OPERANDUM

OPEn-air laboRAtories for Nature baseD solUtions to Manage hydro-meteo risks

GUIDE FOR THE DESIGN AND CONSTRUCTION OF CRIBWALLS

naturalea

Deliverable information	
Deliverable no.:	xxx
Work package no.:	xxx
Document version:	V0.1
Document Preparation Date:	28.01.2020
Responsibility:	Partner No: 19 – Naturalea

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776848

Project information	
Project acronym and name:	OPERANDUM - OPEn-air laboRAtories for Nature baseD solUtions to Manage hydro-meteo risks
EC Grant Agreement no.:	776848
Project coordinator:	UNIBO
Project start date:	01.07.2018
Duration:	48 months

Document Information & Version Management			
Document title:	Guide for the design and construction of cribwalls		
Document type:	Public report		
Main authors:	Albert Sorolla; Inma Rueda, Bet Mota		
Contributors:			
Reviewed by:			
Approved by:			
Version	**Date**	**Modified by**	**Comments**

Short Description
This document provides a clear guideline to have better knowledge in the design and construction of new Nature-Based Solutions (NBS). Naturalea has written a document in the OPERANDUM framework to create a base for the use of cribwalls a soil bioengineering technique which represent a useful alternative to face hydrometeorological hazards instead of classical solutions.

Dissemination level		
PU	Public	
CO	Confidential, only for Members of the Consortium, including the EU Commission Services	

TABLE OF CONTENTS

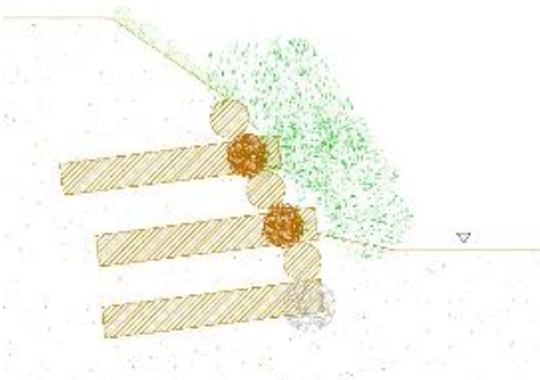
1. INTRODUCTION

The cribwall structure is linked to the history of civilization. There are foundations of cribwalls on Roman bridges of 2.000 years, probably the walls of the Celtic villages were a type of cribwall... but it is difficult to find evidences of these works. Certainly, the technification of the structure developed at the beginning of the 20th century in the Alps by Austrians and Italians was the birth of the technique as a slope engineering tool.

In recent years, we have verified the existence of cribwalls works that omit basic aspects for the success of these structures. The lack of preparation of the staff that designs and executes makes serious mistakes such as the foundation, the maximum permissible height, the structure and the role of the plant. Some of them have collapsed compromising the credibility of the technique. This document intends to be a guide to design and build a cribwall. In the case of construction, we recommend practical training in specific courses such as those organized from EFIB.

2. WHAT IS A CRIBWALL AND HOW IT IS BUILT

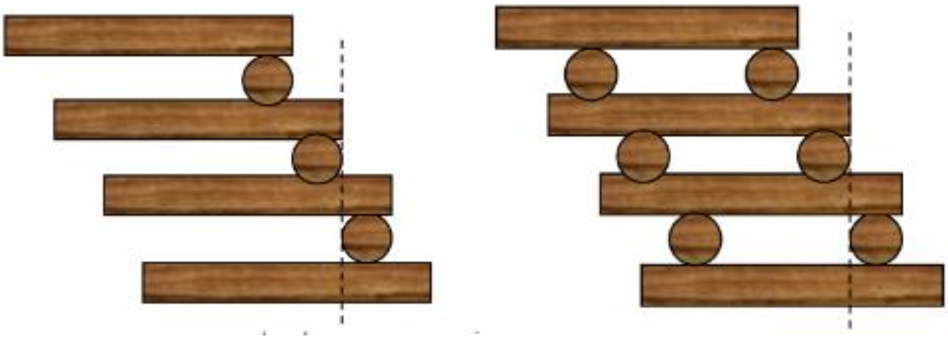
The cribwall is a wooden structure consisting of several logs forming a three-dimensional cell that creates a block that is filled with soil and a frontal with live stakes or container plant, with the aim that the future development of the plants replaces the structure of logs. On the front is placed a fascine to retain the ground. This fascine also has an important role in moisture retention.



The structure always needs a foundation, determined according to its location and the load it supports. The depth of the cribwall will depend on the needs in each performance that will determine the necessary foundation height. Furthermore, if this technique is used as a structural wall to stabilize margins and the structure must support heavy loads, it is recommended the reinforced cribwall named Krainer.

The front of the live cribwall should not be vertical but inclined in favour of the slope. As the cribwall is lifted, the logs parallel to the current will be removed until they are aligned with the back of the lower log.

Section of the cribwalls with the maximum admissible slope:



2.1. Logs

The selected wood must be the one that degrades slowly enough to allow the development of the plant. Generally, conifer bare, chestnut or acacia. In some cases, you can take advantage of invasive exotic wood, such as *Robinia pseudoacacia* conveniently treated to prevent regrowth. In others, the available wood can be used as long as it can be estimated (it is difficult to guarantee it in living structures) that its loss of structure due to rot will occur after a correct development of the plant.

The logs are fixed with nails or rods of corrugated steel so that they structure the wood well and although it has some mobility, it can work as a block.
Wood degradation is caused by bacteria, xylophagous or termite insects and fungi that are one of the main sources of degradation. Humidity and temperature are favorable to fungi. For optimal growth, rot fungi require a moisture content close to the saturation point of the fibres. With humidities below 20%, they become inactive but do not die.
For this reason, we reduce the degradation time if:

- We perform the minimum of the perforations in the wood to guarantee solidity.
- We use machinery to cut the fibre and to make clean holes.
- We do not make wooden lace: no need.

Finally, it is better to cut the wood in a crescent moon (INIA National Institute of Agricultural and Food Technology).
It is best to dry the wood, but it is rarely done, so keep in mind that when the diameter dries it can vary between 4 and 6%.

2.2. Plants

The planting should be done while it is being built so that the structure is well compacted and therefore it is difficult to replace the plant once it is finished. For this reason, it is planted in very large densities every 0,2 or 0,25 meters per row, so if there is any loss, it will not affect the final structure. It is essential to choose a plant of species, ecotype and quality appropriate to the area of the work because the plant is the one that will guarantee the future viability of the technique.

If the area has a constant humidity, stakes can be used, otherwise, a plant in forestry cell tray format is used. Plants with larger pots can be placed, but in general and by Naturalea's experience, a small plant but with a good root structure has greater survival.

Not all species can be used, the best are those shrubs that have more root system than the aerial part. It is not necessary to introduce potential vegetation species of the working area. The plantation should be done with those shrubs with a regrowth capacity that provide the structure in the slope to allow its consolidation in the first instance and create conditions of future implementation of the potential vegetation.

The species that have a better response to this type of technique are those that belong to the genus Salix except for the white willow (*Salix alba*), tree bearing and bad-developed root system; and the crack willow (*Salix fragilis*). Elderberries (*Sambucus nigra*) and common dogwood (*Cornus sanguinea*) are also interesting as initiator species. In Mediterranean environments, we have also worked successfully with species such as tamarisk (*Tamarix sp.*).

For better development of the root structure, it is important to do two pruning's during the first four years. Generally, these pruning are done without affecting the entire area so we do not leave it without vegetation, and to complete the pruning of a structure you have to go on more than one occasion.

This allows the vegetation to branch out and stabilize the entire slope, occupying it with a radicular and aerial mass distributed. If pruning is not done, the structure may work, but some plants end up taking more power and the rest disappear.

It should also be taken into account that the humidity of the slope, especially in river spaces, can vary greatly, therefore, the selected species may vary according to the distance to the water table of each of the levels

2.3. Soil

The soil with what we fill the structure is important. It is not necessary to compact with machinery. Generally, we work with soil from the area, and in case that an external contribution of soil is made, it must be of a loamy-clayey texture and with a minimum content of organic matter.
Depending on the texture of the ground, the cohesion values of the same fact vary, which influences both the stability of the whole slope and the stabilization structures, as well as the development of the vegetation.

In any case, can the cribwalls be filled with gravel, unless it is at the base and is permanently flooded because otherwise, it will be a draining system that will not allow the good development of the vegetation due to lack of moisture availability in the root system or directly by drying the roots.

2.4. Construction

The cribwalls are constructed starting with the foundation, there are usually between 1 and 4 levels of the cribwall as a foundation, below the level base of the slope. Normally 1 level is placed on slopes and at least 2 levels on riverbanks.

These levels respond to possible oscillations of the ground level. This is one of the basic aspects for the construction of a cribwall, having defined the reference level before starting the construction process. During execution, once the earth movements are started, it is easy to lose the reference level if the dimensions at a fixed point have not been indicated.
A first decision is whether the post corresponding to level 0 (ground level) is located parallel or perpendicular to the front of the slope, or in the direction of the flow in the case of a river or stream. As the lower part of a slope is a point of erosion and the future of the structure is the stabilization consequence of the development of the vegetation, we recommend that it coincides with the perpendicular.
The disposition criterion of the first log could be changed to level 0 in the following situations:

- If it is a cribwall in a channel, therefore, with low and controlled flows.
- If it is the base of a slope in an arid place that collects water from a field.

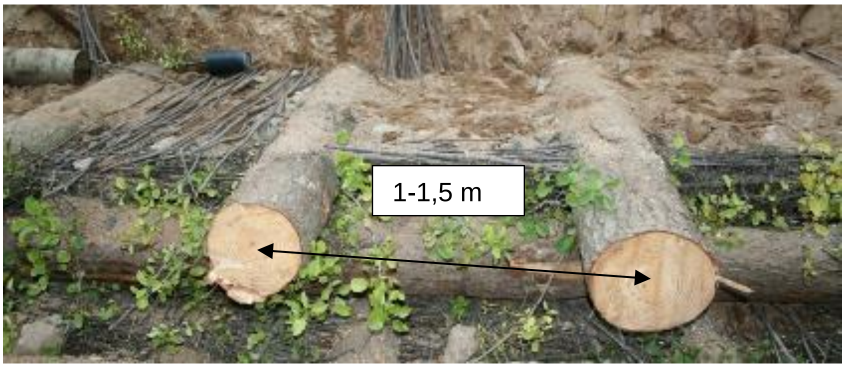
The cribwalls must have a very slight slope towards the internal part, usually an angle of between 10-15º. In this sense, the perpendicular logs have a very important role.

Constructive process:

1. Implementation of logs parallel to the front of the slope. In the case of the simple cribwall, only one line of logs is placed at each level, in the case of the double cribwall or Krainer, two lines are placed (except in the upper level).

2. Contribution of quality material to fill this level with soil or soil and stone if it is part of the foundation.

3. Installation of the perpendicular logs that will belong the next level. The distance between them must be between 1 and 1.5m, 2m maximum in the case that the logs parallel to the front are very long.



4. Anchoring with corrugated steel bars of 1m in length to fix the logs together and between 1.5 and 2m to fix the foundation.

5. Plantation in the free space between logs with the indicated density and the selected species according to the established criteria.

6. Installation of a fascine or a high-density coconut fiber roll.

7. New material contribution to cover the second floor and restart the process.

8. Once the structure with the levels decided in the design is completed, the sowing and the appropriate actions defined for the surface protection of the slope are carried out.

Executive details:

- It is common for logs parallel to the direction of flow to move slightly to avoid vertical lines of the junction points between logs. If so, they would be weak points, individual blocks, and not a unique structure along its entire length.

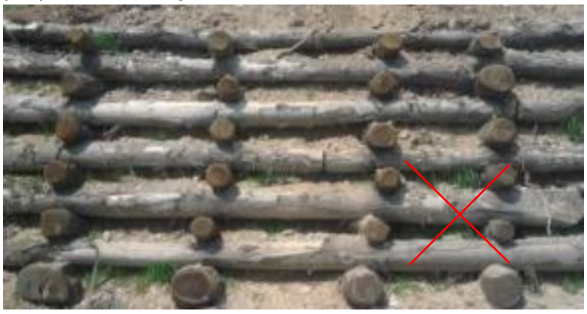
- It is very important to consider the provision of the logs so that each one parallel to the flow contains two perpendicular.

- The cribwall is always finished with a log parallel only to the front.


- There are two major trends in how to structure perpendicular logs: interleaved or in a row. We tend to make the interleaving system, since when it rots there is no weak line and the slope distributes the structure of the roots more homogeneously.

Image of the frontal aspect of a structure with intercalated perpendicular logs:

Image of the frontal aspect of a structure with perpendicular logs in a row:



3. WHAT IS IT FOR

It is used as a stabilization technique for the slope base, both riverbank and mountain. With its implementation, the base or the total surface of a slope can be stabilized. It can be applied in watercourses with high energy and solids transport knowing its behaviour and dimensioning the structure based on the necessary technical data. This structure allows loads on the upper part from the first moment as seen in the image.


4. DIMENSIONING AND CALCULATIONS

The cribwalls are designed to have a permanent duration, but with a period of evolution towards the vegetal cover of 15 years according to the wood and the place. They are generally located in natural and naturalized environments where extraordinary impacts can be generated. For example, a change in the drainage of a track can dismantle a slope or a car dragged by the river can crash into a structure. However, a cribwall is a living and resilient structure that if it is well done has a great capacity to resist and heal.

The cribwall must have a height of no more than 2m. If the height to be protected is higher, they can be made in terraces (always making the pertinent calculations). Many times, if the slope is higher in the upper part of the cribwall, a simpler surface stabilization technique such as slope grid is continued.

The logs perpendicular to the front is not larger than 2m in length.

Regarding the calculation of structure and stability, we must take into account:

- **Internal stability**: related to the dimensioning of the structure
- **External stability**: Good conditions must be fulfilled about to sliding, tipping and bearing capacity.
- **Global stability**: stability of the total of the slope and the structure.

External stability:

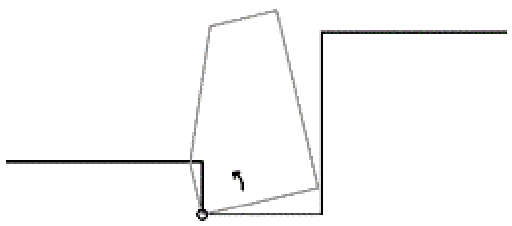
To calculate the external stability of a cribwall, it is necessary to know and take into account the data specified below:

- Inclination over the horizontal (usually designed contrasting the angle of 10 to 15º).
- Density (which will depend on the filling material of the structure and the material that forms it).
- The angle of internal scrubbing (face of the structure in contact with the contained material).

It is necessary to make checks of tipping, sliding and bearing capacity

<u>Landslide checking</u>

Details for calculations of the landslide safety coefficient:
To know the safety coefficient about the landslide, it is necessary to know the stabilization forces (the weight of the structure to the base) and the destabilization forces (the active thrusts to the height).



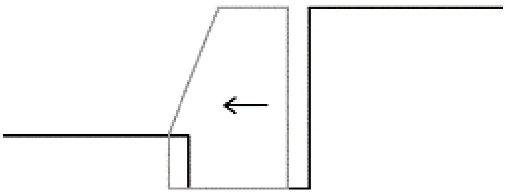
It is necessary to know the weight of the structure: it will be obtained from the dimensions and density established by the materials that comprise it.

The horizontal and vertical components of the active thrust must be obtained. The Coulomb theory is used to calculate the active thrust coefficient.The minimum safety coefficient must be of the order of 1.8-2.

Landslide base check

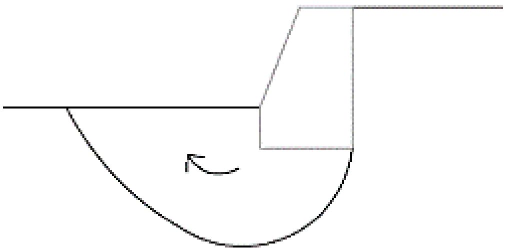
For this calculation, it is necessary to know the result of vertical and horizontal forces and the angle of friction between the structure and the ground.

The minimum safety coefficient must be of the order of 1.5



Bearing capacity check

Check that there is no excessive ground plasticization and that the tension is admissible to the ground base.



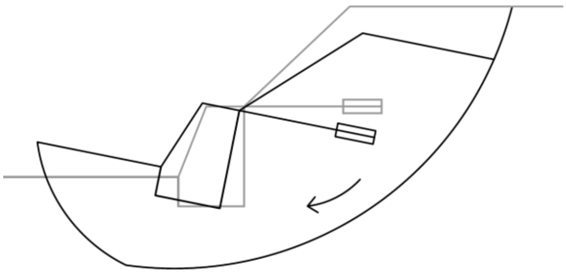
Internal stability:

Check whether the diameters of the logs withstand the existing bending forces. To know if the structure is resistant, it is necessary to verify that the log that is at the base can withstand the flexion caused by the pressure of the ground on it. The value cannot exceed the strength of the log, which will vary depending on the characteristics of the wood used.

The maximum tension on this log includes: the lateral pressure caused by the ground of the base of the structure on the log, and must be lower than the maximum tension of the log subjected to bending, avoiding reaching the breaking point.

Global stability:

Checking the overall stability of the whole cribwall, avoiding slope landslides that include the cribwall (deep landslide). The calculation methods used are those of limit equilibrium.



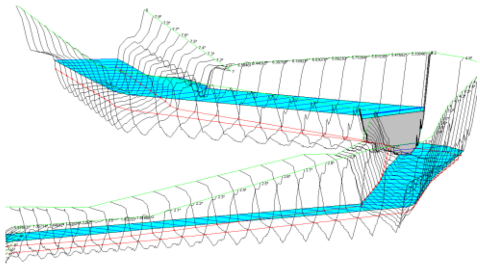
Calculations and validations of cribwalls in river courses

Moreover, concerning hydraulics in the case of cribwalls built in rivers, it is necessary to know the data of the level of transient erosion, tensions and speeds at the base of the structure. To obtain this data to validate landscape bioengineering structures, the generation of hydraulic studies with two-dimensional calculation models is recommended.

In moments of flooding, the values that can be given of tension and speed for the ordinary one can suppose a remarkable increase. Water and suspended elements generate a lot of energy that can lead to damage, but we must define a structure that is resistant to calculated values taking this dynamic into account.

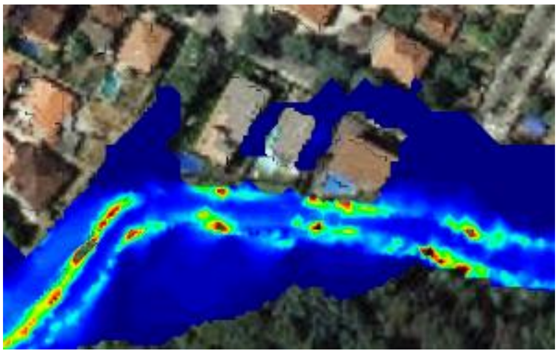
The determination of all these factors is not a simple task, much less precise. In most cases, the availability of data is very low. This is where the work of people with technical criteria in hydrology, hydraulics and sediment transport is essential. Yours is the responsibility of making the most concrete diagnosis possible, interpreting the existing data and those provided by the different simulation models, based on knowledge and experience (one of the essential values in hydraulics). Because we must not forget that a hydraulic model, or hydrodynamic, is just that, a model. It should never be confused with reality. Data (very valuable) are extracted from the model, which, when confronted with the rest of the parameters, allow us to interpret reality and draw conclusions to find the best solution to the problem that arises.

For a preliminary analysis, we can use a calculation of the normal draught level (technically uniform permanent free-flow). Fortunately, this is no longer the definitive step. Hence, it has been passed to the calculation in a gradually varied permanent regime and the variable regime in 1D (with models such as Hec-Ras, for example). In them, only one direction of flow is assumed.



Nowadays, and more and more frequently, models are imposed in 2 dimensions (with models such as IBER), which allow evaluating the behaviour of the river obtaining variables such as speed, with the two directions in the horizontal plane, draft or tensions, as well as risk maps. These models allow you to accurately simulate sections or meanders, flood lands, estuaries, where the flow behavior is not in one direction. While there are many situations in which it is not necessary to reach this level of study, its facility and effectiveness push its use. These numerical models (based on shallow water equations) are in high demand by the administrations themselves. In summary, we have a very wide range of tools and levels when creating a model, but the task is to choose the appropriate instrument and, above all, a correct interpretation of the data obtained.

Example:

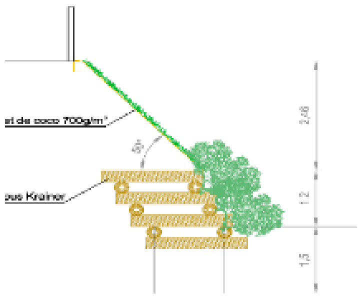


	Total velocity (m/s)	Total tension (N/m2)
QMCO	2.81	448.53
Q5	3.49	576.58
Q100	2.81	545.29

Table 1: Velocities and tangential tensions for MCO, 5 and 100 years.

Two-dimensional hydraulic to dimension the causes of the erosion of the margin of a house in a stream, and that give us some requirements to which it is necessary to add the temporary erosion.

Initial state of the slope, solution and works done:



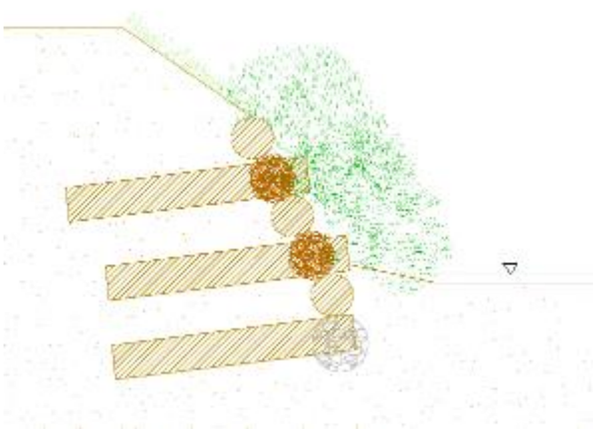
Evolution of the slope in the first months:

5. WHICH TYPES OF CRIBWALLS EXIST

In recent years, the cribwalls have been deeply studied starting from the fact that a cribwall is a gravity wall with a present of wood and a future of vegetation. The search for new cribwall systems that are easier to build or that require less material is a research project that engineers like Paolo Cornellini are carrying out. The idea is to look for the optimization of the construction time and the amount of material needed, but obtaining good results. Down below, we review the most important ones.

5.1 Simple cribwall

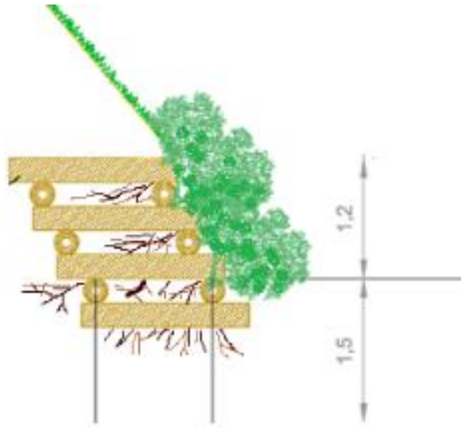
It is the simplest cribwall. A wooden structure that consolidates the structure of the soil and that works the front part of it. It is used as a transversal work for the stabilization of ditches in steep beds and the stabilization of slopes. As a longitudinal work, it is used for the defense of riverbanks subject to erosion.



This technique withstands equal or lower values at speeds of up to 3m/s and voltages of 250N/m^2, although the slope of the land and the structure of the soil must also be taken into account when working on a river. The resistance data of this structure is similar to that of a reinforced green wall.

5.2 Double cribwall or Krainer

A wooden structure consisting of a cribwall of logs (bare coniferous and Chesnut trunks ...) that form a structure, which is filled with soil, in which live stakes or container plants are planted, on the front of which a fascine is installed to retain the ground. It is, therefore, a wooden structure with plants and is one of the bioengineering techniques of the landscape of greatest resistance.



This technique withstands equal or lower values at speeds of up to 6m/s and voltages of 550N/m^2, although the slope of the land and the structure of the soil must also be taken into account when working on a river. It is a stronger solution than the previous one since it works as a solid gravity wall. This model can accept loads on its surface.

5.3 Simple cribwall or Naturalea Krainer

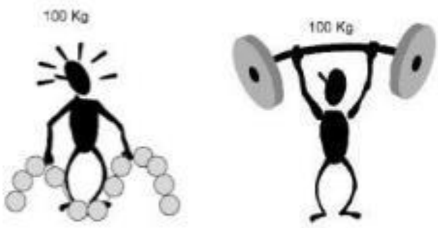
A variant of the previous systems to improve the tightness of the structure until its total development with two significant elements:

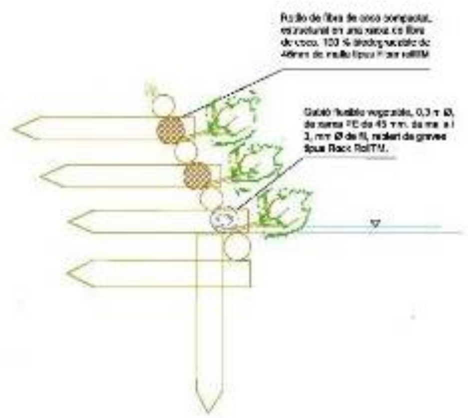
- On the front, instead of installing fascines, a roll of coconut fibre of high density structured in a network is placed to retain the ground. The coir roll has more durability than a fascine and does not suffer significant variations in volume due to changes in ambient humidity.

- The structure always needs a foundation, depending on its location and the load it supports. In this case, since it is an adaptation of the cribwall to riverbeds, we protect the base of the slope with a Rock Roll (tubular gabion). This allows building a continuous structure that links the entire foundation and with a weight of 175kg/m that presents little resistance to the passage of water. Besides, the gravels have a diameter that ranges between 7 and 15cm which allows it to be colonized and integrated by the roots. In foundations made up of large stone, such as the breakwater blocks, the roots will hardly structure it.

Rock Roll (Tubular gabion)

As exemplified in the following scheme, this gabion structure also has advantages over the force of water since it is more difficult to mobilize than other more monolithic structures, in addition to dissipating energy:






5.4 Loricata cribwall

It is a construction technique based on a metal structure, with a front frame welded to a bar in the direction of the ground, which ends in a flat platform that acts as an anchor within the slope. From the basic principles of mechanics, the strength and length of the anchor structure with a center of gravity can be determined without a problem, and we can easily compensate for the weight of a facade of more than 8m².

The frontal appearance is very similar to that of any cribwall. This can be easily vegetated, although the stability of the structure no longer depends on the vegetation. The structure has a known, stable and permanent resistance from the moment of its installation and allows the vegetation to develop without any impediment.

It should be noted that this system avoids drilling the trunks.



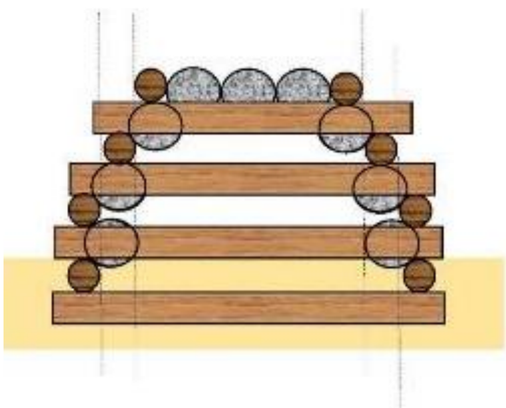

5.5 Cribwall Krainer with stones

In mountain areas or streams, soil and liquid flows are mixed. This fact gives high energy to river courses in a flooding situation where we construct perpendicular structures that are known as hydrological-forestry actions. A cribwall as a gravity wall formed by a cellular structure of logs of wood, stone and living stakes or container plants is a viable technique if it is well built.

5.6 Krainer cribwall with Rock Roll (tubular gabion)

If in the previous system, the roots could colonize this stone structure without losing its overall structure (weight) we would facilitate the initial growth of the plants and the evolution of the structure. This property is given by the flexible tubular gabion structured in a network of high-density polyethene and gravel filling (Rock Roll).

This permanent structure prevents the loss of soil while the root mass develops. A Rock Roll type gabion is placed on the front, which in many cases is located on both sides since it is built as a baffle.



A final advantage is that it remains like a cohesive block along the entire length since the gabions are tied between them.

5.7 Latin cribwall

The uniqueness of the Latin cribwall, designed by the engineer Paolo Cornelini, simplifies and, therefore, optimizes the internal structure of the cribwall by saving wood. The logs are placed at 45º from the front of the slope so that they overlap inside. The front of the Latin cribwall should not be vertical but inclined in favour of the slope. As the cribwall is lifted, the logs parallel to the direction of the flow will be removed until they are aligned with the back of the log located at the level immediately below.
The depth of the cribwall will depend on the needs in each performance that will determine the necessary foundation height.

5.8 Cribwall Roma

This cribwall works especially reinforcing the front and the base. This type of construction has a size limit with the height (maximum 1,8 – 2,2m), due to static creation controls, while the depth (width) of the structure is not generally greater than 2,0-2.5 m.

Scheme and image belong to AIPIN

6. ADAPTATIONS FOR CRIBWALLS IN FLUVIAL SPACES

Building cribwalls in riverbeds means that the foundation is basic for its resistance. The depth of the foundation must be calculated so that it is below the level of transient erosion. The base is protected with rock or more resistant materials such as Rock Roll (flexible tubular gabions). In this case, in addition to the structure's stability, which depends on the filling material or on the possibilities of carrying loads at the upper area, the effects of river dynamics must be evaluated. A calculation of speeds and tangential tension is made at the construction point of the Q100. The dimensions of the drafts in Q100 are also calculated to know if it can be permanently flooded and add elements that consolidate the upper part. A flood is a phenomenon of great energy and dragging can cause damage, but it is part of a fully consolidated structure.

Installing material in front of the structure waiting for protection is anecdotal. The cribwall works as a block and at the point of confluence between the ground and the structure local erosions can be generated.

Finally, keep in mind that you have to cut the logs following the inclination line of the front so that no trunk protrudes. The vegetation developed will protrude from the front, but taking into account that they are adapted species they will resist the floods bending in the direction of the flow, but without breaking.

7. OBSERVATIONS FOR CRIBWALLS ON A SLOPE OUTSIDE THE FLUVIAL AREA

The cribwalls in terrestrial slopes are usually made in areas either where there are serious structural problems, because of the type of soil, or because they collect runoff waters or because they host infrastructure in the lower or upper part.
As always, the necessary foundation must be analyzed to ensure the overall stability of the whole slope and structure. For example, if the slope is formed by contribution lands, it is necessary to generate fixations between this slope and the original terrain.

There are two key aspects to ensure the success of the cribwall in a terrestrial slope: the selected species and the availability of water. It is a technique that is hardly applicable or will have an expiration date in arid or semi-arid areas.
In the Mediterranean world, it is essential to work taking advantage of runoff. If we manage it badly, we can collapse the slope, but if we avoid it, eliminating the contribution of water in the slope, we can dry it. It is, therefore, appropriate to create systems that allow runoff to enter but that, at the same time, evacuate the waters in episodes of heavy rains. One possibility is to put gabions or fiber rolls that allow water to enter but divert water that is not able to infiltrate during peak flow times and, therefore, by controlling the inflow into the structure.

Cribwalls can enter in the urban space. Due to the loss and limited availability of green spaces in metropolitan areas, because of rapid urbanization in recent decades, there is a need to promote more sustainable cities for the future.


8. CRIBWALLS IN URBAN AREAS. FIGHTING AGAINST THE CLIMATE CRISIS

In the urban environment, very often associated with "hard" structures and the use of concrete, the fact of replacing traditional containment elements such as breakwaters, riprap, concrete walls or gabions with landscape bioengineering techniques that, also, ensure the same stability. They have many advantages for their ecosystem services: landscape improvement, aquifer recharge, soil humidification, nutrient retention, CO_2 fixation, runoff management, diffuse pollution reduction, flood risk reduction, temperature and humidity regulation, wind control... basic aspects of the framework of the climate crisis in which we are already immersed.

The cribwalls are included within the lines of the NBS (Nature-Based Solutions), a concept closely linked to the SUDS (Sustainable Urban Drainage Systems) and which are developed within the broader framework of the *Smart Cities*.

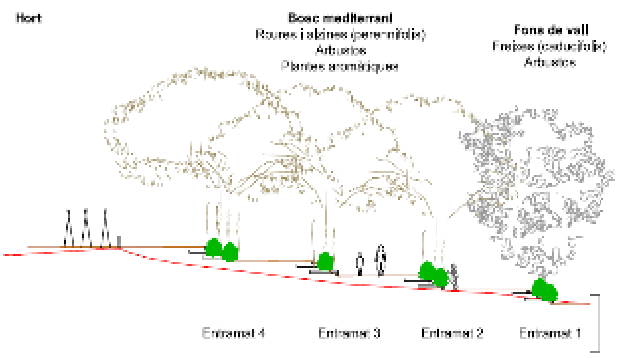


Cardedeu, Barcelona


Barcelona

Roques Blanques Cemetery, El Papiol, Barcelona (Batlle and Roig Architects project)

Example in Sant Jordi school in Montmeló, Barcelona. Images before the works.



Images at the end of the works

And our team did not work alone