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Elastic wave simulation in ground anchors for the estimation of pre-stress

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ABSTRACT

Application of pre-stress on strand wires inside a structure is a way to reinforce the low tensile strength of concrete and soil materials. After years in service, the strands may lose the pre-stress due to corrosion or other reasons endangering the whole structure. Since there is no accessibility to the strands inside the structure, any inspection should be conducted on the anchor head. In this study, elastic waves on the anchor head are numerically simulated. Parameters like the wave amplitude and propagation time are influenced by the stress of the strand wires which affects the contact between the threaded steel rod, and the surrounding anchor head influencing the acoustic impedance mis-match on the interfaces. The change of contact pressure between the strands and anchor head is simulated by modifying the rigidity of a model interphase material. Results are compared with experimental under different levels of pre-stress. Therefore, an easy and fast procedure for non-destructive inspection of the pre-stress load on the strands is discussed.

1. Introduction

Application of pre-stress in civil engineering structures is a common way to protect against tensile overloads (Gerwick, 2008). It is usually conducted by applied tensile load on a number of metal strands (tendons) which are anchored on the surface transmitting compressive load to the structure. This way even if an overload occurs, the materials, typically concrete or soil, will not be loaded in tension (Pisani, 1998). Especially in rock engineering, rock bolts have been used for stabilization purposes for decades. The rock bolting system prevents joint movements forcing loose blocks to bind together and act as a composite medium (Kilic et al., 2002). However, it is possible that the initial pre-stressing load of the tendons is partially lost after a period of time (Wong, 2001). This is more likely for old anchors which have been installed based on corrosion protection standards which are not considered adequate for contemporary constructions. Any loss in pre-stress may accelerate the deterioration process of the whole structure (Kiviste and Miljan, 2010). A typical test is visual survey of the physical condition of the structure and the anchorages, as well as measurement of the deformation and, if possible, measurement of the load of selected tendons, by the "lift-off" method. However, this test requires the anchor head to be raised by some mm using a hydraulic jack and therefore may jeopardize the safety of the structure (Littlejohn and Mothersille, 2007). A method that has been applied is X-ray imaging (Mitchell, 1991). Although an insight into the physical condition of the anchor and the tendons can be obtained, pre-mature symptoms like pre-stress loss cannot be detected. Additionally, it is time consuming and costly while special care should be taken for the public and personnel safety from radiation. A routine, fast and easy inspection method which can confirm the pre-stress level of the tendons is sought for in order to nondestructively determine the safety of anchored structures (Littlejohn and Mothersille, 2007; Chen and Wissawapaisal, 2002).

Methods based on elastic waves have been used for the inspection of metal wires since their loading affects pulse or group velocity, frequency dispersion (Chen and Wissawapaisal, 2002; Washer et al., 2002; Chaki and Bourse, 2009; Laguerre and Treyssede, 2009), as well as nonlinear behavior (Bartoli et al., 2008). Apart from the wave transit time and velocity dependence on frequency, the transmitted energy and main frequency components are sensitive to the applied load, when measured on the longitudinal direction of the tendons with a pulser–receiver configuration (Rizzo, 2006). This technique does not produce reliable results for anchors installed deep into the ground where the access is limited to one single side. The propagation time depends not only on the tendon length but also on the boundary conditions at the embedded end of the strand (Madenga et al., 2006), as well as the curvature of the tendon and the particular shape of the edge installed inside the ground (Kawai et al., 2009) which affect the reflection from the end.

The specific type of anchor studied herein is used for slope protection against landslide. Deterioration of these systems may eventually cause rupture of the tendons or the anchors leading ultimately to slope failure. The possibility of such accidents poses

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threats for the safety of traffic as well as of the property beneath the slopes. Therefore, it is crucial to identify problematic anchorages in order to follow the appropriate repair program (Kawai et al., 2010). Since there is no accessibility in the interior of the structure, the assessment should be conducted through the only area located in the surface, the anchor head (Kawai et al., 2009). This study presents results on elastic wave propagation aiming at the estimation of the pre-stress level of metal rods used as anchors. The applicability of the method is examined numerically and experimentally and suitable wave parameters are sought for in order to yield a robust correlation with the applied stress on the rods. Fig. 1a shows the cross-section of the pre-stressed structure. As the pre-stress on the rod increases by means of the hydraulic jack (see Fig. 1a and b), the rod obtains stiffer contact with the nut material due to the threaded geometry of the rod (Kawai et al., 2010). Therefore, elastic waves are introduced into the anchor head and the time of flight, as well as amplitude parameters are measured for different levels of pre-stress. The experiment is numerically simulated by the use of finite difference method software. The contact between the threaded rod and the surrounding nut is modeled with an "interphase" material of varying pulse velocity, as defined by varying its elastic constants. This concept has been applied on a different geometry of large anchor head including seven metal strand wires and wedges showing that the pre-stress influences crucially the wave parameters (Kleitsa et al., 2010). The large number of interfaces in that case, created an accumulated effect on the wave propagation delay and the scattering attenuation of the signal rendering the characterization possible. In this case the geometry of the model is different as it applies to rock bolt operations. It is smaller and contains only one center hole in the matrix which is reasonable to minimize the interference and the multiple reflections, making the characterization troublesome. Experimental trends are also described and compared to numerical, showing strong qualitative agreement.

2. Experimental setup

Fig. 1c shows a snapshot of the ultrasonic experiment. The pair of sensors (pulser and receiver) were applied on the center of opposite sides of the anchor head (nut) with the use of small quantity of ultrasonic gel. Piezoelectric transducers with nominal frequency of 1 MHz, 5 MHz and 10 MHz were used to examine the possible effect of applied frequency. The electric waveform introduced to the pulser consisted of one cycle of the corresponding frequency. Pulser and receiver were transducers of the same type. The excited ultrasonic waves propagated trough the nut and were detected by the receiving sensor. The waveforms were recorded by

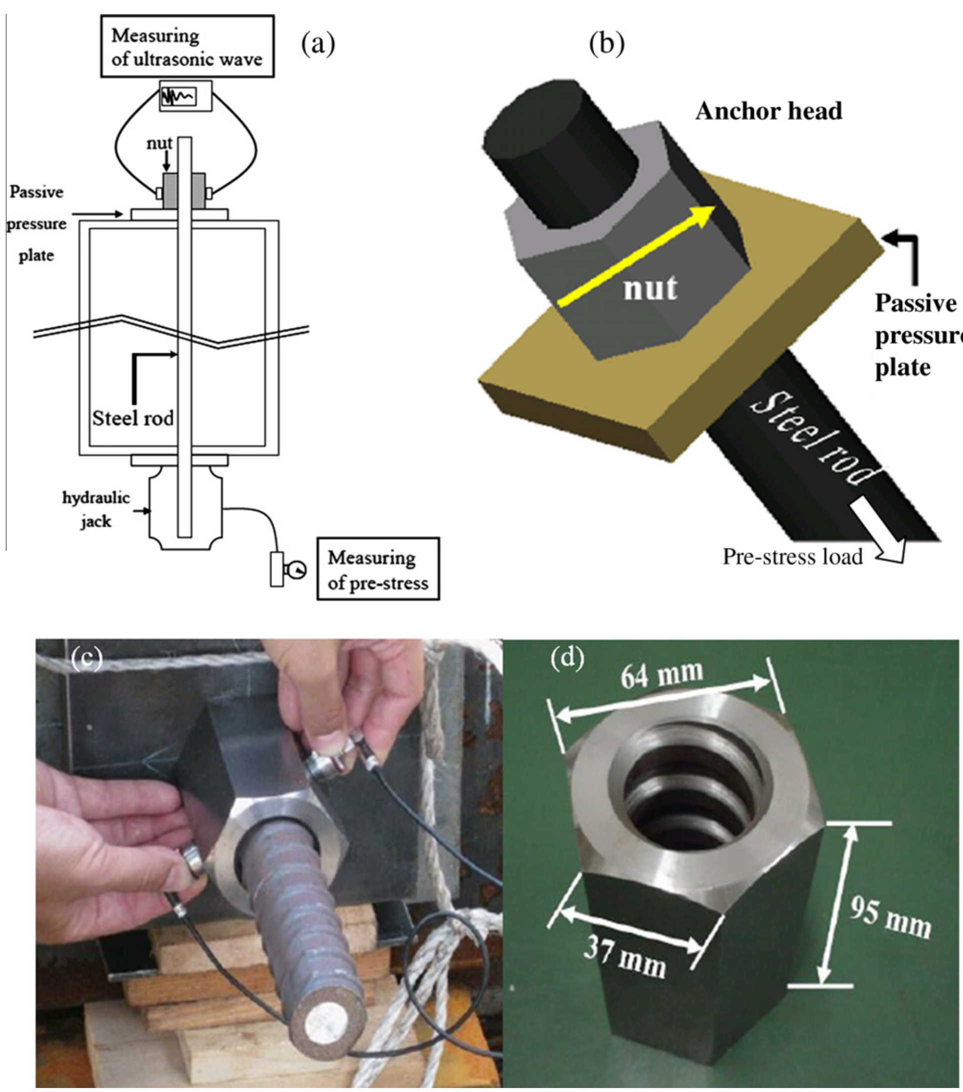

Fig. 1. (a) Schematic representation of pre-stress, (b) wave propagation through the nut, (c) photograph of the experiment and (d) details of the nut used in the anchor head.