Abstract

My Thesis is based on five papers dealing with gravity changes related to various geodynamic, geomechanical and hydrological processes and phenomena. In the first part of the Thesis the gravity changes are defined as a geophysical quantity. The two principal causative parameters are highlighted – variation in elevation of the earth surface, and temporal excess of mass (negative or positive) in the subsurface.

I also discuss different groups of parameters and environmental phenomena disturbing the gravity measurements, as the data accuracy is an essential condition of gravity monitoring (4D gravity). I performed a special test with the LaCoste&Romberg D-188 gravimeter in a pressure chamber with notable result showing negligible impact of small and medium size air-pressure variations on this instrument. The calibration stability was proved during two world comparison/calibration campaigns of absolute and relative gravimeters in Sevres, France. The instrument's repeatability was evaluated as 2 μGal (0.02 μm/s^2). As well, calibration is being controlled by measurements on the Czech latitude calibration line between Prague and Dolní Dvořiště in South Bohemia.

In order to achieve best accuracy we developed special software Drift to control the gravimeter's drift. In principle the software provides a chance to check the value of each repeated reading during a daily loop, and to eliminate/disable the outliers. Final drift curves can also be improved using the option of changing the curve's rigidity, which is already interpretative style of data processing based on experience. Examples from both research and exploration gravity networks showed the improvement of accuracy up to 50 %.

The first case history is focused on gravity monitoring in the seismoactive region of West Bohemia, characterised by repeated occurrence of earthquake swarms. The gravity observation network was partly identical with the GPS one. The gravity differences observed since 1993 have shown quite strong correlation with the periods of swarms. Already before the Dec. 1994 swarm a sharp increase of gravity near Nový Kostel was identified. Similar amplitudes of about 20 – 40 μGal were evaluated during the Jan. 1997 swarm period. However, the most significant Autumn 2000 swarm gave a chance to investigate a complex geodynamic scene. Despite the magnitudes reached only M=3.2 in maximum, there were remarkable surface displacements identified from GPS and precise levelling networks. They prove the stress evolution during such an active period. After the 1998-1999 dextral movement on the active fault plane near Nový Kostel, the GPS vectors showed a reverse sinistral movement in 1999-2000 in good agreement with seismic fault plane motion solutions. We observed the same sense of gravity changes regime, completed in 2000 by indication of sinistral stress from increased relative gravity values on the eastern side of the fault near N.Kostel. The coincidence between gravity and GPS geodynamic indications corresponding with this significant earthquake period can be considered as valuable result.

The second case history is located in Upper Egypt, on the west bank of the Lake Aswan. This area is also tectonically active with M=5.5 in 1981. This earthquake on the Kalabsha E-W fault crossing the reservoir inspired a detailed geodynamic study in seismology, but also in geodetic observations. In 1997 we introduced gravity monitoring within the Kalabsha, Seyial and Kurkur networks. We observed significant positive gravity change in 2000, located south of the fault near the shoreline of the Lake. This shoreline is changing significantly due to water level seasonal, but also long-term variations. In 2000 the shoreline was relatively very close to the nearest observation station # 153. This station was already after the 2000 gravity campaign considered as affected by water infiltration from the Lake (about +50 μGal), while the rest of the area was still expected to exhibit small impact of tectonic stress change.

However, the next campaign in 2002 exhibited reverse drop of gravity values close to zero level, while station # 153 was the only one to add about +10 μGal. The recent analysis indicates that most likely all the regime of observed gravity changes is controlled by water infiltration. I also performed gravity/density modelling of such process with two possible models of hydrological events – water infiltration from the Lake surface water, and simple groundwater level rise. Further gravity observations are needed to identify in more detail the hydrological processes.

The third case history deals with the application of gravity monitoring to the investigation of geomechanical processes in the near subsurface. The usual problems in engineering geology comprise the propagation of voids with possible collapse of the surface, evolution of landslide process, fluids movement in reservoirs, and stress changes in deep coal mines. Two examples are studied in more detail.

The rocks disintegration in the form of the so called 'arch effect' above underground voids can be detected by gravity monitoring due to the propagation of the disintegration process to surface. The physics behind is that such process results in significant decrease of bulk density of the rock formation, as well as propagation to surface with time. Both these phenomena are favourable for detection by repeated gravity measurements as the anomalous rock volume gets closer to surface, and to the gravimeter. So, even if the void itself is too small and deep to be reflected in the gravity data, the disintegrated volume can be observed.

I also described how the gravity monitoring can identify variations of groundwater level in case of a waste dump of an open-pit coal mine. The data from four profiles on such man-made 'geological' body were corrected for elevation and terrain correction changes and correlated with direct observations of groundwater in monitoring wells. Based on such controlled correlation, the groundwater level inside the dump was evaluated. At certain stage, the data clearly showed an increased groundwater level that triggered a disastrous mass slide down the valley.

Theoretical modelling showed that a water movement in both horizontal, as well as vertical directions in reservoirs can be identified by 4D gravity. Even in great depth of e.g. 3000 m, relevant to current producing hydrocarbon reservoirs could be observed, but the signal may become too smooth and wide, so that practical determination of e.g. water-gas contact at such depth is tentative.

I concluded that gravity monitoring can contribute to geodynamic investigations, as well as to solving some problems of engineering geology, provided high resolution data are acquired and properly processed.
