Instability phenomena, geoelectrical investigation and mitigation measures in the area of the city of Sighisoara, Romania

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Abstract: The medieval complex from the city of Sighisoara (Romania), with military, ecclesiastic and civil architecture, was well preserved during many centuries. Nowadays Sighisoara citadel, situated on a hill, is affected by some landslide instability phenomena, endangering the walls, towers and other constructions.

The main objectives of the study are the investigation of the geological engineering conditions in the area of the medieval fortress, the human impact and its influence on the instability phenomena and on the causes of cracking and collapse of medieval buildings. The activity was dedicated to detailed geoelectrical studies on some historical buildings from the citadel of Sighisoara affected by instability phenomena and to design the mitigation measures. Casa Wagner, for instance, a building from the XVIIth century, partially damaged (fissures in walls and basement), was investigated by geoelectrical measurements. The results of the studies are presented by interpretative geoelectrical sections and confirmed by some geotechnical soundings allowed in the area. From this geoelectrical sections some geological and geotechnical elements have resulted and mitigation measures have been recommended.

Résumé: La cité médiévale de la ville de Sighisoara (Roumanie), avec son architecture militaire, écclésiastique et civile, a été bien préservée pendant des siècles. Aujourd'hui, la citadelle de Sighisoara, située sur une colline, est affectée par des phénomènes d'instabilité de type glissements de terrain qui périclitent les murs, les tours et les autres bâtiments.

Le principal objectif de l'étude a été l'investigation des conditions géologiques et géotechniques dans l'aire de la forteresse médiévale, l'impact humain et son influence sur les phénomènes d'instabilité et sur les causes de la fissuration et de l'écroulement des bâtiments. L'activité a été dédiée à des études géoélectriques sur quelques bâtiments historiques de la citadelle de Sighisoara affectée par des phénomènes d'instabilité et sur la désignation des mesures de mitigation. Casa Wagner, par exemple, un bâtiment de XVII-e siècle, partiellment endommagé (fissures dans les murs et sous-sol), a été investigué par des sondages géoélectriques. Les résultats des études ont été présentés comme des sections géoélectriques interprétatives confirmées par quelques sondages géotechniques permis dans les environs. Des éléments géologiques et géotechniques ont résulté de cettes sections géoélectriques et des mesures de mitigation ont été recommandées.

Keywords: case studies, geophysics, landslides, soils.

INTRODUCTION

Sighisoara is located in the southeastern part of the Tarnava plateau, belonging to the Transylvanian basin. The medieval complex has been built on the Citadel Hill in more stages between the 12th and the 17th century. The fortified area and the ecclesiastic buildings from the 13-15th century and the buildings from the 15-17th century are still well preserved: the Clock Tower, the Furriers' Tower, the Butchers' Tower and Bastion, the Ropemakers' Tower, the Tinsmiths' Tower and Bastion, the Leather Dresser Tower, the Church from the Hill, the Monastery Church, the Vlad Dracul House, etc. Some of them have been affected in the last years by instability phenomena, for instance Casa Wagner, a building from the XVIIth century. A contemporary picture of the area is shown in the Figure 1.

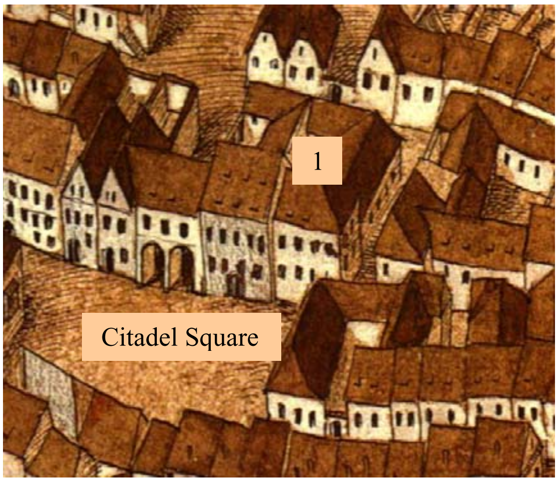

Figure 1. Citadel Square in the XVIIth century. 1- Casa Wagner

GEOLOGICAL AND MORPHOLOGICAL ELEMENTS

The geology of the Citadel Hill is represented by quasi-horizontal Pannonian sedimentary deposits (clays, marly clays and clayey sands alternating with fine to coarse sands). These deposits are covered with Quaternary deluvial formations and anthropogenic deposits, up to 9 m in thickness. Morphologically, the Fortress Hill is a witness of Tarnava Mare river erosion. The maximum level of the hill is of 432 m, with a relative height of 80 - 85m.

METEOROLOGICAL AND HYDROGELOGICAL DATA

The data referring to precipitations show a mean multiannual value of 614.4 mm, with a weight of 424.5 mm in the warm seasons (April-September) and of 189.9 mm in the cold seasons (October-March). The mean monthly values are different from month to month (23.4 mm in February and 93.0 mm in June). The surface runoff was estimated as 150 l/s·ha, with a probability of 5%. The velocity of the runoff can exceed 3 m/s, especially on the northeastern slope of the hill, with inclination of 0.5 - 0.6. The underground water was found at different depths proving a discontinuous and suspended aquifer, drained to the foothill. The chemical analysis of the waters evidences a high content of nitrates and ammonium.

GEOTECHNICAL CONDITIONS

Deluvial soils of 1.50-3.50 m thickness lay at the surface or under the filling in the studied area and are constituted predominantly by clay and silty clay. The mean physical-mechanical characteristics of the soils are presented in the table 1 (Marunteanu & Coman, 2000).

Table 1. Mean physical-mechanical characteristics of the deluvial soils

Physical-mechanical index	Mean value
Plasticity index, I_p (%)	28.20
Consistence index, I_c	0.89
Wetness, W (%)	19.80
Volumic weight, γ (KN/m^3)	20.20
Porosity, n (%)	38.60
Porosity index, e	0.67
Saturation degree, S_r	0.70
Friction angle, ϕ_u (degrees)	21
Cohesion, c_u (KN/m^2)	30

The bedrock (Pannonian deposits) is formed of marly clay, sandy clay, fine-grained sands and sometimes sandstones.

INSTABILITY PHENOMENA

The main object of the geoelectrical and geotechnical investigation was Casa Wagner, a building from the XVIIth century. The basement ceiling vaults have been built by bricks directly on the soil. In the last years the building was partially damaged by fissures in walls and basement. A fissure in the eastern front of the construction is shown in the figure 2.

Figure 2. Fissure in the eastern front of Casa Wagner

In the covering deposits, the accumulations of the water provided by the rainfall storages, the leakage from the supply and sewerage pipes or from cesspool exfiltration and by the irrigation of the gardens produce an important reduction of the shear resistance of the soils and of the filling determining the main cause of the ground instability. For this reason, the geoelectrical method was considered the most suitable for the ground investigation.

GEOELECTRICAL MEASUREMENTS MITIGATION MEASURES

The main purpose of the geoelectrical survey was to investigate the geological and hydrogeological structure of the ground around the building of the Casa Wagner. The survey method was the resistivity method by vertical electrosounding in DC current using a high-resolution device (Terrameter SAS 300C ABEM - Sweden) with 8.00m depth of investigation.

Apparent resistivity pseudo sections by geoelectrical information were built using Surfer 8 interpolation methods (Figure 3). The geoelectrical elements for the geotechnical interpretation of the geophysical data are the minimum and maximum resistivity anomalies and the geoelectrical gradient. The geoelectrical images show the geological structure and the anthropogenic works effect on the foundation ground.

The processed resistivity data can be interpreted as geological-geotechnical and hydrogeological elements:

- filling/deluvium limit (interpreted also as an incipient landslide of the filling on the deluvium), deluvium/Pannonian limit, lithological limit inside Pannonian,
- ground and basement infiltrations from damaged sewerage,
- depth of sewerage and sewer pipes,
- highly saturated zones, etc.

The minimum resistivity anomalies (10-25 Ohmm) at about 3.0 m depth in VES w3 - w10 (Figure 3a) represent the effect of the sewerage infiltrations, present to the deluvium/Pannonian limit. The resistivity gradient is contouring these highly saturated zones. The influence of the infiltration phenomena on the building damage and ground instability became obvious after the first measurements in 2002.

As a result of the geoelectrical investigations some mitigation measures have been proposed and taken in the view to decrease the risk of degradation or even destruction of this historical site of Sighisoara:

- Rehabilitation or repair of the sewage system with the deepening of the sewage pipes from 1.3 m to 3.0 m from the street level;
- Consolidation of the basement by under building of the vaults at a lower level than the initial level and reinforcing of the new foundation by concrete beams;
- Draining of the basement by gravel trenches.

After the remediation works the geoelectrical measurements have been repeated in 2005 on the same profiles. The new interpretative geoelectrical section (Figure 3b) reveals:

- Disappearing of w8 and w10 minimum anomalies;
- Maintaining of w3 minimum anomaly related to the still active wall fissure;
- Decreasing of the resistivity gradient related to a real increasing of resistivity values, reflecting the reduction in degree of saturation and the stabilization of the ground.

CONCLUSIONS

The geoelectrical measurements and monitoring provide a powerful tool in urban engineering geology. The interpretative geoelectrical sections allow the deciphering of the geological and hydrogeological structure in zones where the geotechnical drillings are difficult to carry out or expensive. The influence of the damaged sewerage on the ground properties and foundation stability are very well revealed by the geoelectrical measurements and allow the design of the suitable mitigation measures. The geoelectrical measurements after the rehabilitation and consolidation works of the sewerage and foundation (monitoring) evidence the mitigation effects on the ground properties.

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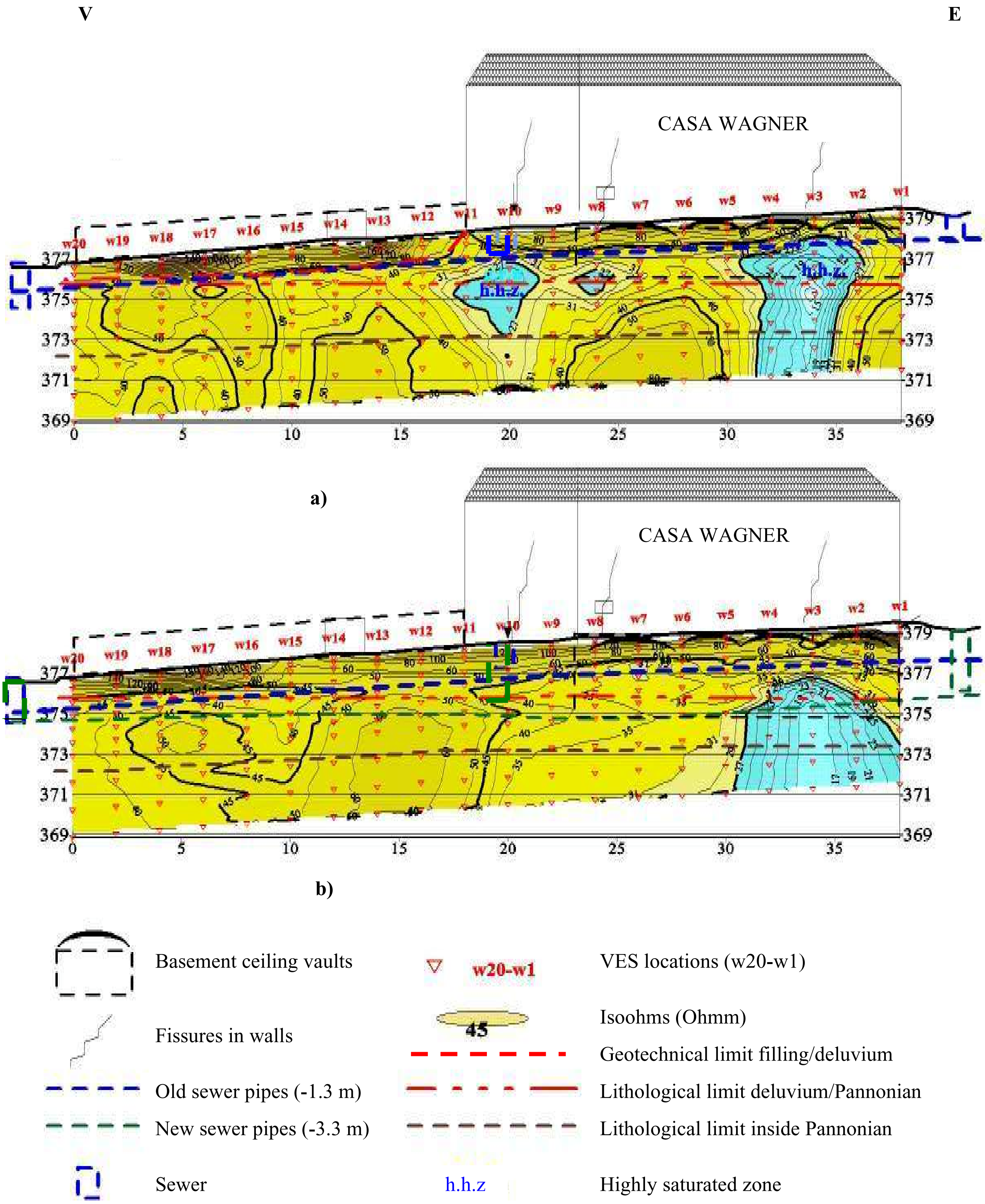

Figure 3. Interpretative geoelectrical cross sections along the Casa Wagner building and yard a) 2002; b) 2005