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Investigation of Vilnius Upper Castle Vertical Deformations

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Abstract. The aims of this study were to to review the monitoring methodology of the vertical deformations and to identify the reasons of deformations that occur in structures of Vilnius Upper Castle, Lithuania. Collected systemized data is processed with mathematical–statistical methods. In order to investigate the state of the buildings, a new cycle of measurements (XIV) was carried out in 2016. Data of all measurement cycles is presented and compared with previous data that was provided in technical reports of measurement cycles (first measurements began in 1968). In order to investigate conditions of the structures, data is presented graphically. When analyzing the graphics, it is possible to investigate changes of the buildings and possible causes of their appearance are presented. Long-term research and results have shown, that all the cracs and crevices that were found during monitoring (1968 to 2016) in Upper Castle's structures were caused by large and uneven deformations.

Keywords: Vilnius Upper Castle, Gediminas' Tower, Grand Duke Palace, construction deformations, vertical deformations, cycle.

Conference topic: Technologies of geodesy and cadastre.

Introduction

There are two types of deformations: vertical deformation and horizontal displacement of the soil (landslide). The most common causes of vertical deformation of buildings are: uneven structure of the geological ground under the building; the rise of the soil before installing the foundations; soil elevation (swelling) because of the cold, moisture and the warming of soil, weight of the building, alteration of the ground pressure during weight changes of the building, uneven pressure distribution depending on weight of the building under the foundations, dimensions of the foundations, hardness and shape, dynamic loads to the ground, variations of the strength of soil during underground constructions, influence of the human, working mechanisms etc. All the cracs and fractures are caused by large and uneven deformations. Geodetic techniques have traditionally been used mainly for determining the absolute displacements of selected points on the surface of the object with respect to some reference points that are assumed to be stable. Non-geodetic techniques have mainly been used for relative deformation measurements within the deformable object and its surroundings (Çelik *et al.* 2001; USACE 2002). Each main measurement technique has its own advantages and drawbacks. Geodetic techniques, through a network of points interconnected by hight, angle and/or distance measurements, usually supply a sufficient redundancy of observations for the statistical evaluation of their quality and for a detection of errors (Erol *et al.* 2004).

Vilnius Upper Castle is an important 16th – 19th centuries architectural, historical and archaelogical monument that has a high national meaning. As it is necessary to save this object for the future generations, on the 6th of April 2016, a new (XIV) measurement cycle was completed in order to follow further conditions of the castle and to be able to predict future vertical deformations (Baselga *et al.* 2011). Measurements were carried out in acordance with leveling accuracy of second order, and the received data was compared with data of previous measurement cycles that was provided in technical reports (the first measurements began in 1968).

The main objective of this work is to investigate vertical deformations on the Vilnius Upper Castle.

Methodology of the research – collection and processing of the long-term monitoring data.

Sizes of vertical deformations obtained during measurements are compared with the previously set values. Research is carried out to determine the changes occuring in buildings and the reasons of vertical deformations to make a conclusion about the certainty of situation in the area (Henriques, Casaca 2007).

Data from the technical reports of the long-term measurements that have been prepared for each cycle of measurements were used to implement this study. The monitoring works started in November 1968 and lasted untill April 2008. During the 40-years period, XIII cycles of measurement were carried out. Measurements performed by Ltd. "Inžineriniai tyrinėjimai". Developer of the measurements was Public Enterprise "Vilniaus pilių direkcija". Vertical and horizontal deformations of Gediminas Hill and other structures were monitored during the measurements. During XIV cycle of measurements it is chosen to analize vertical deformations of Vilnius Upper Castle structures.

The object of research

The objects of the research are the Gediminas' Tower and a part of Southwestern Defensive Wall, Grand Duke Palace, Foundation of the Southern Tower, Northern Wall, Southern Retaining Wall, Eastern Retaining Wall and North-Western Retaining Wall (next to the Gediminas' Tower). During the cycle, it was decided to abandon monitoring of the Northern Wall deformations because of the negligible displacements of geodetic marks. It was also found, that using data from the technical reports of the long-term measurements, it is difficult to draw conclusions about the Northern Wall vertical deformations and tilting. Gediminas Upper Castle structure, geodetic marks of vertical deformations and levelling scheme are shown in Figure 1.

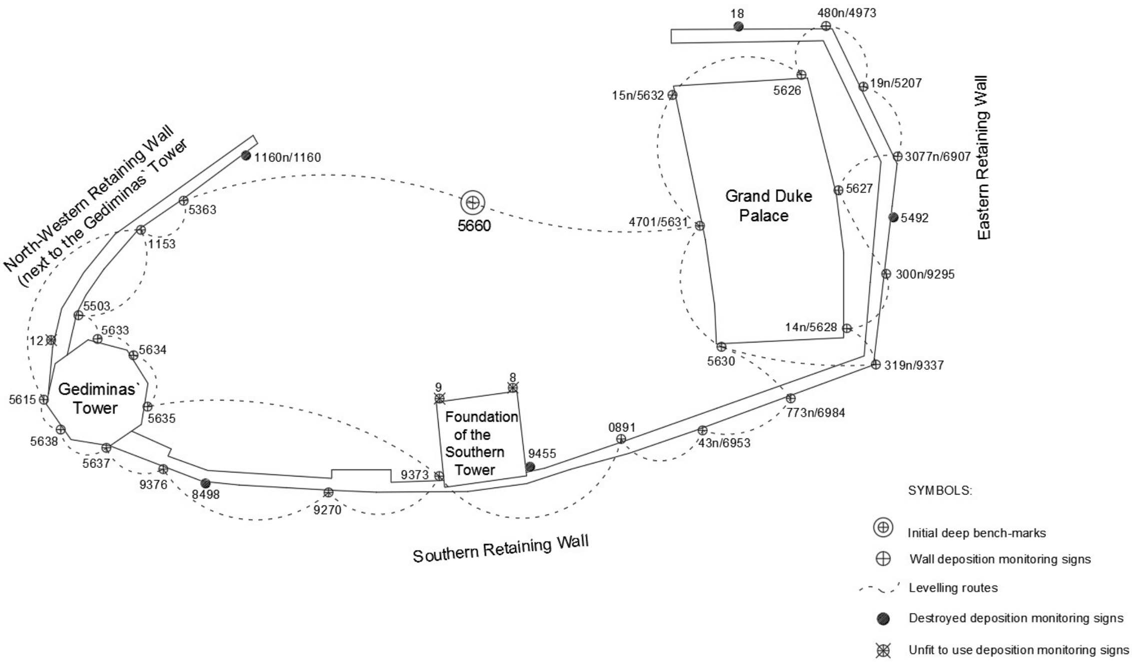

Fig. 1. Monitoring of geodetic marks of vertical deformation and levelling scheme on the 6th of April, 2016

Methodology of vertical deformations monitoring

Monitoring of vertical deformations was carried out according to the accuracy requirements of geometric levelling of second order. All other measurements were carried out trying to stay close to previous cycles principal schemes of geodetic marks levelling. The first monitoring cycles were based on initial deep bench-marks Num. 5656, Num. 5657, Num. 5658 and Num. 5660 (vertical deformation monitoring technical reports of Gediminas Hill structures from 1995 to 2008). Minor changes in the scheme occured due to the merging of analogue measurement schemes into a common complex, additionally established and destroyed marks or new bench-marks. State standart GOST 24846 - 81 "Soil. Methods of strain measurement of buildings and equipment framework" and requirements as well as measurement methods from „Buildings and equipment foundations and framework strain foreseing manual" (in force at the time) were used during the measurements. Measurements were carried out using automatic level NA 3003 and code rods of different length made by company "Leica". Visual FoxPro software was used to compensate levelling moves and calculate altitudes of marks.

Steep slopes, marks established in hardly accessible and barely visible areas, and difficult weather conditions (due to the strong wind it was hard to hold the code rod horizontally) were the main problems during the measurements.

Results

Data of technical reports was systematized and filled into sheets, of which one of the monitoring vertical deformation data was recorded since 1968 and the other data since 1995. Investigation was carried out to complete XIV measurement cycle using 26 of 34 values of vertical deformation marks.

Durring the second last cycles data (2008), on average, most of the vertical deformations of the structures were established in foundation of the Southern Tower (46.7 mm) and the least at Northern Wall (11.7 mm) using data from November, 1968 (40-years period). The biggest vertical deformation was established of the mark Num 5627 (at Grand Duke Palace) – 59.3 mm, the lowest of the mark Num. 5630 (at Grand Duke Palace) – 10.8 mm. Within 13 years since December 1995 the biggest average vertical deformation was detected on Southern Retaining Wall (21.8 mm) and the lowest – at Northern Wall (5.1 mm). Southern Retaining Wall's mark Num. 9455 vertical deformation during data of measurements was the biggest – 41.0 mm and the East Retaining Wall's mark Num. 19n/5207 contrariwise – 0.9 mm.

Comparing all data (from November 1968) with the data of the last cycle in 2016 (48-years period), most average vertical deformations were established at Grand Duke Palace (35.2 mm), Gediminas Tower and a part of Southwestern Defensive Wall (28.7 mm). Foundation of the Southern Tower has not been recorded due to the corrosion of marks. The biggest vertical deformation during period since 1968 was observed at Grand Duke's Palace mark Num. 5627 (73.3 mm); the lowest 8.1 mm of mark Num. 5630. Since December 1995 (21-years period) the biggest average vertical deformation was detected on Southern Retaining Wall (26.4 mm), the lowest – 10.6 mm of Southwestern Defensive Wall (near Gediminas Tower), the vertical deformation of East Defensive Wall on average was 17.7 mm. South Defensive Wall's vertical deformation value (48.7 mm) was established of the mark Num. 9270; the lowest – of the mark Num. 19n/5207 (East Defensive Wall) – 1.2 mm.

To investigate conditions of the structures, vertical deformation values are displayed graphically in Figures 2 to 7. All the charts can be used to identify risk areas of cracks and the heel angle of the structure by a verticale. In order to examine changes of structures, sedentaries of Vilnius Upper Castle's structures are shown by the directions of the major axes. Vertical sedentaries of Gediminas Tower, a part of Southwestern Defensive Wall, Grand Duke Palace and foundations of Southern Tower (since 1968), can be seen sufficiently different in the charts when comparing the IV and III measurement cycles values. The differences are due to the fact that deep bench-mark (that previously was an itial deep bench-mark) was also affected by the vertical deformations and its deformation value was increased by 10.9 mm since 1968. For this reason, all the values of vertical deformations obtained in 1995 were adjusted. These values are considered to be final. All the charts were adjusted by the value changes in the IV measurement cycle.

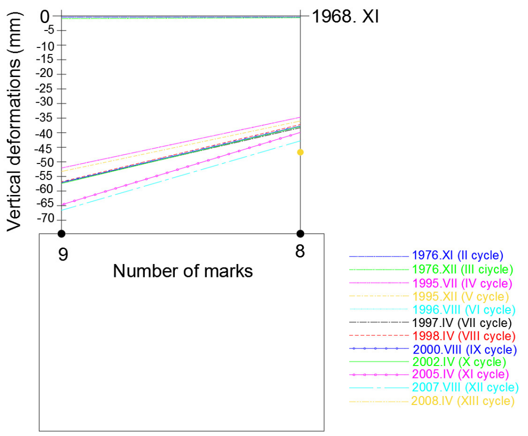

Fig. 2. Vertical deformations of foundations of Southern Tower

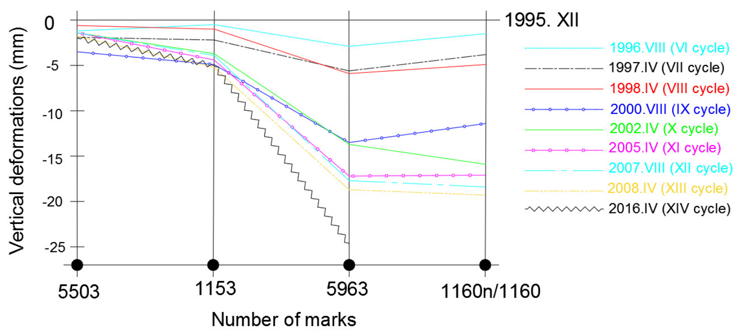

Fig. 3. Vertical deformations of Eastern Retaining Wall

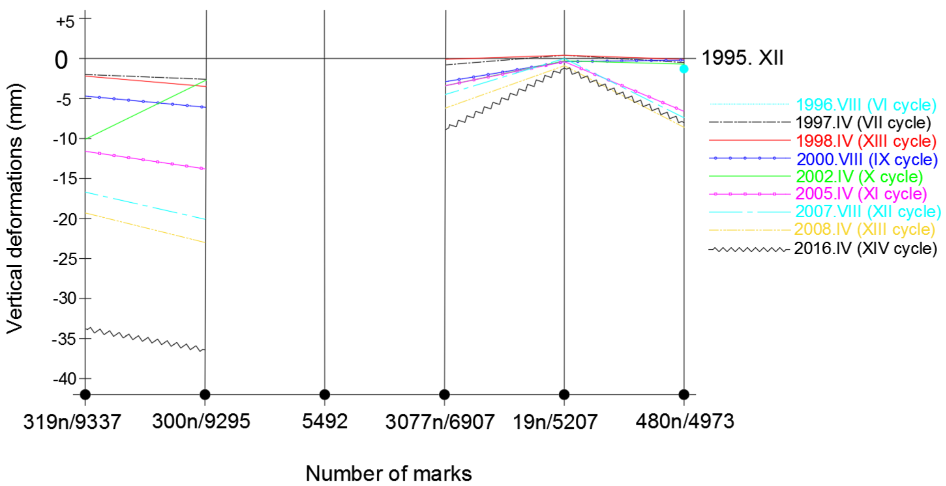

Fig. 4. Vertical deformations of Southern Retaining Wall

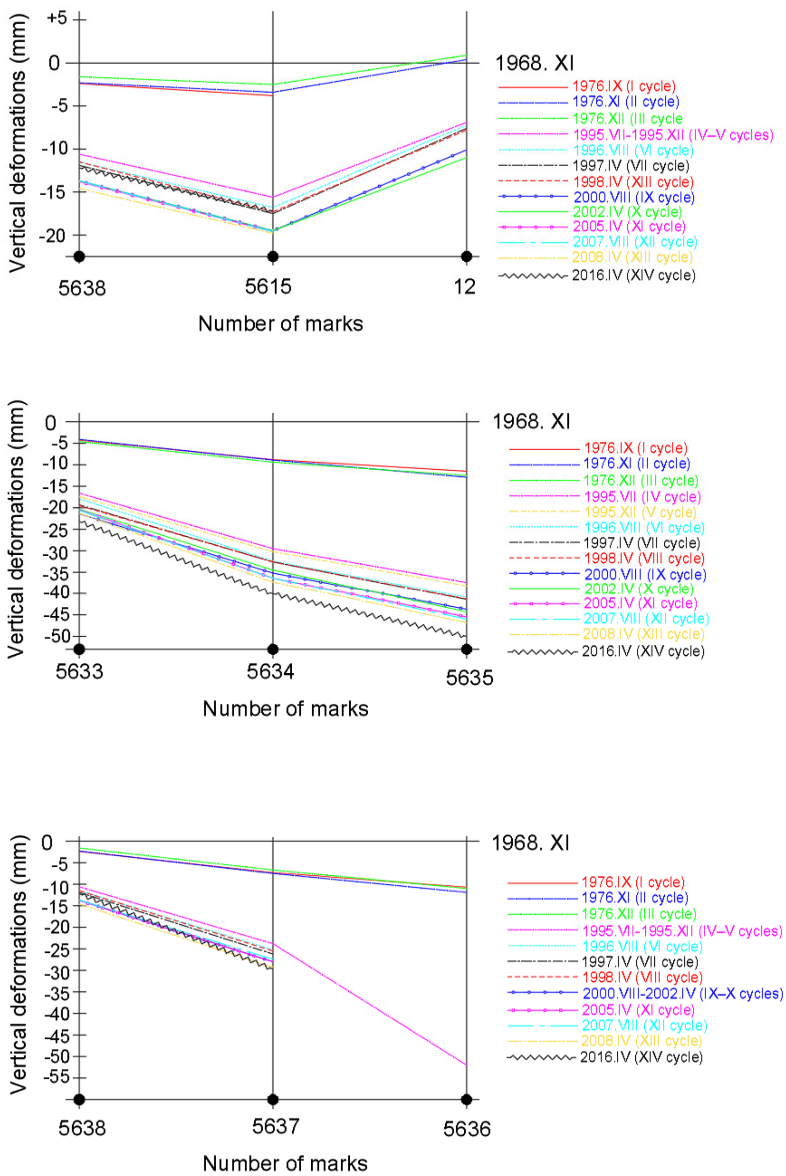

Fig. 5. Vertical deformations of Gedinimas Tower and a part of Southwestern Defensive Wall

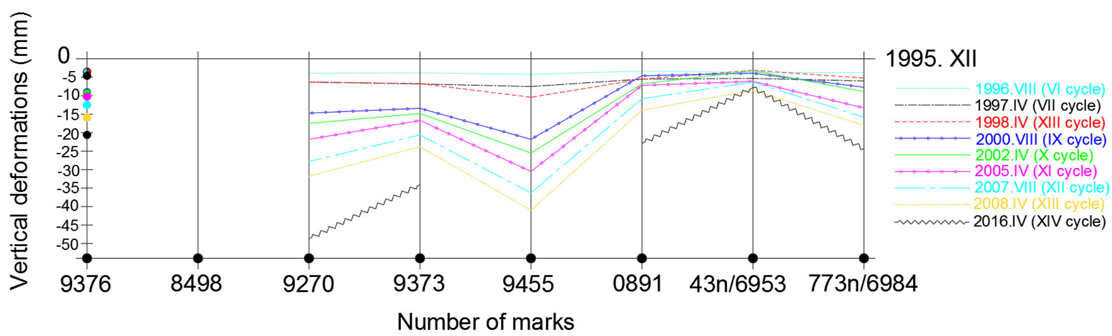

Fig. 6. Vertical deformations of Southern Defensive Wall

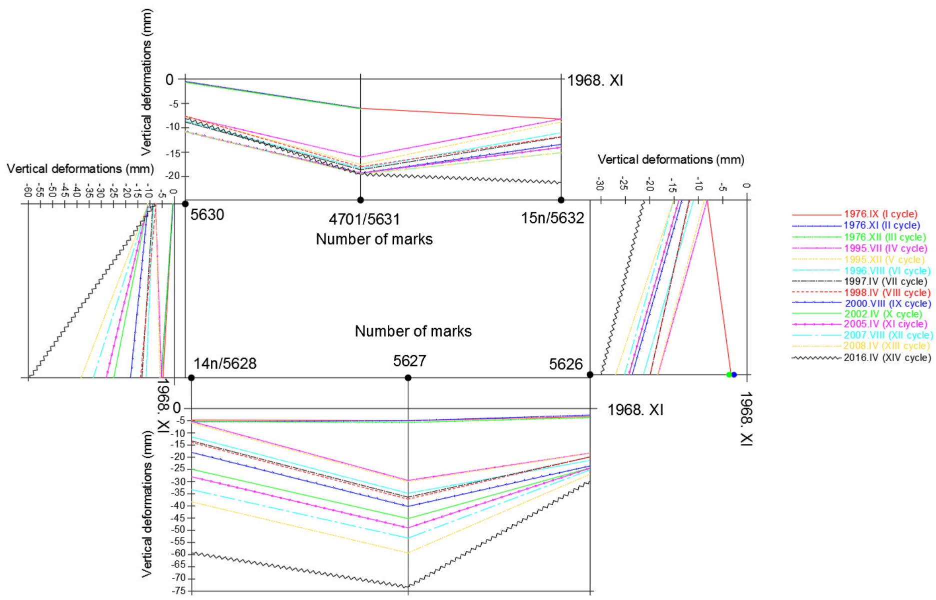

Fig. 7. Vertical deformations of Grand Duke Palace

The whole area was inspected carefully and 26 marks have been found around the Upper Castle. One of the Gediminas Castle marks is shown in Figure 8. Visible cracks in the structures (Fig. 8, on the right) confirm about permanent deformations.

Fig. 8. Mark Num. 5634 on the left; on the right – visible crack on Grand Duke Palace

Causes of deformations

Deformations are caused by natural and technogenic processes. Natural factors are classified according to:

- uneven ground geological structure of the building;
- feature of soil compression and its horizontal displacement (landslides);
- soil elevation (swelling) because of the cold;
- impact of moisture and soil warming;
- hydro-meteorological conditions: temperature fluctuations (seasonal and long-term), changes in groundwater level and soil moisture.

Technogenic factors are classified according to:

- weight of structures;
- changes of soil properties due to the groundwater level change;
- changes in soil durability while constructing underground;
- influence of ongoing nearby constructions of buildings and structures;
- due to human influence: vibrations caused by working machines and other mechanism (Ražinskas, 1979).

Steep slopes, plants, rotting stumps are causing erosion and landslides of the slopes. Several large landslides were mentioned in technical reports (a new landslide was recorded at the end of 2016), which probably influenced vertical deformations of the Vilnius Upper Hill structures. Poor draining, improperly performed works of slope stabilization, trample down vegetation areas, existing underground structures (tunnels and shafts). In the article of "STRUCTUM" magazine (Lekaviciene 2014), it was offered to analyse all previously collected information of Vilnius Upper Castle conditions when the threat has occured. The article also reveals one of the secrets of Gediminas Hill – underground tunnels: mysteriously winding underground corridors entering premises, brick or wood lumber walls, in some places ceilings havewooden supports. Scheme of the tunnels and photos are shown in Figure 9. According to the head of the Public Enterprise "Lietuvos paminklai" V. Drumsta, underground tunnels were dug by prisoners of war during WW II. Condition of these tunnels is not investigates yet, but the fact is that effect exists. It is because of bad conditions of the overall underground structures. While searching for causes of failures and landslides of the hill, scientists raised hypothesis that the main issue is poor conditions of underground structures and failure of constructions (Lekaviciene 2014).

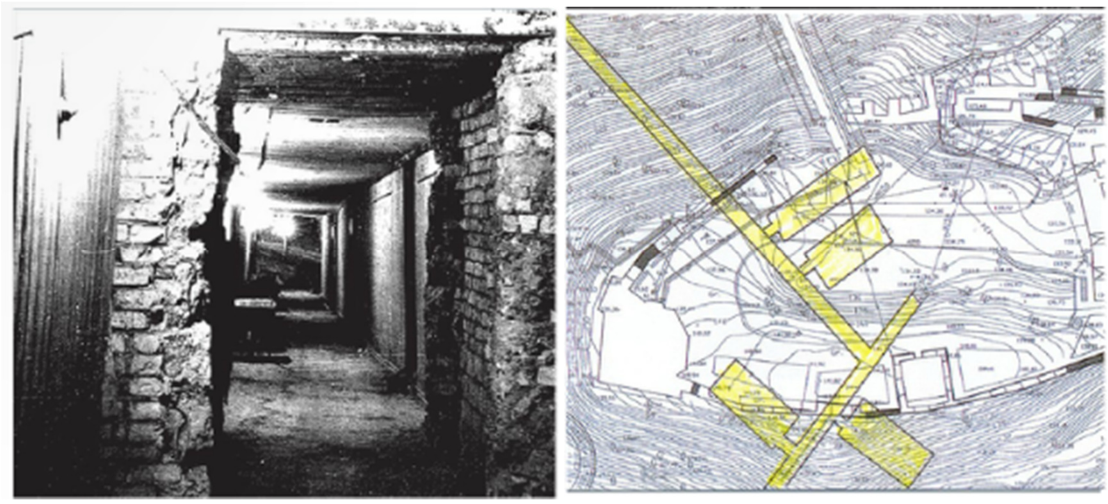

Fig. 9. Underground tunnels of Gediminas Hill (Lekaviciene 2014)

The most problematic area of Gediminas Hill is a wellspring on the eastern slope of the Castle Hill. This area is on top of the hill between bricks of the defensive wall. It is a former water artery of well which opened after landslide. Earlier, this water artery was vitally important for Castle hill defenders but nowadays this may be the cause of the slope erosion.

Another problem causing hills deformations is rain water collection and drainage. It was found that drainage pipes are worn out, cracked and have moved from their places. Some of them are not connected. For this reason, water leaks and erosion of the soil starts (Lekaviciene 2014).

Deformations of structures might have also been influenced by human activities. Lithuanian Grand Duke Palace restoration works that were started in 2002 may be classified as such activity. Also, in 2003, pedestrian and cargo lift was installed on the northern slope. Vibrations caused by the installation of pedestrian and cargo lift, may also have an impact on stability of the slope. All these reasons can influence results of measurements since the cycle (X) was started in 2002.

Conclusions

1. Longterm research (1968–2016) of cracks in the buildings of the Upper Castle have shown that all the features of the castle have been deformed during the time of the measurements (deformations and cracks in the walls have occurred);

2. Investigations suggest that the biggest vertical deformation was seen at Southeastern side of the hill. Since November 1968 (durring 48 years), on average, the biggest vertical deformation of structures has happened in foundation of the Grand Duke Palace (35.2 mm); since December 1995 (durring 21 years) – on Southern Retaining Wall (26.4 mm). The least vertical deformation was detected on north-west side of the hill. The lowest vertical deformation since November 1968 (durring 48 years) was established at Gediminas Tower and a part of Southwestern Retaining Wall (28.7 mm); since December 1995 (durring 21 year) – on Southwestern Defensive Wall (near Gediminas Tower) (10.6 mm);

3. The vertical deformation values depend on many factors: geological, hydrogeological and hydrometeorological conditions, human economic activity, structural stability of buildings. Steep slopes, plants, rotting stumps are causing

the slopes erosion and landslides. Poor draining, improperly performed works of slope stabilization, trample down vegetation areas, existing underground structures (tunnels and shafts), vibrations of pedestrian and cargo lift, restoration works of Grand Duke Palace and former water artery on the eastern side of Castle Hill also have a significant impact;

4. The vertical deformation values were within the limits of the accuracy of measurements;

5. In order to avoid vertical deformations, it is necessary to extend geodetic monitoring, especially in problem areas and carry out reinforcement works. Gediminas Hill is worthy to be monitored by specialists as it is Lithuanian statehood and became the symbol of the cultural heritage of the country's capital, which is the most important dominant object throughout the history of Vilnius city.

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References

Baselga, S.; Garrigues, P.; Berné, J. L.; Anquela, A. B.; Martín, A. 2011. Deformation monitoring in historic buildings: A case study, *Survey Rewiew* 43: 484–492. https://doi.org/10.1179/003962611X13117748891912

Çelik, R. N.; Ayan, T.; Denli, H.; Özlüdemir, T.; Erol, S.; Özöner, B.; Apaydın, N.; Erincer, M.; Leinen, S.; Groten, E. 2001. *Monitoring deformation on karasu viaduct using GPS and precise levelling techniques*. Kluwer Academic Publisher, Netherlands.

Corporation „Inžineriniai tyrinėjimai" branch „Inžinerinė geodezija". 1995–2008 m. Gedimino kalno pastatų sėdimų stebėjimo techninės ataskaitos. Vilnius.

Erol, S.; Erol, B.; Ayan, T. 2004. A general review of the deformation monitoring techniques and a case study: analysing deformations using GPS/levelling, in *The 20th ISPRS Congress*, 12–23 July 2004, Istanbul, Turkey.

Henriques, M. J.; Casaca, J. 2007. *Monitoring vertical displacements by means of geometric levelling – Historical Constructions*. Guimaraes-Portugal.

Lekaviciene, E. 2014. *Gedimino kalnas: išgelbėtas ir nušvitęs*. „STRUCTUM" Žurnalas sekmingam verslui. Vilnius, 2014. 10–19 p.

USACE. 2002. *Engineering & design – structural deformation surveying*. United states Army Corps of Engineers manual, Department of the Army. Washington DC. No. 1110-2-1009, p. 2–5 to 2–6.