Integrating InSAR Time Series Into The City-Scale Assessment Of Tunnelling-Induced Building Damage

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In fast growing cities, tunnels are increasingly adopted solutions to meet the demand for more effective transportation. As settlements caused by tunnel excavations can damage buildings along the tunnel alignment, a large portion of investments in underground construction projects is typically devoted to the assessment of settlement-induced damage to buildings. To contain the project costs, only a limited number of buildings is usually included in the monitoring scheme, and therefore damage assessment procedures are traditionally based on highly conservative assumptions.

Modern space-borne Synthetic Aperture Radar (SAR) missions can provide monitoring data over large areas, guaranteeing high spatial resolutions and short revisit times. Persistent Scatterer Interferometry (PSI) [1,2] can be used to extract building deformations over time from long temporal series of InSAR images, providing measurements with an accuracy comparable to traditional in-situ monitoring, i.e. of the order of millimetre, and at a much lower cost. However, without an integration with structural models, PS-InSAR data cannot provide meaningful information on the building conditions. This integration is particularly demanding for large excavation projects, where hundreds of buildings need to be assessed.

In this research, we present a new methodology for the integration of PS-InSAR-based building deformations within damage assessment procedures to estimate the level of vulnerability of buildings adjacent to tunnel excavations. The methodology combines in an automated workflow PS-InSAR data, GIS (Geographical Information System)-building databases and semi-empirical models of the building response to tunnelling, to provide a more accurate estimate of each structure damage level.

We tested the proposed methodology on the Crossrail tunnel alignment in London, UK. Crossrail tunnelling activities started in May 2012, and resulted in the excavation of 21 km twin tunnels below central London. We used as an input historical PS-InSAR data obtained by processing 72 COSMO-SkyMed descending images from 2011 to 2015 [3]. The processing led to the identification of 228,000 PSs over the monitored area, which correspond to an average density of about 9000 PS/km^2. The map in Figure 1 shows the distribution of cumulative displacements along the Crossrail tunnel alignment, revealing the settlement caused by the excavation. In the region above the tunnels, line of sight (LOS) displacements between -2 cm and -3.5 cm were observed.

PS points were automatically associated to the buildings along the tunnel route, and for each building, the corresponding PS-InSAR-based displacements were used to estimate the actual building settlement profile, using the fitting model described in Giardina et al., 2019 [4]. Figure 2 shows an example of a specific building, for which the PS-InSAR measurements were used to reconstruct the settlement below the structure. Then, the actual building settlement curves were analysed through a semi-empirical model of the building response to tunnelling [5] to estimate the maximum building strains. On the basis of its maximum strain, a level of damage was assigned to each building, and damage maps showing the distribution of building damage levels were the output of the proposed methodology (Figure 3).

The developed algorithm enabled the identification of the structural damage of 858 buildings, highlighting its capability as a city-scale assessment tool. Additionally, the application of the proposed algorithm made available for the first time a large dataset of field observations of the building response to tunnelling. This allowed the identification of relationships between building construction materials, foundation typologies and global building behaviour. The findings can help improving current damage assessment procedures and advance the understanding of building response to tunnelling, with an impact on future excavation projects all over the world.

References:

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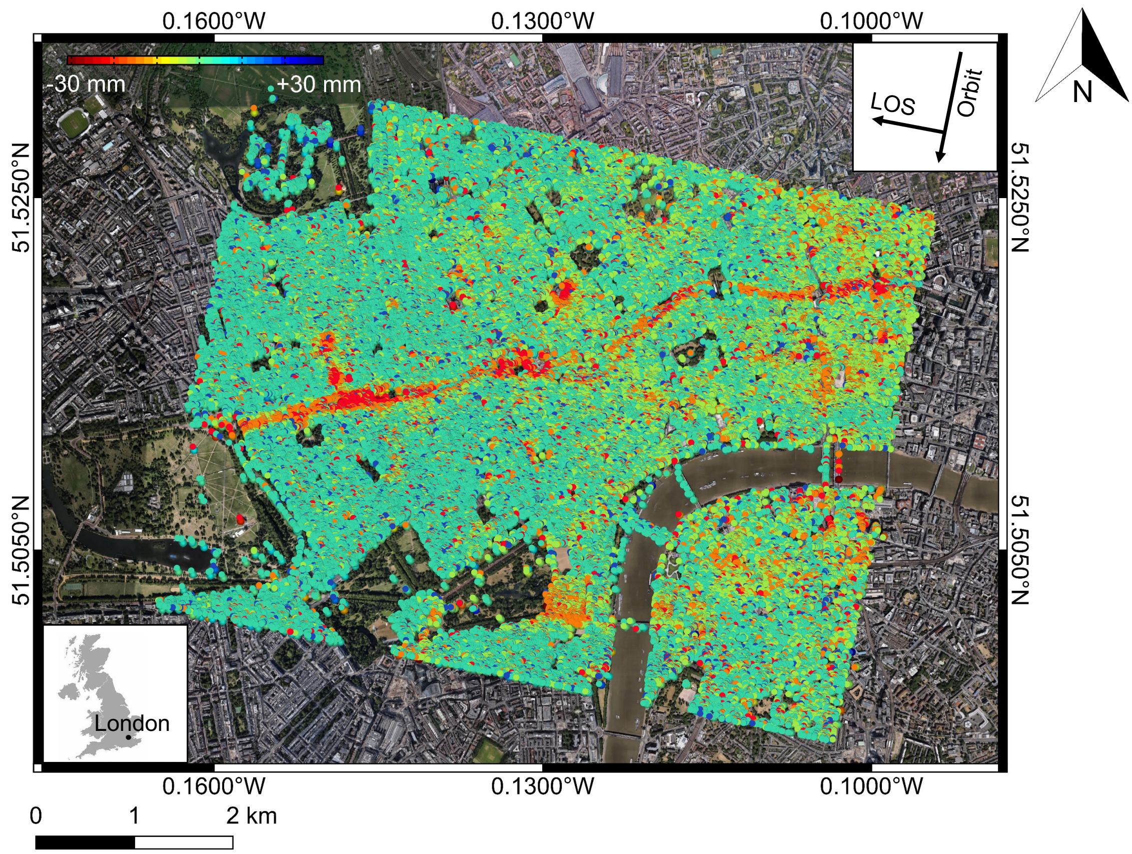

Figure 1: Map of PS-InSAR cumulative displacements over central London. The PS-InSAR data were obtained by processing 72 COSMO-SkyMed descending images between 2011 and 2015.

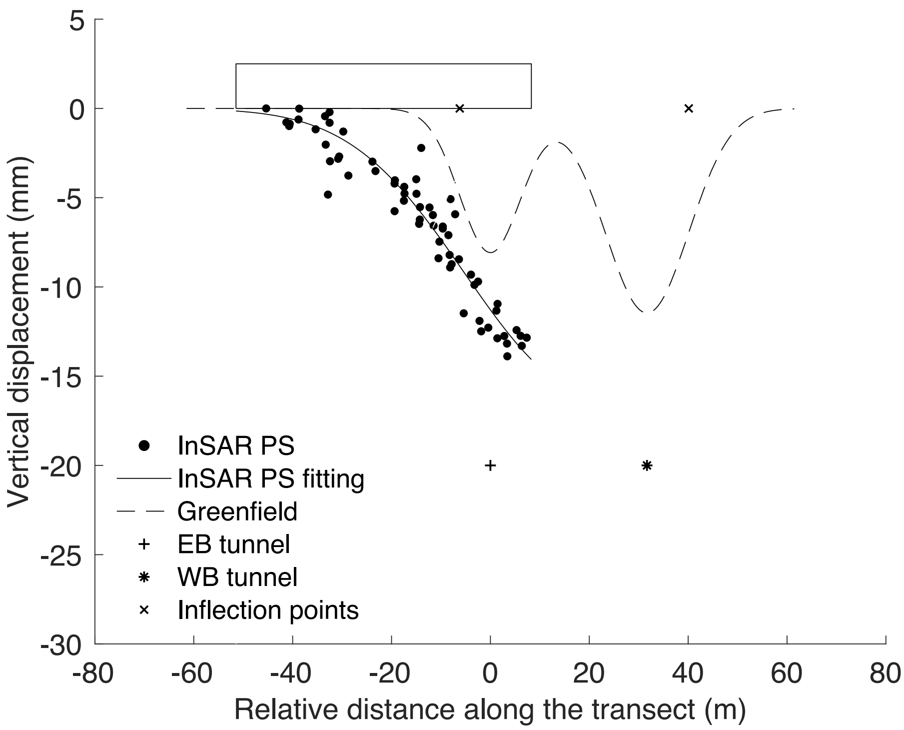

Figure 2: Example of building section along the direction perpendicular to the tunnel axis. The building PSs were interpolated by using a modified gaussian curve to estimate the actual building settlement profile.

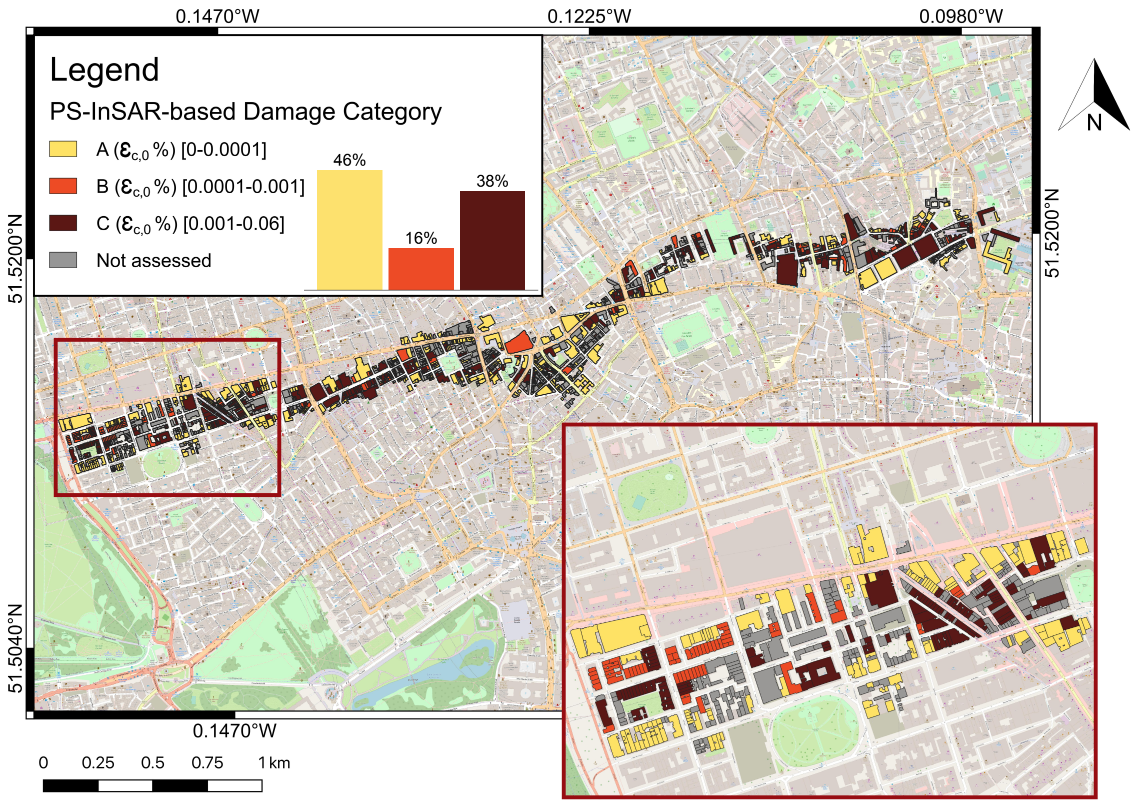

Figure 3: Map showing the actual level of damage for the buildings along the excavation. The categories A, B and C are defined on the basis of the building deformation (quantified in terms of maximum strain ε) and indicate increasing level of damage.