APPLICABILITY OF PSINSAR FOR BUILDING HAZARD IDENTIFICATION. STUDY OF THE 29 JANUARY 2006 KATOWICE EXHIBITION HALL COLLAPSE AND THE 24 FEBRUARY 2006 MOSCOW BASMANNY MARKET COLLAPSE

Zbigniew Perski [(1)], Freek van Leijen [(1)], Ramon Hanssen [(1)]

[(1)] *Delft Institute of Earth Observation and Space Systems; Delft University of Technology*
Kluyverweg 1, 2629 HS Delft, The Netherlands, Email: z.a.perski@tudelft.nl

ABSTRACT

Due to heavy snow fall in winter 2005-2006, two building catastrophes happened in Katowice (Poland) and Moscow (Russia) killing and injuring dozens of people. Roof collapses, caused by heavy snow and ice accumulation were the direct causes, but it was questioned whether other circumstances such as construction stability would play an additional triggering role. Moreover, both buildings were located on unstable areas affected by underground coal mining (Katowice) and karst and suffusion phenomena (Moscow). We performed a stability assessment of the buildings, prior to the collapse, using Persistent Scatterer techniques on time series of SAR data. The main challenge of this study is the identification of a few representative coherent scatterers on individual buildings. The main conclusion of this analysis of ERS-1/2 and ENVISAT data is that we found no significant indication of instability before the catastrophes.

1. CATASTROPHIC BUILDING COLLAPSES IN KATOWICE AND MOSCOW

On 28 January 2006, the roof of a 10.000 m^2 exhibition hall in Katowice (Upper Silesia, Poland) collapsed, killing 63 and injuring 140 people. The exhibition hall (Fig. 1A) was owned by the International Katowice Fair (IKF) and located within a large exhibition park. The collapse was the direct consequence of a heavy half-meter layer of snow and ice covering the roof. Nevertheless, it is still disputed whether the roof loading was the sole reason for the collapse. Construction engineering experts suggested that the construction of the hall might be already weakened before due to ground displacement beneath the hall related to underground hard coal mining. An alternative hypothesis was that the hall was badly constructed or designed. In the first case the area surrounding the hall should be subject to deformation - mainly subsidence. In the second case the construction itself should show deformation, whereas the surrounding area should remain stable.

On 24 February 2006 the snow-covered roof of the Basmanny market, Moscow, collapsed, killing 56 and injuring 30 people. Similar to the event in Upper Silesia, the collapse was the direct consequence of snow accumulation and it raised similar questions: whether the construction was safe and stable enough prior to collapse. Basmanny market is the 17.400 m^2 circular building in Fig 1B. It was constructed in 1974 and therefore only material weakening and ground deformation are considered as potential weakening factors. Surface subsidence and collapse are common hazards in Moscow, related to karst and suffosion.

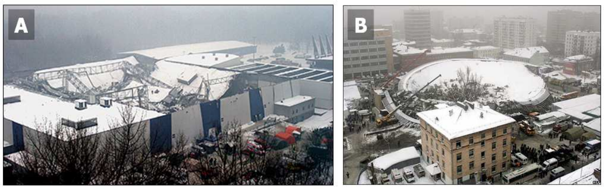

Fig.1 The views on collapsed building in Katowice (A) and in Moscow (B)

2. SUBSIDENCE AND COLLAPSE HAZARDS

Both buildings were located in instable areas, suggesting the risk of potential construction stress by terrain deformations.

Katowice lies in the heart of Poland's coal mining region (Upper Silesia Coal Basin) and stands on a network of derelict mine constructions like tunnels, cavities (goafs), shafts which often cause subsidence, and sinkholes. An area of almost 600 km^2 is affected in Upper Silesia by damage caused by underground exploration. Surface subsidence is the largest and most visible impact of the underground mining activities. It causes changes in topography and hydrography, and damage to buildings and other structures. The subsidence in active mining areas reaches velocities varying from a few millimeters to some centimeters daily and is highly nonlinear in space and time and thus difficult to model. At areas of abandoned mining facilities, sinkholes may appear suddenly, e.g. after

Proc. 'Envisat Symposium 2007', Montreux, Switzerland
23–27 April 2007 (ESA SP-636, July 2007)

heavy rain fall. Such phenomena are typical for these areas where shallow mining existed until the end of 19th century. According to the mining activity records, the most significant and the latest coal exploitation within the area of the exhibition hall have occurred between 1919 and 1925 at a depth of 50 m, and in 1936 at the depth of 90m. Later, there was no further coal exploitation and thus we assume that the area is stable, although the occurrence of pit subsidence (sinkholes) due to shallow exploitation has been noted ..

In Moscow, the surface subsidence and collapse hazards are caused by karst and suffosion phenomena. Karst is there restricted to a thick complex (more than 300 m) of soluble and impermeable Carboniferous carbonate rocks, which usually occur at depth of some tens of meters under Mesozoic and Cenozoic deposits. In the 1960s and 1970s, the intense water withdrawal from the Carboniferous aquifer resulted in a deep groundwater level depression cone in Moscow and activated karst and suffusion and surface subsidence[1]. These phenomena posed a serious risk to both surface and underground facilities. During a relatively short time period, 42 surface collapses occurred in the Khoroshevskij district in Moscow. In 1969 and 1977 three five-storey buildings were ruined in this district during surface collapses [2].

3. PSI FOR MONITORING OF BUILDINGS

Since 1997, the Upper Silesian area is involved in SAR interferometric studies. These studies proved the feasibility of the conventional InSAR technique for measuring terrain subsidence related to active long wall mining. It has been shown that there is a direct relationship between the location of the mining front and the subsidence bowl observed in ERS SAR interferograms [3].

Despite the benefits of InSAR measurements for active mining this technique fails in the case of slow, small scale post-mining subsidence, mainly due to temporal terrain decorrelation and juxtaposed atmospheric signal delay. Due to EU regulations and economic developments, the closing process of the coal mining industry started in Poland in the late 1990's. The mines located under the Silesian cities were among the first to be closed. However, it is expected that damage will continue to occur for many years and its monitoring will be difficult and costly.

Persistent Scatterer Interferometry is an alternative interferometric processing approach for SAR data, which is potentially more suitable for slow subsidence monitoring and for a posteriori studies based on archived data [4, 5]. It potentially allows for mm-level deformation measurements based of a large amount (20-80) of SAR images. It is an ideal method for non-interventive measurements of coherent natural radar reflectors such as buildings in urbanized areas [6]. PSI techniques have already proved to be able to detect individual building deformations, [7].

PSI is an opportunistic technique, that is, for a specific location it is impossible to predict whether and how many coherent scatterers will be available and detected. For both described catastrophic events the PS-InSAR technique is the only available method to detect whether the constructions were subject to deformations during their exploitation before the respective tragedies.

4. METHODS APPLIED

The Delft PSI method [8] has been fine-tuned to enable the evaluation of every pixel covering or surrounding the object of interest.

The Katowice exhibition hall has been constructed in 2000 and therefore the PS-InSAR analysis was divided into two parts. The first part focused on terrain instability detection performed on a stack of 66 ERS-1 and ERS-2 images acquired prior to the construction of the hall. To retrieve information whether the area of future construction was stable, it was needed to retrieve the moment when the construction works were initiated. Unfortunately such information was not available and therefore it was established using a series of ERS SAR amplitude images. Respective to that date all ERS-2 images acquired after August 1999 had been exclude from the processed stack. To avoid temporal unwrapping problems also ERS-1 images acquired before 1995 were excluded because of the long temporal gap with respect to the rest of acquisitions.

The second part of the analysis explored the Envisat ASAR data over the exhibition hall itself in the period 2002-2005. Unfortunately only a small number of images had been acquired and therefore the analysis focused on two descending and two ascending stacks. For two descending tracks only 9 and 12 images were acquired respectively. Finally both descending datasets were excluded from further analysis due to low reliability.

Basmanny market in Moscow was constructed in 1974 and therefore the building is present in all archived ERS-1 and ERS-2 images. For the initial analysis a full stack of 65 ERS-1 and ERS-2 images has been analyzed covering the time period from 1992 to 2001.

During the PS processing an additional mask was applied to force the algorithm to evaluate every pixel within the area of interest. Prior to the PS processing, the interferograms from Katowice area were generated with the public-domain Delft Object-Oriented Radar Interferometric Software (DORIS) [9] and corrected with the best available DEM.

5. RESULTS AND INTERPRETATION

5.1 Katowice ERS-1/2 data

A stack of 36 SAR images has been used for processing covering the period from 1995 to 1999. In total 76 reliable points have been detected within Exhibition Park of the IKF area. Unfortunately only two reliable PS were found within the area of the future hall construction. Calculated linear PS velocities within the IKF area do not exceed 4 mm/year and therefore the area is considered to be relatively stable. The regional analysis of PS results indicates that the IKF Park is located within a large stable area surrounded by zones where active mining is occurring. The stable area within the center resulted from the lack of any coal exploitation at the beginning of the 20th century. Since that time the ground motions were stabilized and no deformation is reported from InSAR data and leveling. The surrounded active mining areas are characterized by highly non-linear deformations with respect to time and space. For some areas deformation exceeds much more than 10 mm/year (Fig.2) commonly reaching several cm/month [3]. The distance from IKF to the closest active mining area is around 4.7 km and therefore IKF area should be considered as not affected by those deformations. The detailed analysis of identified points within IKF confirms that the area was stable. The liner component of deformation does not exceed 2 mm/year however some points reported velocities up to 4 mm/year.

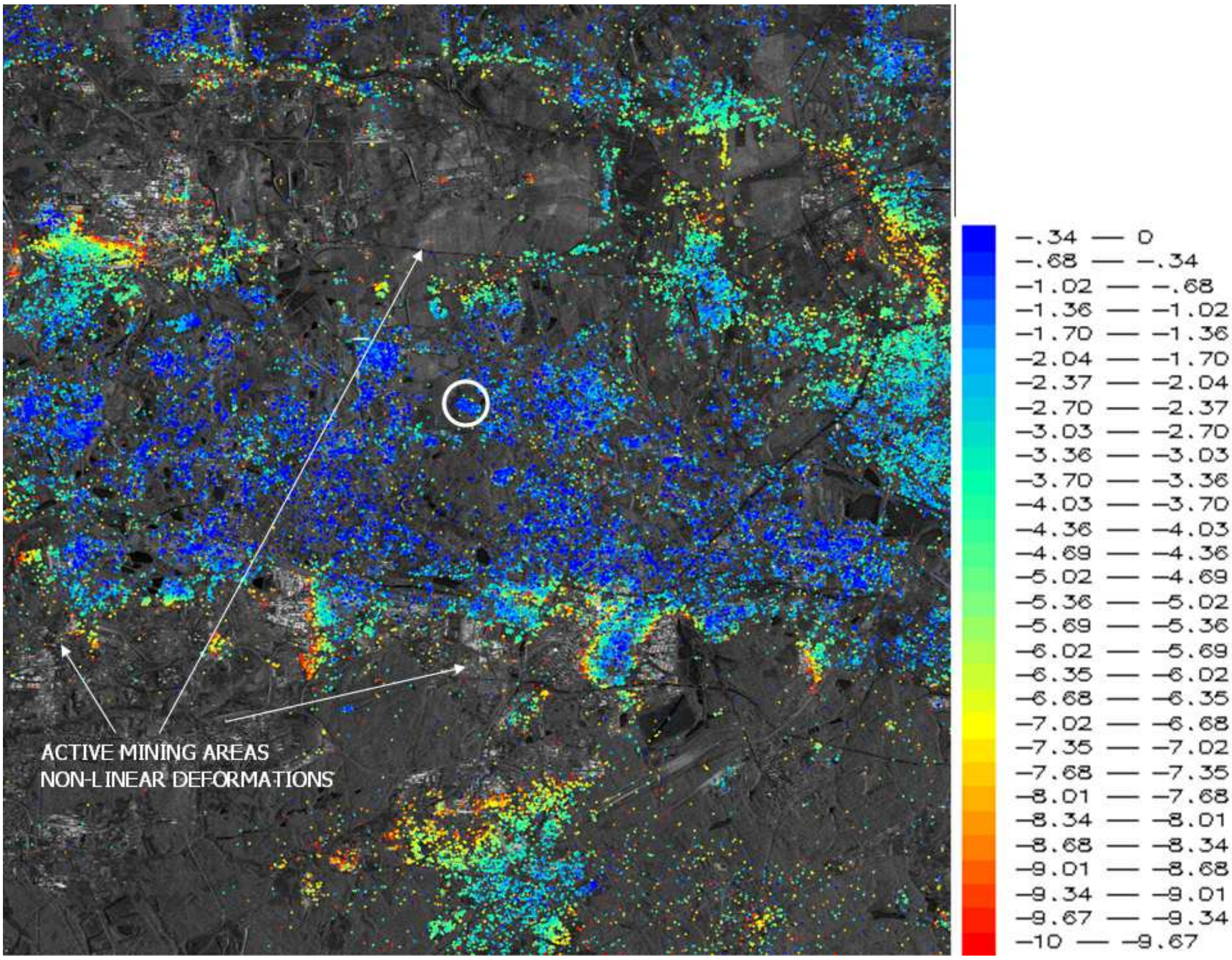

Fig.2. Upper Silesia (Poland). The linear velocities of PS points derived from ERS-1/2 images covering the area of 10 x 10 km and the period from 1995 to 1999. White circle indicates the exhibition park where collapsed building is located.

5.2 Katowice ENVISAT

The analysis of the PS points derived from the Envisat stack focused on the ascending data. The only points of high temporal coherence (> 0.6) were further analyzed. However, due to small number of scenes the results are very noisy and their coherence cannot be reliably estimated to evaluate the quality of the results [10]. For the cross-validation of the results the common targets present on both datasets have been identified. The independent time series for those points show some similarities but due to the small number of images available for PS processing it is not possible to draw a final conclusion about the deformations of collapsed roof (Fig. 3). However, it is clear that the time series does not present any significant trend in deformation. The time series were then compared with ground temperatures records. Meteorological data were derived from the weather station of the Silesian Planetarium located 800m west from the area of collapse. The comparison does not show any clear correlation, which may be due to the fact that the building was artificially heated for the purpose of occurring exhibition events.

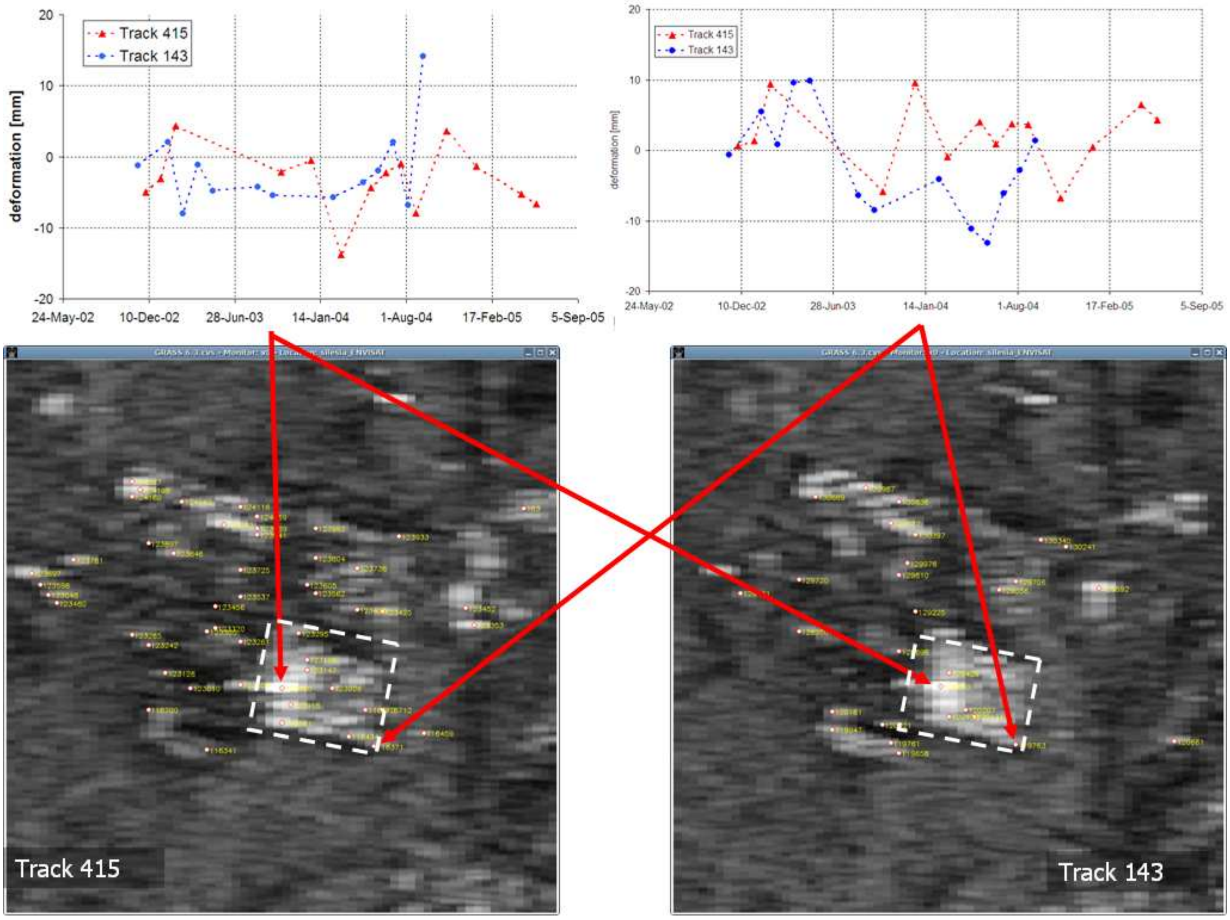

Fig.3. The time series of common PS on the roof of collapsed Katowice exhibition hall identified on two ASAR neighboring ascending tracks.

5.1 Basmanny ERS

The PS analysis was performed based on 65 ERS-1/2 images. To maximize the number of PS detected, the same procedure for the evaluation of all pixels has been applied. Only two reliable PS were identified on the roof of Basmanny market and some additional in the surroundings. The points located on the roof and the surrounding does not show any significant deformation prior to the collapse (Fig. 4).

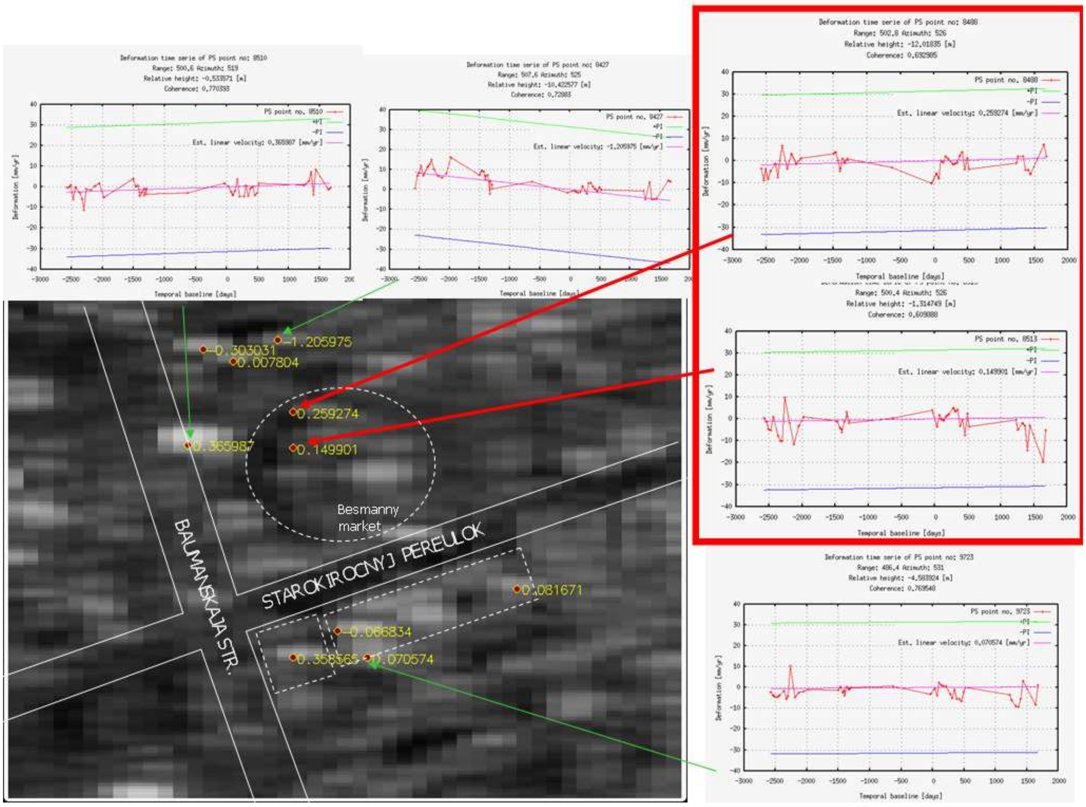

Fig.4. The time series of PSs on the roof of Basmanny market and surrounding identified on ERS -1/2 SAR data series

6. CONCLUDING REMARKS

ERS-1/2 PSI analysis shows that the deformations within the area of International Katowice Fair are around 2.5 mm/year from 1995 to 1999 which is not significant in respect to mining deformations occurring on surrounding areas. Envisat PS analysis of 3 independent tracks does not allow for conclusive results, mainly due to the limited amount of ASAR data available. However, the cause of collapse confirmed not to be mining related.

The analysis of ERS-1/2 PSI results for Basmanny market show that the area remained stable from 1992 to 2000. Two PS identified at the roof of the market do not show significant deformation. The detected signal of +/- 1 cm might be related to thermal construction changes.

7. ACKNOWLEDGEMENT

SAR and ASAR data used in this work are the courtesy of ESA projects: C1P.2851 (Moscow) and AO3-127 and C1P.8320 (Katowice). Air and ground temperature data hav been obtained from daily climatological logs and ground temperature logs provided by the Silesian Planetarium in Chorzów. The authors wish also to acknowledge the Cartography and Geodesy Office of Viovodship of Silersia for providing us the aerial ortophotomaps and elevation data of the study area.

8. REFERENCES

1. Nikonov, A.A., *Underground hazards in Moscow.* Priroda, 2003. **6**: p. 9.
2. *Moscow. The Geology and the City* Osipov V. I Medvedev O.P. ed. 1997, Moscow: Moskovskie Uchebniki i Katrografiya. 399.
3. Perski, Z. and D. Jura, *ERS SAR Interferometry for the Land Subsidence Detection in Coal Mining Areas.* Earth Observation Quartery, 1999. **63**: p. 25-29.
4. Ferretti, A., C. Prati, and F. Rocca, *Nonlinear Subsidence Rate Estimation using Permanent Scatterers in Differential SAR Interferometry.* IEEE Transactions on Geoscience and Remote Sensing, 2000. **38**(5): p. 2202-2212.
5. Ferretti, A., C. Prati, and F. Rocca, *Permanent Scatterers in SAR Interferometry.* IEEE Transactions on Geoscience and Remote Sensing, 2001. **39**(1): p. 8-20.
6. Ferretti, A., et al. *Radar Permanent Scatterers Identification in Urban Areas: Target*

Characterization and Sub-Pixel Analysis. in *IEEE/ISPRS Joint Workshop on Remote Sensing and Data Fusion over Urban Areas, 8-9 Nov, 2001*. 2003.

7. Ferretti, A., et al. *SAR Analysis of Building Collapse by means of the Permanent Scatterers Technique*. in *International Geoscience and Remote Sensing Symposium, Honolulu, Hawaii, 24-28 July 2000*. 2000.
8. Leijen, F.v. and R. Hanssen. *Interferometric Radar Meteorology: resolving the acquisition ambiguity*. in *CEOS SAR Workshop, Ulm Germany, 27-28 May 2004*. 2004.
9. Kampes, B.M., R.F. Hanssen, and Z. Perski. *Radar Interferometry with Public Domain Tools*. in *Third International Workshop on ERS SAR Interferometry, `FRINGE03', Frascati, Italy, 1-5 Dec 2003*. 2003.
10. Colesanti, C., et al., *SAR Monitoring of Progressive and Seasonal Ground Deformation using the Permanent Scatterers Technique.* IEEE Transactions on Geoscience and Remote Sensing, 2003. **41**(7): p. 1685-1701.