MONITORING MEASURES OF SOME NATURAL ENGINEERING WORKS ON THE CHIASCIO RIVER, ITALY

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Abstract
An important aspect regarding the interventions of hydraulic arrangement conducted with bioengineering techniques is the monitoring of the works over the years and after the occurrence of significant flood events along the waterways. The present paper examines the actions performed on the banks of Chiascio River in the municipalities of Bettona and Torgiano (Perugia Province), near its confluence with the Tiber River, interventions made in the year 2010 and subject to significant floods in the subsequent years, with water flows that have certainly affected the examined structures. The monitoring has focused particularly on a piling located at downstream side of a crossing near an old mill and near of a landslide, rather important, which involved a sector of about 20 meters on the left bank of the Chiascio River. The outcome of this activity allowed a first assessment of such works by highlighting the importance of the construction details and the appropriate choice of materials. The methodical continuation of the monitoring activity, together with adequate remedial measures regarding the damages that were found will allow a more accurate assessment of environmental engineering works over time and their more targeted and effective use.

Keywords: bank erosion, flood, stabilized landslide, bioengineering works, drainage

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INTRODUCTION

In the field of Civil Engineering, it happens often that the effects of the interventions are not adequately monitored over time losing valuable information on the evaluation of the intervention and its possible improvement (Buchanan and other, 2010). This aspect is even more relevant for environmental engineering works and where the monitoring and maintenance are closely related to the context of the slope and floating structures, the type of work, and the materials used (Eubanks and other, 2002). Therefore, with the progressive development of these techniques, experiments on monitoring of the works have been also initiated, taking into account the slope contexts, as in (Preti F. and other 2007), for some areas of the Lazio Region, while (Selli L. and other, 2014) evaluates the works in the Apennines between Tuscany and Emilia Regions. However, other studies have examined the effect of climate on the living plants component of the environment (Hoag J.C. and other, 2005), (Preti F. and other, 2014), as well as on the efficiency of particular techniques of intervention, such as piling (Krymer V. and other, 2014) and (Lammeranner W.and other, 2005).

In parallel to the field activities, we are also developing studies involving laboratory investigations particularly on the strength of the typical characteristics of natural materials. Regarding the wooden pallets, (Benfratello S. and other, 2014) and (Benfratello S. and other, 2015) have studied the changes in the physicochemical and mechanical properties of chestnut poles at different time horizons up to 48 months after field implementation. The same field of research that investigates the stabilization mechanism due to the radical reinforcement (Giadrossich F. and other, 2014) can be considered relevant to the monitoring theme of the effects of natural engineering works, regarding the development of the living plants' component.

In this context, the present paper shows the first results of the monitoring activities of two significant environmental engineering works carried out on the Chiascio River in Umbria, Italy, in the latter years that were subject to significant flood events. The methodology aims to highlight the overall behaviour of the work and any critical issues that were identified, distinguishing those occurring due to the improper execution, and which are attributable to deficiencies in the materials that were used.

THE CASE STUDIES AND RIVER BASIN EVENTS

The examined works were carried out in spring of 2010 year and covered a sector of bank erosion, downstream of a crossing near an old mill located on the right bank (Fig. 1A), and the location of a landslide, rather important, that has affected a sector of about 20 meters on the left bank of the Chiascio River (Fig. 1B). The bioengineering techniques were applied in both works. In fact, in the first case, it was required to build an easily accessible track in the vicinity of the river crossing, which possibly would not be submerged and then eroded during flood events. The request was matched to exploit the path for recreational purposes, in the context of a broader green arrangement that is present on a long section of the same bank upstream of the mill. In the second case, the landslide was triggered on a surface of clay slip at a depth of about 3.5 m, on a side portion in a wide rural area on which it is wanted to minimize the impact of the yard and the work.

The hydrographical basin of the Chiascio River has an area of approximately 1950 km^2 with frequent flood events that required the intervention works discussed in this study. Table 1 summarizes the data of water gauges and the corresponding flow rates from 2005 to 2016 (Centro Funzionale della Regione Umbria, 2005-2013).

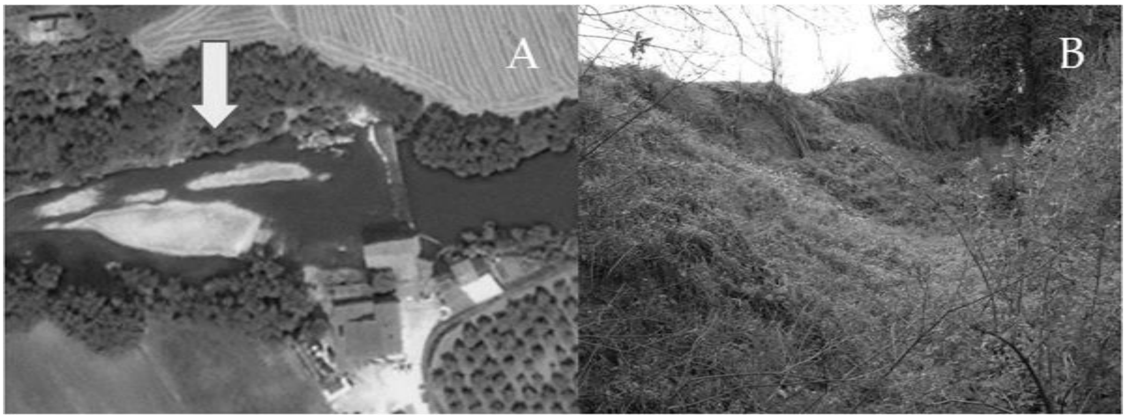

Fig. 1 - Location of the sector with the bank erosion (A), and the left bank landslide (B)

Table 1 - Events recorded at the hydrometric station of Rosciano Bridge on the Chiascio River; the values highlighted with bold are subsequent to the implementation of the works; the 2016 year event was monitored by the authors

Month/Year	H (m)	Q (m^3/s)
11/2005	5.60	569
12/2008	5.02	395
11/2010	**5.05**	**404**
11/2012	**5.53**	**559**
11/2013	**5.04**	**400**
01/2016	**3.84**	**151**

Fig. 2 - The impact of the quick flood of January 2016 on the bankside guard (A) and on the arrangement of unstable bank tract (B).

In particular, the event of 2016, by far the less intense, was monitored to assess the impact on the works, showing for the first intervention the complete submersion, while for the second intervention highlighting a partial involvement of the work, which, however, allowed to estimate a significant impact produced by the floods of 2010-2012 and 2013 (Fig. 2)

All the works of the monitoring objective were designed and executed by the former Defence Management and Hydraulics Service of the Province of Perugia in spring of 2010, according to the criteria that were placed with the goal to avoid the slightest impact on the nature of the sites, both during the work, and after work is completed. For this reason, we tried to minimize the excavation operation, limiting the use of very heavy vehicles, which would have required the opening of large and well-established areas of work. At the same time, we tried to restore the continuity of riparian vegetation after the work was completed, largely characterized by tree species such as oak (*Quercus robur* L.), alder (*Alnus glutinosa* L.) and elm (*Ulmus minor* Mill.).

With this in mind, the first intervention for the riverbank protection was performed with a simple palisade made up of juxtaposed chestnut poles of 15 to 20 cm in diameter and 4 m long, arranged following the natural lines of the riverside (Fig. 3A). In this way, it was tried for providing the work an appearance as little artificial as possible and at the same time, for favouring the formation of calmer water areas, which was important for the life of vegetation and the fish fauna.

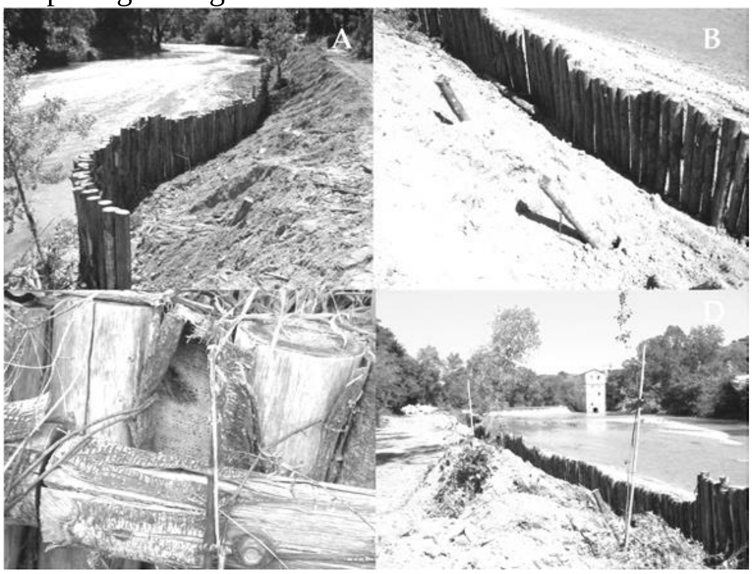

Fig. 3 - View of the development line of the piling (A), particularly of the anchor rod (B), the transverse alignment of the front (C), planting of vegetation in the banks (D).

To provide continuity to the structure, the inclined poles were placed and clamped at the rear of the riverside (Fig. 3B) representing the anchors for the steel rods. Rods were connected with two cross poles placed on the top of the piling edge (Fig. 3C).
In this way, in addition to improving the work with a static behaviour, together in the reaction to stress in the execution phase, the action also favoured the alignment of the piles.
Upon completion of the work with layer of geomat was added for the initial containment of the ground ahead of the piling, thus creating a better condition for the rooting and growth of the abundant shrub vegetation on the riverbanks of this section of Chiascio River. Finally, the tree species have been planted over the piles in the area (Fig. 3D), always following the directions of the typical existing vegetation, and then choosing the alder and the oak as predominant plants.
The second intervention posed instead a much more specific goal, as it was to stabilize a sector of about 20 meters in the landslide with a sliding surface at about 3.5 m deep, consequently with planimetric and elevation constraints well defined along the bank. However, the site problems and the principle to limit the use of quarry stone, determined in this case the realization of a wood piling, structured in such a way as to enclose the unstable ground in a sort of niche (Fig. 4).
Therefore, the chestnut poles with a diameter of 20 cm were arranged in two rows (Fig. 5A) and fixtures for a length of approximately 4 m, to affect the sliding surface of the body in landslide, represented by the layer of clays, interposing in this way the phenomenon dynamics. In the central area of the landslide, the body of a deep drainage was also carried out for controlling the disposal of water infiltration that could be possibly present in the soil (Fig. 5B). Thus, the surface area is searched to better control the action of surface waters, both from raining or water withdrawal after flood events. In particular, the latter were arranged in three levels, with the use of usual species of native types: in the first level (the one closer to the water, upstream of the first piles) were planted alders; in the second level (upstream of terrace oaks have been placed and finally, in the third level (upstream of the second row of poles) elms were placed, which were resistant to graphiosis - *Ceratocystis ulmi* (Fig. 6). This provision follows the positioning generally observed on the typical rivers in the area, bearing in mind that the alder is placed at the foot of the arrangement. Due to the features of its root system, once developed, alder provides more stability.

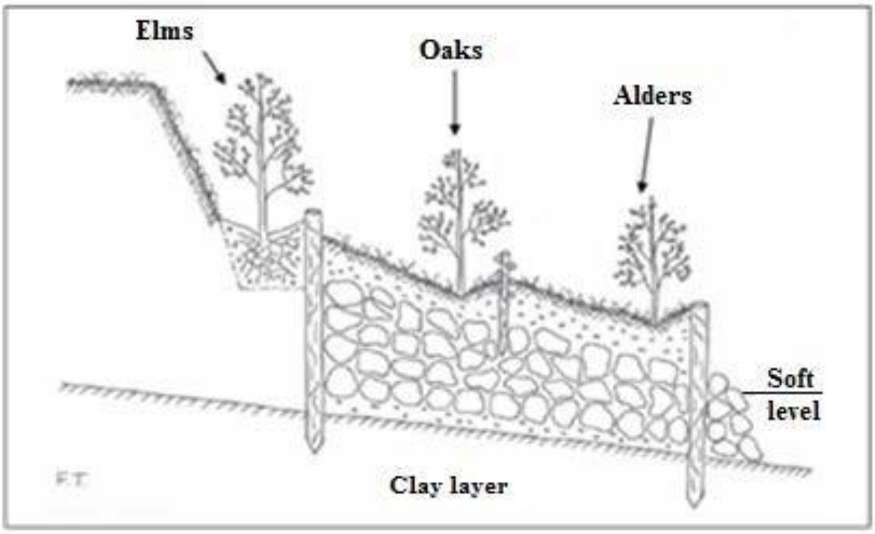

Fig. 4 - Operation scheme of the landslide stabilization in the central section and the corresponding drainage (Torti, 2012)

Fig. 5 - Realization of two rows of wooden poles (A) and of the central drainage (B)

Fig. 6 - View of surface arrangements

RESULTS AND DISCUSSION

Given that all the works have been subject of maintenance following the end of the work by the company carried out in the first summer-autumn period, the Province of Perugia has decided to launch a monitoring activity of works with the support of the Department of Civil and Environmental Engineering, University of Perugia, in order to develop also a method that could then be extended to other performed tasks or that are being planned. For this purpose, a survey form has been prepared with a work evaluation grid, which can be summarized in a final judgment on the following points: global work behaviour; presence of localized problems; behaviour of individual used materials; state of the plant component planted or regrown spontaneously, the latter to assess the effectiveness of some measures and construction details.

The application to the two works described previously took place at a distance of about 5 years after completion of the work. In this time period, the works were not receiving maintenance and significant events have occurred. The results are summarized in the summary card of Fig. 7. One can observe how the first intervention of riverbanks protection has presented a good behaviour during this first period of life (Fig. 7A and Fig. 8A) with the only problem related to a failure localized on the piling. In fact, in correspondence with the curved portion of the upper crossing they were interrupted without any discontinuities. Consequently, the piling woods was disconnected from the rest of the structure and was not supported by any tie-rod (Fig. 8B).

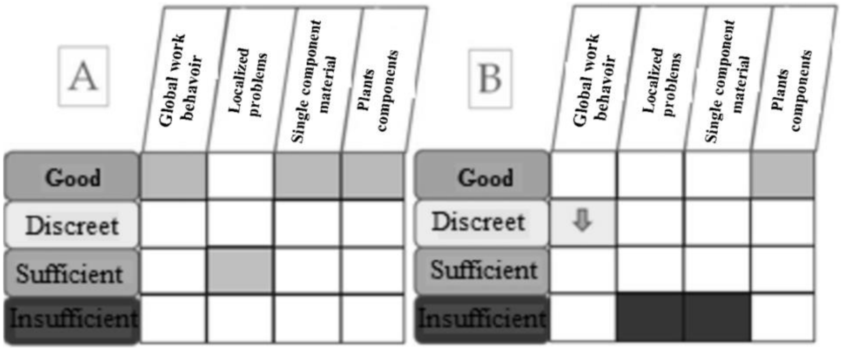

Fig. 7 - Final evaluation sheet of the two interventions, riverbank protection (A), bank stabilization in landslide (B)

Fig. 8 - View of the arranged side (A), and the disconnected piling woods(B)

Such an error in the execution phase was highlighted during the floods that have submerged completely the work, particularly during the withdrawal of the waters; the structure was biased towards the river, resulting in forward sagging and erosion of land behind. In the case of the second intervention, the card shows more critical problems (Fig. 7B), In fact, the case presented localized problems and issues regarding the materials, which determined an insufficient judging of the behaviours, that adversely affected the overall behaviour of the work. The located problem was highlighted since the first flood event and was linked to an incorrect initial connection between the work and the bank (fig. 9A), which led to a marked localized erosion area by the failure of a stump that perhaps it had been attributed excessive consolidation function. Over the years, the regrowth of shrub vegetation has partly concealed the problem, which, however, remains even if it did not show a particularly rapid extension of the eroded area (Fig. 9B).

Fig. 9 – View of the erosion zone at the beginning of the work, the situation shortly after the end of the work (A) and 5 years after (B)

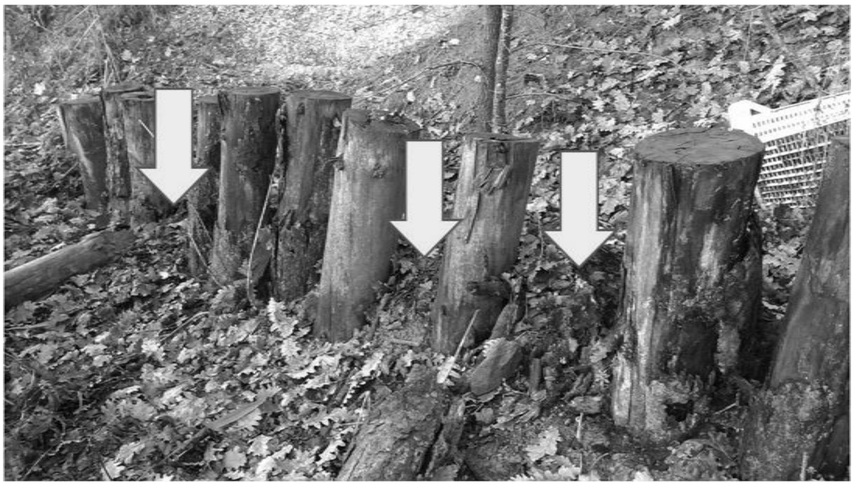

Fig. 10 - Detail of the completely deteriorated pine elements of the piling

The second problem was instead highlighted over the years and was linked to the type of used wood materials. In fact, it was found that not all piles were chestnut. In fact, some were pine and have undergone an evident degradation phenomenon in the aboveground part, until they completely decayed (Fig. 10). This situation needs to be verified in the stuck part that is less subjected to repeated wetting and drying phenomena. However, it indicates that the choice of the wood material has to be examined carefully in the individual elements of the structure.

CONCLUSIONS

The first results regarding the monitoring of studied works have highlighted the importance of this activity and the effectiveness of the adopted methodological approach. The continuation of activities will allow a better study of the monitoring technique, also directing the elaboration of possible guidelines for the specific maintenance and restoration of natural engineering works, which will be exposed to significant issues over time. However, the first analyses show how fundamental is the attention on the devices and on the structural details, particularly in a sector in which the labour activity is predominant. On the same direction, the verification of the used materials is relevant, in particular, those wood materials with static functions, because the characteristics of the wood may vary depending on the species, the variety, and could be linked to the environmental conditions of the growth area.

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