USE OF GABIONS IN SMALL HYDRAULIC WORKS

SECTION 5

MAINTENANCE OF HYDRAULIC WORKS

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It is very unlikely that a hydraulic structure, no matter how accurately built, will never require some kind of ordinary or extraordinary maintenance. In the first paragraph of this chapter, the methodology to follow in designing and building a hydraulic structure so as to minimise future maintenance tasks is considered. In the following paragraph, instead, we will highlight the importance of the participation and involvement of the local population, the direct beneficiaries of hydraulic structures, in the management and maintenance of the structures, and we shall consider some ways in which this involvement can be promoted. In the two following paragraphs, we will focus on the maintenance requirements of, respectively, earth dams and gabions structures. Finally, the last paragraph illustrates a selection of methods to protect a retention dam's storage volume from sedimentation.

5.1 – DESIGN AND BUILDING METHODS TO DIMINISH THE MAINTENANCE

Precautionary measures to avoid substantial maintenance tasks

The chances are few that, in developing countries, a small scale hydraulic structure damaged by excessive runoff will be repaired steadfastly. For this reason, it is necessary to design and build hydraulic works so as to prevent them from being even slightly damaged in the first place. Damages are most often caused by excessive runoff, but other common factors, such as damages provoked by the passage of cattle across the earthfill, should also be taken into consideration.

In order to avoid providing continuous maintenance to a hydraulic structure, a number of precautions should be adopted both in the design and in the building phase. During design, two principal precautionary measures can be taken: over-dimensioning and attention to details. In the building phase, instead, great care should be put in following closely the project's guidelines and technical details. These measures are detailed in the following paragraphs.

Over-dimensioning

One of the main problems facing the engineer charged with designing a hydraulic structure in a developing country consists in the scarcity, if not the absolute lack, of data concerning the hydrological regime of a water course. In order to make up for the lack of information on regional hydrology, the engineer will have to identify other areas that have been interested by the appropriate investigations. The hydrological characteristics of the area in question will then be extrapolated from those available for other, previously studied, areas.

However, this way of coping with lack of data introduces a degree of approximation in one's calculations that is difficult to quantify. Therefore, in calculating the design flow of the hydraulic structure to be built, it is possible to oversize or downsize mistakenly the actual figures. If the approximation adopted leads to results that exceed the actual measures required by the considered area, the only problem which could arise consists in building works which go beyond the effective necessities, expanding unnecessarily the related costs. However, if the calculated design flow is inferior to the one required by local conditions, this may put the structure in serious danger, leading, e.g., to the overflow of an earth dam due to the spillway's inadequacy to evacuate the flow.

In this case, even if the structure's complete failure does not occur, excessive overflow risks to repeatedly damage various elements of the structure. For instance, it could provoke the settlement of a gabions line as a consequence of the erosion of the underlying foundation layer.

If overlooked, these apparently minor damages can progressively increase their significance to the point of putting at serious risk the whole structure. To obviate to this problem, it is preferable to opt for over-dimensioning when, in designing a hydraulic structure, knowledge about hydrological characteristics was reached by approximation. Over-dimensioning will inevitably lead to an increase in total structure costs, but this is compensated by the diminished maintenance requirements. For example, over-dimensioning a dam's spillway, the hydraulic head will decrease, thereby reducing channel usage and, consequently, maintenance requirements.

Taking care of details

In the design phase, even the smallest detail should be accurately taken into account, so as minimise future problems. E.g., designing the spillway channel section, it is always useful to predispose the installation of gutters in the banks' shoulders in order to evacuate rain water and to avoid bank erosion. Particular care should be put in designing the interface area between gabions and natural soil or earthfill. It is expedient to ensure that the soil or other material surrounding the gabions is not removed by water, causing the eventual overflow of the gabions structure. Some methods that, if applied, allow to obviate to this kind of inconvenient were illustrated above, in chapters 5 and 7.

In designing a weir, one should always prepare its cross-section in a way to ensure that the water discharge is concentrated at its centre, reducing the discharge in proximity of the basin's edges, usually the weakest structure parts and the ones in greatest need of frequent maintenance interventions.

To obtain this result, the crest's section should be designed slightly sloping toward the centre. Gabions arranged in a stepped shape can also be added to the crest in proximity to its sides. Installing this auxiliary stepped gabions structure will also protect the earthfill built on top of the weir's shoulders in order to waterproof them.

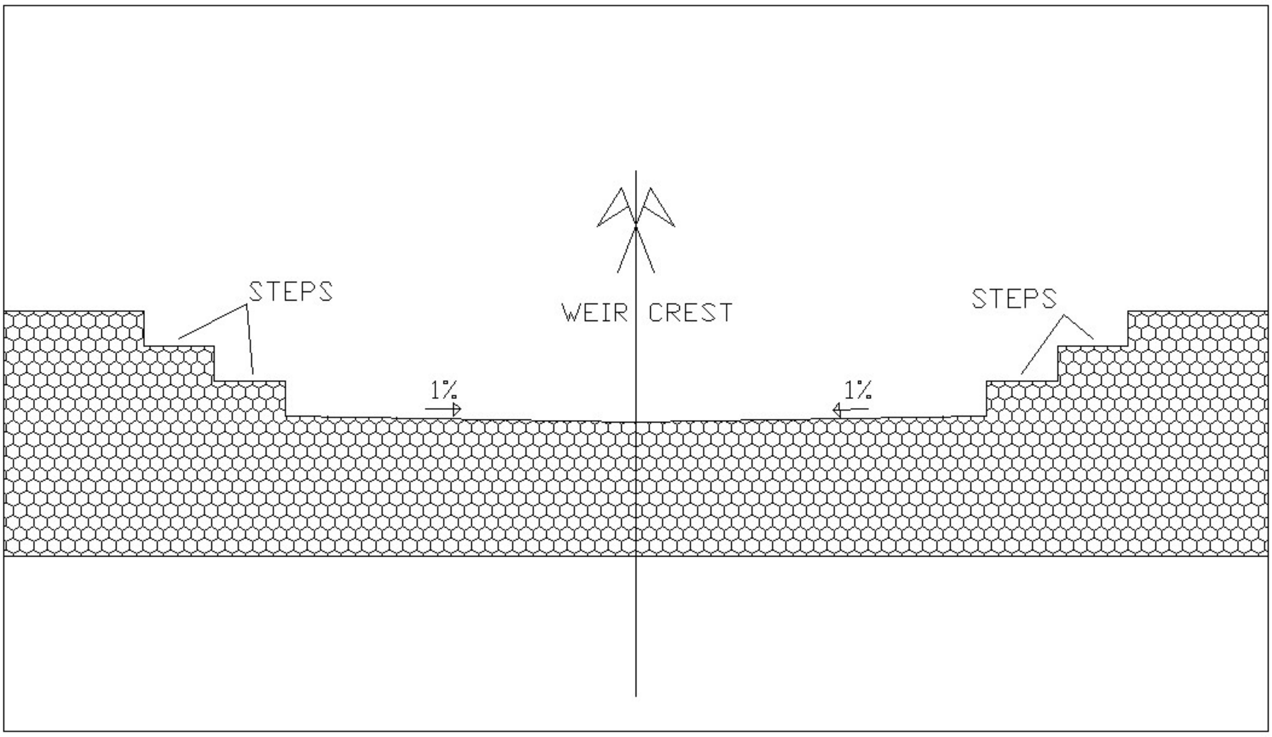

Fig. 5.1 – Weir's cross-section

In arid and semi-arid zones, water stagnation in the spillway and spillway channel should be carefully avoided, as, otherwise, it will facilitate the growth of vegetation. Vegetation has to be periodically removed, lest it partially obstructs the spillway section, reducing the spillway's capacity to evacuate the required water volume. One way to avoid water stagnation is to design the spillway channel with a reverse slope.

Realisation phase

All the structural elements of a hydraulic work have to be skilfully built in order to reduce maintenance requirements. It may help the reader, at this point, to recapitulate the key recommendations with particular reference to the functioning of gabions. Gabions' foundation layer should be carefully prepared, adding, when necessary, a layer of geotextile to protect all the areas exposed to water passage. In applying geotextile, it is necessary to verify that the junction between different rolls is properly realised, making sure that adjacent layers are partially overtopping and sewn together at the edges.

Attention should be given to the earthfill on top of the gabions. The geotextile should be carefully laid and tied to gabions with iron staples. Beforehand, it will be necessary to verify that pieces of wire that could tear the geotextile do not stick out the gabions weir. Finally, the fill is carefully discharged from the trucks, paying attention not to deposit it too close to the gabions, as over-size stones could otherwise damage gabions and/or geotextile. The fill should be laid down in relatively thin layers, trying to avoid agglomerations of large-grain material close to the geotextile. The material should be humidified while it is being spread. Close to gabions, the fill should be compacted with the apposite manual tools, to avoid tearing the gabion weir.

Rubber and stones filling gabions should have a adequate sizes, in order to prevent the emptying out of gabions. Bracing weirs and diaphragms, if present, should be fixed tautly and firmly. Closing up the gabions, the weir should be properly straightened on each side of the gabion. All these measures are meant to ensure that stones do not move and shake when water passes through gabions structures. At the closing up of gabions, it should be accurately checked that parts of weir and wires do not stick out the structure, as grass and/or shrubs could otherwise remain attached to these, augmenting the gabions' volume and endangering their stability.

5.2 - LOCAL PEOPLE'S PARTICIPATION

Involvement of the local population in the maintenance of hydraulic works

The involvement of local people in management and maintenance is fundamental to the efficient and long lasting functioning of small hydraulic works of the kind discussed here. As has already been mentioned, in developing countries it hardly ever happens that the public institutions in charge intervene rapidly to repair a damaged hydraulic structure, due to a lack of necessary resources. In general, it can be said that when a hydraulic work is damaged its functionality is not entirely impaired. However, if damages are constantly left un-repaired, at each subsequent flood the entity of damages is increased in size and number, and the chances of structure failure become higher.

Therefore, primary responsibility for structure maintenance falls upon its direct beneficiaries. However, it is most often the case that the local population disposes of very limited means, and it is therefore necessary to conceive and build the structure so as to minimise future maintenance requirements. What local people can do, instead, is to charge themselves with the careful management of the hydraulic structure so as to prevent maintenance requirements in the first place. This also means that they will take on themselves all ordinary maintenance tasks. The degree of involvement and direct intervention in the management of the structure by the part of beneficiaries depends upon the local social and economic context.

A hydraulic structure damaged, e.g., by a catastrophic flood, will generally require expensive interventions of extraordinary maintenance. The local population cannot usually afford to pay for this kind of interventions, which will have to be financed by the public institutions in charge.

Ideally, when hydraulic structures are built in a developing country, it would be preferable to increase and/or strengthen the local entrepreneurial class through the contemporary promotion of socio-economic development initiatives, in addition to promoting local people's direct involvement in the works. The economic and professional growth of a local entrepreneurial class is, in fact, crucial to the area's development and could take up an important role in the maintenance of local infrastructures.

Management

The expression 'hydraulic structures' management' entails all those measures which should be taken to ensure a smooth functioning and utilisation of the structure/s in question, aimed at minimising maintenance requirements. For instance, when a retention dam is realised in a zone with a pastoral vocation, passages should be predisposed to give animals an easy access to the impoundment. In so doing, it will be necessary to avoid cattle passage through the dam's main body and the gabions structures, which could otherwise be damaged. The transit of vehicles and heavy trucks on the earthfill and gabions structures, which could cause breakage in the weir, should also be avoided. With reference to an embankment, areas adjacent to the earthfill should not be cultivated, as the agricultural exploitation of these areas may lead to rip-rap damage and erosion.

Hunters should be kept from opening or burning gabions structures to catch small wild animals which sometime build their den inside them.

Often, in earth dams, water seeping through the earthfill is used for human needs. However, waterholes and wells should not be dug immediately downstream the earthfill, or even within its valley outreach, because these will diminish seepage paths and increase the risk of seepage causing earthfill blow out. In these circumstances it is appropriate to realise a catch system of seeping waters immediately downstream the earthfill.

Maintenance

A properly dimensioned and carefully built hydraulic structure should not require important maintenance interventions, but only minor periodical checks. This kind of maintenance is usually at the reach of local populations, as it does not imply significant financial resources, but only a certain amount of motivation and organisational skills. For instance, it is essential that the good state of a hydraulic work is ascertained, especially after important flood events, to make sure that major damages have not occurred.

These ordinary maintenance tasks should be entrusted to a properly trained group of local people, charged with periodical controls of the structure, and capable of identifying damages and eventually repair them. Once damages have been identified and their importance toward the structure's functioning has been evaluated, the people in charge will establish whether the necessary repairs can be carried out locally, or if recourse to external support is necessary. The commonest damages which can interest earth and gabions structures, and the respective restoration methods, are illustrated in the following paragraphs.

It would be preferable to select the local group in charge of the management, control, and maintenance of the hydraulic structure since the initial stages of preparation and construction of the structure. Once group members have been selected, they will have to receive appropriate training in the activities that they will be carrying out subsequently. A fundamental part of training takes place throughout structure building, when the group in question will understand how structural elements are realised and will therefore acquire a practical knowledge of all the techniques that they will have to reproduce in their future maintenance interventions. For this reason, it is important for them to be directly involved in the structure's construction.

In order to accumulate funds that may be required at some point, if extraordinary maintenance measures become necessary, various forms of periodical contribution or taxation of the structure's direct beneficiaries should be assessed.

Obviously, the assessment should take into account the local socio-economic context. However, various solutions can be considered, e.g. demanding that a small sum be paid by herders, for each animal watered at the impoundment, or by the farmers irrigating their fields with water from the impoundment, depending upon the acreage of the respective cultivated land area. In this way, a small fund could be established through which even important maintenance tasks could be autonomously subsidised by the local population. It would be possible, for instance, to acquire gabions or cement to accomplish periodical structure restorations.

5.3 – MAINTENANCE OF EARTH STRUCTURES

Earthfill embankment protection

In this paragraph the main interventions of ordinary maintenance required by earth hydraulic structures are described (USDA NRCS. 1997). Also common extraordinary maintenance tasks will be briefly illustrated.

Avoiding vegetation growth

The growth of shrubs and trees on the earthfill's crest and sides should be by all means avoided. In fact, roots tend to reach for humid earth zones, i.e. they extend themselves toward the impoundment. However, if the tree or shrub dies, its roots could putrefy and be eaten by a particular kind of insects. This would open a void channel through the earthfill, in which water could penetrate, thereby modifying the normal seepage regimen of the earthfill. This void channel, could siphon off water, progressively increasing its diameter and eventually leading to the overlaying earthfill's blow out. It is therefore very important to periodically eliminate all the vegetation that grows on or next to the earthfill, preventing the development of roots in the earth of which the structure is made up.

Rip-rap maintenance

Protecting the earthfill with rip-rap is a key measure against erosion. The rip-rap's good state, threatened by the passage of cattle and/or erosion provoked by the thrust of waves in the impoundment, should be constantly checked. In fact, un-protected earthfill areas are particularly susceptible to erosion as, in these weaker parts, the fill is quickly removed by waves and rain water.

Small reparations

We have already mentioned the possibility that the direct beneficiaries of hydraulic works take charge, whenever possible, of minor extraordinary maintenance tasks, periodically required by the structure. Here, 'minor interventions' refer to those repairs which can be easily accomplished without making use of mechanical means. The entity of this kind of intervention is generally rather modest, in the order of a few cubic meters of material to move. The tools required by small maintenance interventions are very basic. A vehicle to carry building materials is usually necessary, and, in the absence of machines or trucks, a small cart will do. A number of manual tools are also needed, such as spades, axes, buckets and small tampers for preparing construction materials, charging them on the apposite vehicle and installing them. Jute or plastic sacks, often easily available locally, might also be required for urgent repairs.

Erosion

Whenever portions of the earthfill are removed by erosion caused by waves or rain water, or by the passage of cattle, it is necessary to intervene promptly in order to re-establish the earthfill original shape. This is a rather simple kind of intervention, consisting in bringing back the removed material in superposed layers. Each layer will have to be adequately prepared, humidified, and compacted, before the following layer can be laid upon it. Layers should not be very thick, so as to achieve a good compacting effect with the manual tools employed. In order to achieve a good bonding between the pre-existing earthfill and the new layers added to repair eroded parts, the former should be properly prepared in advance (all unevenness should be removed and then the surface must be moistened and compacted).

Mending of fissures

Sometimes fissures may form in a dam's earthfill. It is possible to distinguish between two types of crack, depending on their direction in relation to the embankment's orientation, i.e. they can be transversal or longitudinal with respect to the earthfill. These two kinds of fissures signal anomalous phenomena of settlement of earthfill or foundation layer. In particular, transversal fissures (fig. 5.2), often present on the earthfill shoulders, indicate a differential settlement of the earthfill and the foundation layer between earthfill centre and sides. This phenomenon generally takes place when one or both edge/s of the earthfill stand on a shoulder in a material not as soft as that on which the earthfill's central portion stands. To produce this kind of crack, the shoulder should also be characterised by a significant slope. Longitudinal fissures, instead, are commonly generated by slope instability (fig. 5.3). This phenomenon can concern only the earthfill slope, or also its foundation layer.

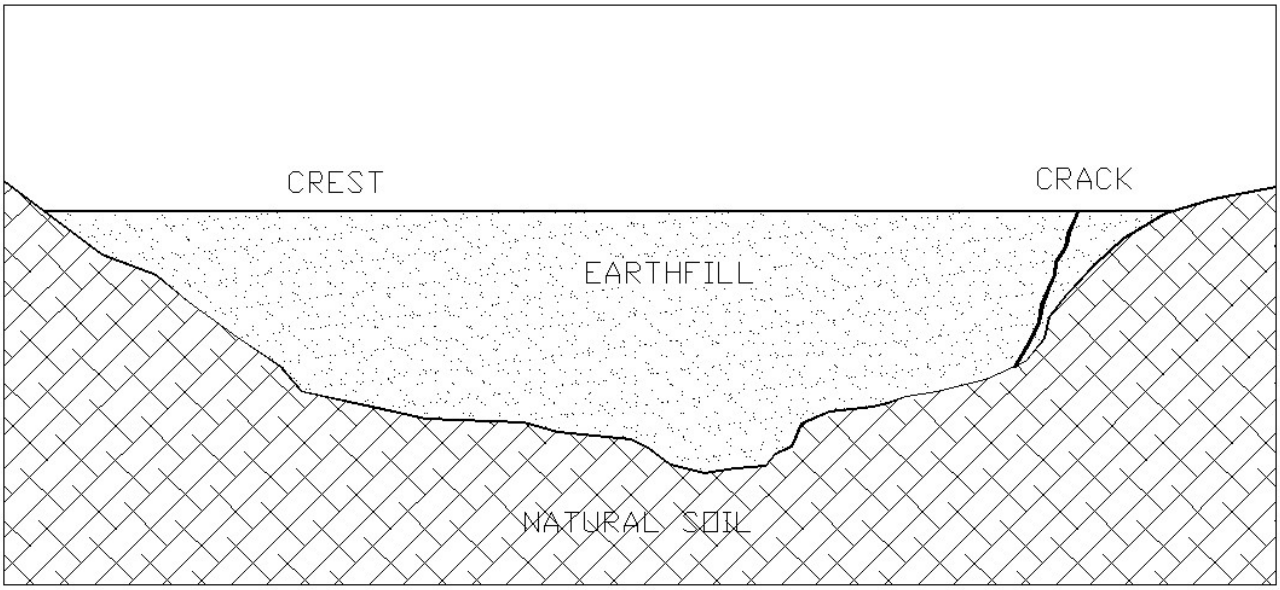

Fig. 5.2 – Transversal earthfill crack

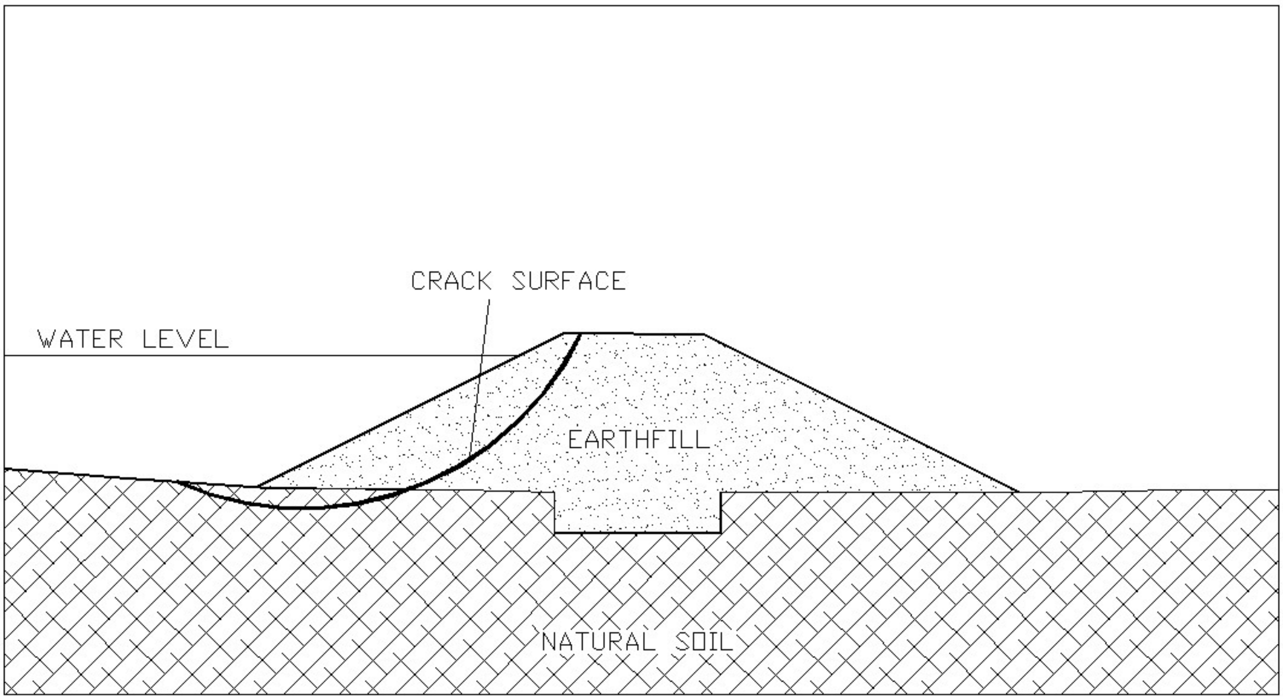

Fig. 5.3 – Longitudinal earthfill crack

Both of the above mentioned phenomena are the outcome of a settlement process which can take place in the initial period of the structure's life, generally within 2 years since completion of its construction. In the first case, the ground settles due to a secondary settlement of the clay component in the foundation layer. A high clay content in the earthfill will contribute to this situation. In the second example, slope instability is usually brought about by the presence of groundwater, appearing in the earthfill as a consequence of the earthfill's partial saturation caused by impoundment filling. In both cases, a discontinuity of materials in the earthfill is realised.

In the case of the transversal crack, the fracture might result particularly dangerous, as it could establish a preferential path for seepage waters, with the consequent risks of excessive seepage in the earthfill. For this reason it is important to take notice of this phenomenon, when it occurs, especially if it is followed by significant seepage. However, for small scale structures of the kind discussed here, the earthfill generally maintains such a high degree of plasticity, and its height is so limited, that the crack tends to close up again, and the material at the crack's sides mixes spontaneously, thanks to the weight of the superposed material. Therefore, the crack is likely to stay compact towards the base and the inner part of the earthfill, while it shows itself at the exterior and on the earthfill crest. If such is the case, the crack in the earthfill crest will have to be closed with an earthfill patch. The outer layer forming the crack should be removed down to the crack's origin in the earthfill. Then, the interior layer of the excavation is compacted, following the procedure which has already been described.

On the other hand, a crack longitudinal to the earthfill, likely to have been caused by slope instability, is subject to further slippages toward the eartfill's inner core, in concomitance to new instability events (fig. 5.3). The earthfill section itself could consequently result modified, and the crest might experience a dangerous drop. This problem can be avoided by altering the earthfill slope adding stability to its section. An earthfill berm can be installed at the embankment's toe (fig. 5.4-a), or the earthfill slope itself can be decreased (fig. 5.4-b).

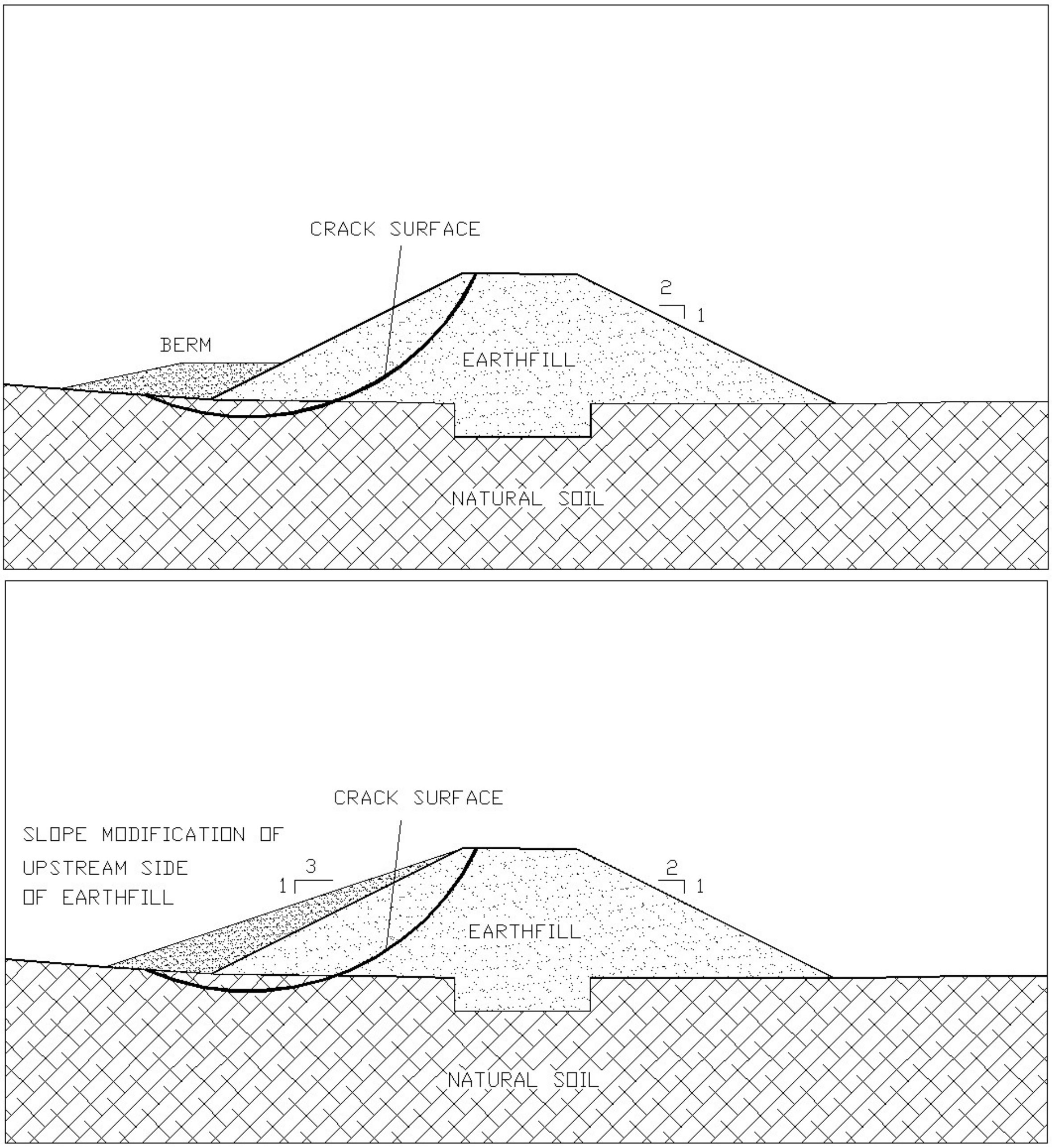

Fig. 5.4 – Methods for stabilising the earthfill upstream side (a and b)

Seepage

Sometimes, a few days after the first filling of the impoundment, extreme humidity and water sources may appear at the earthfill downstream side. In paragraph 7.2.4 the causes which give rise to this phenomenon are illustrated together with the procedure to follow in order to reduce sources' flow when it becomes excessive, i.e. augmenting the water level downstream by building a small bund around the source. If the source flow is modest, the bund can be realised by carrying some earth on the earthfill downstream side manually. However, to assure that this bund resists to source water overtopping, it is preferable to build it with sacks filled with sandy material, rather than merely accumulating loose earth.

5.4 – MAINTENANCE OF GABIONS STRUCTURES

Reparation of minor damages in gabions

One of the commonest damages that occur in gabions structures consists in the opening of the gabion net. The latter can be torn away by the continuous thrust of materials carried by runoff (e.g. sable, gravel and rubble) against iron wires. More rarely, gabions baskets open because they have not been properly closed. When the net opens, the stones filling it up fall out, and the structure loses all its weight and, consequently, its function. It should be noticed that gabions may empty even without net tears. In fact, water out-flowing from a weir falls on the gabions situated underneath the stilling basin. If the water outflow is particularly violent, due to both specific flow and fall's height, the stress against gabions will lead to the shaking and mutual thrust of stones inside gabions. If the material of which the stones are made is fragile (e.g. laterite), stones will start to crush into pieces small enough to fall outside the gabions net.

In all of these instances it is necessary to intervene to repair the gabions. The intervention needed is simple: it consists in opening up the gabions completely and emptying it of the material left inside it. Now, it has to be filled again with new material following the procedure described above (paragraph 7.3.2) and then closed, using the appropriate tools, normally used for gabions closing. Great care should be put in reinstalling the bracing wires and diaphragms, if there were any in the original gabion.

Minor structure repairs (excessive settlement, seepage)

If the appropriate precautions to prevent water from flowing at the interface between gabions and natural soil or earthfill have not been taken (see paragraph 7.3.7), then a portion of material in proximity to the gabion might be carried away with the flow. The removal of the foundation layer will provoke the failure of the gabions structure (fig. 5.5). These problems can take place also if the appropriate protection methods were not accurately realised. In all these situations, a part of the structure falls, settling into a new shape, generally at a lower level. In order to remedy to this damage, two methods can be followed. The first method consists in restoring the gabions weir original shape recycling the damaged part, and placing other gabions on top of it. This method is preferable, especially if the gabions are settled in a stable way. It is also important to eliminate the causes (e.g. excessive water flow in the contact area between gabions and earth) which gave rise to the settlement, and the consequent change in shape, in the first place, by adding semi-permeable or impermeable cut-offs.

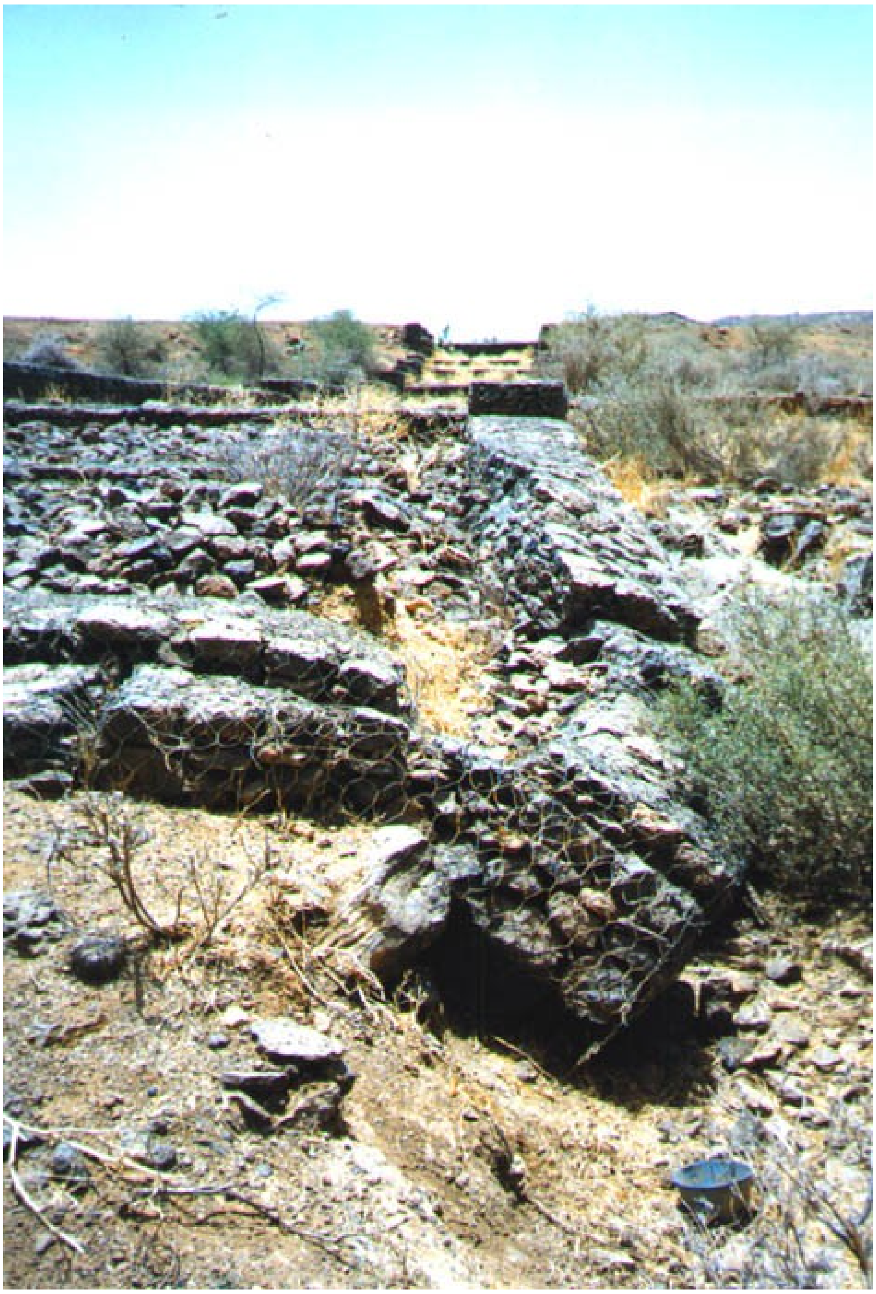

Fig. 5.5 – Damaged gabions' structure with settlement

Instead, when the new shape taken by the structure after its initial settlement is unlikely to be a definite one assuring structure stability, it will be preferable to substitute the damaged structure part with a new one.

Sometimes, the passage of water in the contact area between gabions and earth removes the fill, causing water seepage through the structure, without leading to gabions settlement and structure partial failure (fig. 5.6). In this case the structure must be made impermeable again by restoring the existing impermeable or semi-permeable cut-offs, or installing some new ones.

In all of these instances, in addition to the tools required for gabions installation, geotextile, cement and also new gabions will be required for the reparation of gabions' structures. These interventions, therefore, will require considerable financial resources.

Fig. 5.6 – Damaged gabions structure without settlement

5.5 – RETENTION DAMS MAINTENANCE

Protection of the impoundment from solid sedimentation

An impoundment, built in the aim of stocking a certain amount of water discharge, is always subject to sedimentation of the solid material transported by runoff water. Usually, coarse sediments will be all deposited in the upstream zone of the impoundment, and fine sediments will be deposited in the other zones of impoundment. Quantity of fine sediments deposited mainly depends from the impoundment water's retention time and from sediments' grain size. The amount of sediments that can be transported by water discharge depends upon the entity of sediments production in the basin (e.g. caused by water or wind erosion, or human activities such as agriculture), and on the transportation capacity of the watercourse, as already briefly explained in the paragraph 2.6.

In order to limit the sedimentation of solid material in an impoundment, and thereby retard its silting, it will be generally necessary to intervene at two levels: at the watershed level, and at the level of the watercourse that feeds the impoundment.

Interventions in the stream's watershed

The kind of interventions involving the watershed are mainly focused on fighting soil erosion (USDA NRCS. 1997). These interventions are closely related to the kind of the soil in question: e.g., in the case of sandy dunes, windbreaks are suitable, and in the case of barren clay soils, bunds are preferable.

All human activities carried out within the watershed, which may cause a substantial production of sediments, should also be avoided, or limited as much as possible. Some agricultural techniques, such as ploughing, can give rise to significant amounts of sediments if they are not carried out appropriately.

It is essential to try to avoid locating a watershed downstream areas which, for their very morphology, are particularly likely to produce significant amounts of sediments. A typical morphology to be avoided is, for instance, that of eroded clay hills, with a scanty vegetation cover.

Interventions in the streambed

The easiest kind of intervention aimed at limiting a watercourse solid transportation capacity consists in reducing its slope. In chapter 5, we have seen the method used for installing a series of weirs in an artificial or natural channel, so as to diminish its slope and consequently impede the transportation of solid material exceeding a certain grain size. It is usually the final reach of the main watercourses feeding the impoundment that should be appropriately treated: the reach's slope should be measured and the so-called equilibrium profile of the watercourse should be calculated using Shield's diagram, having established the minimal diameter of material that will not be transported. It will now be possible to design and build a series of gabions weirs along he watercourse in question, so as to modify its original slope and change it into the equilibrium profile.

It will then be necessary to select the weirs' position so as to maximise the volume of sediments that can be supported upstream the weirs, retarding the sedimentation process. An important intervention, which can be considered of ordinary maintenance, consists in periodically raising the weirs' level, especially for the weirs closest to the impoundment, realising a periodical re-adjustment of the volume of sediments that they can support.

Gabions weirs easily lend themselves to a progressive elevation process, which can be accomplished by superposing on the crest successive layers of gabions, slightly staggered toward upstream (fig. 5.7). These lines of gabions will have to be properly tied to the underlying gabions, and waterproofed on their upstream surface.

Fig. 5.7 – Rising of weirs' level

This kind of task can be easily accomplished by the local population, especially if the latter has been preventively trained and it disposes of the funds necessary for acquiring construction materials (e.g. gabions and geotextile), as illustrated in par. 5.2.

Utilisation of the outlet system to remove sediments from the impoundment

If the procedures illustrated above are not feasible, or if they are not fully effective, water discharge itself could be used to evacuate sediments from the impoundment. However, to achieve this purpose, the impoundment should be endowed with an outlet system of a size appropriate to the task. This outlet system should dispose of a closing device, at the same time reliable and easy to manage. The outlet system could be a pipeline inserted in the earthfill (fig. 5.8), with a diameter adequate to support an important water flow, thereby facilitating the evacuation of sediments.

Fig. 5.8 – Pipeline in the earthfill for the evacuation of sediments from the impoundment.

If the flow rate required for the evacuation of sediments has to be higher, it is possible to open a supplementary passage in the spillway section, at a level lower than the spillway crest's level. An appropriate device for closing this newly opened lower portion of the spillway will be identified and installed. In order to facilitate the evacuation of sediments, it will then be possible to remove the closing device from the spillway section's lower opening. Though this portion of the spillway, the water will flow at a specific rate, thanks to the increase in water charge, and its capacity of sediments transportation will result increased (fig. 5.9).

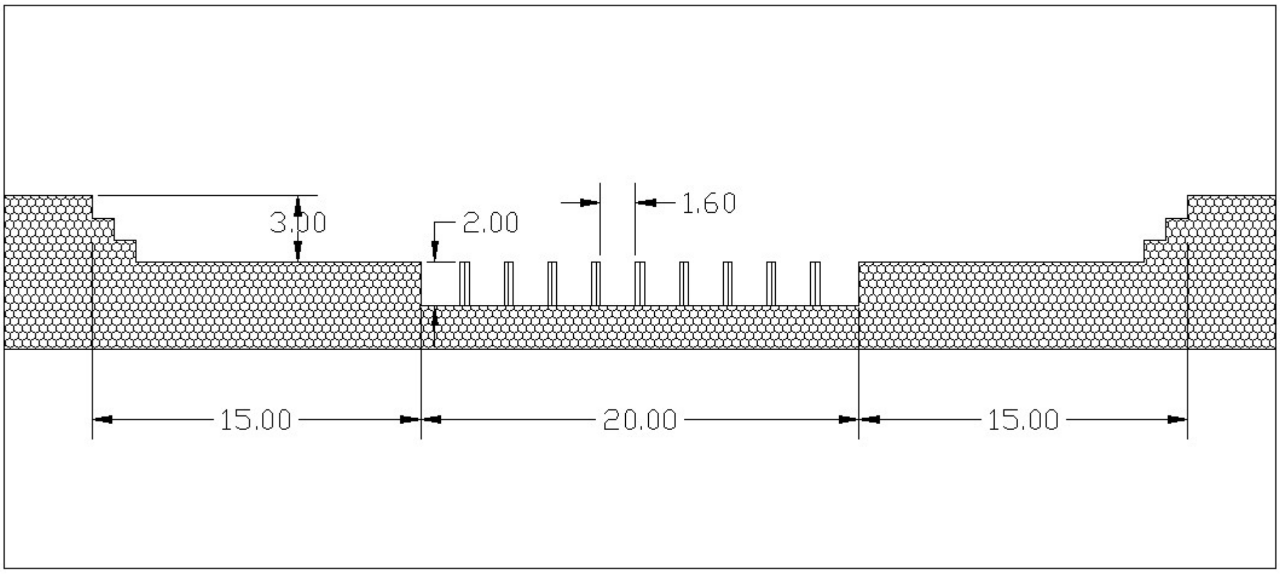

Fig. 5.9 – Spillway cross section modified to allow periodical sediments evacuation from the impoundment

Clearly, these devices have a limited effect toward the evacuation of sediments from an impoundment, and cannot generally evacuate all the debris that the water flow carries inside of it. Nevertheless, if they are properly dimensioned, these devices will evacuate sediments from the area surrounding their inlet, thereby guaranteeing a minimum stockage volume against sedimentation in the impoundment. It is very important to design and build closing devices that are extremely reliable and easily manageable at the same time, thus simplifying as much as possible all the management tasks to be carried out by the local population. To achieve a responsible involvement of local people in the functioning of hydraulic works at all levels, even in specific details such as the choice of a closing device, the local social and cultural system will have to be taken into due consideration.