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NEW METHOD FOR CALCULATION OF THE BUILDING EFFECT CORRECTION IN MICROGRAVITY TECHNIQUE

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Introduction

The corrections applied to microgravity data for high resolution survey include effects caused by variations in earth tides, latitude, elevation and topography. Bouguer anomalies obtained by data processing of micro-gravity observations are then directly related to density variations of the subsurface geology and searched man-made structures.

When the microgravity surveys are carried out inside or in a close vicinity to buildings, the effect of nearby walls decreases measured gravity values. The term building effect correction covers all additional corrections, by which the effects of buildings and known underground spaces (cellars, basements, tunnels, crypts) are removed.

Employment of microgravity technique for cavity detection in historical buildings exploration requires careful data acquisition and modern processing procedures. We have developed new method for calculation of the building effect correction, where geodetic measurements and special photogrammetric software are used.

Objectives

- Using of close range photogrammetry in the field of applied geophysics
- Development of new, effective procedure for calculation of the building effect correction in microgravity technique

Method

Gravitational effects of buildings with complicated ground plan can be approximated by summation of rectangular prisms or by summation of finite length vertical prisms with polygonal cross-section and various thicknesses. In this "old approach", model of building is created in Potent software (Geophysical Software Solution), where the gravitational effect of homogeneous prismatic bodies is calculated using equation derived by Cady (1980) for estimated average density (e.g. 1.7 g/cm^3 for bricks).

PhotoModeler Scanner is commercial software based on close range photogrammetry principles, which is a measurement technique that uses central projection imaging as its mathematical model and measures objects directly from photographs. The "new approach" of building effect calculation consists of these steps:

1. The model of a building is created from images in PhotoModeler Scanner software. Output is three-dimensional polyhedral body of the historical building in chosen coordinate system.
2. The gravitational effect of homogeneous polyhedron is then computed using our program which is based on equation derived by Götze and Lahmeyer (1988).

The combination of convergent photogrammetric method and geodetic measurements provides sufficient accuracy and quality of obtained geometric information (location, size and shape) about object.

The attraction effect of a polyhedron is calculated in our program as the superposition of the gravity effects of its individual surfaces (triangles). The corners of triangles are input in counterclockwise direction. The final formula for the gravitational effect of a polyhedron can be expressed according to Götze and Lahmeyer (1988) as

$$g_z(P) = \kappa\sigma \sum_{k=1}^{K} \cos(\mathbf{n}_k,\mathbf{z}) \sum_{i=1}^{3}\left[w_{k,i}\ln\frac{v_{k,i}+A}{u_{k,i}+B} + \frac{|z_k|}{|w_{k,i}|}\left(\arctan\frac{v_{k,i}|z_k|}{|w_{k,i}|A} - \arctan\frac{u_{k,i}|z_k|}{|w_{k,i}|B}\right) + 2\pi|z_k|\delta\right], \qquad (1)$$

where $A=\sqrt{v_{k,i}^2+w_{k,i}^2+z_k^2}$, $B=\sqrt{u_{k,i}^2+w_{k,i}^2+z_k^2}$,

and $\delta = \begin{cases} 0 & \\ 1, \text{ if } P_\perp = & \begin{cases} \notin S_k \\ \in S_k, \quad 0<\varepsilon<1. \\ \in \partial S_k \end{cases} \\ \varepsilon & \end{cases}$

The variables $u_{k,i}, v_{k,i}, w_{k,i}, z_k$ (k = index of triangles, i = index of triangle elements) used in equation (1) are transformed Cartesian coordinates of point P to the local coordinate system of each triangle; cosine term determines z-component of $g(P)$; κ = gravitational constant; σ = constant density.

Test model

Our program algorithm was tested on a simple model of building's walls composed of two polygonal prisms (Top view, Figure 1a, Left). Building effect corrections were computed for real survey grid points (see Case study) using another two programs (Potent and Pohánka's program).

- Deviations of 10^{-8} mGal from zero value displayed on difference map (Figure 1a) originate in an inappropriate triangulation of the bottom part of the test model.
- The main reasons for 10^{-5} mGal order difference in Figure 1b are: i) a different approach used by Pohánka (1988) in the derivation of the gravitational effect of homogeneous polyhedron; and ii) a different way of the divergence handling. Both results are deeply beneath the standard field repeatability of Scintrex CG-5 gravimeter (≈10^{-3} mGal).

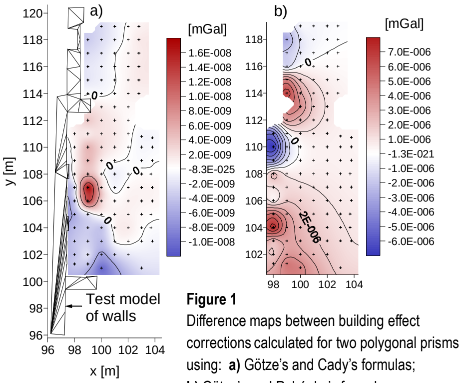

Figure 1
Difference maps between building effect corrections calculated for two polygonal prisms using: **a)** Götze's and Cady's formulas; **b)** Götze's and Pohánka's formulas.

Case study

Small Romanesque church located in western Slovakia, where two medieval crypts were successfully detected using microgravity and GPR techniques in 2009, was photogrammetrically documented for 3D building reconstruction purpose (Figure 2 – Figure 4). The spatial polar method was used for geodetic tacheometric measurements.

Calibrated digital camera Canon EOS 450D (12 Mpix resolution) was used for image acquisition. The model of the church was positioned into geodetic coordinate system using 37 control points marked with coded targets. There was necessary to measure additional 90 points for the reconstruction of building's interior, because they were obscured by a furniture. Spatial **point accuracy of 6.5 cm** estimated from control length measurements was achieved.

Figure 2
Photograph of church's exterior (NW view).

Figure 3
Digital model displayed with original textures in PhotoModeler Scanner software.

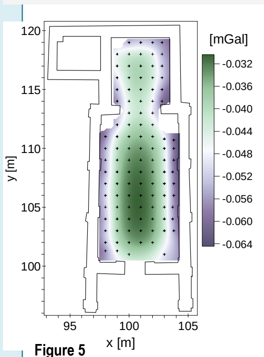

Figure 5
Gravitational effect of the church computed by new method.

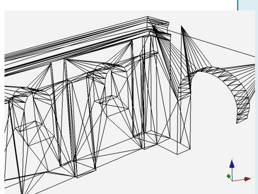

Figure 4
3D wire-frame view of a selected part of the final model.

Results

1. Minimal amplitude of the building effect, computed for the polyhedral model in our program, is relatively low; reaches -64 μGal (Figure 5).
2. The "old approach" ground plane fits well with the "new approach" ground plan in interior parts of the church but the exterior walls differ in shape causing the maximum difference of 30-40 cm in a wall thickness (Figure 6a).
3. The new method allowed high lancet windows and a broken arch to be included into model (Figure 4).
4. Differences in the range of +5 to -11 μGal between building effect corrections calculated from Photomodeler output file and prismatic model (Potent software) arose primarily from the shape discrepancy (Figure 6a). Only the filled cavity is influenced by these differences.

Parameters of model	Lower estimate	Reference model	Upper estimate
Thickness of wall [m]	0.85	1.00	1.15
Height of wall [m]	9.9	10.0	10.1
Density [g/cm^3]	1.7	1.8	1.9

Table 1 Input parameters used in synthetic modelling.

5. The accuracy of the building effect correction depends on the spatial accuracy of a final model and the accuracy of a density estimate. Changing the parameters of synthetic models (Table 1), the accuracy of the building effect correction normalized on a reference model was determined (Figure 6b).
6. To the distance of ≈1.0 m from walls (1.5 m in a case of building's corners), only the anomalies of searched objects greater than 7 μGal are identifiable. As the repeatability of gravity measurement is less than 4 μGal, the spatial accuracy of models from Photomodeler needs to be improved (error threshold of 2 cm).

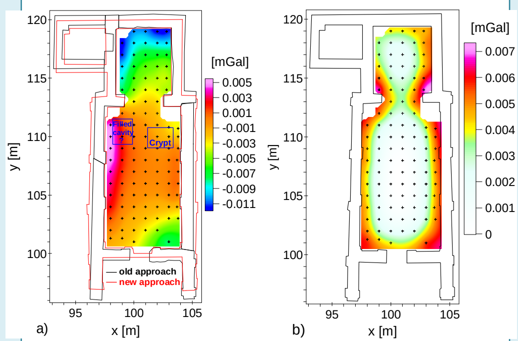

Figure 6
a) The comparison of two ground plans (PhotoModeler output - red, prismatic model - black) displayed along with building effect corrections difference map: new polyhedral model versus old prismatic model. **b)** The uncertainty on the building effect correction estimated from synthetic modelling of church's walls.

Conclusions

Our new method provides high accuracy of calculated building effect corrections, thus improving the ability of microgravity technique to detect more difficult identifiable cavities situated in a close vicinity to man-made structures.

Such an improvement can contribute to a more precise construction of Bouguer anomaly maps and their interpretation.

Moreover, the reconstruction of spatial models of historical buildings using close range photogrammetry represents a valuable contribution to the documentation of cultural heritage sites.

References

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