.

Modification of atmospheric correction in length measurement with use of distancer, analysis of location changes of points in direction transverse to the base line, calculation of additive constant of the distancer-reflector set, which gives results compatible with calculation based on field examination and also distancer control with respect to cyclic errors, have not described in the present study.

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SUMMARY

Increasing requirements related to accuracy of measurements connected with building and mining areas monitoring call for application of precise distancers (tachymeters) with accuracy of sub-millimeter magnitude. Besides still used Leica Di2002, TC2002, TCA2003 distancers, also Trimble S8, Leica TS30 or Sokkia NET05 and NET1 distancers, are accessible. Taking advantage of full performance of this equipment requires detailed checking, including use of tools and methods giving comparable or better accuracy.

Testing baseline belonging to the Faculty of Mining Surveying and Environmental engineering of the AGH University of Science and Technology in Krakow - Poland is located in rectilinear section of the Vistula river flood embankment, on its right bank, within administrative boundaries of Krakow city. It consists of 20 measuring pillars with Kern heads allowing precise centering. Its usable length is 1230m.

Results of measurements with use of Wild (Leica) Di2002 and TC2002W precise distancers and control measurement executed with use of GPS set by HiperPro – Topcon, have been presented in this study. Measurements with use of distancers were executed in the field, including control of their standard frequency using HP 53131A frequency meter. Calculation of current baseline lengths, including calculation of the set constants, was made according to Schwendener's method procedure.

Two full measurement cycles (distancers and GPS) were completed: in April and November 2010. Results of measurements and calculations indicate that the flood in May 2010 did not disturb the baseline points.