# Design procedures for gabion and mattress structures

L. Cesario and A. Gilli
Officine Maccaferri SpA, Bologna, Italy

## 1. Introduction

### *1.1 Traditional irrigation methods*

Irrigation is a vital factor in every part of the world. In arid regions affected by seasonal and violent rainfalls, the main sources of irrigation water are short spate flows. In these regions there is a need for better control of spate flows and to improve traditional irrigation facilities.

Random tipped stone is commonly used: although easier to place than any other system, it is highly susceptible to erosion.

More expensive masonry and brickwork are now only used in short lengths near bridges, culverts or other structures. They are rigid and may be ruptured by settlements.

Hydraulic works in arid regions mainly employ local materials; farmers traditionally build an earthen bank or "ogma" of wadi bed material across the low flow channel of the wadi to divert the entire low stage of the spate flow to their fields. During a large spate, the "ogma" is washed away, often before its total command area has been watered. Water cannot be diverted again to the fields until the "ogma" has been rebuilt. How soon will depend on subsequent wadi flows and availability of machines or animal power. Occasionally the "ogma" cannot be rebuilt before the ensuing spate.

Another local system is short spurs of earth projecting into the wadis which deflect a portion of the spate flow.

The traditional systems are relatively cheap to build, but usually very expensive to maintain. The initial capital cost often equals the annually recurrent maintenance costs. In small to medium size spates the "ogma" and spurs are swept away to the sea or desert. Thus traditional methods, although effective as an emergency solution, must be considered as only temporary.

## 2. Gabion structures for wadi training

Gabions and Reno mattresses for wadi training and bank protection can provide a more permanent solution.

Gabions have been used since the end of the last century, mainly for hydraulic structures in river training works, but also in protection works for roads, railways and land reclamation. They are particularly efficient in the presence of poor soil and under severe hydraulic conditions.[1,2]

In arid regions, gabion structures can be built in the complete absence of water and are mainly used for water diversion and reservoirs.

### *2.1 Gabion spurs and groynes*

Gabion canalization and spurs (or groynes) are commonly used in wadis to divert water. Groyne systems are effective to correct erosion and channel alignment, provided wadi conditions allow. Beneficial reclamation will also result.

There are three types of groynes; straight, hammer head and bayonet. The choice of shape and size are determined by the hydraulic and morphological characteristics of the watercourse, the local environmental conditions and the desired results.

The length of a groyne must not be more than one-third the width of the wadi. The height of the outer end should not exceed the minimum average water level, whereas the height of the inner end must always be higher than maximum flood water level. The width of the base should be at least equal to or greater than its height. The inner end should be inserted well into the bank to avoid outflanking. The groyne must be adequately protected against scouring action. The offshore head is very vulnerable and will require a properly designed apron. The upstream side is subject to undermining and needs similar attention, particularly at its centre.

The spacing between groynes should be approximately six times their projection along straight wadi reaches and four times the projection on bends and at other points exposed to severe erosion. The spacing can be reduced or increased at the discretion of the designer.

The gabions' flexibility allows them to adjust to extreme erosion provided they are properly designed, constructed and maintained.

### *2.2 Gabion weirs*

Gabion weirs are widely used in river training works to make reservoirs and catchment areas. There are three main types, according to the shape of their downstream face at the centre of the flow:

a) *Vertical weirs:* the simplest type, often used for small structures, such as a series of weirs to control a stream reach or in rivers carrying heavy bed loads.

b) *Stepped weirs* differ from vertical weirs only because the water flowing over the weir dissipates part of its energy at each step of the weir face. They are suitable only if the unit discharge is small, and no heavy bed load is carried by the water flow.

c) Sloped Weirs are better, from static and hydraulic points of view, to train river reaches having large discharges, light bed loads, and soils with a poor bearing capacity. It is advisable to protect the crest and the downstream face by means of concrete.

Other types of weir, such as filtering weirs, have recently been developed. Traditional weirs trap all the bed load and most of the suspended material. They last only until the channel upstream has filled to the level of the cill. Filtering weirs have a continuous retaining capacity. They can selectively pass alluvium during low discharges, but stop larger objects such as boulders and logs. The finest material is allowed to flow downstream to maintain equilibrium which is particularly important in the middle reaches of the water courses.

Gabion weirs offer a great advantage against rigid ones: they can be enlarged simply by building up or removing courses on the existing structure.

This can be very convenient when control works are required urgently on rivers where there is hydrological information. Once in operation, the shape of the structure can be adjusted as required.

*2.3 Design criteria for vertical or stepped weirs*
The design of vertical or stepped weirs has been described in detail.[3] Three types of vertical weirs may be identified according to hydraulic behaviour:

1. Gabion weir with a counterweir: the nappe erodes the soil to form a pool deep enough to dissipate the energy of the water.

2. Gabion weir with stilling pool protection built at the same level as the river bed: in the broad crested pool, the counterweir prevents the flow conditions downstream from affecting the behaviour of the flow in the stilling pool.

3. Gabion weir with an apron protecting the stilling pool built below the river bed level, and with jump control downstream. The pool is at the same level as the river bed as in the abrupt rise pool: its behaviour is affected by sub-critical flow conditions downstream.

Gabion permeability is very high. Immediately after construction, gabion structures behave as drains. In sandy and silty soils, a synthetic filter or an impermeable membrane placed under and around the structure will prevent fine particles from being washed through the gabions.

For larger structures, vertical cut-offs are recommended, anchored to the most compact layers of the soil.

*2.4 Resistance of gabion structures*
To investighate the physical and mechanical characteristsics of gabion structures, and thei: behaviour under load, a series of tests was carried out at :he Structural Science

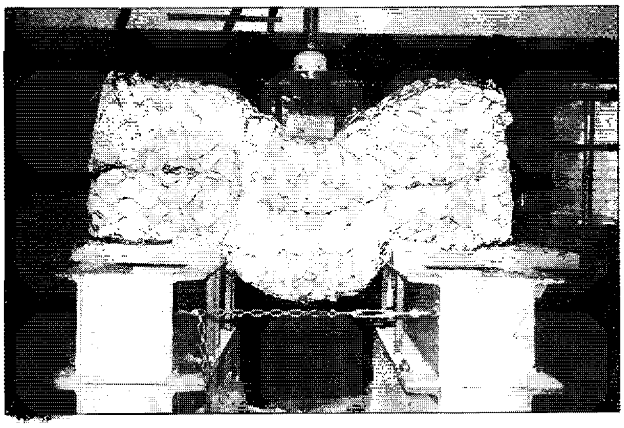


*Figure 1 Simple cut test on single gabion*

Laboratory, University of Bologna, Italy.

These tests involved compression and shear tests on full size gabions and on single mesh panels. These showed that gabion structures can generally withstand differential settlements of 20 percent in uniaxial stress conditions. With loads of less than about 10 kg/cm$^2$, settlement takes place without any mesh wire failing; loads of 30-40 kg/cm$^2$ consistently broke the mesh. The breaking load in these tests was taken as that which caused the first wire to fracture.

*2.75 Common problems*
Experience has shown that the most common mistakes in the construction of gabion weirs fall into two groups:

1) design mistakes include inadequate foundations and side keying, improper use or lack of geotextile/gravel filter under the gabions or mattresses, and a lack of crest protection (when required).

2) execution mistakes include the incorrect choice of filling stones (in terms of resistance and size), lack of lacing in individual gabions and/or amongst adjacent gabions, and lack of maintenance.

**3. Design criteria for canal linings and flood protection with Reno mattresses**

*3.1 Introduction*
The Reno mattress is a special type of gabion with a large area/thickness ratio. Diaphragms are usually fixed at 1.00 m centres to a continuous panel of mesh forming the base and the sides of the unit.

Reno mattresses were introduced after World War II, and are now widely used for bank protection, canal lining, earth dam reinforcement, and as flexible foundations for groynes and longitudinal river works.

Two studies recently commissioned by Officine Maccaferri in Bologna can help in the design of Reno mattresses.

The first,[4] conducted at Colorado State University by Dr Daryl B. Simons, included a series of full-scale and model tests to investigate what mattress thickness should be used in conjunction with which flow patterns, and how the mattresses performed when rapid flows began to make

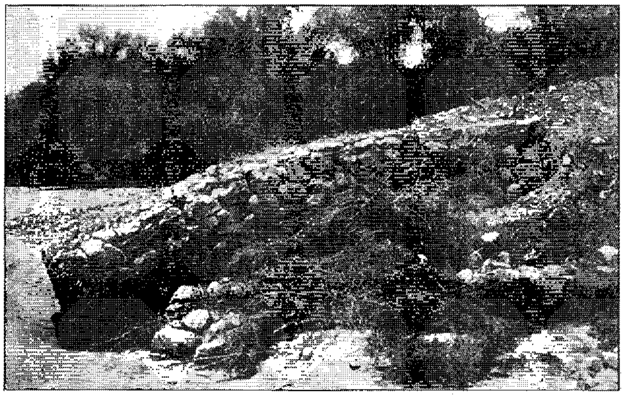


*Figure 2 Example of insufficient side keying*

*Figure 3 Example of lack of lacing amongst adjacent gabions*

the stones within the mattresses move. These studies led to new design criteria for Reno mattress use under different flow conditions.

The second study,[5] carried out by Simons, Li and Associates of Fort Collins, Colorado, assessed the probability of a Reno mattress suffering damage in use.[6] The results led to a series of parameters used in the design of thin Reno mattress linings.

*3.2 Reno mattresses under high flow conditions*

An hydraulic testing programe was developed to provide experimental data on the performance of Reno mattresses. Major tasks were:

1. to review the existing design methodologies and field application experiences of gabions and mattresses;
2. to determine the roughness of mattresses;
3. to evaluate requirements of underlying granular filters or filter cloth layers;
4. to evaluate the stability of mattresses subjected to various flow conditions; and
5. to analyse test results and develop criteria applicable to mattress protection designs.

To evaluate mattress performance over a range of hydraulic conditions, a two-section test scheme was carried out. In developing the test methodology, velocity was assumed to be the major factor controlling matress stability. Data obtained from full-scale testing at the required velocity but reduced depth were supplemented with model testing to determine the effect of depth on mattress stability.

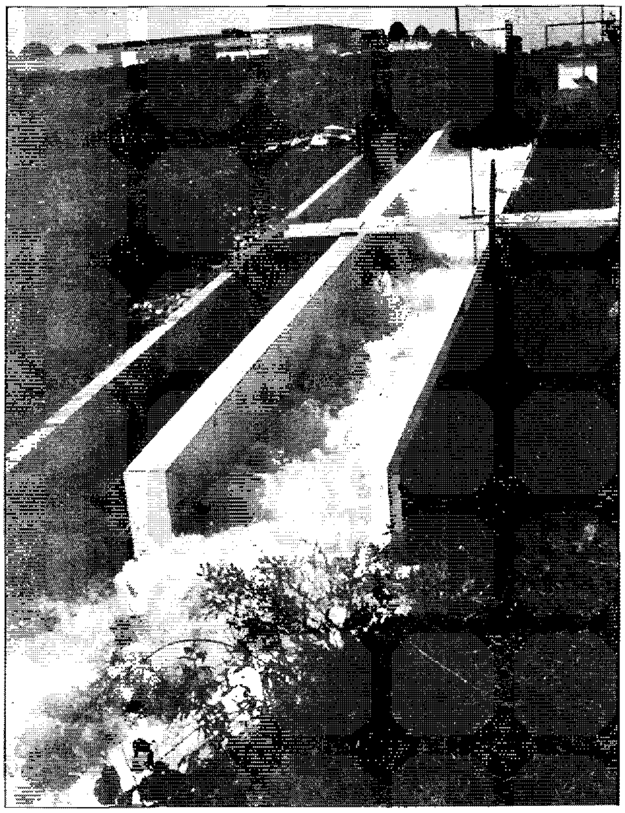
Hydraulic tests of model mattresses were conducted using a flume 2.40 m wide, 1.20 m deep and 60 m long; this flume could be raised or lowered to produce slopes ranging from zero to about 2 percent. A minimum flow rate of approximately 2.80 m$^3$/sec could be achieved.

A number of major conclusions were drawn from these studies. It was found, for example, that the roughness of a Reno mattress could be approximated to that of gravel on a river bed, and that the mesh has little effect on roughness. Methods of predicting flow velocities over Reno mattresses were developed and it was found that shear stress was strongly dependent on velocity but only weakly dependent on depth. Critical velocites—the velocities at which the rocks inside the mattress begin to move—were also determined in relation to velocity and particle size. It was found, however, that even when such movement began, it was often short lived, and the mattress continued to provide the protection for which it was designed. Finally, a series of design precedures was developed for use with Reno mattresses.

*3.3 Risks in hydraulic design of bank protection*

The purpose of erosion protection and channel stabilization is, of course, to maintain a channel and its banks and/

*Figure 4 Flume used for full-scale tests*



or bed in a relatively fixed location to protect buildings and structures from erosion related damage. Various types of engineering analysis are required in developing an erosion protection design. These include hydrology, hydraulics, geomorphology, erosion and sediment transport.

Too often the design of an erosion control structure focuses on only one or a few probable causes of failure and tends to ignore some other key problem. A number of structures fail because one or more important aspects were overlooked.

## REFERENCES


1. Officine Maccaferri SpA.. *1879-1979, one hundred years*. Bologna, 1979.
2. Officine Maccaferri SpA. *Maccaferri Gabions*. Bologna, 1981.
3. Agostini R., Bizzarri A., and Masetti, M. *Flexible structures in river and stream training works. Section one: weirs for river training and water supply*. Officine Maccaferri SpA, Bologna, 1981.
4. Simons, D. B., Chen, Y. H., and Swenson, J. *Hydraulic tests to develop design criteria for the use of Reno mattresses*. Engineering Research Center, Colorado State University, Fort Collins, 1983.
5. Simons, D. B., and Li & Associates, Inc. *Consideration on risk in hydraulic design of bank protection using Reno mattresses and Rip-Rap*. Fort Collins, Colorado, 1983.
6. Li, R. M., and Simons, D. B. *Failure Probability of Rip-Rap structures*. ASCE Convention and Exposition, Atlanta, October 23-25, 1979.