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# An innovative bio-engineering retaining structure for supporting unstable soil

Gianluca Bella [a,*], Monica Barbero [a], Fabrizio Barpi [a], Mauro Borri-Brunetto [a], Daniele Peila [b]

[a] DISEG, Politecnico di Torino, Corso Duca degli Abruzzi 24, Torino, 10129, Italy
[b] DIATI, Politecnico di Torino, Corso Duca degli Abruzzi 24, Torino, 10129, Italy

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ABSTRACT

The paper presents a new prefabricated bio-engineering structure for the support of unstable soil. This prefabricated structure is made of a steel frame which is completely filled with soil and a face made of tree trunks among which scions or autochthonous bushes are planted. Due to the difficulties in interpreting the complex interaction between soil and structure during the installation and lifetime, an in situ test was carried out in order to evaluate the state of stress in the steel frame and to understand the global behavior of the structure under service loads. On the basis of the obtained results, a procedure for checking the structure safety was proposed and discussed. An easy design method was developed during the research. Moreover, the use of this type of prefabricated structure shows several advantages, such as good performances in terms of stabilizing effects, and easy assembly and transport.


## 1. Introduction

Bio-engineering measures for shallow landslide stabilization, erosion prevention and/or control are widely used in engineering practice (Greenway, 1987; Victor and Bary, 1997; Morgan and Rickson, 2004; Norris et al., 2008). To achieve the desired engineering goals, live plants and natural elements such as tree trunks or stones can be used (Gray and Sotir, 1996; Campbell et al., 2006). Live cribwalls, vegetated rock gabions, vegetated rock, walls and joint plantings are common soil bio-engineering techniques that use "porous structures", through which vegetative cuttings are inserted and established. These structural elements provide resistance to sliding, erosion and washout immediately after the installation. As soon as vegetation becomes established, plant roots invade and permeate the external face of the slope and the tree trunks, binding them together into a unified, coherent mass. Over time, the structural elements decrease in importance as the vegetation increases in strength and functionality (USDA and NRCS, 1992).

Over a century, the most widely used structure in bio-engineering has been the double cribwall or some variation on this basic scheme, such as the cribwalls named Vesuvio, Roma or Latina (Greenway, 1987; Cornelini, 2001; Cornelini and Sauli, 2005, 2012) whose composition is complex and subsequently the realization will be more expensive (Fig. 1). The realization of cribwalls, also called retaining structures or mixed wood-rocks structures (Fig. 2a and b), makes use of tree trunks and nowadays they are designed and used as gravity walls to resist shallow displacements, namely for the reshaping of unstable slopes or at the toe of embankments.

In some cases, a larger mechanical strength is needed, so the use of a retaining structure not completely biodegradable would be more suitable (Carbonari and Mezzanotte, 2000; De Antonis and Molinari, 2003; Stokes et al., 2004, 2007, 2010, 2014). Following this observation, a new hybrid prototype has been developed and presented in this paper. It is made of a prefabricated steel frame lying on the ground, and a wooden frame where vegetation is established (Gray and Sotir, 1996). This prototype, called "palificata viva loricata Terrasafe" (plT), has been subjected to an extensive set of full-scale in situ tests to verify the states of strain and stress in the steel frame and in the wooden elements. Moreover, the complex interaction between soil and structure has been investigated. The installation of the plT is quick and easy due to the usage of prefabricated elements consisting of tree trunks and metal profiles

* Corresponding author.
*E-mail address:* gianluca.bella@polito.it (G. Bella).
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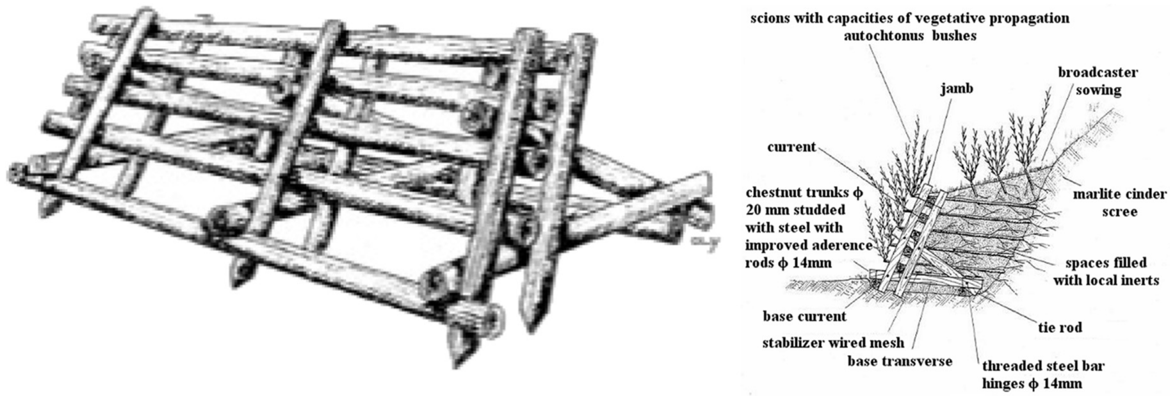
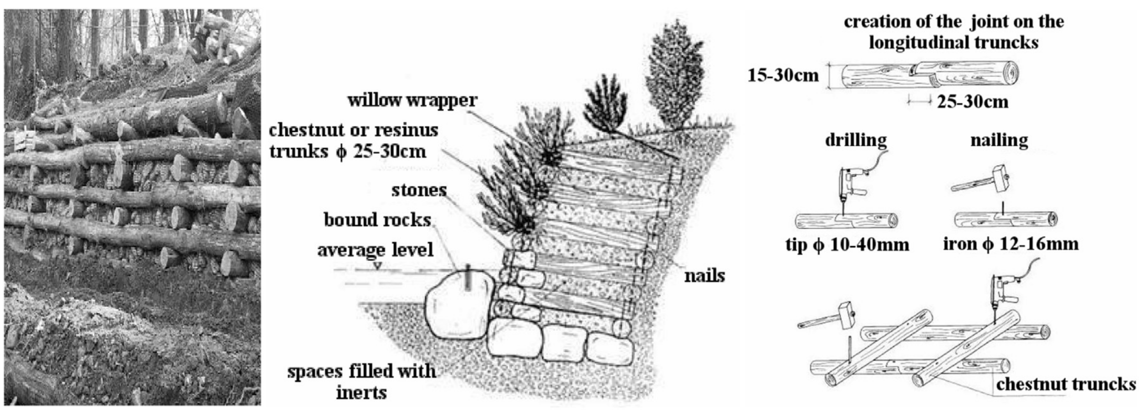



(a) (b)

**Fig. 1.** Roma double cribwall (a) perspective, and (b) cross-section (modified from Provincia di Terni, 2003).




(a) (b) (c)

**Fig. 2.** (a) Double cribwall, and (b) its scheme and (c) construction phases (modified from Provincia di Terni, 2003).

that are light and easy to transport. The trunks are previously cut following the planned measure and do not need fastening with nails and bolts, thus eliminating the drilling. Furthermore, the plT is a durable structure due to the non-biodegradability of its metal elements. Finally, the plT is easily maintainable and environmental sustainable by replacing the trunks of the front face.

The experimental activities consist in the realization of a test site, in which some parts of the plT were assembled and properly instrumented in order to verify its behavior under applied load. After the experimental study, a structural design method has been proposed, based on the principles of the European regulation EN 1997-1 (2004) for assessment of structural safety which is described in the paper. The prototype was verified from the structural and geotechnical point of view, letting to say the proposed design method can be considered reliable. For these reasons, the plT is currently used as sustainable solution to some shallow landslides stabilization (i.e. Roatto and Fuscaldo, Italy). The strains measured by transducers were significantly lower than those calculated within the ultimate limit state theory, allowing to understand that the uniform overload applied on the plT during the experimental campaign was not equal to that required for the mobilization of the active thrust.

## 2. Description of the structure and test site

The single element of the plT, considered as a set of steel support and tree trunks (Figs. 3 and 4), is 3 m wide and 1.8 m high. The wooden frame is inclined by 60° with respect to the horizontal line. The resistant structure consists in a frame made of steel sections, welded or bolted together, ending with a stem connected to an anchor plate, a rope or a bar anchor cemented into the ground.

A transverse horizontal beam is attached to the stem, and two uprights are welded to the cross and sustain the front trunks that are restrained by a chain to prevent large outward movements. The trunks create a grating that provides support for the filling soil and, not being continuous and closed, allows the planting of cuttings and facilitates drainage. Geometric and mechanical characteristics of the structural elements are as follows (Fig. 3):

(1) Stem: hollow steel section UNI EN 10210 50 mm × 50 mm × 3 mm S235JRH;
(2) Uprights and transversal beam: hollow steel section UNI EN 10210 70 mm × 70 mm × 3 mm S235JRH;
(3) Foundation: steel plate 750 mm × 750 mm × 5 mm;
(4) Six wooden trunks with 160–200 mm diameter and 3 m length.

Geometric sizes of the steel structure (1 kN weight) can be summarized as follow:

(1) $l = 0.75$ m (side of the foundation plate);
(2) $h = 1.8$ m (height of the structure);
(3) $d = 3$ m (depth of a standard module of structure);
(4) $\alpha = \beta = 30°$ (angle between the front grid and the vertical line);