Non-Linear Motion Detection using SAR Images in Urban Tunnelling

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Risk Analyses and Techniques for Underground Structures

1. Introduction

The InSAR (Interferometric Synthetic Aperture Radar) technology is used around the world for mapping ground deformation. This technology is used for a wide range of projects in Civil Engineering, particularly for tunnelling projects in order to monitor infrastructures during the different phases, including planning, dewatering, tunnelling, construction of facilities like shafts, settlement and maintenance.

This paper describes a new methodology for detecting non-linear motion along the tunnelling path. This new approach is an effective methodology for monitoring the impact of the progression of the tunnel boring machine in terms of ground motion, with non-linear movement. With this InSAR specific approach, the evolution of non-linear motion can be perfectly monitored in space and time in urban areas.

In addition to the impact of the tunnel boring machine, this technique is very useful for monitoring the impact of dewatering activities prior to the tunnelling and the effect in terms of non-linear ground motion of the recharge of the aquifer once the dewatering phase has stopped. Those dewatering activities may affect a large area that cannot be wholly covered by in-situ instrumentation.

2. Methodology and results

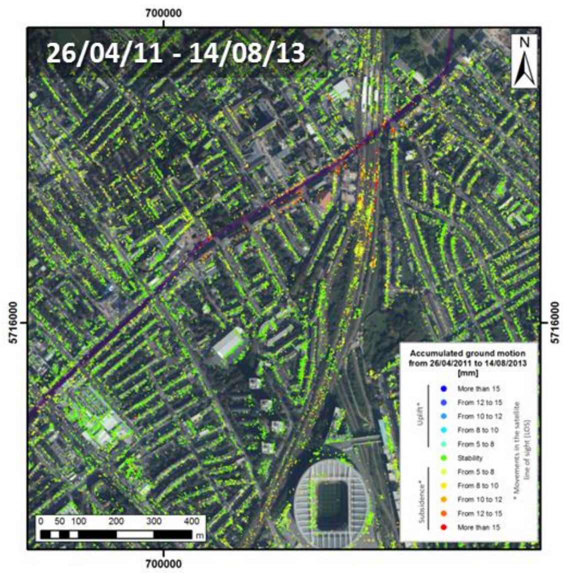

Fig. 1 *Accumulated motion map during the period of study*

The case exposed corresponds to the City of London where a global study has been conducted. Moderate subsidence was detected in the proximity of the underground track of London Power Tunnels (national grid). Altamira Information has conducted a historical motion study which could determine the possible impact of the underground urban tunnelling on the city buildings and other infrastructures located on the surface above the track (see Fig. 1). The period of study spans two years and 4 months, from April 2011 to August 2013. Results are presented as accumulated deformation maps as well as Time Series (TS) and several cross-sections (CS) across the tunnel track.

The approximate track of the tunnel extracted from project website noticeably coincides with the detected motion. The impact on the level of ground motion seems to be higher and constant in the areas where a shaft is constructed.

The radar phase is affected by delays in the signal caused by the atmosphere. The latter in addition to the fact that the stack contains acquisitions in different atmospheric conditions results in statistically unpredictable and random behaviour. This random statistical feature of the atmospheric behaviour allows for the removal of atmosphere in linear PSI methodology via a regular process but does not work when the trend of motion is non-lineal. Note that PSI algorithms are very effective-cost to monitor motion with a low level of non-linearity, but when strong non-linear components are affecting motion, PSI must be combined with Classical DInSAR.

According to the interferometric stack of the study, the ground motion occurs at the very end of the study, thus having an inappreciable impact on the trend of the Time series. In order to follow up and survey the non-lineal motion caused by tunnelling, classical Differential Interferometry (DInSAR) must be combined with the PSI technique, to detect non-linear measurements.

The non-lineal Global**SAR**™ methodology focuses overall on the variability of the phase over the timespan analysed. The issue of detecting non-lineal motion is that it has unpredictable behaviour in space and time, since it could be spatially variable over time and has different intensity. In the case of tunnelling it is easy to imagine how the motion could evolve throughout the track as the boring machine advances in its path, and how subsidence around the shafts could occur prior to the beginning of the tunnelling.

With only the accumulated map it is complicated to extract and evaluate the whole information a process of these features can offer. It is essential, especially in the case that non-lineal subsidence is expected to painstakingly analyse them to generate ancillary data like Cross-Sections and Time Series in order to extract conclusions.

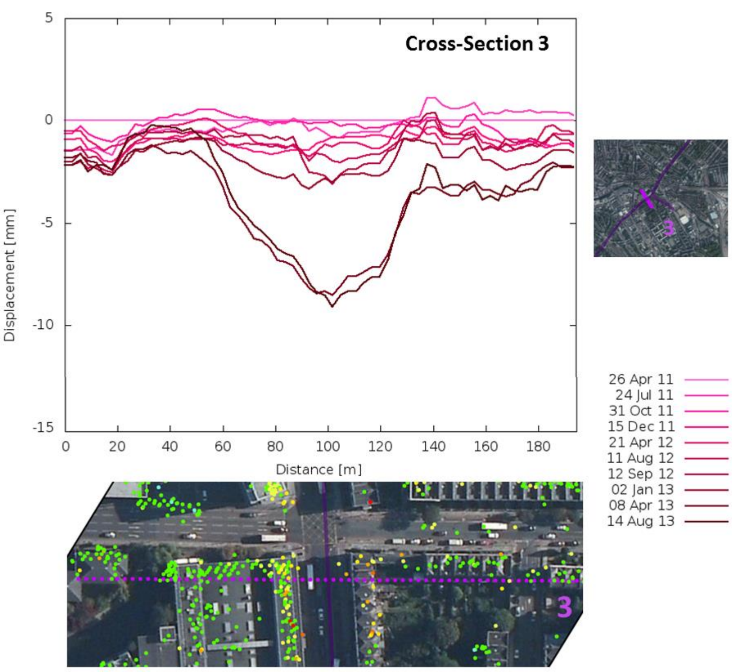

Fig. 2 *CS3 shows the sudden increase of motion between January and April 2013 and its subsequent stabilization after that period*

Not all the infrastructures underneath tunnelled areas have a continued tendency of settlement once the initial motion, triggered by the tunnelling, has occurred, as demonstrate the CS3 example from Fig. 2. CS3 shows that the involved area has no apparent motion between April 2011 and January 2013, despite showing an increasing motion around the street where the tunnelling may have been occurred. After this detected motion, the accumulated motion in August 2013 is the same as April 2013, hence the results show a general stability after the tunnelling.

For these reasons, Cross-Sections allow ease of determining the date when the main subsidence occurred and its affected range. Cross-sections over infrastructures affected by non-lineal motion are able to mix spatial and temporal dimensions all together to ease the understanding of the behaviour of the motion and its evolution in the critical areas.

This new approach is a valuable technique for the future surveying of construction work scenarios. It can follow up the risk on buildings and impact of the progression of the tunnel boring machine in terms of ground motion. With this PSI non-lineal specific approach, the evolution of non-linear motion can be perfectly monitored in space and time in urban areas.

If you are interested in accessing the full paper, please contact borja.salva@altamira-information.com