Chapter 4
Construction of the Civil Structures

4.1 Site Inspection and Preparation

Based on the detailed design, the locations of the various MHP structures should be verified and then clearly marked at the site. This includes placing centre line pegs along the headrace and penstock routes and along the boundary of other structures such as the settling basins, forebay, anchor blocks, and powerhouse.

At this stage the layout design should already have been finalised and no changes should be necessary. However, a final survey should be carried out to verify that, since the design phase, there have been no changes in the site that might necessitate relocation of structures. The layout should only be changed if there have been major geological changes such as landslides, along the headrace or penstock routes.

The site preparation should include clearing the route from the intake to the tailrace. Shrubs and other vegetation should be uprooted if they are likely to obstruct the construction work. If some structures are to be located along cultivated fields, these fields should be left barren before commencing the construction work. The area required during the construction phase will be larger than the actual area that the various structures will eventually occupy. This is because adequate space is needed for labourers to work freely, for storing construction materials such as stones and sand, and for dumping excavated soil.

4.2 The Construction Sequence

The construction of the scheme should start from the most critical location, i.e., where a slight misalignment or improper orientation may result in significant expenditure for remedial measures. Usually the machine foundation in the powerhouse is the most critical location. This is because, once the machine foundation anchor bolts are set in concrete, the turbine and generator locations cannot be readjusted. Therefore, the machine foundation should be constructed first. Then work should commence on the installation of the penstock pipe from the machine foundation to the forebay. Except for the last 300mm in height, the support piers can be constructed as the penstock installation work progresses upstream, including expansion joints at given locations as per design. The pipe is first supported by temporary stonework, wooden planks, or other materials. The final height of the piers should be adjusted once the entire pipe length has been installed so that the pipe can be properly aligned and bending stresses avoided when it reaches the end point in the forebay. The anchor blocks should also be completed after the entire penstock pipe length has been installed. This is because once the anchor blocks are constructed, the penstock pipe cannot be readjusted.

The forebay is usually located on an elevated terrace (flat area) on a steep slope above the penstock. Sometimes excavation of the location is required to provide a sufficient area for the forebay. If this is the case, then it could affect the length of the penstock pipe. Hence, the forebay should be constructed after the penstock pipe reaches this structure.

Once the machine foundation, penstock, and forebay have been constructed, the logical sequence is to continue the construction work upstream to the location of the intake. If the construction work is carried out in this sequence, there will be less chance of misalignment or errors in the elevation of the structures. However, if the survey work has been accurate enough, and the staff at the site are well experienced, some construction work on the higher structures can be carried out concurrently with other structures. For example, different portions of the headrace canal and the settling basins can be constructed concurrently. However, it should be noted that if, for example, the elevations of the headrace canal do not match and the downstream section is higher, remedial measures will be costly.

Construction work at the intake, in particular for the diversion weir, should normally start after all other structures have been completed. This is because the flow cannot be diverted for power generation until all other structures are ready. Furthermore, there may be additional risks from floods if work at the intake and weir is completed prior to the onset of the monsoon but other structures are still incomplete. Some retaining work along the intake bank can be carried out concurrently with construction of other structures, provided that the MHP scheme can be commissioned prior to the onset of the monsoon rains.

4.3 Machine Foundation, Powerhouse, and Tailrace

4.3.1 Construction of the Machine Foundation

Figure 4.1 shows a typical machine foundation pit with reinforcement bars. The foundation for the machine should be constructed as follows.

- Demarcate the floor area of the powerhouse and the location of the machine foundation according to the design plan.
- Excavate the machine foundation pit to the required depth and compact the floor using a manual ram. If the pit base is not a rock, then a 250mm stone soling should be provided above the base.
- Excavate the tailrace section inside the powerhouse before commencing the concrete work for the machine foundation. This will prevent any misalignment developing be-

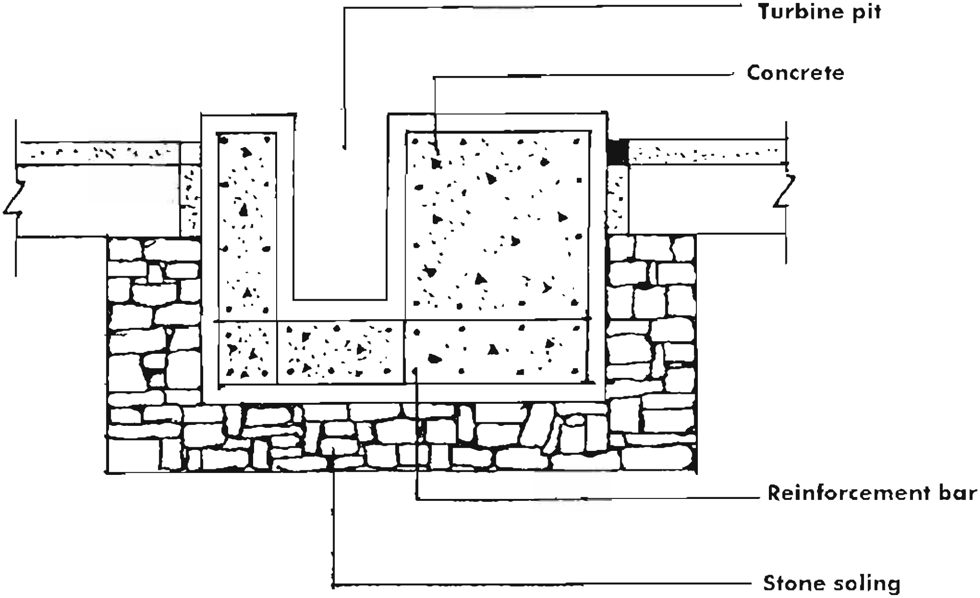

Figure 4.1: A Typical Machine Foundation Pit

tween the machine foundation and the tailrace. (If the tailrace is excavated at a later stage, a gap of about a week should be left after the construction of the machine foundation to allow the concrete to cure.)

- Place formwork around the periphery of the excavation and arrange the reinforcement and anchor bars for the base frame as specified in the design. If wood is expensive, dry stone walls can also be used for the formwork. Unlike wooden formwork, dry stone walls need not be removed. The threaded ends of the anchor bars should be greased and then covered with clean pieces of cloth or plastic sheets so that they are not damaged while pouring the concrete. Sometimes the base frame can also be welded to the reinforcement bars and cast into the foundation.
- When the formwork and reinforcement of the machine foundation have been put in place, prepare the concrete mix at the required ratio (usually 1:1.5:3 cement, sand, water, aggregate) and then pour it up to the generator/turbine base frame level. Concreting work is discussed further in the next section.
- Manually compact/vibrate the poured concrete using long steel rods. Once the required level is reached, place the base frame for the machines on the concrete so that it fits snugly over the anchor bars (the holes in the base frame are in line with the anchor bars), then tighten the anchor bolts. The base frame must be level, and this should be checked constantly (using a 'spirit level') while tightening the bolts. Note that the lie of the base frame can only be adjusted while the concrete is still wet.
- Protect the newly poured concrete structure from direct sun and rain for at least 24 hours.

- The concrete is cured by keeping it moist, usually by gently pouring water on the concrete structure. Curing should start 24 hours after the construction of the machine foundation and continue for at least a week. An uncured concrete structure will not gain full strength. During hot and dry weather it may be necessary to pour water on concrete structures twice a day (mornings and afternoons) to ensure that they gain full strength.
- Wait at least seven days after completion of the construction before removing the formwork from the machine foundation.
- Once the machine foundation and the tailrace section in the powerhouse are complete, work on the powerhouse walls and roof can commence. As a result of the confined space, it may not be feasible to construct the powerhouse structure, machine foundation, and the tailrace section concurrently.

4.3.2 Preparation of Concrete

The quality of cement, sand, and aggregates for concrete work should be as follows.

- Cement used for concrete and masonry work should be fresh and preferably less than six months from the date of manufacture. Cement that has been stored over a long period loses strength significantly.
- The sand for concrete work should be granular, clean, and free from organic materials and soil. Sand mixed with soil or organic material should be thoroughly washed before use to remove these and other water-soluble materials.
- The aggregates for concrete work should be collected either from quarries or riverbeds, or prepared by crushing stones. Aggregates need to be hard, angular, and non-porous.
- Concrete should never be mixed directly on the ground. It should be mixed on a clean and watertight platform (such as a tightly paved stone surface), or some other adequate surface.

The process of mixing concrete is as follows.

- Mix dry cement and sand thoroughly until the colour is uniform.
- Add the required volume of coarse aggregates on top of the cement-sand pile and mix the entire mass again so that the aggregates are uniformly distributed.
- Make a well in the dry concrete mix, gently pour in the required amount of water, and turn the mix thoroughly. Ensure that water does not seep away from the mix. If there is too little water, the concrete may be too hard to be poured properly and voids may form. Equally, excess water weakens concrete, leads to shrinkage cracks, and decreases the density. A water:cement ratio of 0.5 (25 litres of water per 50 kg of cement) should be used for manually mixed concrete.
- The concrete mix should be poured on to the structure within a few hours of its preparation. Concrete stored overnight loses significant strength and should never be used.

Figure 4.2 illustrates the right and wrong methods of pouring concrete on masonry or other structures. Concrete should not be prepared in separate lumps or poured from high above the structure under construction.

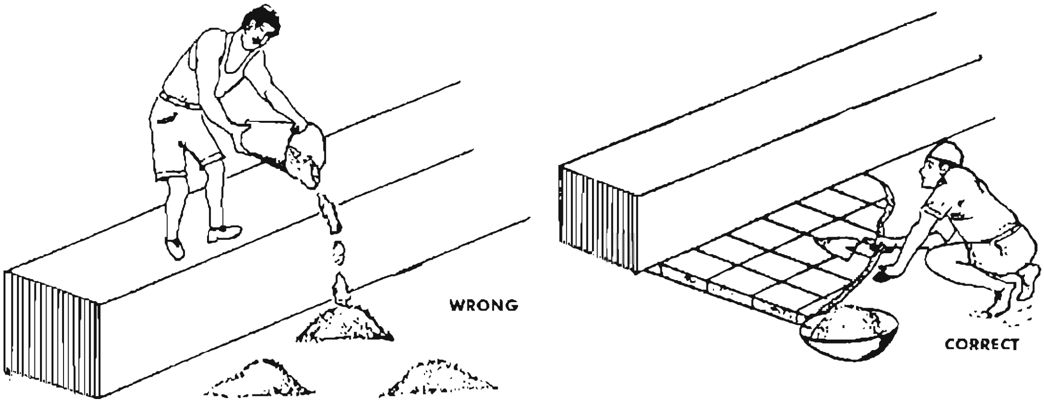

Figure 4.2: Pouring Concrete

4.3.3 Construction of the Powerhouse

As discussed in the layout design manual, the powerhouse structure should be similar to that used for local houses since this will be much easier to construct. In the HKH region, this usually means constructing the walls from 450mm thick stone masonry in mud mortar. The construction of the powerhouse structure is as follows.

- Demarcate the plan of the powerhouse at the proposed site as specified in the design. Then mark the excavation lines for the construction of the foundation and the walls. This is done by placing pegs along the inside and outside wall edges of the powerhouse. These pegs should then be joined with powdered lime, ash, or thin rope. Note that, to optimise the space in the powerhouse, the length or width should be at right angles to the final length of the penstock pipe.
- Excavate the foundation for the walls along the lines prepared above to the desired level (usually 1m) and compact the ground using a manual ram.
- Construct the front and side walls of the powerhouse. Generally the back wall involving the penstock should be constructed after the penstock installation is complete so that there is no interference between these activities. It is also easier to bring in electromechanical equipment, such as the turbine and the generator, if one wall is left open. During the construction phase the walls should often be checked with a plumb line to ensure that they are vertical. Doors and windows should be placed at appropriate locations.

- Construct the back wall after the turbine and the generator have been fixed on the machine foundation and the installation of the penstock is complete.
- Once the powerhouse walls have reached the desired height (about 2.5m), place the wooden trusses and roof according to the design, e.g., using corrugated, galvanised iron (CGI) sheets.
- Use only seasoned wood for doors, windows, and trusses.

4.4 Civil Works for the Penstock

4.4.1 Penstock Pipe Installation

The civil work for the penstock involves installing the pipe and constructing the support piers and anchor blocks as specified in the design layout. Both the latter must be located on original firm soil and not on backfill. The procedure is as follows.

- Clear all vegetation along the penstock route and mark the centre line by fixing a tight string. Mark excavation lines for the support piers and anchor blocks.
- Fix the turbine together with the manifold and gate/valve (if provided) to the machine foundation.
- Start the installation of the penstock from the machine foundation and proceed upstream This is usually the more convenient method and avoids any misalignment between the penstock and the turbine housing. Since the turbine needs to be firmly fixed to the machine foundation, there is almost no tolerance at this end after the machine foundation has been constructed. In contrast, any minor deviation in the pipe position can be adjusted easily at the forebay wall. A further reason for starting at the lower end and working up is that the pipe sections below the expansion joints can slide down if the installation proceeds downstream from the forebay. The installation is started by connecting the first link of the penstock (usually a bend) to the turbine manifold.
- Install the expansion joints at the required locations as specified in the design layout (i.e., downstream of the forebay and anchor block locations). Tightly pack jute (or similar fibre) inside the expansion joints during the installation process to prevent leakage during the operational phase.
- Construct the support piers at the required locations as the pipe installation work progresses upstream, but leave construction of the last 150 to 300mm of the height of each pier until after the entire penstock pipe has been installed. This allows for some adjustment of the pipe at the end. During the installation process, temporary dry stone walls can be used to balance the penstock on top of the unfinished support piers.

The construction of the support piers involves first excavating the ground to the required shape as per the drawings. Once the required foundation depth is reached (usually 300mm at the downstream face and the value dictated by the slope at the upstream face) the earth should be compacted using a manual ram. The piers should be constructed of stone masonry in 1:6 cement mortar, as discussed below.

4.4.2 Cement Masonry Work

The following steps are recommended for stone masonry in cement mortar.

- Stones should be washed and kept immersed in water for a day prior to construction. Dry stones do not adhere well to cement mortar and thus reduce the strength of the masonry.
- The ratio of the mortar for the construction of support piers should be not less than 1:6 cement to sand.
- Use good quality sand and cement as described in sections 4.3.1 and 4.3.2 and follow other relevant instructions in these sections regarding pouring time, protection from sunlight, and curing.

4.4.3 Anchor Blocks

As mentioned above, anchor blocks should only be completed once the penstock pipe installation work is complete. The following procedure should be used to construct the anchor blocks.

- As with the support piers, first excavate the ground according to the design. Once the required foundation depth is reached, compact the earth using a manual ram. Note that the excavation and compaction work should be done as the pipe installation proceeds.
- Prepare the concrete (usually 1:3:6 with 40% plum) by mixing cement and sand aggregates to the required ratio. Place the specified number of reinforcement bars of the given size (usually 3 bars of 10mm in diameter) as shown in Figure 4.3. The concrete prepared should be poured at the anchor block location and the plums should be placed evenly through the block. Either wooden planks or dry stone walls can be used for the formwork depending on the availability of wood at the site. Once the concrete work has been completed, the blocks should be cured for about a week. It is recommended that a final check be carried out on the penstock pipes and the expansion joints to ensure that there are no errors before pouring the concrete.

4.5 Construction of the Forebay

Generally the forebay should be constructed after the installation of the penstock is complete. The construction of the forebay involves the following.

- Mark the excavation lines for the forebay at the proposed location according to the design, as described above.

- Excavate the ground to the required depth and shape. Note that it is important to check the floor elevation after excavation but before construction. If errors are found in the elevation after construction work has commenced (the forebay is higher than the headrace canal upstream, for example), remedial work can be expensive.
- Compact the earth surface using a manual ram after completion of the excavation work.

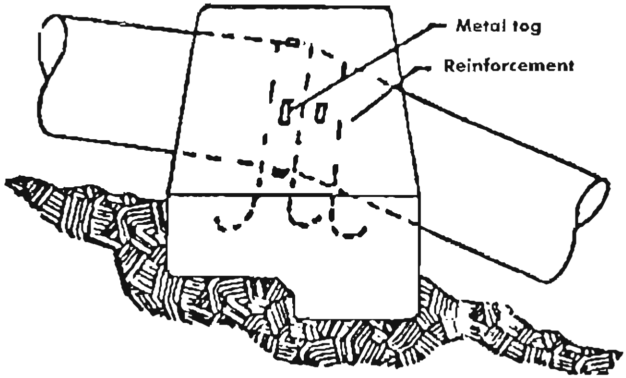

Figure 4.3: A Typical Anchor Block

- Construct the structure according to the design. The forebay and other water retaining structures are usually built using stone masonry in 1:4 cement mortar (see Section 4.4.2). Once the cement mortar has been prepared it should be used within two to three hours.
- If possible the inside faces (water retaining surfaces) should have dressed stones as this minimises the thickness of plaster required.
- As the masonry work proceeds, install the gates, flush pipes, and spillways at the given locations according to the design.
- After completion of the gates and masonry work, plaster the water retaining surface (i.e., the inside surface) of the forebay. An approximately 12mm thick 1:2 cement mortar layer is recommended for the plaster.
- Once the construction of the forebay is complete, it should be cured as described earlier. If there is a delay between completion of the masonry work and plastering, then the structure should be cured for another four days after completion of the plaster.

4.6 The Headrace Canal

Once the canal type (or types of different lengths) has been selected and the sizes worked out, the actual construction procedure involves the following stages.

- Setting out of the course of the canal and marking the centre line with pegs
- Preparing the bench for the canal
- Fixing the excavation lines
- Excavating the canal
- Constructing/lining the canal

4.6.1 Setting Out the Canal

Before setting out the canal, first ensure that all necessary equipment and manpower is available. The equipment used for the detailed survey work, for example an Abney level or a theodolite and a tape, is usually sufficient for the construction and for setting the specified slope of the canal bed. A transparent water-filled tube can also be useful for checking the level of the canal bed at various locations as the construction progresses.

The canal is set out as follows.

- First place pegs along the headrace canal route. Depending on the topography, such pegs should generally be driven into the ground at 5-20m intervals along the route. Pegs should be placed more closely at bends as well as at other important locations such as drops and the beginning and end of crossings.
- Place some intermediate pegs or reference pegs just outside the canal path. The differences in elevation between the reference pegs and the canal route pegs can be calculated using a levelling instrument. These pegs will serve as reference levels for the excavation work. An alternative possibility is to paint marks on exposed rocks just outside the canal path and calculate their relative elevations.

4.6.2 Preparation of the Bench

The bench of the canal is a strip of land of uniform width and slope along the hillside side of the canal. It is like a road of generally constant width and slope at the level of the top of the canal. The bench should be prepared as follows.

- Excavate a strip of land of even width along the path of the pegs placed along the canal route. If there is a possibility of material being washed down by rain from the slope above, or of small landslips being deposited directly in the canal, increase the width of the bench such that it is larger than the finished canal top width. This extra width is called the berm and stops debris or water coming down the hillside from entering the canal. Any such excess water should be channelled away from the canal through a proper drainage system. If it is not possible or practical to drain all the excess flow away, the flow can be allowed to enter the canal at a predetermined and properly constructed location such as near a spillway. The berm can also be used as a walkway for people or for workers during construction. Generally, a berm width of 300 to 500mm is sufficient along the uphill side for people to walk and for construction work. The slope of the bench should be the same as the slope of the canal section. Where there is a change in the canal slope (in the design), the bench slope should change accordingly. The bed slope of the bench should be verified using a levelling instrument. The elevation of the canal at different locations can be calculated using the intermediate pegs placed outside the canal path.

Once the initial elevation at the intake has been fixed, the subsequent elevations for the canal route can be calculated from the distances and bed slopes. The initial elevation can be estimated using contour maps of the area or measured with an altimeter. Another method is to carry the trigonometric points established by the survey department, but this may require more time and resources.

The absolute elevation figures (i.e., the exact elevation above sea level) need not be very accurate but the differences in elevation between the canal bed and the intermediate pegs should be accurate, since it is these differences that determine the slope of the canal.

The following is an example of an elevation calculation.

The designer has recommended a slope of two per cent for a certain canal section. The topographical map of the area indicates that the elevation at the intake is around 1,400 metres above sea level (MASL).

In this case the first peg placed at the intake area can be assumed to be at a level of 1,400masl. If the second peg is to be placed 20 m (horizontal distance) downstream, the bench elevation here should be

20 m x 2.0/100 = 0.40 m lower than the intake, that is at
1400m - 0.40m = 1,399.6masl.

The subsequent differences between the heights of intermediate pegs (i.e. reference points) can be noted in sequence using similar calculations.

4.6.3 Fixing the Excavation Lines

Once the canal bench has been prepared, the excavation lines need to be set out as described below.

- Place pegs to mark the centre line and the top and bottom edges of the canal (for trapezoidal sections). Note that, in the case of a lined canal, the position of the excavation line for the top and bottom edges should be calculated as the distance of the final edge of the canal from the centre plus the width of the side walls.
- Join the pegs using thin ropes. Then mark the lines along the ground for the centre line and top and bottom edges (five lines for trapezoidal sections) using powdered lime or ash. When a canal has a rectangular section the top and bottom edges lie above each other, and three parallel lines are sufficient for the excavation work.
- Check the dimensions against the design specifications continuously during this process.

4.6.4 Excavation of the Canal

This consists of excavating the canal with the required shape and slope according to the design. The main steps are summarised in the following section.

- For a rectangular canal, start the excavation from the sides down to the required depth.
- For trapezoidal sections, start the excavation along the lines for the bottom edge and dig down vertically to the required depth. Then excavate the sides with an even slope to meet the line for the top edge at the limit of the excavation. In this way, you will arrive at the required trapezoidal shape. This method of excavation minimises the use of construction materials and the need to backfill. This is important since the side walls of a trapezoidal cement masonry canal are more likely to crack if constructed on backfill. It is helpful to prepare a wooden frame, using rectangular sticks matching the trapezoidal cross-sectional shape of the canal, and to use this to check the shape as the excavation progresses.
- Check the canal bed slope frequently using a levelling instrument. Note that an inaccurate slope can be very costly. If the slope is less than required, the canal will not have the capacity to convey the design flow. Similarly, if the slope is steeper than required, the velocity may exceed the maximum value for the canal type and start eroding it.

4.6.5 Construction of the Canal Lining

Once the excavation work is complete, the construction of the canal lining can start, if part of the design. All that is required for an earthen canal is to trim the side walls and bottom anywhere where the excavation work has been poor. If a masonry-lined canal has been chosen, it will be necessary to collect stones, dress and size them, and place them along the excavated surface according to the design.

The following points should be noted when constructing stone masonry in cement mortar canal lining.

- The minimum thickness for bed and side walls should be 150mm. Thinner walls require more stone work for the lining (dressing and sizing) and may not have the required strength. This also applies to stone masonry in mud mortar linings.
- Since the canal is a water retaining structure, the ratio used for the mortar should be not less than 1:4 cement to sand.
- Use 1:2 cement to sand mortar for any plaster work. The plaster should be about 12mm thick (~1/2 inch). Plastering is expensive and should only be applied where really necessary, to prevent leakage for example.
- The instructions given in Sections 4.3.1 and 4.3.2 for this type of construction should also be followed.

4.7 The Construction of the Settling Basins and Spillways

The construction of the settling basin is similar to that of the forebay. Since the function of the settling basin is to remove the sediment from the flow, more than one of these structures may be required if the headrace canal is long (more than about 300m) and unlined. The flow in a long, unlined canal can erode the bed and side walls and increase the sediment load, which then needs to be removed.

Generally at least two spillways are required for an MHP scheme. The first one should be located immediately after the intake to divert excess flow during floods. If there are any chances of the headrace canal being blocked by landslides from above, intermediate spillways should be provided along the canal route. One spillway should always be incorporated at the forebay to divert the design flow in case of valve closure at the powerhouse (e.g., during emergencies). A spillway may also be required at the settling basin if there is a possibility of excess flow reaching this structure during floods.

Spillways can be constructed as part of other structures, such as the settling basin or the forebay, or as independent structures just for spilling the (excess) flow. They are simply openings (with or without a gate) along the top wall sections of the structure or canal that divert any excess flow.

The basic steps in the construction of a settling basin are as follow.

- Demarcate the excavation lines for the settling basin at the location shown in the design and then excavate the ground.
- Compact the earth surface using a manual ram.
- Then construct the structure as per the design. The settling basin is usually lined with stone masonry in 1:4 cement to sand mortar. Construction of cement masonry structures is described above.
- If possible the inside faces (water retaining surfaces) should have dressed stones. This minimises the thickness of plaster needed.
- Install the gates, flush pipes, and spillways at the required locations as the masonry work proceeds.
- After completing the gates and masonry work, plaster the water-retaining surface with a 12mm thick layer of 1:2 cement to sand mortar.
- Once the construction of the settling basin is complete, the channel that diverts the flow from the spillway should also be constructed if required.
- Follow the instructions provided in Sections 4.3.1 and 4.3.2 for this type of construction.

4.8 Intake Structures

At the intake, the flood protection walls and mouth should be constructed first as shown in the detailed drawings. Such work may require diverting the flow towards the opposite river bank The weir should not be constructed until all other work at the intake is complete. Depending on the design flow and the nature of the weir (temporary or permanent) this too may require diverting the river flow temporarily towards the opposite bank. The construction work is easiest when the water level in the river is low and the water is not too cold.

4.9 Retaining Structures and Stabilisation

Small potentially landslide prone slopes can be stabilised with dry stone walls, masonry walls, or gabions. Gabions are usually the most suitable and economical way of stabilising slopes in MHP projects. The construction of gabions requires a skilled person who is able to weave the boxes using galvanised iron (GI) wires. Gabion boxes can be made in different sizes, depending upon the requirement.

The following wire sizes are recommended for gabions for MHP projects.

Mesh size: 80mm x 100mm
Mesh wire: 9 SWG (3.66mm)
Selvedge wire: 6 SWG (4.88mm)
Binding wire: 11 SWG (2.95mm)

The assembled gabion box should be tightly packed with stones. It is better to use dressed stones on the outside surfaces of the gabions. Once the boxes are filled, the cover should be closed and tied using the selvedge wire. Note that gabions should be placed in such a way that the lengths are parallel to the flow.

Table 4.1 can be used together with Figure 4.4 as a guideline for selecting the width of the gabion wall for the height of soil that it needs to retain.

Terracing and plantation are also suitable methods for stabilising small areas prone to landslides on hillsides at MHP sites. The method of terracing is shown in Figure 4.5. Terraces are constructed on landslide prone areas with an overall slope of less than 30°. Dry

Table 4.1: Gabion Sections for Retaining Walls

Wall height required, H (m)	Width, W (m)
1	1
2	1.5
3	1.5
4	2
5	2
6	2.5

stone walls should be used for the vertical face of the terraces. These walls retain the soil while allowing surface water to drain out.

Terraces also help to reduce the surface erosion since the surface water can be diverted by constructing small drains. Note that dry slopes are more stable than saturated ones, and that landslides generally occur on wet slopes.

Planting grass or shrubs that have deep root systems (such as bamboo or Napier grass) on terraces also contributes towards the stability of slopes. However, fast growing trees that do not have deep root systems should be avoided since they may fall during storms as a result of their own weight.

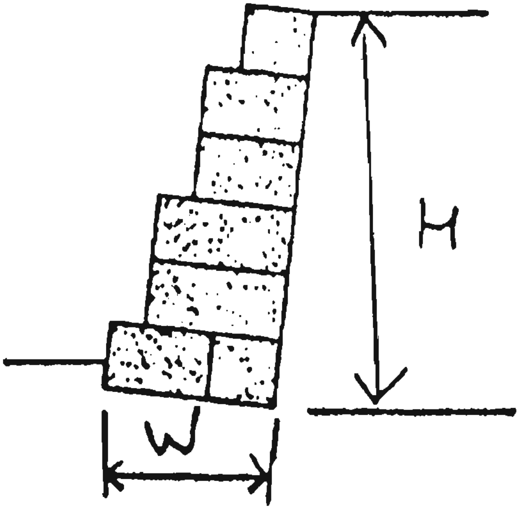

Figure 4.4: A Gabion Retaining Wall

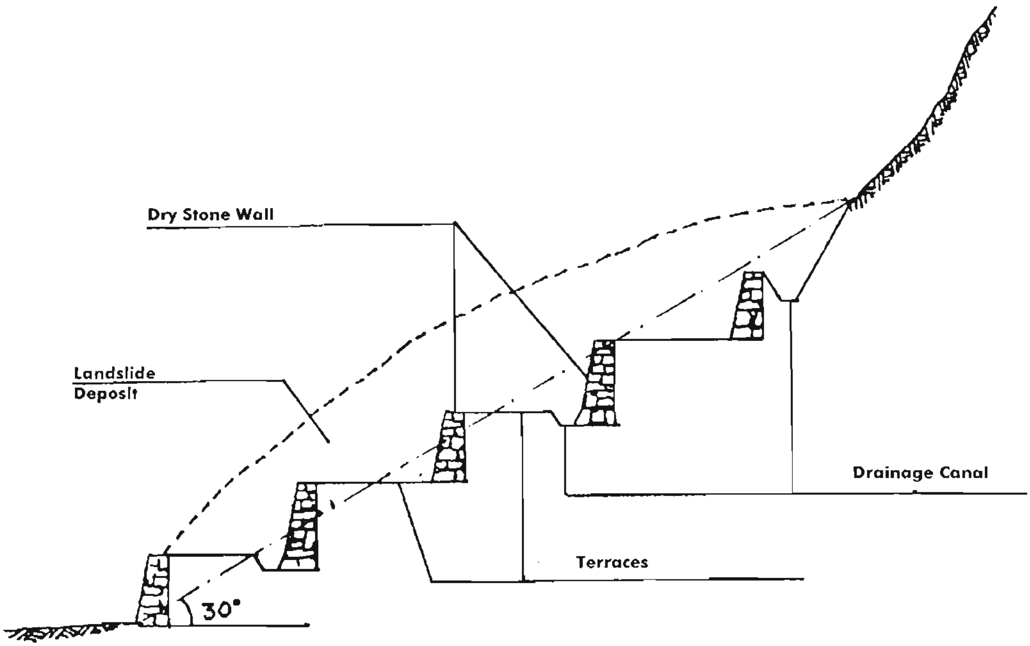

Figure 4.5: Use of Terraces to Stabilise Slopes