USE OF GABIONS IN SMALL HYDRAULIC WORKS

SECTION 4

METHODS OF CONSTRUCTION AND CONTROL

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There is hardly a chance that a well-designed hydraulic work resists to runoff stresses for a long time if it is not very accurately constructed. Many factors should be checked, already in the building phase, to obtain a good realisation of the structures (e.g. moisture content in the earthfill, right percentage of water, cement, gravel and sable in the concrete, proper stone size in gabions). The main phases of the realisation procedures of embankment and gabion structures are illustrated, respectively, in the second and third paragraphs of this chapter. These paragraphs contain both general and detailed recommendations: the former touch on issues such as site preparation or methods for the exploitation of borrow areas; the latter, instead, will deal with issues such as gabions building or cut-off screens realisation.

Many practical examples of structure building, accompanied by pictures or designs, are provided by way of illustration. The majority of these recommendations have been derived from the experience of the Rural Development Project of the Ader Doutchi Maggia (PDR/ADM). This Project, financed by the Italian Co-operation and the Word Food Program, and conducted by FAO, has been operative in the Keita District of the Republic of Niger, since 1984. Many small earthfill dams (40, for a total earthfill volume of about 1.500.000 m^3) and gabion weirs (200 for a total volume of gabions of about 1.500.000 m^3) were built in the PDR/ADM in this period.

Before addressing the various phases of hydraulic structures building, the first paragraph deals with the preliminary phases. These phases mainly concern the individuation of all the resources required for the works, the redaction of a work plan, and the preparation and organisation of the workshop.

4.1 – WORKS PLANNING

4.1.1 - Resources required for hydraulic works building

One should start worrying about the availability of all the different sorts of resources necessary to build a hydraulic work since the ‘feasibility phase’ of works’ design. In designing a hydraulic work, especially in developing countries, one has to assess carefully the quality and the quantity of resources that can be found locally. Four main categories of resources are necessary for the construction of hydraulic works:

- material (natural materials, water availability, construction materials),
- human (skilled and non-skilled workers),
- mechanical (earthwork engines and dump trucks),
- financial.

Materials requirements depend on the kind of hydraulic work that has to be built. For example, proper earth and water will be necessary for an embankment, rubble and gabions for a weir.

Human resources refer to skilled workers needed for gabions building or for driving engines and trucks. A team of technicians will also be generally necessary to carry out the site’s topographic survey and to conduct the workshop.

The type and the quantity of mechanical means, depend largely on the work’s typology and dimensions. A bulldozer is generally indispensable for the site preparation (e.g. surface scraping, service roads opening, borrow area preparation). An excavator is also necessary for the preparation of structure foundations. Mechanical loaders and dump trucks are required to load and carry earth and rubble from the borrow area to the structures' site. If natural conditions are favourable (e.g. the ground is well levelled and the distance between borrow area and work site is less than 400-500 m) bowl scrapers could be used to carry the fill.

It should be noted that bowl scrapers demand an important initial investment and are very specialised engines. On the contrary, loaders and dump trucks are much more versatile than bowl scrapers, as they can easily cover any distance between borrow area and dumping place. Dump trucks can also be used to carry different materials.

Roller engines and tank trucks are necessary for embankment compacting. A grader should always be accessible in embankment workshops for haul road maintenance. The grader can also spread and level the earth discharged by trucks. A tractor could also be needed to tow roller machines, disks and harrows.

In minor hydraulic works, the variety and number of mechanical means can be considerably reduced. It will be worthwhile to use versatile engines such as an excavator or a backhoe-loader. Very small hydraulic works can be entirely manually built, if construction materials (e.g. rubble and proper earth) can be found in proximity to the site and skilled labourers are available locally.

Financial resources consist of the funds necessary to buy the construction materials required, such as gabions, cement and steel bars for concrete reinforcement. Funds are also necessary to finance various workshop activities (e.g. staff salaries, purchase of spare parts, fuel and lubricant for mechanical means).

First of all, it will be preferable to list, by category, the various kinds of resources required for all construction phases, according to the hydraulic work design. We shall then verify if these resources are really available. At some point, a lack or scarcity of resources might become manifest, if the conditions considered in the designing phase have changed, or if the preliminary investigations were not accomplished carefully. Insufficient resources can be dealt with either by modifying the hydraulic work design, or by increasing the funds allocated to this purpose.

4.1.2 – Work plan redaction

Before beginning to build the structures, which compose the hydraulic work, it will be useful to prepare a detailed work plan. This plan should take into account all the construction phases. Great care should be put in organising both each individual phase and the interaction between different phases.

The engineer preparing a work plan should have an in-depth understanding of all the aspects involved in every scheduled activity (e.g. construction of the earthfill embankment, gabions building). In particular, he/she should be aware of the time and the resources necessary for the accomplishment of every activity. For example, to estimate the amount of time required for embankment construction, it is necessary to know the quantity of earthfill that can be built daily. However, also this datum depends on several factors:

- distance between borrow area and dumping point,
- number and capacity of loaders and dump trucks (or bowl scrapers) employed in earth carrying,
- tank trucks employed in water carrying and distance between water point and embankment site,
- roller machines and other engines used for spreading, mixing, levelling and compacting the earth layer on the embankment's surface.

This method for establishing the amount of time required for embankment building can be profitably adopted only if the workshop organisation allows the development of different activities at the same time. Otherwise it will be necessary to take into account works interruptions for some activities, while other activities are being accomplished.

A working schedule has to be defined for each workshop member, and maintenance turns have to be foreseen for the mechanical means.

During the actual construction of the hydraulic work, it will be useful to verify if the work plan is being respected. Evaluation errors in the work plan will have to be corrected. Problems encountered during construction (e.g. foundation sand layer thicker than estimated, mechanic problem in the engines) could also call for modifications of the original work plan.

4.1.3 - Workshop organisation

Before moving on to the actual construction phase, it will be useful to set up a plan for the workshop's organisation. In fact, the workshop's efficiency largely depends on a systematic and efficient organisation. The emplacement of the different structures, which will compose the hydraulic work, has to be prepared. In preparing the construction site, the engineer has to take into account the structure's design. Moreover, he/she should identify areas, in proximity to the structure's location, where various subsidiary activities could take place; for example, he/she will have to make sure in advance that enough place is left for the engines' motion.

If concrete will be used for the construction, an area for concrete mixing, with stocks of cement, gravel and sable, has to be set up close to the structure. A zone for stocking other construction materials, such as gabions and pipelines, has to be prepared. Stocking and parking areas must be sheltered from runoff.

In the construction of a retention or detention dam, the borrow area must by all means be sited out of the impoundment's watershed, lest runoff carries in the impoundment the sediments provoked by earthworks, significantly reducing the impoundment's volume.

In the organisation of a workshop, where different activities (e.g. embankment construction, gabions structures building, concrete preparation) will be carried out, a thorough site preparation is indispensable. The development of different activities at the same time should be made possible. Otherwise the workshop's efficiency will be greatly reduced.

Structure sites have to be connected to the quarries through proper service roads. An accurate preparation of service roads will avoid mechanical problems to the trucks.

The technician conducting the workshop should record various kinds of data concerning the works' progress on a daily basis (e.g. number of trips made by dump and tank trucks to the earthfill, number of gabions installed, volume of concrete realised, quantity of fuel consumed by engines and trucks, hours worked by engines and trucks). All these data will result useful for evaluating the workshop's efficiency and the final cost of the hydraulic work.

The workshop responsible will also have to document the realisation history of each structure. The main data to be recorded should be:

- structure building starting and finishing dates,
- characteristics of foundation soils (e.g. depth, thickness and material of layer),
- principal problems encountered during structure building.

These records might contain key elements for understanding the causes of structural breakdowns and/or problems risen after the work's realisation.

Example: Work planning for a detention dam, built at the Integrated Rural Project of the Ader Doutchi Maggia (PDR/ADM)- Rep. of Niger

What follows is a concrete example of the procedures described above; it illustrates individuation of resources, working schedule preparation, and workshop organisation for the construction of an earthen detention dam in Seyte (District of Keita, Niger). This detention dam, realised on a watercourse belonging to a 12 km^2 catchment area, has an earthfill volume of 80.000 m^3. The 50 metres wide spillway is dug in the right hand shoulder of the hill upon which the earthfill is built. Gabions, for a total volume of 1500 m^3, are expected to be set up to protect the channel banks and the spillway, and to realise a series of weirs across the channel. The detention dam is endowed with an outlet system, consisting of a pipeline with a diameter of 140 centimetres inserted in the earthfill, in order to increase the detention capacity in the event of floods. Pipelines are composed of two-metres-long prefabricated elements in reinforced concrete that are assembled on site.

Resources required

First of all, it is necessary to establish the requirements in means (engines and trucks): the quantity and quality of all kinds of means should be established in advance. Requirements should be evaluated in relation to the local availability of construction materials (i.e. fill, water, and rubble) and to the production capacity of the single means. On Seyte's workshop the following means were available:

- 1 excavators,
- 1 vibrating rollers,
- 2 bulldozers,
- 1 grader,
- 2 loaders,
- 6 dump trucks,
- 2 tank trucks.

It is equally important to predetermine the requirements in personnel needed to carry out the various scheduled activities. The staff for the workshop in question consisted in:

- 1 workshop responsible,
- 1 mechanician,
- 15 workers specialised in gabions set up,
- 2 workers specialised in pipelines set up,
- 60 generic workers supporting the specialised workers at different tasks,
- an adequate number of trucks drivers and engines conductors.

Then, the availability of all the other materials required in the construction of different types of structures must be ensured. With reference to the hydraulic structure considered here, the following materials were deemed necessary on the basis of single structure projects:

- 8 tons. concrete,
- 600 gabions sized 2x1x1 m^3,
- 300 gabions sized 2x1x0.5 m^3,
- 2000 m^2 geotextile.

Having completed the list of resources, in different materials, required for the work's realisation, the funds necessary to cover construction costs must then be quantified. These costs should cover the acquisition of all the building materials and the general expenses related to the workshop's functioning. Amongst the latter, fuel and lubricants for the machines and personnel salaries are particularly relevant.

Works planning

Workshop activities should be programmed taking into account the requirements of every individual activity and co-ordinating the interaction between different activities so as to ensure a smooth functioning of the workshop. For this purpose, activities might have to be prioritised. It is possible to refer to Gant and Perth's theories in order to optimise the working programme. In Seyte, activities had been arranged in the following succession:

- borrow area preparation,
- service roads preparation,
- precasting of pipeline's elements,
- excavation of foundation trench,
- excavation of a trench for the pipeline,
- excavation of spillway channel,
- building of weirs in the spillway channel,
- pipeline realisation,
- earthfill building in the foundation trench,
- stripping of the embankment's footprint,
- earthfill building,
- rip-rap realisation.

While some of the activities listed above can be carried out simultaneously, others can only be accomplished once the previous ones in the list have been completed. For an efficient timing of the activities, a thorough practical understanding of the productive capacities of all the resources involved is indispensable. It should be noticed, however, that the presence on the workshop of all the above mentioned machines and trucks is not necessary simultaneously, but at any one time only the mechanical means required by the activities in progress should be available.

Workshop organisation

A well thought-out workshop organisation is fundamental to the smooth unfolding of the scheduled activities. At the opening of a hydraulic structure's workshop the following arrangements should have been provided for in advance:

- service roads
- parking area, properly evened out, also used for machines upkeep and servicing, and for keeping fuel stocks,
- area for stocking construction materials and tools (i.e. cement, gabions),
- properly levelled area for precasting the pipeline's elements.

At this point, quarry areas for each construction material (i.e. fill, rubble, sable and water) should be identified and access to them must be prearranged. It is now possible to begin the actual building phase, following the work plan. All various activities should be organised so as to limit as much as possible interactions and overlapping between two or more of them. The interactive unfolding of different activities, in fact, implies the risk that delays in one activity's development hinder the completion of the other one.

Workers should be kept away, whenever possible, from the areas where engines and trucks are working, in order to minimise the risk of accidents and to ensure a fast and smooth operation of the machines. Specialised workers should rely on the constant support of generic workers to optimise their efficiency. An appropriate number of workers should always be available on the earthfill to eliminate organic material or oversized blocks from the material discharged by the dump trucks. The upkeep and refurbishment of engines and trucks should be organised according to a timetable. Ideally, these operations should be carried out at the end of every working day. Otherwise, the worker in charge should see that the interruption in a machine's work does not cause delays in the operation of other machines.

An adequate stock of construction materials always available on the workshop significantly helps preventing possible delays due to damages and/or lack of materials.

4.2 - EARTH WORKS

4.2.1 - Site preparation

Embankment pegging

The first step in the construction of a hydraulic work is structures siting. The sites of different structures, which compose the hydraulic work (e.g. earthfill, spillway, and pipeline), have to be marked with pegs, according to the structure plan. In the earthfill footprint siting, it will be useful to mark axe and limits of the embankment downstream and upstream (see fig. 4.1). The distance between two pegs should be less than 50 m.

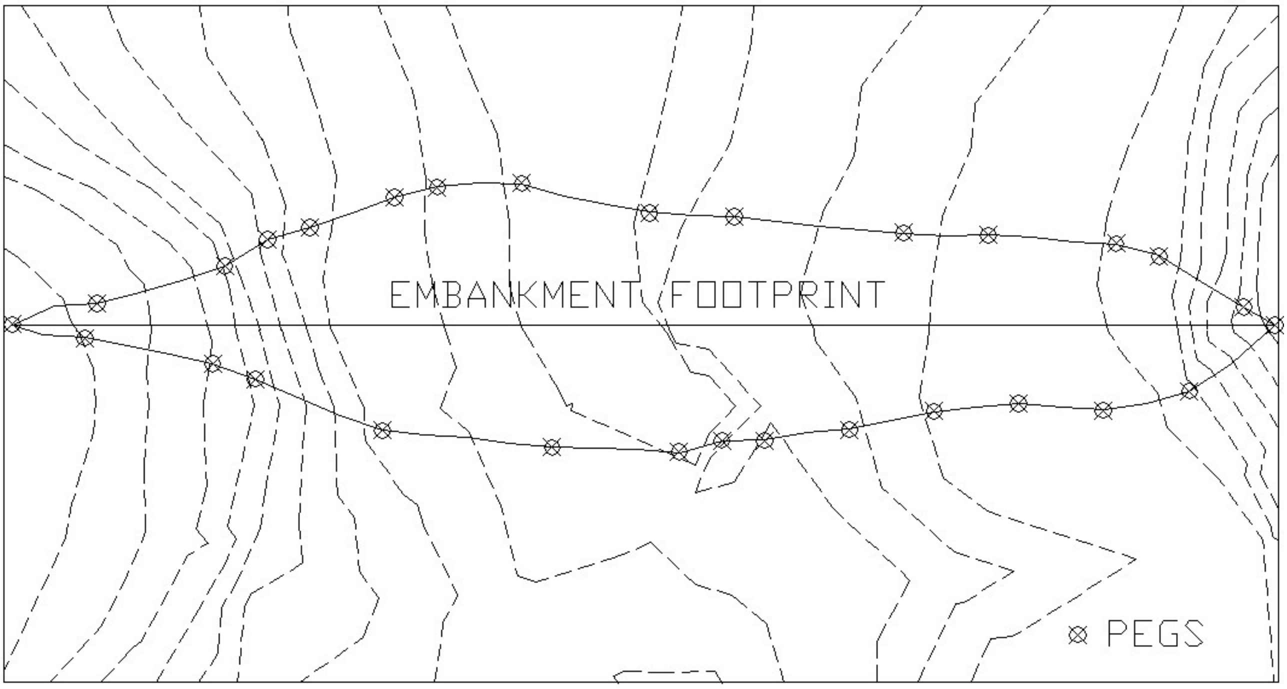

Fig. 4.1 – Embankment pegging

Service roads preparation

Service roads are meant to connect all the structures located in one site with the related quarry. For example, the embankment’s location has to be connected with the borrow area, and the spillway’s location has to be connected with the rubble quarry. In the preparation of haul roads, which connect the embankment’s site with the borrow area, trucks’ safety should receive primary attention. Hence, it can be suggested to build two separate one way roads, to reduce the risk of trucks’ crashes caused by scarce visibility. While the embankment is being built, lower lateral access roads become obstructed as the earthfill is progressively raised. Therefore, various lateral access roads should be built in advance in order to give access to different earthfill levels and avoid work interruptions. Haul roads should be adequately dimensioned to support a heavy traffic of large trucks. Therefore, it is necessary to prepare these roads carefully and to maintain them in good conditions. A grader should even out the roads whenever they get damaged. Periodical haul roads watering could also be necessary to prevent the formation of dust clouds. Skilfully built haul roads can be determinant toward the smooth functioning of trucks and the reduction of the incidence of mechanical problems.

Runoff diversion structures

Sometimes, depending on the selected site and on the period when constructions will be taking place, important runoff events might risk compromising the work already done. In this case, the construction of a runoff diversion structure could represent an essential safety measure worth taking in advance. The diversion structure has to be dimensioned according to local runoff characteristics (e.g. design flow). If the hydraulic structure's design contains a huge pipeline, the pipe can be built preventively to serve as runoff diversion structure (see figure 4.2).

Fig. 4.2 – Runoff passing through a pipeline inserted in the earthfill during embankment construction (Akala I, Keita, Rep. Of Niger, 1990).

Quarrying methods

The borrow area, of a material suitable to embankment construction, has to be well prepared. First off all, organic debris (e.g. roots, sod and shrubs) must be entirely removed through surface scraping of the zone. Sometimes it could also be necessary to remove the earth's surface layer because is not fit for the earthfill (e.g. it contains too much clay or rubble). The organisation of the borrow-area largely depends on the methods used to carry the fill to the embankment.

If bowl scrapers are used to carry construction materials, the ground of the borrow-area has to be properly levelled. If the soil is particularly hard, a bulldozer can be an essential support for scrapers in the loading phase. If trucks will be used to carry the earth, the latter must undergo a preventive treatment in the borrow area. The earth has to be crushed, removed from its location and gathered in heaps by bulldozers. Then it is loaded in the trucks by proper engines (e.g. loaders and excavators) (see figure 4.3).

Fig. 4.3 – Borrow area

Surface stripping

The surface layer of the embankment footprint has to be removed, because it generally contains some organic material (sod and shrub) which does not have good resistance characteristics. Large stones must be taken away as well. Then, before starting to build the embankment, it will be useful to water and compact the footprint surface, in order to facilitate the bonding between natural soil and earthfill. Surface scraping is generally done with bulldozers. They push the material to be evacuated downstream, out of the embankment footprint. However, if the distance to cover is long or the quantity of material is considerable, it may be more convenient to remove this material with dump trucks.

Foundation trench

Excavators generally dig the foundation trench of the embankment. These engines can dig up to a 4÷5 meter deep trench. During trench excavation, the dug out material should be deposited downstream the trench. Later, this material can be carried away from the embankment footprint by bulldozers or trucks. Final refinements are not unimportant. All the roots, stones and rubble have to be removed before starting the earthfill construction. As in the embankment footprint preparation, trench watering and compaction will facilitate the bonding between natural soil and earthfill. The foundation trench has to be almost 4 meters large to let in engines and trucks. Steeps should also be installed to give trucks and engines access to the trench for carrying, levelling and compacting the fill.

4.2.2 - Earth filling (embankment construction)

When the preliminary phases of workshop preparation (e.g. borrow area, service roads, embankment footprint and foundation trench) are concluded, the building of the earthfill embankment can start.

Layer preparation

Fill material is carried in the dumping area by dump trucks. Then bulldozers or graders should spread the earth discharged by trucks in a layer not thicker than 25÷30 cm. While they are carrying the material, bowl scrapers can also spread and level the soil. During soil spreading, it is fundamental to avoid the fill’s segregation and the partition of earth particles into lumps of the same grain size. This phenomenon can be very dangerous because the fill’s permeability will in some zones be different than the general permeability of the embankment. For small embankments, proper material is not selected with care during the preparation of the borrow-area. In fact, the type of machines, which allow an accurate material selection, is too expensive for small hydraulic works. This is why in the latter’s fill it will be possible to find oversize rocks or an excessive quantity of gravel or rubble material, carried in the embankment by trucks. These materials will have to be removed from the layer to which they belong before its compaction. Sometimes, it will be useful to leave some workmen in the embankment to carry out from the fill oversize rocks and other improper materials (e.g. roots, rubble and shrub). (See figure 4.4).

The technician overseeing the works should regularly verify the earthfill’s dimensions (e.g. level, layer thickness and width), using instruments adequate to each task, such as an automatic level and band chain.

Fig. 4.4 – Fill spreading

Watering

In watering the fill, one should aim at achieving the optimum moisture content, previously calculated through the Proctor compaction test. There are two principal procedures to correct the moisture content of the borrow material. The first one consists in sprinkling the soil in the borrow area, before or after bulldozers do the earthworks. It happens rarely that the moisture content is higher than the one desired, and that the borrow area has to be drained rather than moistened.

The second procedure consists in sprinkling the fill with water directly in the dumping zone, when it has already been spread and levelled (see figure 4.5). In this case the lift has to be disked and mixed (with disks and barrows), before, during and after sprinkling. The moisture content should be uniformly distributed throughout the spread lift before compaction. The first procedure to correct the moisture content in the fill normally ensures greater moisture homogeneity, but it is not always suitable for arid and semi-arid regions. In these zones, the material's moisture can be substantially reduced while it is being shifted from the borrow area to the embankment construction. The first procedure is also engine and truck 'un-friendly', as earthworks are harder to carry out if the soil is wet.

Fig. 4.5 – Fill surface layer watering

Compacting

When the lift is well levelled and the fill has reached the right moisture content, it is possible to start the layer compaction with the proper roller device. There are four main kinds of roller machines:

- pneumatic tyred rollers
- tamping rollers
- sheepsfoot rollers
- vibrating rollers

The selection of the proper roller device depends to a great extent upon the characteristics of the borrow material and particularly from its grain size. Sheepsfoot rollers have to be preferred when the clay content is particularly high. Otherwise, tamping rollers are more effective. Both of them are generally towed by a tractor. Vibrating rollers have been introduced recently, and they can be used on all kinds of fill (see figure 4.6). However, they tend to be more expensive than sheepsfoot and tamping rollers. Pneumatic tyred rollers are preferable for soil consolidation. The embankment design will normally specify how many trips the roller should do for achieving a good compaction of the layer. The roller has to complete its trip one or more times on the whole lift before moving on to the subsequent layer.

There are also two kinds of small manually operated machines, frog rammers and vibrating plates, used for compacting narrow areas, or concrete or gabion structures, where roller machines cannot work (see figure 4.7).

Fig. 4.6 – Vibrating rollers

Fig. 4.7 – Frog rammers

Bonding between earth layers

Due attention should be paid to achieving a perfect bonding between two superposed lifts, especially if vibrating rollers are doing layers' compacting. In fact, in this case, the layer's surface is very smooth, and it will be necessary to scarify it with disks for obtaining a good bonding with the superposed layer (see figure 4.8). If the lower layer is too dry, preventive watering of its surface is also necessary to improve the bonding between the two layers.

Sometimes, for a better organisation of the workshop, the earthfill can be preventively divided in two portions. So, as trucks carry the fill to one earthfill portion, the engines will be preparing and compacting the material previously transported to the other portion. In this case the line separating the earthfill in two portions should be parallel to the embankment axe (see figure 4.9). If, for workshop organisation purposes, the separation between the portions has to be perpendicular to the embankment axe, then particular attention should be paid to the layers' bonding. The lower layer's bonding surface should be scarified thoroughly before starting to build the adjacent one.

Fig. 4.8 – Layer scarifying

Fig. 4.9 – Layer division in two zones

Vertical and horizontal drains

Sometimes drains of graded material have to be inserted in the embankment to control the water seepage in the earthfill. In small embankments trench drains are normally used. When these drains do not have to be particularly large or deep, the most suitable method to construct them is as follows:

- build the earthfill up to the upper level of the drain,
- dig the drain's trench with an excavator,
- fill-in the trench with the proper material.

It can be useful to mark the drain's lower exit downstream the embankment.

Insertion of water pipes

Pipes inserted in the embankment must be placed directly on natural soil to minimise the risk of settlement. In fact, if the pipe were placed on the earthfill, a differential settlement of the earthfill could give rise to leakages. Some cut-off collars (at least two) have to be realised around the pipe to lengthen, and thereby retard, the infiltration path and to minimise the risk of an important seepage (USDA NRCS. 1997). It is necessary to take care of the fill's compaction around the pipe (see figure 4.10).

Each pipe ought to be installed in a trench dug purposely into natural soil. The trench should be wide enough to contain the pipe and a layer of earthfill surrounding it. Methods for pipe placement largely depend on pipe size and material. Plastic pipes can be installed manually. Instead, cranes or excavators, which will generally be available in situ, are used for installing steel and reinforced concrete pipes (see figure 4.11). A lot of care should be put in joining the pipe elements, because leaks from the pipe provoke important seepage, which can be very dangerous for the embankment's overall safety.

Fig. 4.10 – Cut-off collars preparation

Fig. 4.11 a

Fig. 4.11 b

Fig. 4.11 c

Fig. 4.11 d

Fig. 4.11 (a,b,c,d) - Placement of pipe elements in a small dam built at Akala, in the Keita zone, Niger. Pipe elements are built manually with reinforced concrete. They are 2 meters long each, their interior diameter is 1.4 m and the concrete's thickness is 0.1 m. Pipes are built with the moulds that are used in the construction of well casing.

4.2.3 - Finishing works

Protection of the embankment's up- and down-stream slopes

In a large impoundment, the wind can produce waves, the height of which depends on the wind fetch. Upstream, the embankment must be protected from these waves. On the other hand, downstream it has to be protected against the erosion provoked by runoff or by the passage of cattle. A layer of rip-rap is generally enough to protect the embankment of small dams. Stones composing the rip-rap should weight between 7÷70 kg. This layer is generally put in place manually and it requires a small foundation trench on its foot (see figure 4.12). Sometimes the interposition of a gravel layer can function as a filter between the embankment and the rip-rap.

Fig. 4.12 – Rip-rap realisation

Gutters on the embankment's wings

Earthfill erosion provoked by the runoff sliding down from the hills on the embankment's shoulders represents a constant menace to all the different structures composing a hydraulic work. To protect the latter, gutters can be constructed with the function to collect and evacuate the runoff coming from upstream. (see figure 4.13).

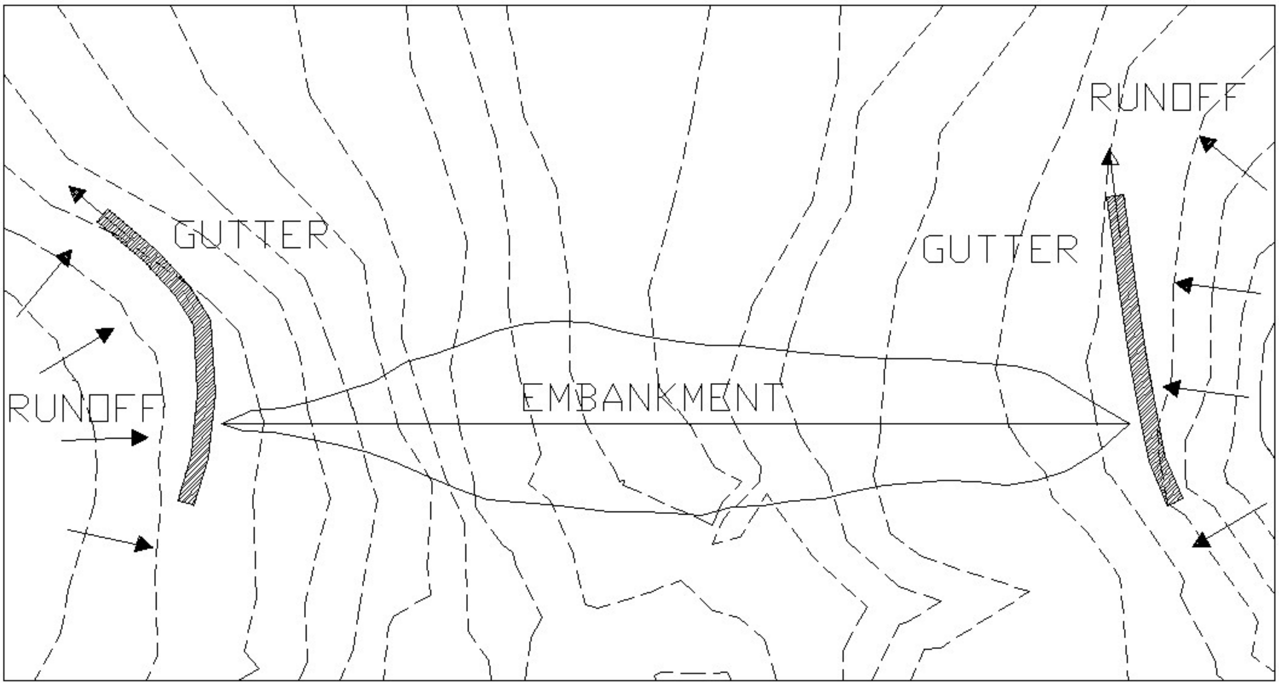

Fig. 4.13 – Gutters

4.2.4 - Supervision and control

In situ compaction test during construction

Normally, in the course of the embankment's construction, some tests have to be performed to verify if a number of characteristics specified in the design are present in process of compaction. These tests mainly consist in earthfill's density and permeability checks. The procedure used for conducting these tests are illustrated in chapter III. In situ tests should be performed by a skilled technician provided with the proper equipment. A preliminary verification of the fill's moisture content can be done, for example, computing the quantity of water added to the fill and carried by tank trucks on the embankment in a determinate period of time.

Seepage checking under and within the embankment

A small dam undergoes its first test when water fills the impoundment for the first time. If the water reaches a relatively high level in the impoundment and remains stable at this level for some days, a portion of the embankment becomes saturated and a steady-state seepage condition is reached in the earthfill (see figure 4.14). If the steady-state phreatic surface is close to the downstream side of the embankment, the latter is dampened by capillarity. If, as sometimes happens, springs appear on the sides of the embankment, it generally means that the phreatic line has intercepted the embankment's slope. These springs can also be caused by an imperfect earthfill realisation, with some zones with higher permeability than the average. One should always take note of the time elapsing between impoundment filling and the emergence of wettings or springs downstream the embankment. If this time figure is significantly shorter than the time theoretically required for the water infiltration in the earthfill, then we can deduce that wettings and springs are caused by a discontinuity in the earthfill's permeability.

When springs appear downstream the embankment, their flow rate should be constantly checked. If the quantity of water flowing is negligible and the water is very clear, there should not be immediate danger of earthfill blow-out. On the contrary, if the sprinkling water is not clear, it means that the water seeping through the earthfill contains some clay. This can be very dangerous because the discharge of flow usually tends to rise, transporting increasingly higher amounts of material, until it creates a drain in the earthfill, causing the embankment's blow-out for seepage.

If a spring with the above mentioned characteristics appears downstream the earthfill, a small bund, made of earth or of sacs filled with sable, should be built around the spring to increase the water level. This should cause the water gradient between the embankment upstream and downstream to reduce and consequently diminish the seepage. Generally, the fine material carried in the impoundment by runoff water tends to settle in the earthfill as the water keeps seeping. For this reason the earthfill's impermeability tends to increase and wettings and springs tend to disappear from downstream the earthfill.

Fig. 4.14 – Steady-state seepage condition in the earthfill

Checking the settlement of earthfill and underlying soils

The actual levels of the substructures of which a hydraulic work is composed (e.g. embankment top, spillway crest and pipeline) should match as closely as possible the values established in the design. The settlement of each level should therefore be carefully attended to. Earthfill and foundation soils are subject to a primary settlement that takes place in the short term, while the embankment is still being constructed and immediately afterwards. A secondary settlement takes place, instead, in the long term, due to the water retained by the clay component of the soil. This settlement requires greater attention by our part, as its prolonged unfolding involves higher risks for the structure. In general, it can be said that the higher the soil's clay content, the more protracted its settlement. If the clay content in the soil foundation or in the earthfill is high, checks will have to be carried out periodically for about two years. In presence of a high clay content, it will be convenient to build the earthfill up to a level slightly higher than the one specified in the design, in view of the subsidence caused by the foundation soil's settlement.
Differential settlement paces of earthfill and foundation soil can also cause a leak in the embankment. The risk that a leak of this sort appears remains for up to two years after the completion of the earthfill's construction.

4.3 – GABIONS WORKS

4.3.1 - Site preparation

The general remarks concerning earthworks' site preparation hold true also for gabion structures. However, in gabion structures building the means employed and the manoeuvres involved are significantly reduced.

Siting of works

The first step in building gabion works consists in pegging the structures, according to the design. Then it will be possible to begin the excavations for the gabions' foundation layer.

Preparation of the foundation layer

An important advantage of gabions with respect to other construction materials is that they can be directly placed on any type of soil. In spite of that, especially in hydraulic structures, it will be preferable to avoid direct contact between gabions and natural soil. In fact, particularly if there is a high clay percentage in the soil, water passing through and on the structure can scour the soil. In this case, it is suggested to interpose a layer of graded material (i.e. with a small percentage of clay) between gabions and soil. This layer has to levelled and compacted thoroughly before gabions are placed upon it (see figure 4.15). This layer can be easily compacted with the aid of manually operated machines, with small engines, such as frog rammers and vibrating plates. Roller engines, in fact, would not suit the purpose, due to the limited size of the foundation layer. If small machines are not available, then adequate manual tools must be employed (see figure 4.16).

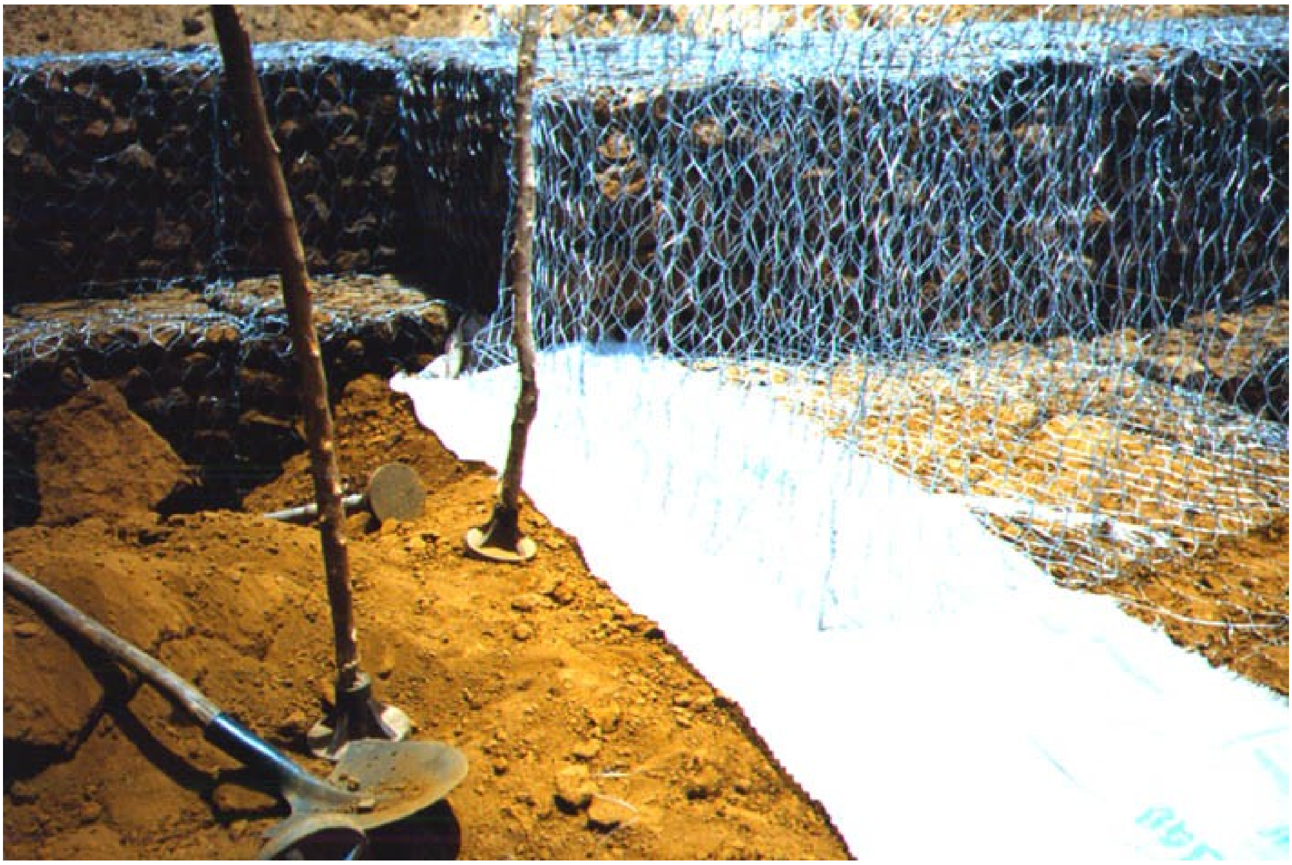

Fig. 4.15 – Preparation of foundation layer for gabions placement

Fig 4.16 – Manually compacted layer

Use of geotextile

As mentioned above, where water could flow directly through gabions, the contact between gabions and natural soil should be protected against scours. If the water flow is expected to be heavy, the interposition of a foundation layer would be inadequate, and the insertion of a layer of geotextile between gabions and natural soil or foundation material is always preferable. Geotextile is a tough woven permeable plastic sheet. There are several kinds of geotextile, suitable for different requirements. However, the best suited to be used with gabions is the quality weighting between 500 and 700 g/m^2. For its peculiar characteristics, geotextile allows the passage of water, but protects from scours the material placed upon gabions. To avoid leaks in the geotextile, a smooth foundation layer has to be preventively prepared, and gabions must be placed on the geotextile with great care. (see figure 4.17).

Given that geotextile is relatively expensive, as well as generally hard to find in developing countries, it may be substituted with different, cheaper materials, easier to find locally. In particular, it has been some years now that in the above-mentioned PDR/ADM, plastic sacks appropriately sewn together to form rolls of the required height are used instead of geotextile. These sacks are made of interwoven thin plastic stripes, and are therefore sufficiently permeable to the purpose required here.

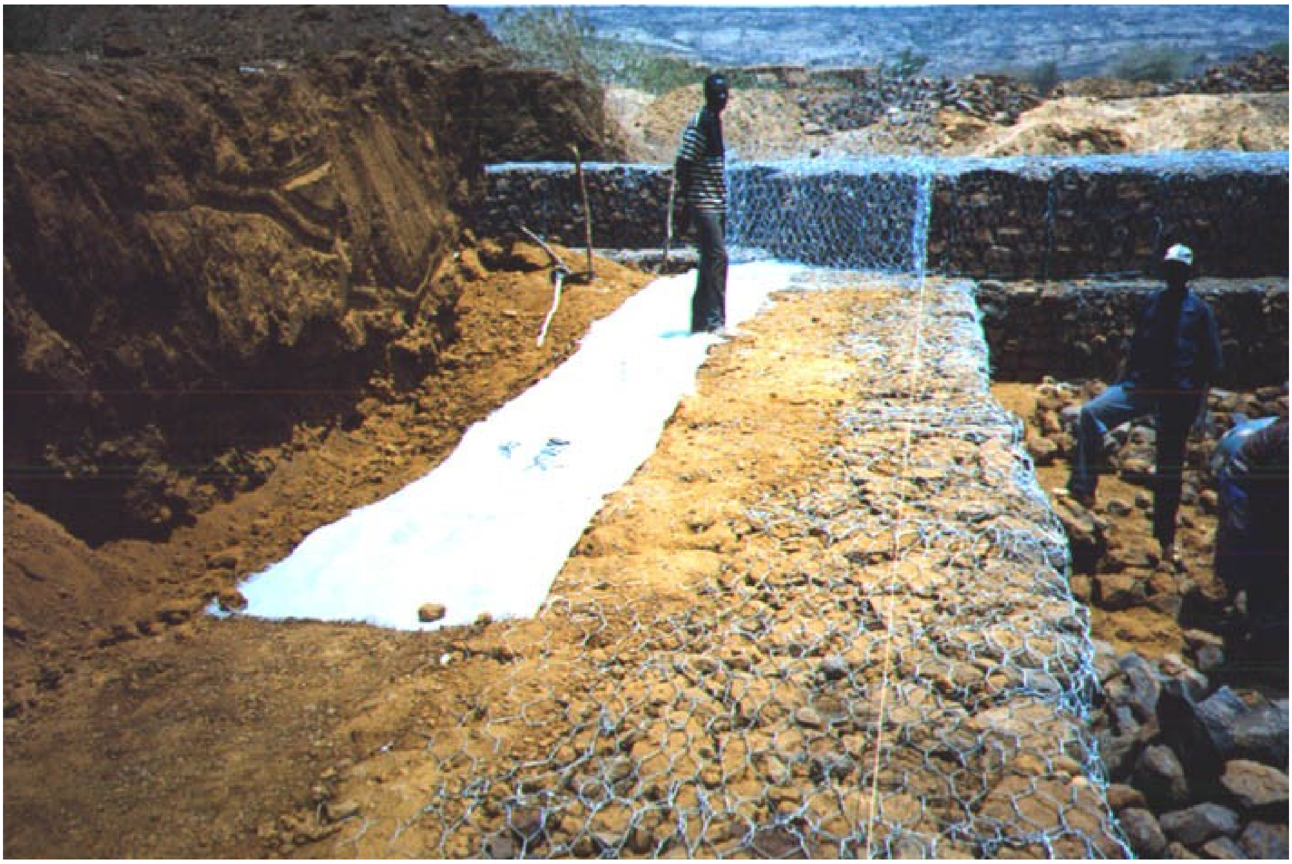

Fig. 4.17 – Placement of geotextile

4.3.2 - Gabions building

There are several techniques for gabions basket assembling, filling and closing (TerraAqua Gabion Systems. 1998, Maccaferri 1990c). In developing countries, the financial means available for building gabions are generally extremely limited, in which case the most convenient method for gabions construction is detailed below. Each phase of the procedure is schematically illustrated in figure 4.18.

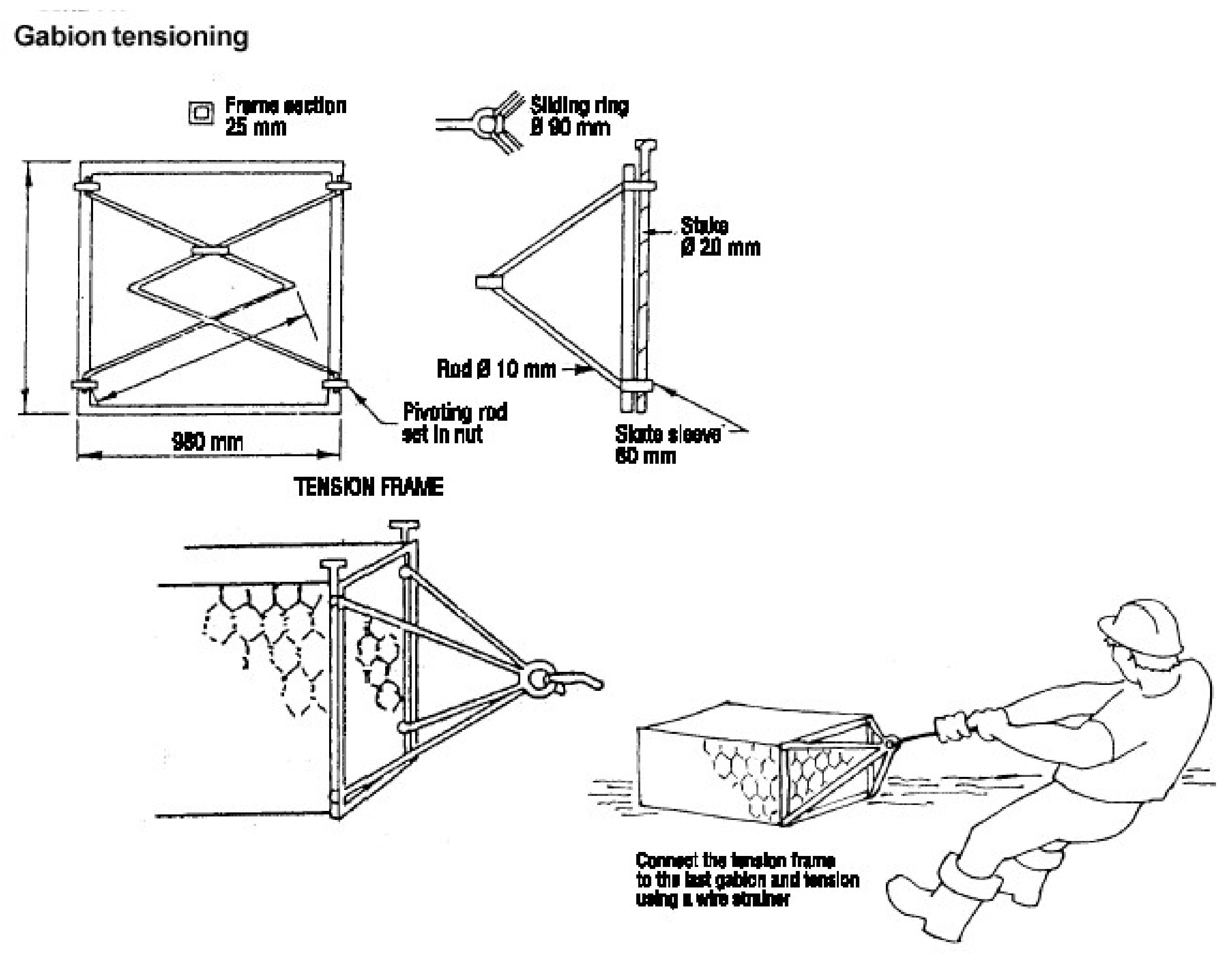

Fig. 4.18 – Method for gabion construction

Setting up gabion baskets

Gabions are carried to the workshop folded. First of all, once they reach the workshop, gabion nets have to be completely opened and stretched out on the soil (see figure 4.19). Then, they have to be assembled, lacing the sides of the four corner-edges (see figure 4.20). The lacing can be done with manual or automatic tools. In developing countries, the utilisation of manual and self-made tools is always more appropriate than the utilisation of automatic or semi-automatic tools. In this phase, it is also necessary to lace interior diaphragms, if they exist, to the bottom and to the sides of the gabion basket. Meshed diaphragms are meant to divide the gabion in different compartments, so as to avoid stones shifting and to contribute maintaining the original gabion shape.

Fig. 4.19 – Gabions net opening

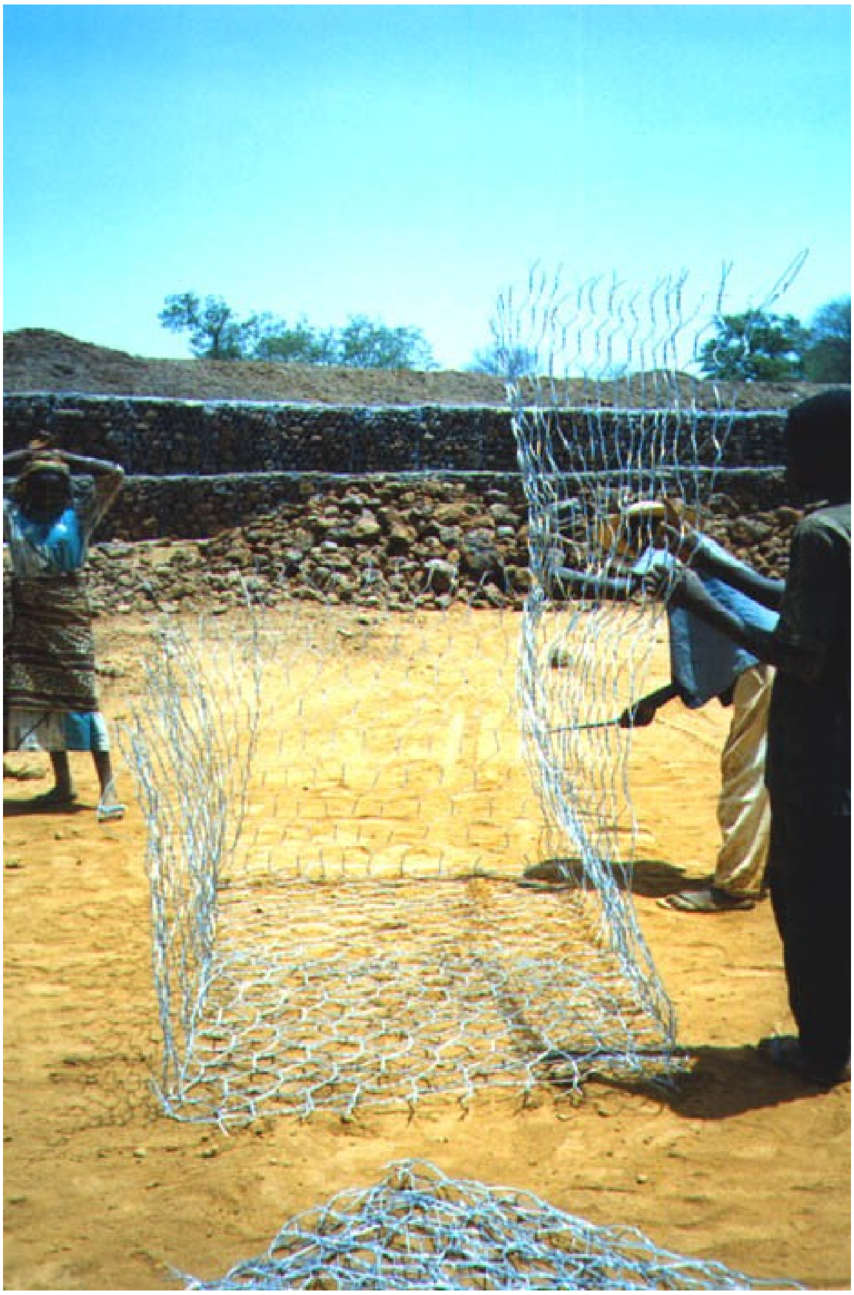

Fig. 4.20 – Gabions basket assembling

Placing

The assembled gabion basket is then put in place and joined, by lacing, with the next one. The same method adopted for assembling gabion baskets has to be used to join gabions between one another, and to the structure. In doing so, it will be very important to respect gabions and structures dimensions and ranging (see figure 4.21).

Fig. 4.21 – Gabions positioning

Filling

The number of gabions to be positioned before starting to fill them up, largely depends on the structure's overall shape and the workshop's organisation. For example, if there is a chance that runoff occurs during gabions building, as many gabions should be put out as can be readily filled and closed. The rubble for gabions filling has to be selected in advance. Ideally, gabions filling should be composed of durable stones, free of cracks or major flaws. Sometimes, the structure is located close to a streambed, where rounded cobbles are plentiful. In this case, especially if the stream is rather small, to preserve the streambed's natural armour cobbles should not be extracted downstream the structure, but only upstream.

Rubble gradation is based on gabion thickness and grid size (U.S. Army Corps of Engineers PROSPECT Training Course. 1994). The smallest stone must generally be larger than the wire mesh openings (usually of about 10 cm) and the largest one should still be easy to pack in the gabion with the other stones. The stones' size is generally 15-30 cm. Manual filling of gabions is to be preferred to mechanical filling, because the rubble can be placed in the basket more precisely, diminishing the occurrence of voids. Mechanical filling can also cause unwanted stress to the net. The rubble has to be arranged in layers in the baskets, so as to minimise the voids in the gabions and to respect gabions' shape. Horizontal and vertical bracing wires should be put inside the baskets to strengthen them by pulling together the baskets' opposite sides (see figure 4.22). These bracing wires are generally made of the same material used for the confection of gabions baskets. The distance between two bracing wires must not be higher than 35 cm. It will be useful to verify that the top level of a line of gabions is straight before closing them (see figure 4.22b).

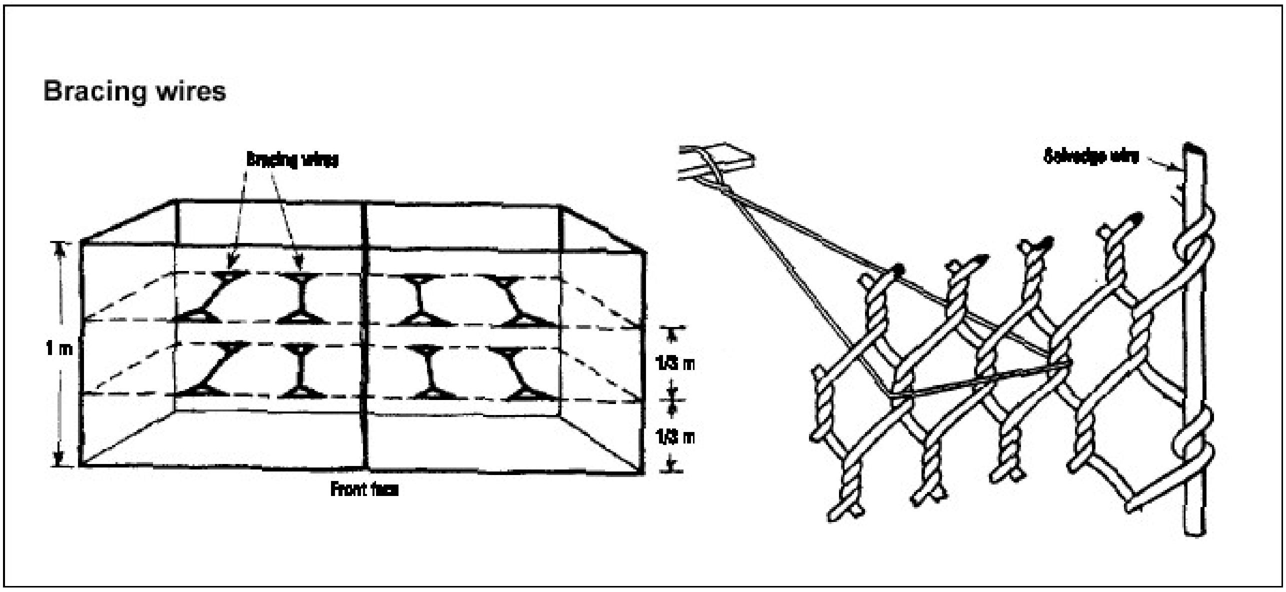

Fig. 4.22 – Bracing wires placement

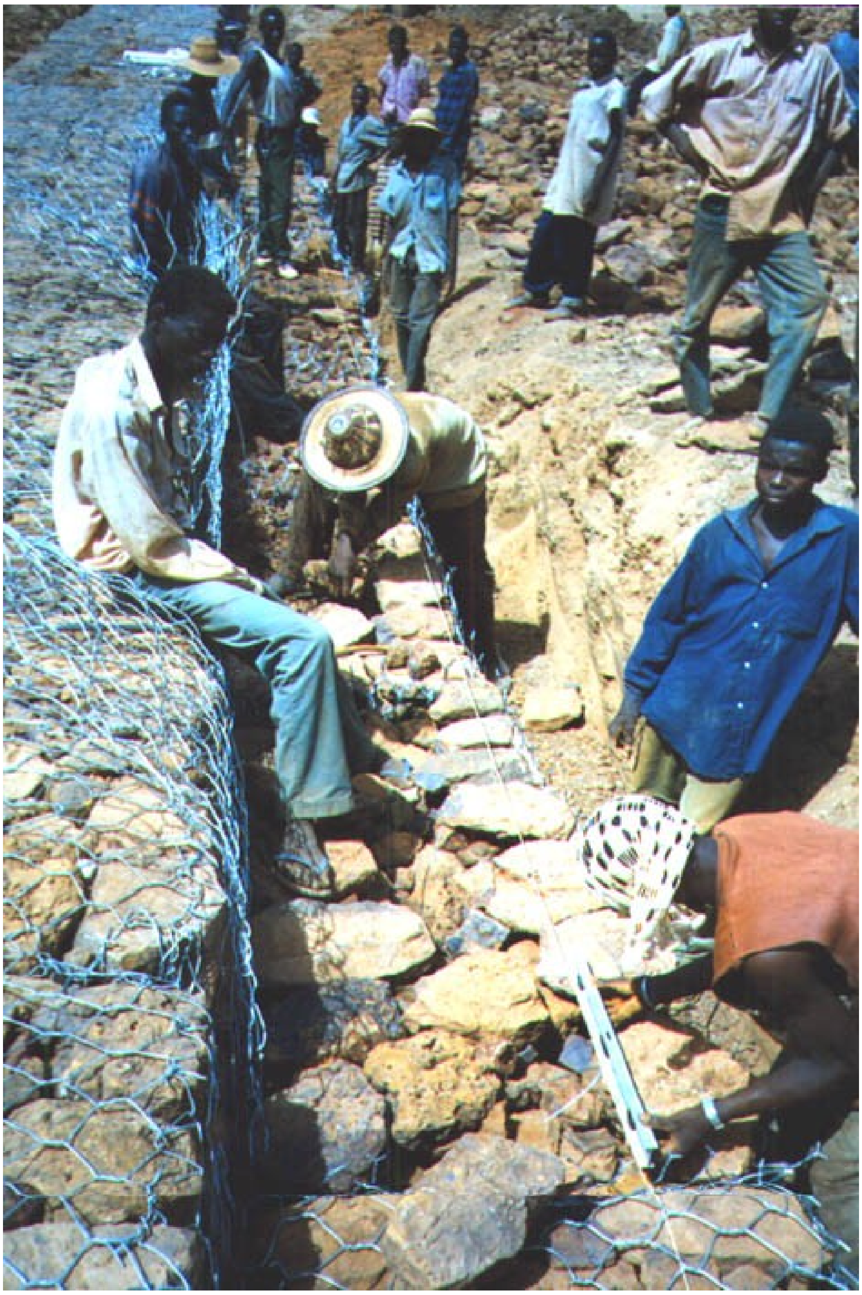

Fig. 4.22 b – Verification of top level of gabions before closing them

Superposing

Hydraulic structures are generally composed of superposed layers of gabions. The first layer has to be completed before starting to build the overhanging one. When a layer of gabions is superposed to another layer, the two layers should be strongly laced to one another before starting to fill the overhanging one (see figure 4.23). Sometimes, in structures with a stepped shape, only a part of the superposed layer rests on a lower layer of gabions. The remaining part rests directly on the earthfill. In this case, the underlying earthfill has to be compacted carefully, and its adherence to the lower layer of gabions should be ensured before superposing the next layer (see figure 4.24).

Fig. 4.23 – Superposing of gabion layers

Fig. 4.24 – Fill compaction next to the gabion

4.3.3 - Making weirs impervious

After completion of the gabion weir structure, it is generally necessary to make it impervious to keep the water level atop the weir.

Geotextile and earthfill

The best way to waterproof a weir structure is to realise an earthfill layer in contact to the structure upstream, as shown in figure 4.25. In this case, a stepped superior surface of the structure will facilitate the bonding between weir and earthfill. Before building the earthfill, a geotextile layer should be laid on the weirs, as shown in figure 4.26. The fill has to be put in place with care to avoid damaging the geotextile.

Fig. 4.25 – Earthfill used to waterproof the weir

Fig 4.26 – Geotextile placement

Plaster

Another method to make a weir impervious consists in plastering the structure's superior surface with a particular cement mortar. This lining is a few centimetres thick and can be damaged by structure settlements. Hence, this method should be adopted only if the above-mentioned method, which uses earthfill to waterproof the weir, is not practicable. Plastering should be avoided by all means if the foundation soils contain an important percentage of clay, because in this case substantial settlements are particularly likely to occur.

4.3.4 - Protection of stilling basin bottom

Filter layer and lining with blocks

Sometimes, as already explained in paragraph 3.3.3, the portion of stilling basin bottom close to the weir is lined with gabions, and the other portion is lined with large stones. In this case, a rubble layer has to be spread in the stilling basin before placing the layer of stones. Rubble is meant to keep the stones from sinking in the natural soil, especially if the soil contains a high amount of clay. If a proper compactor is not available in the workshop, the rubble layer can be compacted with an engine, such as a bulldozer or an excavator. When the rubble layer is completed, dump trucks can carry the stones in the stilling basin. During stones placement attention should be paid to avoid damaging the gabions (see figure 4.27).

Fig. 4.27 – Lining of stilling basin with blocks

Reinforced concrete lining

Sometimes, it is not enough to shield the stilling basin with stones, and a apron made of gabions should be added to protect the weir's foot in particular. A number of factors should be kept under control (e.g. weir height, water level, characteristics of rubble filling the gabions, and grain size of the material transported by runoff), lest gabions are damaged. A typical kind of damage is net tear, provoked by the rubbing of runoff debris against the wire of gabion baskets. Another frequent type of damage consists in gabions emptying, caused by the crumbling of rubble within the baskets due to the continuous collisions provoked by water's motion (see figure 4.28). However, most of these damages can be avoided by adding a lining in reinforced concrete (see figure 4.29). The lining is realised with concrete slabs about 20 cm thick and of limited dimensions, to avoid cracks provoked by thermal stresses. They have to be two-way slabs with welded wire fabric. Reinforcing iron bars have to be placed along the two principal axes if welded wire fabric is not available. The bars diameter should reach almost 14 mm. The slabs' reinforcement has to be anchored to underlying gabions with steel bars. These bars must be sunk with concrete in the rubble of gabions (see figure 4.30). Plastic pipes have to be inserted vertically in the slabs to discharge the water pressure underneath the concrete. The distance between two pipes should be of about 1 m.


Fig. 4.28 – Damages in the gabions

Fig. 4.29 – Lining of stilling basin with slabs of reinforced concrete

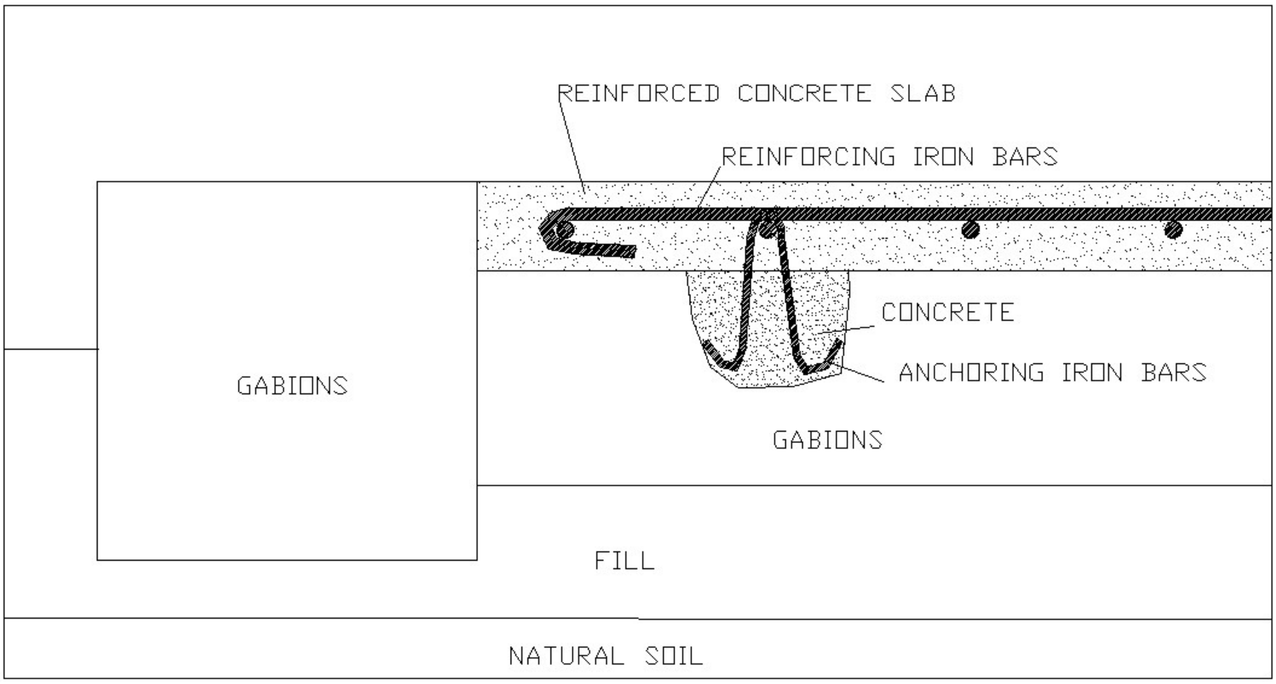

Fig. 4.30 – Anchoring bars for slabs

4.3.5 - Lining of weir crest

Sometimes the weirs crest also requires a lining in reinforced concrete, to prevent damages in the gabions provoked by transported material rubbing on the wire. This lining also contributes to avoid that grass and shrubs, transported by water, get entangled in the net wire. It should be noted that the entanglement with these transported materials normally tends to modify and enlarge the shape of the weirs structure. All the recommendations already suggested for the stilling pool's lining should be considered valid also for the weirs crest.

4.3.6 – Counterweirs lining and anchoring

Grass and shrubs carried by water can cause to counterweirs the same problems seen with reference to weir crests. For this reason, the lining of counterweir can sometimes be necessary. The same procedure used to build the stilling basin and the weir crest lining can be used to line the counterweir. It might be useful to anchor the counterweir to the foundation soil, to prevent structure sliding. In this case, some anchor piles, in wood or steel depending on material availability, should be placed in the counterweir. The depth at which piles should be anchored is conditional upon the expected stress entity and the foundation soils' characteristics. An example of the construction of a counterweir anchored with steel piles is shown in figure 4.31.

Fig. 4.31- Lining and anchoring a counterweir, Keita's Valley in Niger, 1999.

4.3.7 - Earth-gabions interface

In the first part of this paragraph we have already discussed the contact between gabions and earthfill or natural soil. This is the most delicate aspect of gabion structures, especially if they are exposed to water passage. Water flowing through gabions can give rise to scouring in the earth layer, below and at the sides of the gabion. This phenomenon is generally caused by the acceleration of water flowing in the channels created by gabion voids as gabions narrow down. The water flow progressively removes the finest earth particles, resulting in the gabion's settlement. Once gabions stabilise after their initial settlement, this phenomenon could stop, if all the clay contained in the soil has been transported away. However, the scour could also continue, removing other portions of earth below and around the gabion until the complete failure of the structure eventually occurs.

Two main precautionary measures can be adopted to stop the scour created by the water flow:

- avoid the direct contact between gabions and natural soil or earthfill,
- reduce the amount and/or the rapidity of waters flowing through the gabion structures.

In the first part of this paragraph, we have already shown how the interposition of a layer of properly graded material or of geotextile could avoid the problems caused by the direct contact between gabions and natural soil or earthfill. This precautionary measure is generally sufficient for all normal gabion structures. But, if the water flowing through the gabions is heavy, it will be useful to provide extra protection to the weakest parts of the gabion structure. In fact, a substantial water flow, in the long run, can damage even geotextile or properly-graded material layers placed below or on the sides of gabions structure.

Critical points that could require extra protection in a gabion structure are:

- anchorage of a weir in the earthfill on the gabions structure's shoulders,
- toe of a weir or a counterweir,
- gabion walls on the wings of a water channel,
- stilling basin downstream of a weir.

In these points, it will be useful to insert semi-pervious or impervious cut-off screens to stop or reduce the water flow. Semi-pervious screens can be realised with a layer of geotextile inserted between two gabions. In this case, to secure a good lacing between the gabions, staples should be inserted in the geotextile layer after its placement on the gabion side (see figure 4.32). Then these staples will be used to lace the first gabion with the second one, once the latter has been placed.

On the contrary, impervious screens can be realised inserting walled gabions in the structure. These walled gabions are built in the same way as normal gabions but, during basket filling, voids between stones are completely filled with concrete (see figure 4.33). Adding a small percentage of bentonite to the concrete mix will give some flexibility to the structure for the first curing period.

Semi-pervious screens, realised with the interposition of a layer of geotextile between two gabions, are generally more functional than impervious screens in concrete. Two are the main advantages of the first technique:

- semi-pervious screens are permeable to air and water,
- concrete screens do not settle together with structure settlement as semi-pervious screens do.

Fig. 4.32 – Semi-permeable cut-off screens

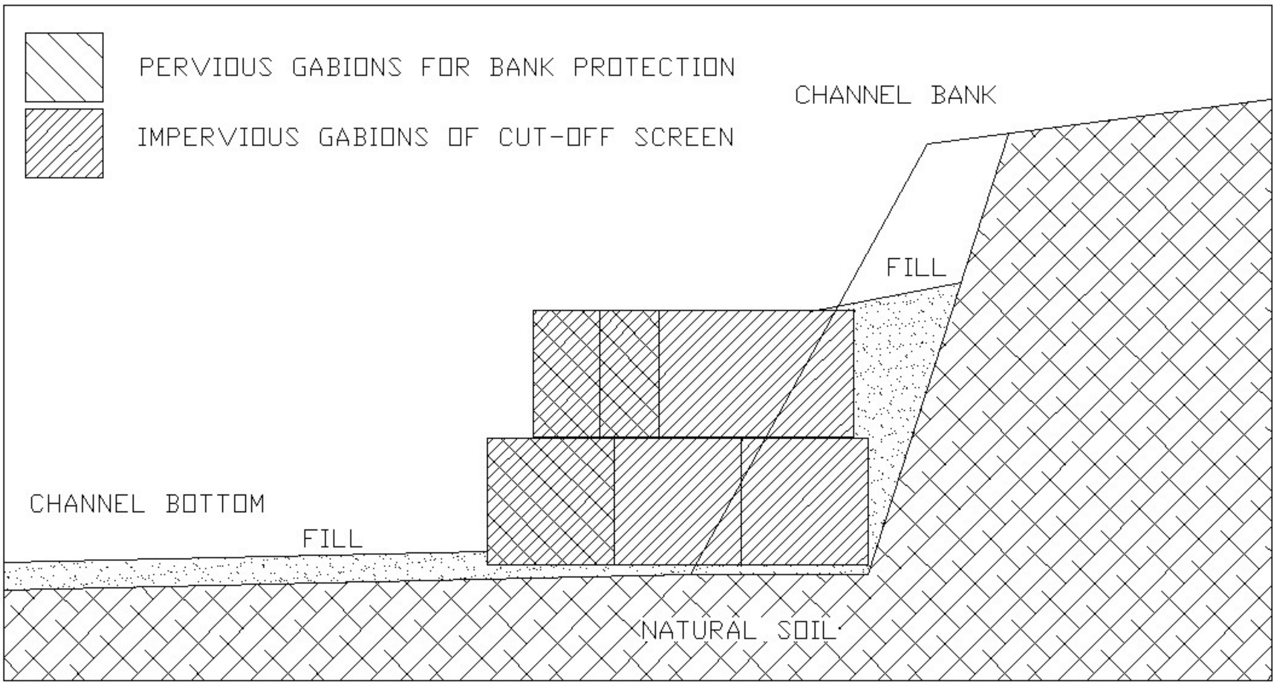

Fig 4.33 – Impervious cut-off screens