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Tunnelling-induced landslides: The Val di Sambro tunnel case study

Annalisa Bandini, Paolo Berry, Daniela Boldini *

Department of Civil, Chemical, Environmental and Materials Engineering (DICAM), University of Bologna, via Terracini 28, 40131, Bologna, Italy

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ABSTRACT

Tunnel excavation in mountainous or sloping regions can sometimes reactivate or accelerate landslide phenomena with a potential important impact on the stability of such constructions. The problem of tunnelling-induced landslides, that represents an important issue for many areas of the world, is very complex to analyse and demanding to solve. In addition, there are very few well documented case histories in literature. The paper presents the case of the Val di Sambro twin tunnels excavated in a structurally complex formation, in a geomorphological setting characterised by landslides of various areal sizes, whose depth was not well known before tunnelling. After a description of the main technical features of the tunnels, the geological setting and the geomechanical site conditions, the paper illustrates and comments the most significant outcomes of the monitoring system in the Southern zone of the tunnels, one of the areas where the major deformative phenomena occurred. The Val di Sambro tunnels represent a unique case study for the large amount of monitoring data collected before and during the tunnel excavation through an integrated system, consisting of various measure methods (inclinometers, piezometers, underground and surface topographic measurements, SAR interferometric technique). The combined use of surface, subsurface, underground and satellite data allowed analysing the characteristics of the landslide movements before the tunnel excavation and in relation to the tunnel construction.

1. Introduction

The excavation of a tunnel causes a stress redistribution inducing deformations in the ground surrounding the opening. In areas prone to instability, such as in the case described in this paper, the induced stress state can trigger or accelerate landslide movements, even on large scale (Sciotti and Calabresi, 2000; Picarelli et al., 2002; Barla et al., 2006; Noferini et al., 2007; Urcioli and Picarelli, 2008; Wang, 2010; Bozzano et al., 2011; Jiao et al., 2013; Sciotti and Pigorini, 2013; Maiorano et al., 2014). In particular, Urcioli and Picarelli (2008) reviewed some Italian case studies of the interaction between landslides and man-made works. Wang (2010) showed a number of damage patterns of the tunnel lining in relation to different slope instabilities. Noferini et al. (2007) and Bozzano et al. (2011) focused on GB-SAR technique applied to monitor landslides affected by tunnelling. Sciotti and Pigorini (2013) reported the case study of the railway tunnel Scianina–Tracoccia that induced a slope collapse 156 m long. However, all these studies are characterised by a limited amount and types of monitoring data, that prevent a deep understanding of the ongoing phenomena.

The present case study concerns the Val di Sambro (hereinafter, indicated as VDS, in brief) twin tunnels, excavated in a geomorphological unstable setting in the Northern Apennine (Emilia Romagna, Italy). Indeed, over 70,000 landslides bodies have been identified in Emilia–Romagna region (Bertolini, 2010), most of which are complex landslides, including roto-translational and earth-flow movements and involving structurally complex formations (Esu, 1977; D'Elia et al., 1998). According to the regional Inventory Map (Bertolini and Pellegrini, 2001) one-third of them are active, while the remaining two-thirds are dormant, but they can be reactivated by triggering factors, such as snowmelt, earthquakes and intense and/or prolonged precipitations (Carboni et al., 2001).

The rock-mass crossed by the VDS tunnels is a structurally complex formation and is characterised by extremely slow landslide bodies (sensu Cruden and Varnes, 1996) of various areal sizes but whose depth was not well known before tunnelling. With the start of excavation, an acceleration of the slope movements and light damage to buildings in the neighbouring inhabited areas were observed in some sections of the tunnel route, especially near the tunnel entrances. This scenario, very complex and difficult to outline with simplified models, required to set up a structured monitoring system in order to evaluate the stability conditions of the area affected by the construction works.

After describing the main technical features of the tunnels, the geological setting and the geotechnical site conditions, the paper is basically aimed at illustrating and commenting the most significant outcomes of the monitoring system in the Southern zone of the tunnels, where the major deformative phenomena occurred. In this study, surface (topographic measurements), subsurface (inclinometers, piezometers) and underground (convergence measurements) conventional monitoring data, together with space-borne Synthetic Aperture Radar interferometry (InSAR) data, were interpreted to analyse the magnitude

* Corresponding author.

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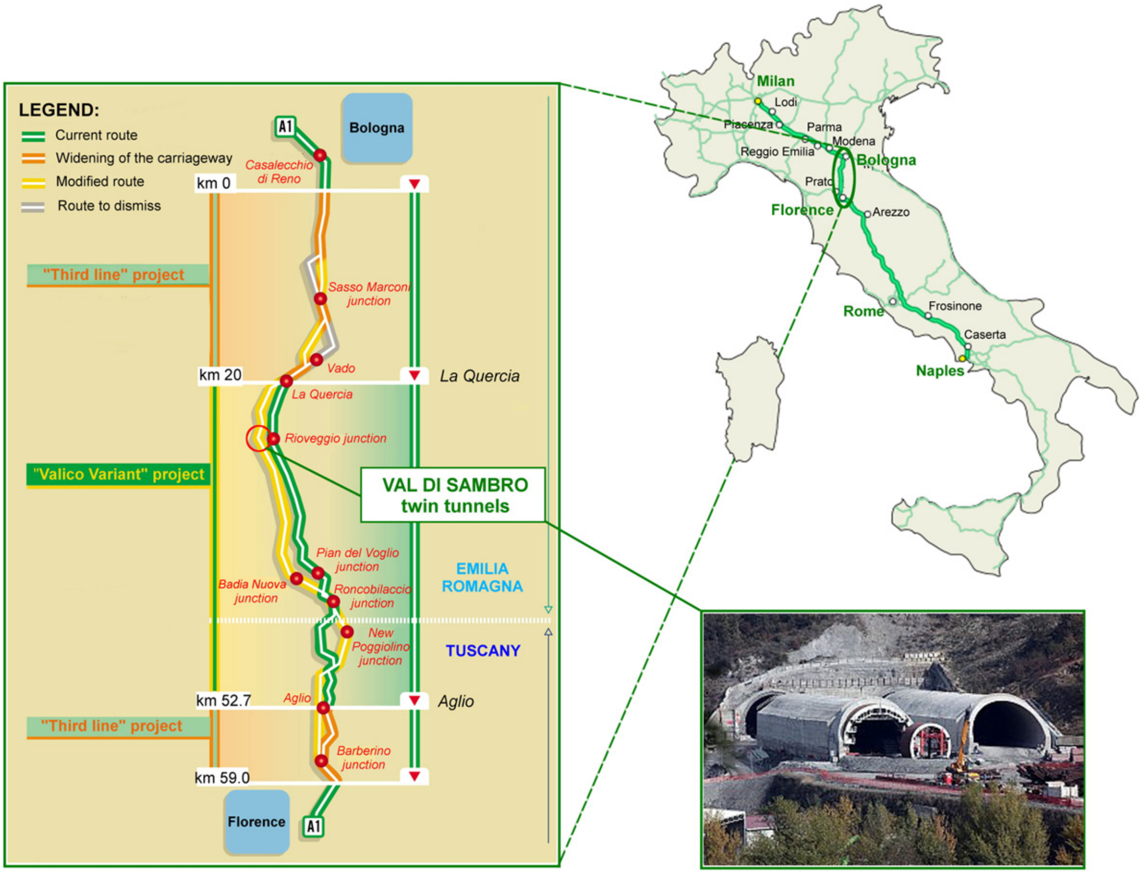

Fig. 1. Location of the "Valico Variant" project and of the VDS tunnels (modified from Autostrade per l'Italia, 2006). On the right, a picture of the Southern entrances of the two tunnels.

and the rate variation of the slope movements before, during and after tunnelling.

The combined use of different monitoring techniques and the large amount of acquired data allowed assessing the main features of the landslide movements in undisturbed conditions and their relation with the tunnelling activities. In particular, thanks to the ESA ERS archives of images gathering data since the early Nineties, satellite data were very useful to estimate the surface ground movements well before tunnelling, integrating the information provided by the traditional monitoring techniques, here implemented only after the start of tunnel excavation.

In recent years, thanks to the development of Multi Temporal Interferometry methods, as the Persistent Scatterers Interferometry (PSI) (Ferretti et al., 2001), the InSAR has increasingly shown its usefulness

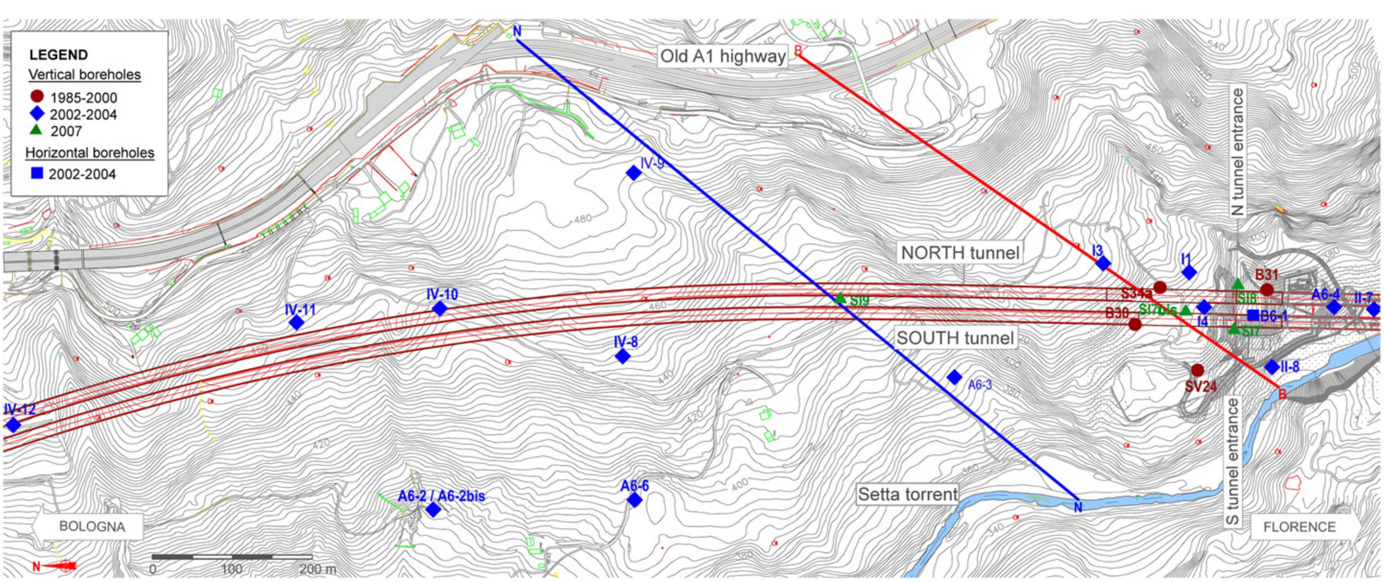

Fig. 2. Map of the area under investigation in proximity of the Southern entrances of the VDS tunnels. The location of the vertical and horizontal boreholes and the sections B–B and N–N, represented in the Figs. 12 and 13, are also shown.