Editorial to the special issue: deformation monitoring

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This special issue contains extended versions of six peer-reviewed papers originating from the 4th Joint International Symposium on Deformation Monitoring (JISDM) held in Athens, Greece, from 17 to 19 May, 2019. Since 1975, the FIG organised symposia on deformation measurements; later on this series was merged with an IAG symposia series in 2006; and in 2011, their denomination was changed to JISDM, since the ISPRS joined the series. These symposia have become a forum of excellence reuniting researchers, product developers and stakeholders in the field of deformation measurement, analysis and interpretation. Scientific topics cover the complete spectrum of deformation monitoring for engineering surveys ranging from traditional approaches to modern technologies, new concepts for optimization techniques and novel applications of monitoring both natural phenomena and man-made structures.

The papers contained in this issue provide an excellent outline of the scientific advances in the area of deformation monitoring. The first article of this special issue (Kuras *et al.* 2021) treats classical geodetic measurement techniques supplemented by ground-based radar to continuously monitor an earth-filled flood embankment. The influence of water level as well as atmospheric parameters was considered. The results of long-term geodetic monitoring show mainly horizontal displacements depending on the influence of the water level.

They indicate that earth-filled embankment behaves to some extent like an elastic structure. These measurements were compared to ground-based radar measurements using an IBIS-L interferometric radar instrument. For correction of the radar data, atmospheric data was recorded every 15 min. The comparison of displacements obtained by geodetic measurements and radar shows differences between the results of both methods reaching significant values, which may be due, e.g. to the impact of atmospheric changes. Nevertheless, the movement trends are similar for both methods.

Numerous active fault zones are detected into the central and northern part of Greece. In Lazos *et al.* (2021), 7 consecutive years of GNSS data from 58 permanently installed GNSS stations were used for determination of local active tectonics regime in this area. The calculation of the east and north velocity components and their errors, respectively, derived from each GPS/GNSS station, was carried out implementing the triangulation methodology. The deformation parameters were determined. The results confirm the tectonic activity in the central and northern part of Greece compared to that in southern part of Greece.

Nsbuga *et al.* (2021) deals with the development of artificial intelligence (AI) methods for the prediction of displacements in a tunnel. In more detail tunnel crown settlements are to be predicted by artificial neuronal networks (ANN). Two approaches were compared: the classical numerical finite element method (FEM) and the newly developed ANN. The data used to train the ANN was derived from a highway tunnel in Greece. The input of the neuronal network are indirect parameters such as, e.g. the overburden factor, the stress reduction factor and the modulus elasticity. The output should be the displacements of the tunnel crest over time. For input, 107 training and 10 test data sets were available. The comparison between measurement and ANN prediction shows a testing RMS of 9 mm only. The FEM approach does not fully represent the complex nonlinear behaviour of the tunnel environment. The ANN prediction clearly outperforms the FE model prediction.

In Roberts *et al.* (2021), the GPS and FBG (fibre Bragg grating) sensors were used to measure and analyse the

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dynamic displacement of an operating ship in the North Atlantic Ocean on the Faroe Islands. Various frequencies due to the movements of the ship in the ocean as well as the vibrations caused through the ship mainly due to the engine were identified through the measurement. One dominant frequency of 12.25 Hz was measured at all the FBG locations, due to the engines operating. Common frequencies were evident for both the FBG and GPS results for lower frequencies, caused by the movements in the sea. These measurements could be used to monitor the long-term displacement characteristics and changes, in both time and frequency domains, and to help understanding the health characteristics of the ship. Furthermore, such measurements could be used to analyse the noise characteristics of the ship for both operational and environmental reasons.

Themistocleous et al. (2021) present an integrated ground deformation monitoring approach based on the combined use of Satellite SAR data, campaign-based GPS/GNSS observations, and aerial images from UAVs within the Choirokoitia UNESCO World Heritage Site in Cyprus. The results show displacement rates of the order of 0.03 m/year and indicate the importance of the integrated ground deformation monitoring of this culture heritage site. The combination of such

monitoring technologies can be used to monitor and assess potential geo-hazards on archaeological sites with increased accuracy.

The last contribution made by Vassilakis et al. (2021) presents the results obtained from motion photogrammetry and SAR interferometry as complementary techniques for measuring ground deformation induced by the massive open-pit landslide in Amyntaio, Greece (June 10, 2017). This unexpected slide damaged the entire westernmost marginal area of the pit, significant number of buildings and infrastructures of the nearby village of Anargiri. The described methodology includes the generation of a multi-temporal data set of very high-resolution surface topography, based on the analysis of imagery collected by remotely piloted airborne systems (RPASs). Satellite observations involved interferometric processing of TerraSAR-X data for a complementary estimation of ground displacement rates. Height differences from consecutive aerial photography campaigns as well as space-borne measurements provided valuable information on the evolution of the deformation and its spatial characteristics during the post-event period, an important aspect for future hazard and risk considerations.