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Measurement system with angular encoders for continuous monitoring of tunnel convergence

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ABSTRACT

This paper presents a system for measuring tunnel convergence called CANG (**C**onvergence by means of **ANG**ular Sensors) that enables monitoring of the positions of the points of a wire situated on the perimeter of the workings. This measuring system records the angles and lengths of each section of wire at all times, determining the shape of the wire and the convergence values.

There is no need to remove the CANG system to allow the movement of personnel or material, as the wire is always kept close to the perimeter of the tunnel, freeing up most of its useable cross-section. It may therefore be left installed over long periods of time, thereby providing a continuous record of convergence.

The mechanical and electronic components of this convergence system are reported, in addition to its pilot implementation in the Rellon road measurement tunnel located on the *Autovía del Cantábrico* dual carriageway in Asturias (northern Spain).

1. Introduction

The current requirements in tunnel construction call for the control and monitoring of settlement and convergence, as well as the development of techniques for processing recorded data. Monitoring plays an important role in every stage of tunnel construction: at the design stage involving an exploration tunnel for site evaluation; during construction, to accurately evaluate the impact of geological conditions, the effect of the tunnel on nearby structures and the construction methods to be used; once the tunnel is in service, to enable long-term monitoring, thus ensuring the safety of the tunnel over its life span (Hudson, 1995).

Instrumentation is used to accurately quantify certain parameters of structural behaviour and to monitor their rate of change. It is thus possible to observe movement stabilization or to deduce the possibility of failure. The comparison of measured values with design values enables the monitoring of tunnel stability and the possibility of implementing corrective measures at the appropriate moment.

The measurement of convergence is a direct and highly reliable system for controlling possible unexpected behaviour of the ground or the support system, providing the technician with a tool to prevent accidents (Lunardi, 2008). Closure of tunnel sections is a major manifestation of this deformation and an important factor for excavation stability. The ideal situation is to have monitoring systems that allow continuous recording over time, since in many cases measurements recorded at specific times do not record phenomena that may be generated in a short space of time (sudden settlement of the land, blasting effects, structural failure of support elements and so on). Furthermore, continuous measurement of convergence is the best way of verifying that the tunnel support is working properly.

Direct measurement of convergence is usually performed by distometers to control the variation in tunnel perimeter, or indirectly by other types of sensors such as strain gauges, slope gauges, subsidence recordings, load cells or inclinometer (Dunnicliff, 1993; Martin et al., 1996). Tunnel convergence is measured in several conveniently spaced sections, positioning these elements as shown in Fig. 1.

The convergence of the tunnel is determined by measuring the position of significant points, called control points, located on the tunnel perimeter. Optical or mechanical systems that record changes in diametrical or perimetric magnitudes in the tunnel can be used to perform these measurements. Optical systems include surveying equipment based on laser distometers, total stations, photometric reconstruction systems or, more recently, laser

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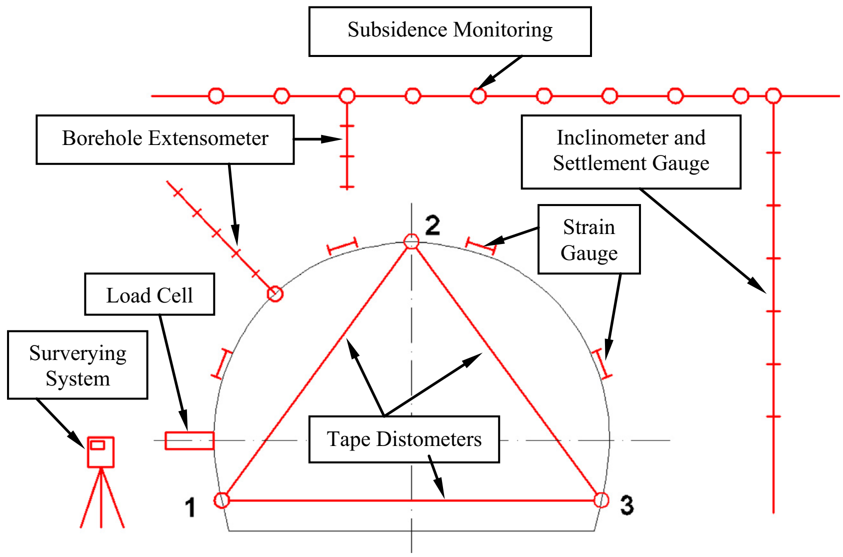

Fig. 1. Tunnel control and monitoring systems.

scan systems (Schroedel, 2002; Miura et al., 2005; Matthew and Mark, 2014).

Among mechanical systems, the most widely used is the distometer (Carvalho and Kovari, 1977; Simeoni and Zanei, 2008). This distometer usually consists of a tape, invar wire, rod, or tube in series with a deformation indicator. This constitutes an inexpensive measurement technique that allows the user to estimate the relative movements between diametrically located control points on the perimeter of the tunnel with an accuracy of 0.01 mm. Measurements are made by sections and as a function of the phases of advancing the tunnel heading. The distometer is usually portable and is attached at the time of reading to permanent anchors mounted at each end of the measuring span.

Using distometers, the change in the relative lengths between one control point and the others are measured following different schemes, as shown in Fig. 2. Options (a)–(c) are commonly used when advancing the heading. When the full cross-section of the tunnel has been excavated, schemes (d)–(f) are anchored at diametrically opposite points on the tunnel perimeter. The arrangement of these distometers affects the entire useable cross-section of the tunnel and significantly hampers excavation work.

Tunnel deformation curves are obtained by plotting convergence against time. When correlated with the advance and support stages, these curves are important in the analysis of tunnel stability. These convergence graphs usually include an indication of when tunnel support begins to be installed and when the installation of this support system is completed.

The monitoring of these convergence curves provides valuable information about the behaviour of the cavity, as well as indicating how the support system performs. In this respect, it is important to record how the advance of the heading or the removal of the core or of the side walls affects the different measurements.

At the same time, the distances between diametrically separate points on the tunnel perimeter can be determined (convergence measurements), or just the settlement of specific points on the perimeter can be measured with respect to a reference point that remains fixed (levelling measurement). In many cases, these measurements refer to the distance between the cross-section measured and the excavation face.

While these curves provide valuable information, they are expensive to obtain due to the inconveniences involved in their continuous recording.

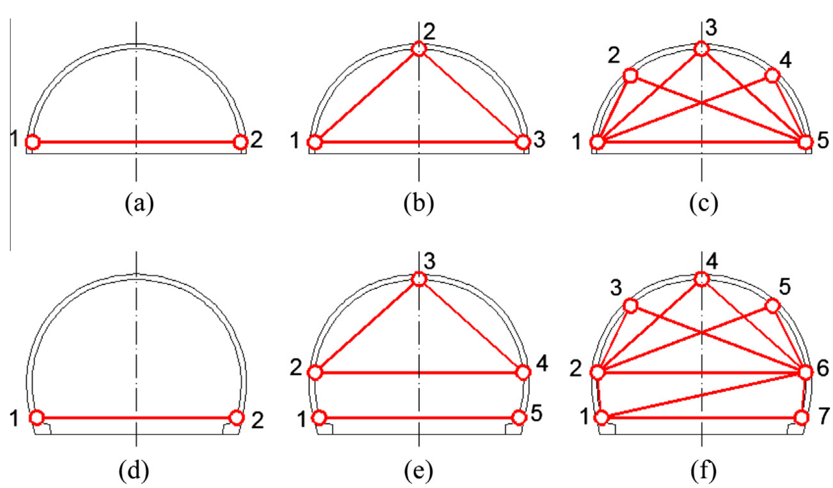

Fig. 2. Measurement system employing distometers when advancing the heading (a)–(c) and with the full cross-section of the tunnel (d)–(f).