Preparations for new realizations of vertical reference systems in Slovakia

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Motivation

Facts

- Recently some European countries have presented implementation of the new vertical reference systems in their territory (Latvia, Lithuania) or plan to do it in near future (Germany)
- Vertical reference system currently obligatory in Slovakia is Baltic vertical system after adjustment with realization from 1957!!!
- GKÚ (geodetic control administrator) asks:
  - Are provided heights still accurate?
  - Is relative precision of points sufficient for surveyors?
- GKÚ has also interest to increase the accuracy of transformation ETRS89-h to Bpv/EVRS (target accuracy is 1,5cm)
Baltic vertical system after adjustment (Bpv)

<table>
<thead>
<tr>
<th>CRS identifier</th>
<th>SK_KRON/NH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal effects</td>
<td>mean tide</td>
</tr>
<tr>
<td>Datum point</td>
<td>Kronstdat, Russia</td>
</tr>
<tr>
<td>Datum alias</td>
<td>Baltic</td>
</tr>
<tr>
<td>Datum type</td>
<td>Vertical</td>
</tr>
<tr>
<td>Datum realization epoch</td>
<td>Sea level 1833 (Kronstdat)</td>
</tr>
<tr>
<td>Coordinate system identifier</td>
<td>Normal heights</td>
</tr>
<tr>
<td>Coordinate system type</td>
<td>Gravity related</td>
</tr>
<tr>
<td>Dimension</td>
<td>1</td>
</tr>
<tr>
<td>Axis name</td>
<td>Height</td>
</tr>
<tr>
<td>Axis direction</td>
<td>up</td>
</tr>
</tbody>
</table>
(Czecho)Slovakian vertical network development

- **1947 – 1960** - creation of the Czechoslovakian vertical network
  - name: Czechoslovak unified leveling network
  - abbreviation: ČSJNS
  - number of closed polygons: 26/12 (SVK)

- **1993** - Creation of the Slovakian vertical network
  - name: National leveling network
  - Abbreviation: ŠNS
  - number of closed polygons: 15
ČSJNS/ŠNS Leveling lines measurement development

- ČSJNS leveling - basic epoch
  - 1\textsuperscript{st} order ČSJNS measurement: up to 1952
  - 2\textsuperscript{nd} and 3\textsuperscript{rd} order ČSJNS measurement: up to 1960

- 1\textsuperscript{st} repeated leveling - complete network 1961-1972

- 2\textsuperscript{nd} repeated leveling - complete network 1973-1981

- „3\textsuperscript{rd}“ repeated leveling – cca. 35% of network 1984–1996

- ŠNS leveling - basic epoch
  - 1\textsuperscript{st} order ŠNS measurements - complete network 1996-2002
  - 2\textsuperscript{nd} order ŠNS measurements - 76% of network 2003-2016
## Bpv realizations development

<table>
<thead>
<tr>
<th></th>
<th>Bpv57 Current realization</th>
<th>Bpv83 Not implemented</th>
<th>Bpv07 Not implemented</th>
</tr>
</thead>
<tbody>
<tr>
<td>Datum point</td>
<td></td>
<td>Kronstdat</td>
<td></td>
</tr>
<tr>
<td>scale</td>
<td></td>
<td>SI – Meter</td>
<td></td>
</tr>
<tr>
<td>realization of the scale</td>
<td>rod scale correction</td>
<td>rod scale correction</td>
<td>rod scale and temperature correction</td>
</tr>
</tbody>
</table>
| adjustment          | normal height correction + normal height adjustment | normal height correction + normal height adjustment | 1. normal height correction + normal height adjustment  
2. geopotential numbers adjustment |
| realization of the datum | 58 nodal points (TCH) / 25 nodal points (SVK) | 72 points (TCH)/ 35 points (SVK) | 1 point (EH-500) |
2. geopotential number from EVRF2000 |
| physical parameter  | normal gravity field of Krassovsky (Helmert form. 1901) | normal gravity field of Krassovsky (Helmert form. 1901) | normal gravity field of  
1. Krassovsky (Helmert form. 1901)  
2. GRS80 |
| kind of heights     |                           | normal heights         |                        |
| tidal effects       |                           | mean tide              |                        |
Modernization of Slovakian vertical reference system realization

- **2015** Decision of modernization
  - set by Slovak Republic geodetic authority geodetic control conception for the years 2016-2020

- **Objectives:**
  - Modernization of Slovakian vertical reference system realizations (Bpv as well as EVRS)
  - Improved possibility of height determination with GNSS methods (and SKPOS®)
  - Detection of height variations (creation of recent vertical movements map)
  - Integration of new geometric and new physical components
  - New quasigeoid implementation
Concept of modernization

- **Leveling data homogenization + preparation (2015/2016)**
  - Usage of the newest leveling measurements
  - Usage of the newest gravity measurements/information

- **Adjustment (2018)**
  - Geopotential numbers adjustment
  - Normal height adjustment
  - 2 step adjustment: 1\(^{st}\) order separate adjustment, 2\(^{nd}\) order adjusted to 1\(^{st}\) order results with covariance matrix consideration

- **Implementation realizations into routine (+2020)**
  - New geoid fitting to new realizations (GNSS/leveling point)
  - Model determination for the transformation between old and new realizations
The newest leveling measurements

- 1st order ŠNS
  - 15 polygons, 68 leveling lines, 3787 km, 11 035 points
  - Complete measured between 1996 - 2002
The newest leveling measurements

- Control measurements on the 1st order ŠNS leveling lines
  - done when the 2nd leveling lines were connected to the 1st order points
  - measured between 1996 – 2016;
  - Statistics: 1026 km; 3292 height differences
The newest leveling measurements

- Re-measurements of the 1\textsuperscript{st} order ŠNS leveling lines
  - task for 2016
  - plan: 380 km
The newest leveling measurements

- 2\textsuperscript{nd} order ŠNS
  - 76% of leveling lines measured between 2003 – 2015
  - Statistics: 667 leveling lines; 7288 km; 18,796 points
The newest leveling measurements

- 2\textsuperscript{nd} order ŠNS as ČSJNS
  - 24\% of leveling lines measured between 1987 – 1996
  - Statistics: 211 leveling lines; 2302 km; 5.935 points
Leveling measurements

Some information from guidelines

- Distances between leveling instrument and staff can be max. 35m long
- Staff reading have to be at least 0.8m above ground
- Used sequences of readings (B=backsight, F=foresight) - BBFF
- Fore and back measurements of a section not allowed at the same day
- Allowed difference between fore observation and back observation of a section between 2 points:
  - for 1st order lines: $1.5 \cdot \sqrt{R}$ [mm]; $R$ = distance in km
  - for 2nd order lines: $2.25 \cdot \sqrt{R}$ [mm]; $R$ = distance in km
Leveling measurements
Leveling instrument and staff inspection

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Manufacture</th>
<th>Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA03</td>
<td>Leica</td>
<td>2011-2016</td>
</tr>
<tr>
<td>NA3000(3)</td>
<td>Wild (Leica)</td>
<td>1995-2010</td>
</tr>
<tr>
<td>DiNi 11</td>
<td>Zeiss</td>
<td>1995-2006</td>
</tr>
<tr>
<td>Ni002</td>
<td>Zeiss</td>
<td>1987-1995</td>
</tr>
<tr>
<td>Ni007</td>
<td>Zeiss</td>
<td>1987-1995</td>
</tr>
</tbody>
</table>

- **Calibrations and testing:**
  - Leveling rod calibration: every two years at the beginning of the period of measurement
  - Leveling instrument calibration: every two years
  - Instrument/staff testing: Every year at the beginning of the period of measurement on leveling testing round
1\textsuperscript{st} order leveling lines height differences analysis

- Analysis of height differences on 1\textsuperscript{st} order leveling lines composed of comparison of basic epoch with re-measurements and control measurements
  - Standard deviation of repeated leveling was determined
  - Errors and mistakes were eliminated
1\textsuperscript{st} order leveling lines height differences analysis

- Result statistics:
  - Height differences: 3292
  - Achieved standard deviation: 2,3 mm
  - Number of eliminated height differences (over 3\(\sigma\)): 173

Quality of repeated leveling confirmed!
1\textsuperscript{st} order leveling lines height differences analysis

- Height differences analyzed according to dependency on:
  - time span
  - length of section
  - height difference
The newest gravity measurements/information

- ŠNS points with direct gravity measurements
  - only 2% of all ŠNS points (5% of 1\textsuperscript{st} order ŠNS points)
  - relative gravimeters LaCoste & Romberg and Scintrex CG5 used
  - Gravity system: S-Gr95
The newest gravity measurements/information

- Points with missing gravity => Decision to use interpolated gravity from CBA2G_SK software (Marusiak et. Al, G-trend company)
CBA2G_SK software (Marusiak et. al, G-trend)

- Code: C++, Windows 32 bit
- Gravity database: 320 000 points with cleared measurements from 1959-2014
- Geodetic system support: all Slovakian reference geodetic systems
- Allow computation of complete Bouguer anomaly from gravity and vice versa:
  \[
  (1) \Delta g_{\text{CBA}} = g_{\text{mer}} - \gamma_0 - \delta g_{\text{vv}} + \delta g_{\text{atm}} - \delta g_{\text{sf}} + T \\
  (2) g_{\text{rek}} = \Delta g_{\text{CBA}} + \gamma_0 + \delta g_{\text{vv}} - \delta g_{\text{atm}} + \delta g_{\text{sf}} - T \\
  \]
- DMR used for topo-correction determination:
  - T1 (0 – 250 m) – Slovakian DMR-3 (step 10m)
  - T2 (250 – 5240 m) - Slovakian DMR-3 (step 30m)
  - T31 (5240 – 28800 m) - SRTM-3 (step 3’´)
  - T32 (28800 – 166735 m) - SRTM-30 (step 30´´)
CBA2G_SK software testing
Measured versus interpolated gravity

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>CBA2G_SK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-5.92 mGal</td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
</tr>
<tr>
<td>Standard deviation</td>
<td></td>
</tr>
<tr>
<td>Number of values</td>
<td>1277</td>
</tr>
</tbody>
</table>
ŠNS points HZ coordinates quality

- HZ coordinates quality of ŠNS vertical points in Slovakian geodetic control database was in 2014:
  - $\sigma_Y = 14.29$ m
  - $\sigma_X = 14.41$ m

- In 2015/2016 - decision to improve this quality to cm level was set (important for gravity interpolation)
  - leveling marks on buildings, bridges, etc. - coordinates is gotten from vector Cadastral maps and ZBGIS© (50%)
  - other points – coordinates is gotten from direct/indirect field measurements (RTK, PPK, GNSS static, RTK+crossing from distances, etc.)
    - 50% - field measurements done till May 2016
    - missing 50% field measurement planed for 2017 (only 1st order)
Next steps (2016/2017)

- Complete leveling lines reprocessing (1987-2016) with consideration of:
  - Invar rod scale corrections
  - Invar rod temperature corrections
  - Correction from unequal instrument-staff distances
  - Gravity corrections (for normal heights adjustment)
  - Tidal corrections (in past not considered) – SPOTL software
Next steps (2018)

- adjustment:
  - Geopotential numbers adjustment
  - Normal height adjustment + computation of normal height corrections

- 2 step adjustment:
  - 1\(^{st}\) order separate adjustment,
  - 2\(^{nd}\) order adjusted to 1\(^{st}\) order heights (covariances considered)

- Type of adjustment:
  - mathematic model and software not selected yet
  - datum point/points not selected yet
Next steps - Quasigeoid

- **DVRM05** = quasigeoid DMSQ03B fitted to ŠNS/ŠPS points
  - DVRM05 quality: from testing (563 points): $\sigma_{DVRM05} = 34$ mm

- New precise gravimetric quasigeoid on SUT Bratislava is before completing – we plan to use it
Next steps - New quasigeoid fitting

- Prepared GNSS leveling points for fitting
  - SKPOS® + SGRN points
  - Equally distributed
  - ETRS89–h quality: $\sigma_\phi = 2.4$ mm, $\sigma_\lambda = 1.8$ mm, $\sigma_h = 3.9$ mm
  - H - leveling quality: 1st order points quality

- Prepared GNSS leveling points for testing
  - 670 equally distributed points (ŠPS)
  - 2 x 6 hour GNSS campaign
  - ETRS89–h quality: $\sigma_\phi = 7.2$ mm, $\sigma_\lambda = 8.3$ mm, $\sigma_h = 13.4$ mm
  - H - leveling quality: 1st order points quality
Conclusions

- The new realization of vertical reference system in Slovakia is needed
- Both new Bpv frame and new EVRF2007 national realization is planned to compute
- Some steps are not selected/decided yet (e.g. mathematical model of adjustment, datum points, etc.) so cooperation with Slovak university of technology was set
- Inspiration was taken mainly from Germany (BKG concept)
- Owned data (leveling measurements and gravity from CBA2G_SK = 0.5mGal) are very precise so high quality results are awaited
Thank you for your attention

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