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Implementation of eco-engineering design into existing slope stability design practices

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ABSTRACT

Eco-engineering techniques involve the use of both plants and inert materials where, in the latter, non-treated wood is usually present. The two different elements will both evolve with time and change their mechanical properties differently. On one hand, the wood will degrade decreasing its effective cross sectional area with time. On the other hand, the live plant material will grow and propagate new roots as time progresses. Both root development and inert material changes must be accounted for in order to realistically simulate a bioengineered slope evolution and design effective eco-engineering solutions.

The dynamic nature of a bioengineered work sets different scenarios throughout the slope design life. All these different stages must be taken into account in the work design process. In this work, we propose an adaptation of the existing routines and procedures of both geotechnical practice and civil engineering design scheme in order to closely reflect the inclusion of bioengineering methods in the classic geotechnical engineering problems. A design methodology covering different critical points within the lifecycle of a bioengineered slope is proposed and put into practice into the design stage for a case study in Scotland. By detecting critical points at the design stage the proposed methodology was proven to offer an improved eco-engineering work design scheme. With the use of the proposed method both external and internal stability checks with their corresponding safety factor values increase with time and there are no conflicts between the two evolving processes involved in this kind of works.

1. Introduction

Ground bio-engineering, also termed eco-engineering, is the use of living plants or cut plant material, either alone or in combination with inert structures, to control soil erosion and the mass movement of land in order to fulfil engineering functions (Schiechtl, 1988). The self-repairing characteristics of the vegetation used, and the resilience capacity of the bioengineered area (Mickovski, 2014) are very important allies in the eco-engineering design philosophy.

The eco-engineering solutions have inherent advantages over classic civil engineering solutions with respect to economy, ease of construction, low landscape impact and opportunities for incorporation of vegetation or plantings within the structure (Gray and Sotir, 1996). One of the main design disadvantages are related to this latter issue since the use of both living and inert biological materials (e.g. wood) involves incorporating temporary variable elements in terms of design and performance reliability of the eco-engineering works (Stokes et al., 2014). The eco-engineering philosophy follows the sustainability idea of design with readily available materials on or adjacent to the site which involves the use of materials such as wood or rocks. The use of wood coming from nearby silvicultural treatments (Coppin and Richards, 1990) entails the use of materials with a wide variety of properties (young and mature wood) from different species.

The eco-engineering solutions provide a combination of the benefits of immediate protection against soil instability and the long-term stabilization due to the reinforcement effect of the roots on the soil. As with any stabilization technique, there is a stress (or load) transfer between the soil and the structure but, in contrast to other solutions, this initial response is substituted by an evolving role of the living material used in the eco-engineering work as the time progresses. Once the plants become established, the subsequent vegetation gradually takes on more of the structural function of the inert members (Gray and Sotir, 1996). The way roots reinforce soil can be explained by both mechanical and hydrological effects. From the former perspective, roots can bind the soil together and contribute to both a higher soil bearing capacity and shear strength

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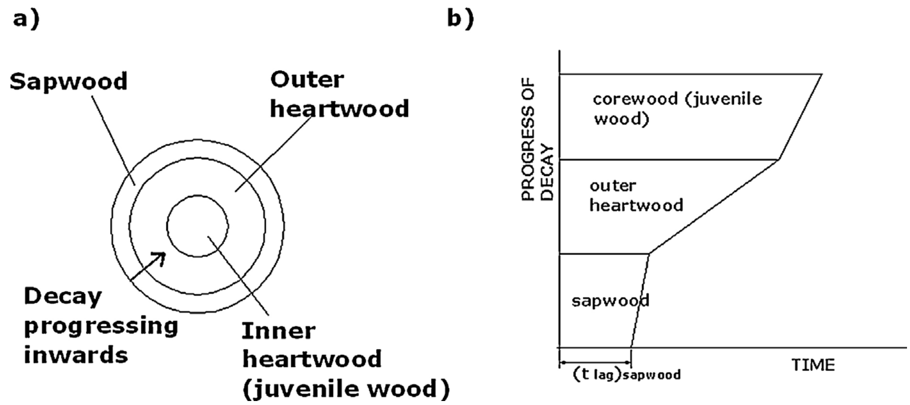

Fig. 1. a) Wood parts, b) deterioration rates for the different wood parts adapted from Leicester et al. (2003).

(Willat and Sulistyaningsih, 1990) whereas, from the latter, they can decrease the soil pore water pressures and, therefore, soil effective stresses (Terzaghiís principle; Lambe and Whitman, 1979) thus improving the slope stability.

Over the past eighty years, extensive engineering and research studies have provided a sound set of soil mechanical principles and analytical procedures for slope stabilization (Terzaghi, 1936; Sowers, 1979; Duncan and Wright, 2005). An improved understanding of the changes in soil properties that can occur over time is one of the most important developments of slope stability design schemes. The presence of other material in the soil (including plant roots) changes the properties of the continuum and, if these changes can be predicted, the engineers can choose the best additions for stability. The recognition of the requirements and limitations for the use of non-inert (live) material in slope stability design standards would usher in a more mature phase of the use of ecotechnological solutions for soil stabilization purposes.

With bioengineered slopes, the nature of the materials used generates a natural evolving dynamic into the slope design life. One of the most important changes in the soil conditions takes place when plants, the live components, begin to grow and propagate new roots (Bischetti et al., 2009). Besides, the wood, one of the inert components used in eco-engineering techniques, is generally not treated and, as a consequence of this, its mechanical properties deteriorate as time progresses (Leicester et al., 2003). Therefore, for bioengineering slope design the time and elements durability must be considered more explicitly throughout the design life of the slope.

The existing structural timber design standards (e.g. EN 1995-1-1:2004/A1:2008 Eurocode 5) provide a regulatory framework for eco-engineering work design. Similarly, the existing structural/geotechnical design procedures for slope stabilization solutions (e.g. manufacturers standard designs, trade associations standard designs, state and federal agencies, Eurocode 7, etc.) do not accommodate the particularities derived from the dynamic and changing nature of the eco-engineering solutions. However, the eco-engineering design is more complex due to both the presence of different materials and the need to take into account the combination and integration of the particularities of the wooden elements used for specific eco-engineering works (e.g. wood decay rate, wood natural durability and the use of small diameter round wood) with the live materials used. Furthermore, the ground bioengineering techniques are designed according to soil stabilization or geotechnical design general methodologies (Coppin and Richards, 1990; Menegazzi and Palmeri, 2013) and they do not have a standardised specific approach as it is the case with other traditional stabilization techniques. To the best of our knowledge, the engineering approach comprising a sequence of stages reflecting the design life stages and associated changes in the eco-engineering structure has not yet been applied to eco-engineering design.

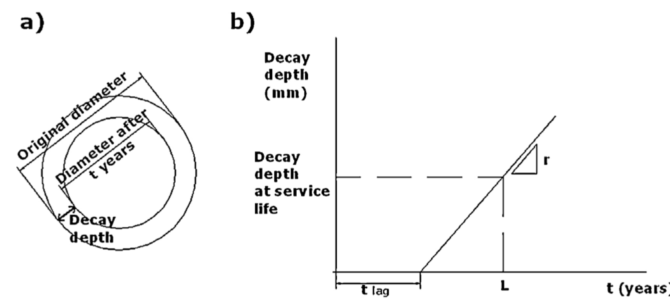

Fig. 2. a) Diameter variation and decay depth (d_t), b) idealised progress of decay depth with time (adapted from Leicester et al., 2003). t_{lag} (lag time) and L (service life) are shown.

To cover the apparent gap in the design with vegetation for stability (Stokes et al., 2014), there is a need for a clear methodology, based on existing structural/geotechnical design procedures, to put the eco-engineering solution design into practice and justify its application from sustainability, resilience and stability point of view (Mickovski, 2014). The aim of this paper is to use the existing engineering approach and attempt incorporating both wood deterioration and live plant processes and effects within a temporal framework. To achieve this, our objectives are to integrate the stress transfer process between the inert elements and the vegetation, as well to incorporate both the typical dynamic nature and the evolution of an eco-engineering work into eco-engineering design methodologies, demonstrated on a real life case study.

2. Materials and methods

2.1. Background

In designing and constructing new earthwork slopes, it is important to attempt to anticipate the relevant changes in properties and conditions that may affect them during the design, ensuring that the stability is not compromised by any foreseeable change (Duncan and Wright, 2005). In the case of bio-engineered slopes, one of the major changes in the long term is the growth and development of the plants used in conjunction with inert materials. Additionally, the changes in the loads or stresses acting on the slope will result in changes in the stability of the slopes. Therefore, it is often necessary to perform stability analyses corresponding to several different scenarios, reflecting different stages in the life of a slope. This is a well established principle in the standard slope stability design (Duncan and Wright, 2005; EN 1997Eurocode 7),