Modelling of ground surface deformations with Finite Element Method in fault zones for the purpose of designing geodetic observations.

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Key words: Finite Element Method, Middle Odra Fault Zone, surface deformations

SUMMARY

Geodetic measurements provide information on displacements of points located on the rock mass surface. In tectonic fault zones covered with Cainozoic deposits these displacements are the result of sub-Cainozoic stratum movements and processes taking place in overlying loose rocks. For the purpose of identifying movements of tectonic units, the most favourable location of points on the ground surface in places of expected maximum deformations is necessary. This is particularly true for objects that have not been previously monitored. In the article modelling of ground surface with Finite Element Method has been presented. For specified movements of sub-Cainozoic stratum and in accordance with geological models, deformations of rock mass surface were calculated. Numerical modelling was performed in the ABAQUS Software. The research described in the paper is carried out in connection with geodynamic studies of the SW Poland area in the Middle Odra Fault Zone, which lies in the Central European Subsidence Zone.

STRESZCZENIE

Pomiary geodezyjne dostarczają informacji o przemieszczeniach punktów zlokalizowanych na powierzchni górotworu. W strefach uskoków tektonicznych pokrytych utworami kenozoicznymi przemieszczenia są wypadkową ruchów podłoża podkenozoicznego oraz procesów zachodzących w pokrywie skał luźnych. W celu identyfikacji ruchów jednostek tektonicznych konieczne jest optymalne rozmieszczenie punktów na powierzchni terenu w miejscach spodziewanych maksimów deformacji. Dotyczy to zwłaszcza obiektów dotychczas nie monitorowanych. W artykule przedstawiono modelowanie przemieszczeń powierzchni terenu metodą elementów skończonych. Dla zadanych ruchów podłoża podkenozoicznego zgodnego z istniejącymi modelami geologicznymi wyznaczano deformację powierzchni terenu. Modelowanie wykonano w programie ABAQUS. Prace badawcze przedstawione w artykule prowadzone są w związku z badaniami geodynamicznymi na obszarze południowo-zachodniej Polski w strefie uskoków środkowej Odry położonej na obszarze wschodnioeuropejskiej strefy subsydencji.

1. INTRODUCTION

Geodetic studies of present-day geodynamics, even on areas of little tectonic activity, provide significant results for large underground mining works and urban and industrial agglomerations risk assessment. Important fundamental part of such research is location of research network points (GPS network, precise levelling network). Their number is determined among other things by economic factors.

In 2007 the regional network for geodynamic research in SW Poland has been established on the fault zone covered by 300 m thick Cainozoic deposits. Deformation of the ground surface on such area are caused by both the activity of the Sub-Cainozoic bed and factors influenced acting in the layer of overlying deposits. Exact proportions of those factors influence are unknown in initial period of the monitoring these objects. In the paper, the results of modelling ground surface displacements by Finite Element Method have been presented.

2. DESCRIPTION OF THE RESEARCH AREA

The analysed area is located in SW part of Poland in the contact zone of two regional tectonic units: the Fore-Sudetic Block and the Fore-Sudetic Monocline (fig.1). These units are separated by The Middle Odra Fault Zone, that is a part of the Central-European Subsidence Zone (Stackebrandt, 2004) extending in the axis from the North Sea, through Hamburg, Berlin, Wroclaw to Cracow.

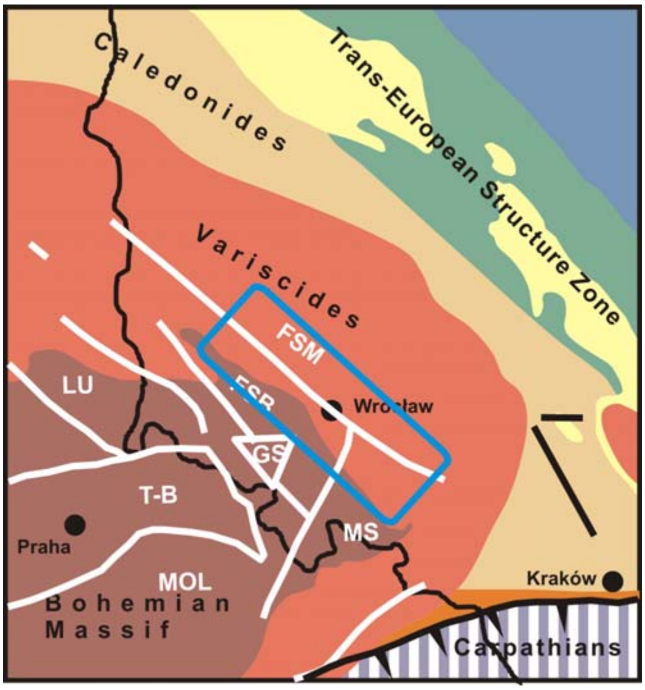

Fig.1. Location of the research area and the European tectonic units in the background (geological background Majdański et all., 2007 after Cymmerman).

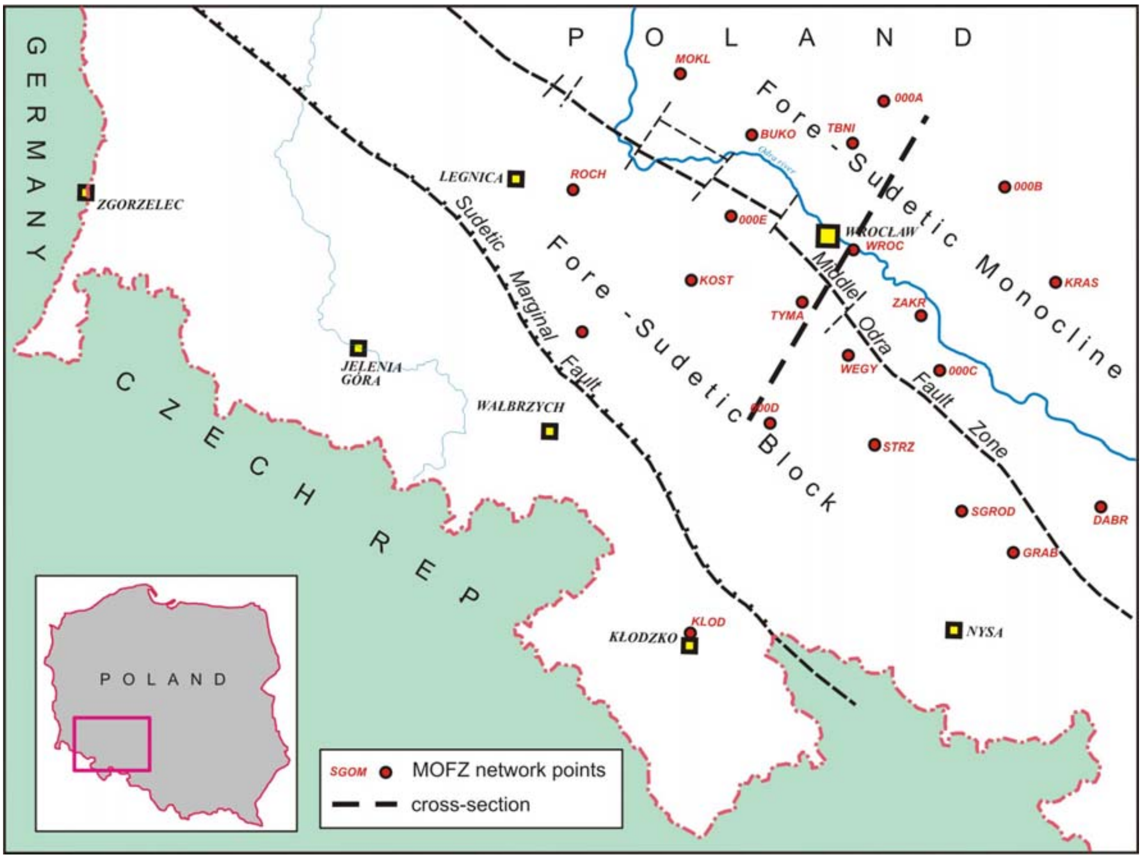

Fig. 2. Location GPS points and the regional tectonic units in the background.

The research area is an aseismic region, in which earthquakes occurred from the 15th to the 19th Century and did not exceed 5 degree on the MSK scale (Guterch, Marciniak-Lewandowska, 2002). Present day earth tremors are detected approx. 50 km to the west from the research area and are inducted by mining activity. Velocities of the IGS permanent stations' movements, in this part Eurasian, reach 25 mm/year towards NE whereas intraplate velocities of points determined from GPS annual epoch measurements on the Sudetic Marginal Fault, that is parallel to The Middle Odra Fault Zone, range from 0.8 to -0.7 mm/year (Kapłon, Cacoń, 2009, Kontny, 2003). Analysis of relative benchmark height changes in precise levelling network revealed, that for 46 years vertical displacement of the ground reached -100 mm in the axis of the Middle Odra Fault Zone (Grzempowski et. all, 2009). The most significant changes of height differences occurred in the areas of northern and southern borders of this zone. The roof of bedrock is covered on all of the research area with an up to 300 m thick layer of Cainozoic deposits, This does not allow for unequivocal ascertainment of the influence of tectonic activity on ground surface deformation. This it also concerns processes occurying in this layer that are connected, among others things with groundwater level table changes caused by water intakes (Grzempowski, Cacoń, 2005).

In 2007, in this region, GPS network covering an area of 6000 sq km has been established and in 2008 and 2009 its measurements have been done. Due to short period between annual epoch measurements there are no foundations for definite conclusions in this subject, yet.

3. PREDICTION OF THE GROUND SURFACE DISPLACMENTS

With the aim of predicting influence of the Sub-Cainozoic bed movements on ground surface displacements modelling by finite element method has been applied. Simplified geological cross-section 65 km in length and 15 km depth, perpendicular to the fault zone, has been created. For this purpose data from: hydrogeological boreholes, maps of Cainozoic strata thickness, Sub – Cainozoic topography maps (Badura et all., 2004), geological cross-sections and information from scientific publications, among others Majdański et all. (2007), were used. On the basis of the constructed geological cross-section, the geometrical model divided into blocks assigned to tectonic units was created. Boundaries of blocks (contact zones) were set in locations of main tectonic faults on geological maps (Kłapcińki, 1983, Cymerman, 2004). Material properties, appropriate for linear-elastic model, were assigned for individual geometrical elements.. The mesh was generated automatically using three-node triangular elements (3-node linear plane strain triangle). Calculations were made in plane strain state and a linear-elastic relationship between stress and strain. Modelling was done in two variants:

- in the first one, vertical movements of rock blocks located in axis of the Middle Odra Fault Zone was considered,
- in the second one, additional horizontal compression for this zone was added.

The velocities of vertical blocks displacements were established on the basis of repeated measurements of the 1st order national levelling networks, whereas horizontal displacements in the results of GPS measurements on the parallel Sudetic Marginal Fault (Kapłon, Cacoń, 2009, Kontny, 2003). As the model's boundary conditions shifting support and vertical displacements for blocks in axis of the Middle Odra Fault Zone were assumed. Annual vertical displacements equal to -1.2 mm/year and horizontal displacement for the left side of the block equal to 0.6 mm/year were used.

Young's modulus (E) values were established as mean values of the rocks' moduli occuring the most often in individual blocks. However the Poisson's ratio (ν) of 0.25 was assumed equal for all the layers.

The model's boundary conditions and the results of modelling for the second variant have been shown in Fig. 3. It is necessary to point out that the results concern potential changes, that can possibly occur during one year between annual measurements, and between locations of local extrema of the displacement function in relation to the fault zone axis.

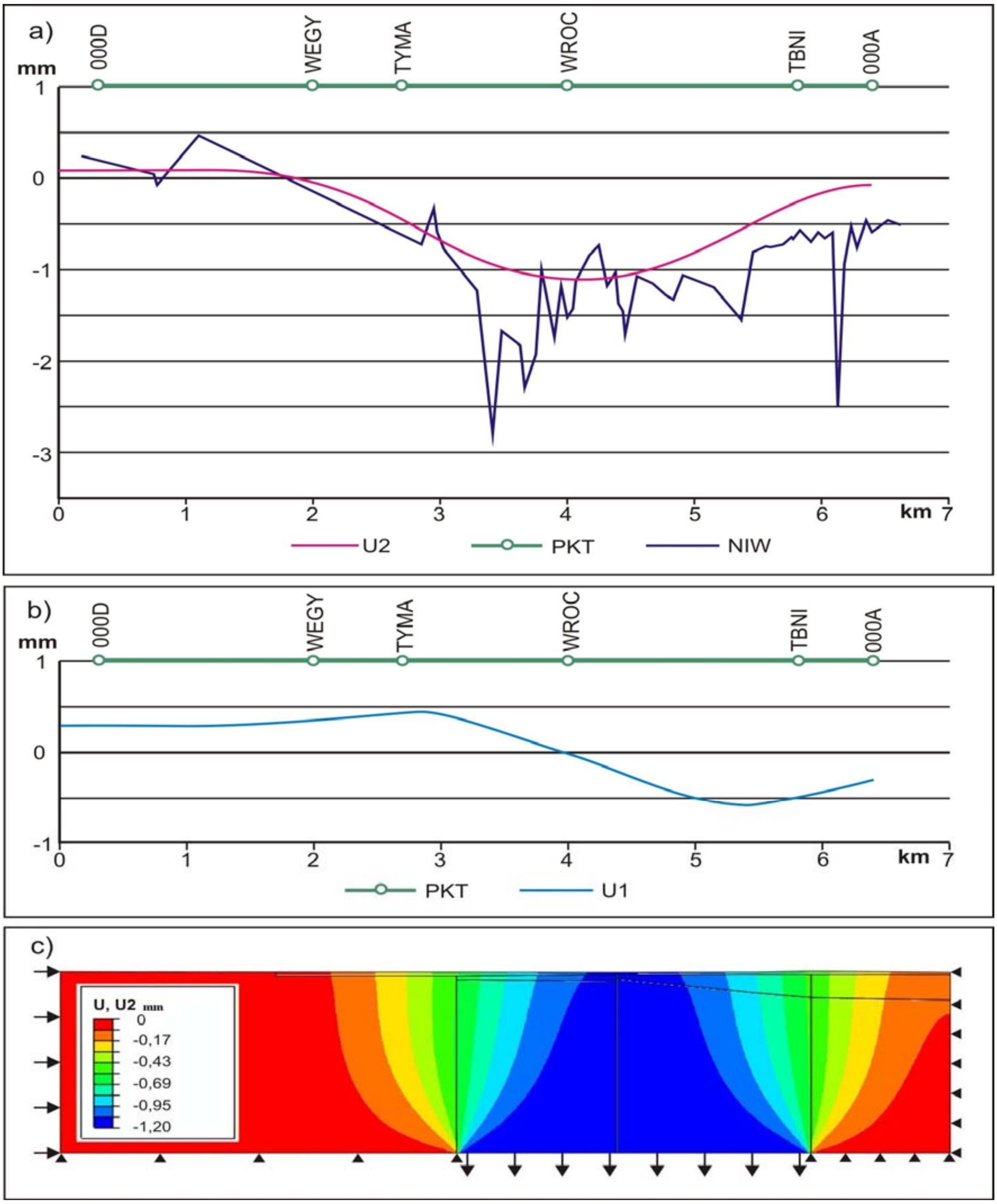

Fig. 3. Results of the FEM modelling and boundary conditions

a) vertical displacement (U2) from FEM model, velocities of vertical displacements in precise levelling lines (NIV), GPS point (PKT)

b) horizontal displacements (U1)

c) boundary conditions and vertical displacements from FEM model (U2)

Location of the GPS points on the research area have been adjusted to the predicted ground surface displacements. For the presented example points 000D and 000A are located outside the fault zone in regions of the smallest expected ground surface displacements. The points: WEGY, TYMA and TBNI are located near the expected extrema of horizontal displacements on the southern and the northern borders of the Middle Odra Fault Zone. In the zone's axis, the expected area of maximum vertical displacement, the permanent GPS station "WROC" is located. The values of maximum vertical velocities of the ground surface displacements determined from levelling measurements (Fig. 3) inconsistent with the trend curve obtained from FEM modelling are the results of local factors acting in Cainozoic layers (Grzempowski, Cacoń, 2005).

4. CONCLUSION

The presented dissertation related to the problem of reliable monitoring of the lithosphere's surface in the Middle Odra Fault Zone in Poland are a preliminary stage of research on the subject. The interpretation of vertical displacement results determined on the basis of repeated epoch measurements of precise levelling network perpendicular to this zone confirms existence of influence of tectonic faults on these changes. To determine the expected horizontal displacements in this zone, analysis using FEM has been done. The already started *in situ* research is based on epoch measurements in GPS network points. Locations of these points have been correlated with the regions geology and tectonic structure and results of analyses, whose example was presented in the paper. The first measurements of this network (48 hour sessions) carried out in 2008 and 2009 provide no foundations for concrete results yet.

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REFERENCES

Cymerman Z., 2004, Tectonic map of The Sudetes and Fore-Sudetic Block, 1:200000, Polish Geological Institute, ISBN 83-7372-7038-8.

Badura, J., Przybylski, B. and Zuchiewicz ,W.: 2004, Cainozoic evolution of Lower Silesia, SW Poland: a new interpretation in the light of sub-Cainozoic and sub-Quaternary topography, Acta Geodynamica et Geomaterialia, 1, 3(135), 7-29.

Majdański M., Kozlovskaya E., Grad M., SUDETES 2003 Working Group 2007, 3D structure of the Earth's crust beneath the northern part of the Bohemian Massif, Tectonophysics 437 (2007) 17–36.

Grzempowski P., Cacoń S., 2005, The cause analysis of benchmark movements in the city of Wrocław, Reports on Geodesy No.3 (74), 2005, s. 271 - 281.

Grzempowski P., Badura J., Cacoń S., Przybylski B., Recent vertical movements in the Wroclaw section of the Middle Odra Fault Zone, Acta Geodynamica et Geomaterialia, Vol. 6 No. 3 (155), Prague 2009, pp. 339-349.
Guterch B., Lewandowska – Marciniak H., Seismity and seismic hazard in Poland, Folia Quaternaria 73, Kraków 2002, pp. 85-99.
Jarosiński M., Sources of the present-day tectonic stresses in Central Europe: inferences from finite element modelling (in Polish), Prz.Geol., 54: 700–709.
Kłapciński J. Geological conditions near Wrocław and earthquake in 1976 (in polish), Geological Review 3/1983
Kapłon J., Cacoń S., Research on the marginal sudetic fault activity with use of GPS and precise leveling techniques, Acta Geodynamica et Geomaterialia, Vol. 6, No. 3 (155), pp. 323-329, 2009.
Kontny B., 2003, Geodetic research of contemporary kinematics of the main tectonic structures of the polish Sudetes and the Fore-Sudetic Block with the use of GPS measurement, Scientific papers of the Agricultural University of Wroclaw, 468, dissertation CCII.
Stackebrandt W., Zur Neotektonik in Norddeutschland, Z. geol. Wiss., Berlin 32 (2004) 2-4: 85 - 95, 6 Abb.

BIOGRAPHICAL NOTES

Stefan Cacoń is a full professor in the Institute of Geodesy and Geoinformatics at the Wroclaw University of Environmental and Life Sciences. Research interests include: engineering geodesy and geodynamics. Participated in the European research COST Action 625 „3D Monitoring of Active Tectonic Structures" (2000-2006). Co-organiser of international geodynamic studies in the Polish and Czech Sudetes. He has published over 200 scientific papers.

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