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Widespread surface subsidence measured with satellite SAR interferometry in the Swiss alpine range associated with the construction of the Gotthard Base Tunnel

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ABSTRACT

Drilling deep tunnels in alpine rocks might induce surface settlements of a few centimetres because of groundwater drainage and associated pore pressure reduction. Settlements of this order of magnitude are sufficient to pose a potential threat to the integrity of any large concrete structure such as arch dams located above the tunnel and an accurate survey of surface deformation before, during and after construction is of high importance. We present the spatial and temporal evolution of surface subsidence measured with satellite SAR interferometry associated with the construction of the 57 km long Gotthard Base Tunnel in Switzerland. Significant deformations of 1 to 12 mm/year were detected between 2003 and 2010 with ENVISAT ASAR data above the tunnel on villages and sparsely vegetated alpine slopes where no displacement was recorded between 1992 and 2000 with ERS-1/2 SAR data. Our results, available also for sectors where there is no information from any other surveying technique, are important not only to assess the hazard posed on any large concrete structure but also for the development and calibration of numerical models - to be employed to simulate the expected surface deformation before and during the construction works - and to study the effect of groundwater drainage on the dynamic of large deep-seated landslides.

1. Introduction

A new rail link through the Alps (NEAT, "Neue Eisenbahn-AlpenTransversale") is under construction in Switzerland with base tunnels through the Gotthard and Ceneri massifs. The Gotthard Base Tunnel (Fig. 1) consists of two 57 kilometres-long single-track tubes where passenger trains will travel at maximum speeds of up to 250 km per hour (AlpTransit Gotthard AG, 2016). Both tubes have a diameter of approximately 10 m and are separated laterally by a distance of 40–50 m. For construction purposes, the Gotthard Base Tunnel was subdivided into various sections where work proceeded simultaneously. In addition to the north and south portals at Erstfeld and Bodio close to Biasca, adits in Amsteg, Sedrun and Faido provided access to the underground construction sites. Excavation works started in 1999 using conventional drive (i.e. blasting) for cross passages, access tunnels and around the Sedrun section for a total of 36% of the tunnel system and with tunnel boring machines for the remaining 64% of the system (AlpTransit Gotthard AG, 2016). The final breakthroughs took place in the east tube on October 15, 2010 and in the west tube on March 23, 2011. Operational opening of the tunnel is scheduled at the end of 2016.

Drilling deep tunnels in the alpine range may induce surface settlements of a few centimetres because of groundwater drainage and associated pore pressure reduction. In Switzerland, examples were reported in the cases of the construction of an investigation audit 1.5 km away of the Zeuzier arch dam (Lombardi, 1988), of the Gotthard highway tunnel (Zangerl et al., 2008a, 2008b), and of a headrace tunnel for a hydroelectric scheme in the Western Swiss Alps(Strozzi et al., 2011). While in the first two cases surface settlement was measured with repeated levelling surveys, subsidence in the last case was observed using satellite SAR interferograms from the ERS and JERS satellites. Although settlements of a few centimetres are small compared to those associated with oil, gas and groundwater withdrawal from more compliant porous media, they are large enough to pose a potential threat for the integrity of large concrete structures on the surface like thin arch dams. Curnera, Nalps and Sontga Maria are three large double curvature arch dams, that are part of an integrated hydro-electric network in the Rhine Valley and situated on the route of the base tunnel. A very demanding monitoring network, including local geodetic stations, precise levelling over a network of more than 100 km length, and differential GPS, was thus

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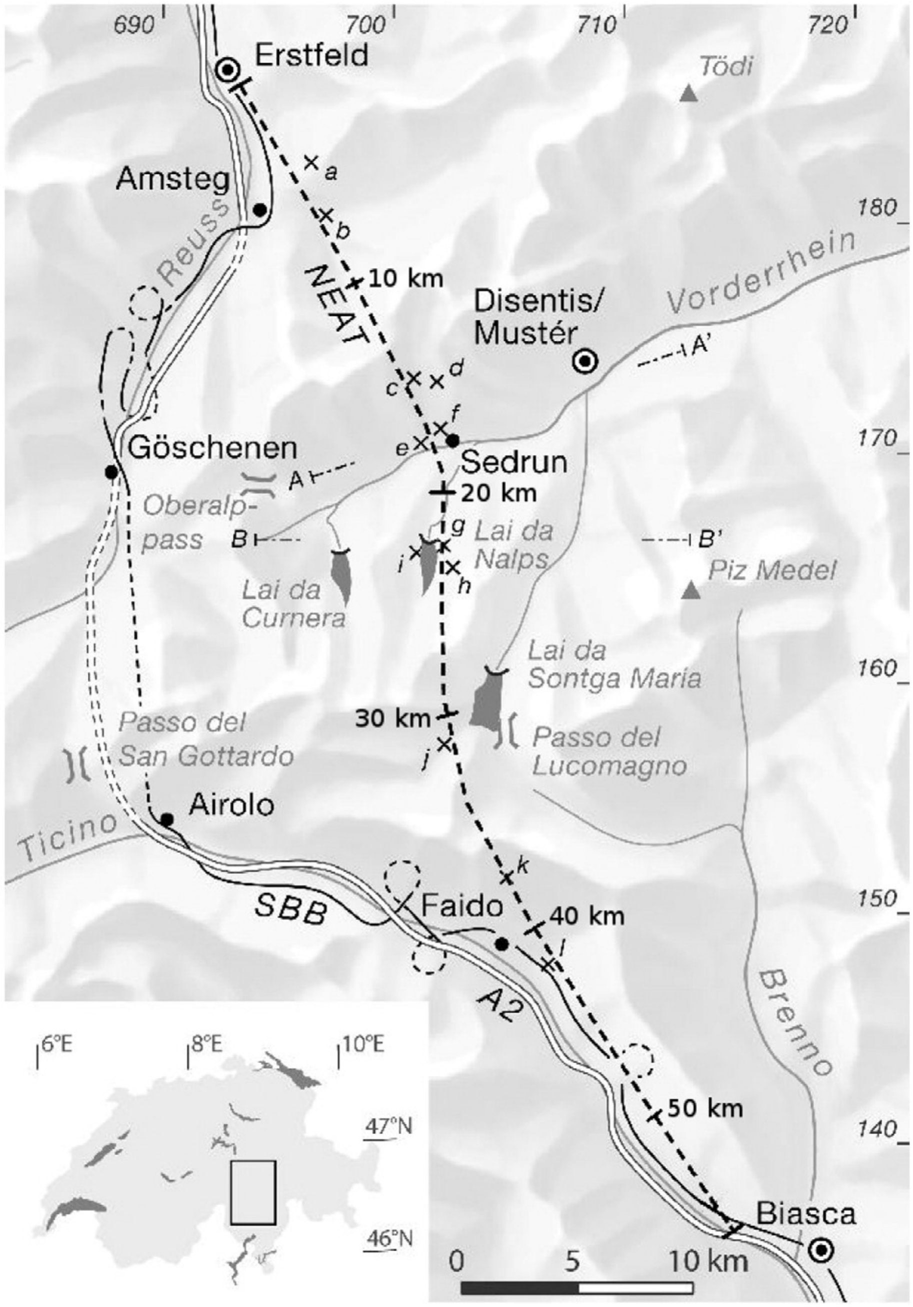

Fig. 1. Overview map of the study region with the tunnel outline (NEAT). The crosses indicate the locations of the time-series presented in Fig. 7. The two dash-dot profile indicators (A–A′ and B-B′′) represent the position of the two longitudinal profiles presented in Figs. 10 and 11.

undertaken in order to survey any ground deformation that may have occurred during the construction of the tunnel on the three dams and close vicinity (AlpTransit Gotthard, 2006; Ehrbar et al., 2010; Hansmann, 2012; El Tani and Bremen, 2013; Studer and Ryf, 2014; Loew et al., 2015). Vertical displacement profiles were measured during annual campaigns along the valleys close to the tunnel axis as well as in hydropower drifts oriented parallel and orthogonal to the tunnel axis. Even if the tunnel inflows to the excavation lots have been very moderate, settlements following the tunnel advance were recorded in the Valley of Nalps, reaching until 2013 maximum values of 9 cm about 1 km south of the lake (Hansmann, 2012; El Tani and Bremen, 2013; Studer and Ryf, 2014; Loew et al., 2015). Moreover, contrary to expectations, a cyclical movement of opening and closing of the valleys, with annual period, was recorded (Loew et al., 2007).

2. Geological setting

The Gotthard Base tunnel runs more or less perpendicular to the main alpine tectonic structures and intersects many of the tectonically deep units that were strongly deformed during the tertiary Alpine orogeny into complicated structures and metamorphosed at variable grades (Loew et al., 2000). A schematic representation of the geology along the tunnel axis is shown in Fig. 2. The northern entry of the tunnel starts in the (par)autochtonous crystalline basement of the Aar-Massif, where mainly ortho and paragneissic rocks are present. More towards the south, the degree of alpine metamorphosis increases and cataclasites and biotite gneisses and schists are the dominant rocks at the transition to the following Tavetsch-Massif. The separation of the Aar- and Tavetsch-Massif units is marked by two faults of ~40 m width followed