CHAPTER VI

RIVER TRAINING AND FLOOD PROTECTION WORK

6.1 Design of Flood and Bank Protection Structures

Sustainability of the flood and bank protection works in the river bed depends on sound design of the protection works. The protection will establish an equilibrium flow regime and prevent the banks from eroding and overtopping. The prevailing flow velocities will increase as reported in Chapter-V on application of river modelling. The design process is as follows:

- Interpreting the results of the mathematical model studies and evolving hydraulic design parameters for the river training and bank protection works
- Alternative layouts for the river training works:
  - two types of erosion protection works, spurs and revetments
  - Level of filling for reclamation
- Design of river training works

6.1.1 Hydraulic Design Parameters

Construction of the protection works, reclamation raising the ground level behind the river front slopes, etc requires fill material. This material is to be obtained by dredging the existing river bed to a depth of two metres over a width of 300m. The flood then passes through a deeper, wider and more regulated flow path. Dredging the river bed also makes construction of the launching apron and toe wall simpler. The two dimensional model studies were carried out with this channel, and run for ten consecutive design floods.

The hydraulic parameters obtained from the river modelling with the constricted channel are:

- Profile of maximum water levels along the left and right bank within the constricted reach
- Profiles of the bed levels covering both left and right bank within the constricted reach (Figures 5.21 and 5.22).
- Profiles of maximum velocities along the left and right banks within the constricted reach (Figure 5.20).
Using the profiles of the modelled water levels, bed levels and velocities, profiles of maximum depth and maximum intensity of discharge are calculated along the left and right bank. (Intensity of discharge (m$^3$/s/m) is the discharge passing through the channel over a width of one metre.) The combined effect of changes in depth and velocity are thus seen in the value of the intensity of discharge.

Perusal of the velocities in Figure 5.20 indicates:

- The flow velocities along the left bank are consistently higher, partly due to the bend curvature.
- Velocities around 5.0m/s prevail over a long reach in the mid section (chainage 1,250 to 6,500m) on the left bank, with velocities reaching a maximum value of 5.6m/s (chainage 5,250 to 6,000m).
- The profile of maximum velocities along the right bank has a high peak value of 5.6m/s, with velocities of 4.5m/s prevailing along short reaches (between chainage 1,000 and 2,500m).
- The velocity distribution along the right bank shows a high peak covering only a short length. The highest maximum velocities are found not along the outer but the inner curvature of the river reach.

Analysis of the bed material samples indicates that the bed material is well graded, ie a range of grain sizes is present, with a mean grain diameter from 18mm upstream of the protection works to 2.6mm downstream. The prevailing large size of stones (D90 of the distribution curve) is between 25 and 30mm (Figure 5.9).

The velocity and depth are individually computed hydraulic parameters. The maximum velocities and depths occur at different times and locations. Superimposed profiles of maximum velocity, depth and intensity of discharge for the first and tenth cycle of design discharge hydrographs (Chapter-V) are prepared separately for the left bank (Figures 6.1 and 6.2) and right bank (Figures 6.3 and 6.4).
Figure 6.1: Depth, Velocity and Intensity of Discharge along Left Bank (1st Cycle)

Figure 6.2: Depth, Velocity, and Intensity of Discharge along Left Bank (10th Cycle)
Figure 6.3: Depth, Velocity, and Intensity of Discharge along Right Bank (1st Cycle)

Figure 6.4: Depth, Velocity, and Intensity of Discharge along right bank (10th Cycle)
Comparison of Figures 6.1 and 6.2 for the left bank shows there is little change in the maximum velocity derived from the first cycle and from the tenth flood cycle. However, velocities have increased marginally in the lower reach. A similar trend is observed in figures 6.3 and 6.4 for the right bank. These results show that the channel design leads to a relatively stable river.

The hydraulic design parameters are divided into three reaches for both the left and right bank, and derived separately for each, as presented in table 6.1.

**Table 6.1: Hydraulic Design Parameters**

<table>
<thead>
<tr>
<th>Chainage</th>
<th>Hydraulic design parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>From</td>
</tr>
<tr>
<td>Left bank – (from U/S end of protection works)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1867</td>
</tr>
<tr>
<td></td>
<td>6413</td>
</tr>
<tr>
<td>Right bank – (from U/S end of protection works)</td>
<td>Balance u/s reach</td>
</tr>
<tr>
<td></td>
<td>427</td>
</tr>
<tr>
<td></td>
<td>Balance d/s reach</td>
</tr>
</tbody>
</table>

**6.2 Layout of Protection Works**

For flood and bank protection of the constricted portion of the river, the following alternatives are considered:

- Construction of a series of spurs
- Construction of revetments along the river bank
- Combination of revetments and spurs

The three methods are discussed in the following sections.

**6.2.1 Spurs**

For jacketing a river, a series of spurs can be constructed along both banks. The heads of the spurs are located at the desired alignment of the constricted river channel (Figure 6.5). Opposing pairs of
spurs are constructed on both banks to hold the channel between the two heads, either directly opposite or staggered. The advantages and disadvantages are:

**Figure 6.5: Schematic View of River Jacketed by series of Spurs**

River channel is kept away from the bank - the spurs project into the river channel keeping the flow of the river away from the bank, which does not face direct attack from the river. However, reclamation of the land behind the embankment is planned, and the ground between the head of the spurs and the bank will not be available for reclamation, leading to a significant loss of prospective land.

Spurs repel the river flow from the bank, causing a change in the direction of flow towards the opposite bank. A series of spurs may cause zigzagging of the flow, creating an unstable flow pattern and inducing instability downstream of the reclaimed reach in India.

High turbulence at the head of each spur will lead to higher maintenance.

### 6.2.2 Revetments

The mathematical model studies show streamlined and smooth flow conditions along both banks. This has important advantages and disadvantages:

- **Clear and unobstructed channel** – as there are no projections, the smooth and streamlined flow will be maintained along the length.

- **A deep channel can develop along the revetment causing high intensity flow during floods, increasing maintenance.** This can be minimised in the design.
Uneven distribution of flow - development of a channel along the revetment and corresponding high discharge intensity creates an uneven distribution of flow across the channel, with sedimentation in the slack flow region. The revetment is constructed along both banks with a uniform channel width and gradient. Sedimentation could occur in the centre of the river.

6.2.3 Combination of Revetments and Spurs

The disadvantages of spurs with the danger of overall instability and reduction of the potential land reclamation would not be avoided by combination with revetment.

With both types of protection, attention has to be given to the transition between the protected hard bank and the natural soft bank upstream and downstream, otherwise severe erosion of the natural bank will result.

After weighing the qualitative advantages and disadvantages of the three methods discussed above, it is decided to adopt only revetments for the design of the flood and bank protection works for the River Toorsa at Phuentsholing.

6.2.4 Reclamation Level

The land behind the bank protection works can be used for expansion of the city of Phuentsholing. This land may be filled to different levels, discussed relative to high flood level (HFL):

- Above HFL
- Up to HFL
- Below HFL
- Maintaining present land levels

In comparing the alternatives, the following factors are considered, based on sound engineering principles:

- Loss of reclaimed land
- Cost of filling the reclaimed area
- Foundation of structures on the reclaimed area
- Drainage of the reclaimed area
- Flooding of the reclaimed area

**Loss of land:** Between the hills on one side and the river on the other, an area of land becomes available for reclamation. The maximum area is when the level of the land equals the height of the flood and bank protection. Thus the reclaimed land level should equal the HFL plus freeboard.
Cost of filling: The higher the land level, the more filling is required for reclamation, resulting in additional capital cost. The land as an asset would more than offset this drawback.

Foundation of structures: In all cases, foundations of structures on the reclaimed land should not pose any problems. The non-cohesive material excavated from the river bed will be filled in uniform layers. High rise building foundations would be on piles. With a construction period of 30 months, the area will be naturally compacted by the time the project is completed.

Drainage problems: As the area is a new development, planning and designing the sewer and storm water drainage is straightforward. The sewage and storm water drainage can be laid fully underground. The storm water drainage will be divided into different sections by the natural drainage from the hill slopes to the river. Each section will have its own independent drainage system. The governing level for storm water drains will be their invert level at the river outfall. The higher the land level, the higher the drain invert, with less likelihood of river flood levels backing up the drains on to the reclaimed land.

As the level of reclamation is reduced, there may be a problem of storm water discharge under high flood conditions. Measures such as pumping and flap valves at the outfall and balancing ponds to store the local storm water have to be evaluated.

Flooding of Reclaimed Area: An extreme flood in the River Toorsa may exceed the design standard of once in 50 years, plus the freeboard or safety margin incorporated in the design. The flooding of the reclaimed land could be at the river water level. If the land is at a low level, the depth of flooding could be several metres, whereas with a high land level the depth of flooding will be relatively low.

In the light of the above factors, the merits and demerits of each option are given in the following sections.

6.2.4.1 Filling above HFL

This alternative is shown schematically in Figure 6.6. The advantages and disadvantages are:

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Figure 6.6: Schematic View of Reclamation with Filling above HFL
- Ease in drainage of the reclaimed area
- Safety of structures on the reclaimed area from flooding
- Maximum width of reclamation along the river
- Higher cost of filling and raising the reclaimed ground

6.2.4.2 Filling up to HFL

This alternative is shown schematically in Figure 6.7. The advantages and disadvantages are:

- Normally, storm water from the hill slopes will drain before high flood levels occur in the main river. Given a sequence of severe rainstorms, storm water may coincide with high river levels, leading to drainage congestion and flooding of the reclaimed land.
- The area reclaimed is less than filling to above HFL.
- The cost of filling, procurement of material for filling, foundation works, etc will be high, though less than that of filling above HFL.

![Figure 6.7: Schematic View of Reclamation with Filling to HFL](image)

6.2.4.3 Filling below HFL

Governed by the cost, availability of material for filling, etc, the reclamation level may be fixed at an intermediate level between the existing bed level and HFL. Generally, the problems and disadvantages given for filling up to HFL will be aggravated with the reduction in the reclamation level. The most significant problems are provision of an impermeable embankment core, and removal of water from the protected area.
Since the ground level is below HFL, the protection embankment needs to be impermeable in order to prevent seepage on to the reclaimed land. A clay core is required for prevention of seepage, as shown in Figure 6.8.

![Figure 6.8: Schematic View of Reclamation with No Filling](image)

The drainage of storm water requires pumping and gated outfalls to prevent back flow from the river on to the reclaimed land.

### 6.2.4.4 No Filling

While the capital cost will be considerably less, this option has similar disadvantages to the previous option and is not practical.

The following points have been considered in finalising the design:

- Locally available material for reclamation
- Raising the reclaimed land above the computed HFL
- Provision of only revetment all along both banks, avoiding even short spurs and bed bars
- Special attention to protection works for the transition reach between the existing bank and the new revetment both upstream and downstream of the protection works
- Protection works to have specially designed transitions at the outfalls of the drains, and the drains appropriately designed
- Provision of culverts and bridges on each drain, as required.
- Catch drains between the hill slopes and the reclaimed land to convey storm water to the nearest drainage channel.
In view the above factors, the alignment of the embankment incorporating the natural drains is drawn as shown in Figure 6.9. Some of the smaller drains could be combined. These drains offtake from collector drains along the foot of the hill slopes, and discharge to the river through culverts below the reclaimed land. The number of drains and their design is discussed subsequently in this section.

6.3 Design of Protection Works

Important design aspects are the alignment, top level, top width, side slopes, core material, etc. These are discussed below.

6.3.1 Alignment

The alignment and the section of the bank protection has already been tested on the model and finalised considering smooth, streamlined flow in the river.

6.3.2 HFL profile

The HFL computed in the model for the design flood is taken as the basis for the design of the top level of the river embankment. From the model results, the maximum super-elevation, i.e. the difference between left and right bank water levels across the channel, usually owing to river bends, is 0.5m.

![Figure 6.9: Alignment of Drains and River Protection Works](image_url)
The HFL profile varies from a linear gradient by ±0.7m. This is natural for non-uniform unsteady flow. For ease of construction, an enveloping linear gradient is prepared, including super-elevation.

Freeboard is added to allow for waves washing over the banks owing to wind, eddies, etc during high floods, and as a margin of safety. A freeboard of 1m is taken above the design HFL to obtain the top level of the protection works, and also the level of the reclaimed land.

6.3.3 LWL Profile

The mathematical model analysis indicates an existing trend of bed erosion of the river reach in Bhutan (section 6.4), which will be reduced but not eliminated with the excavated channel. The LWL profile is taken as the lower linear gradient envelope for the minimum water levels over the 11 year simulation period for the design of the top level of the aprons.

6.3.4 Side slopes

The core material for the embankment is the local material available in the river bed. The clay content in the material is negligible, and the cohesion can be taken as zero. Sieve analysis of the bed material indicates that the dominant material is shingle (D50 ranging between 3 to 17mm). In the absence of cohesion, a side slope of 1:3 is adopted. Where applicable, the same 1:3 slope is also adopted for the landside slope.

6.3.5 Berm

The height of the protection works for both right and left bank, measured from the top of the apron to the top level of the protection works, is 6m. Safety of the protection works and the provisions indicated in BIS norms suggest a berm width of 2m at a height 3m from the top of the apron. CC blocks for the horizontal berm will be of the same size as the sloping bank protection.

6.4 Core material

As the reclaimed ground is to be raised above HFL, there will be no landside face to the embankment (Figure 6.10). The locally available riverbed material will be used as core material.

There can be reaches along the bank where raising of the reclaimed land is not feasible due to practical reasons. In this case, a core of a suitable percolation resistant mixture of clay and sand, etc (imported as not available locally) is required for the embankment along that reach.

This clay core should extend 50m upstream and downstream beyond the limits of this reach. The clay core should have top width of 2m at HFL, side slopes of 1:2 and a foundation level at least 3m below the apron level. Geofabric filter should be provided around the clay core for proper drainage of the pore water of the core.
6.4.1 Protection Materials

The protection works are designed to cater for the increased velocity in the river, and provide protection against bank erosion for all flow conditions. The protection comprises a protective armour layer, below which a cushion layer of granular material is provided. Below this cushion layer a permeable geofilter will be provided, followed by a filter layer. The geofabric filter will reduce the loss of fine material from the reclaimed area, under seepage flow. The following paragraphs describe alternative armour materials which are available and could be used for bank protection.

- Some commonly used armour materials are:
  - Stone blocks
  - Stones in crates (wire mesh boxes)
  - Patented types of crates (Gabion)
  - Cement concrete blocks
  - MS steel boxes.

Their merits and demerits are discussed below.

6.4.2 Natural Stone Blocks

Figure 6.10 shows bank protection works carried out with stones. The size of the stones depends on the flow velocities – those for the Toorsa River protection will be considerably larger.

The merits and demerits of the protection works using stone blocks are:

- The irregularity of natural stones can pose a problem of cavities and voids between the stones. Protection of the underlying soils against high velocity currents requires special attention.
- This option has the advantage of flexibility of construction and maintenance.

Figure 6.10: Bank Protection Works using Stones
6.4.3 Gabions

Frequently stones of a suitable size and weight are not readily available, or are costly. Environmental considerations may not permit use of local stone for protection works. As an alternative to natural large size stones, smaller stones are placed in crates made up of MS wire nets so that the whole crate is able to withstand the high velocity currents. Figure 6.11 shows typical protection works carried out using stones in crates. The spurs in the River Toorsa at Phuentsholing sewage treatment plant have this design.

![Figure 6.11: Protection Works using Stones in Crates](image)

The merits and demerits of the use of stones in MS crates are:

- Smaller size stones can be used, which may be readily available from nearby riverbed or stone quarries, making this alternative more economical.
- The wire net boxes are made up of MS steel wire, normally fabricated on site. The opening size of the mesh can is such that the available stones will not pass through.
- Due to flexibility of the wire mesh, the crate can, to some extent, deform in case of settlement occurring in the bed. This helps to protect the bed from the development of scour holes, voids, etc.
- Safety and efficiency of stone crates made up of MS wires depend fully on the strength of the MS wire mesh. If a strand breaks, the size of the opening increases, and the stones are sucked out from the broken crates. Damage and subsequent loss of crates thus becomes certain.
- The MS wire is susceptible to corrosion, endangering the wire crate. The sediment load carried by the river flow during floods creates a continuous abrasion on the wire net and
damages the wire. Breaking of the wire and subsequent damage could result in total collapse of the structure.

6.4.4 Patented Crates

In order to reduce corrosion of the wire net, abrasion of the wire and subsequent damage, patented wire crates are available in the market. Hydraulically, there is no difference in the overall performance of ordinary MS wire crates and the patented types. However, the wire used for the crates is corrosion and abrasion resistant by patented methods. The cage of the crate is also made stronger by pre-fabricating the crates with strong joints, etc. While there is an advantage of ease of construction and longer life, the fabrication involves a higher cost.

6.4.5 Cement Concrete Blocks

Instead of natural stones, cement concrete blocks can be used for the protection. Normally, the blocks are cast as cubes. Figure 6.12 shows protection works using cement concrete blocks, with a staggered layout. Figure 6.13 shows concrete blocks being cast at their final location on the site. Layers of granular filter are laid below the blocks being cast.

The advantages of the use of cement concrete blocks for bank protection works are:

- Constructed from locally available material.
- Due to long life of concrete, the protection works are virtually permanent.
- Cubes can be made of a suitable size.
- Due to uniformity of material, voids between the blocks are avoided, making the surface more uniform and smooth.
- The surface of CC blocks is hard and resistant to weather action and against abrasion during floods due to floating debris and sediment carried by the flow.
Casting of CC blocks is possible close to the site, and the cost of transportation is reduced.

While the disadvantages are:

- Availability of cement of suitable quality and in sufficient quantity is a crucial aspect of construction.
- Environmental problems due to cement dust pollution need to be guarded against.

6.4.6 MS Steel Boxes

As an alternative to CC blocks and stones in crates, a combination of the two offers greater durability and strength. Crates are formed using MS steel angles and the six sides are made by cross bars. The crates are hard packed with graded stone. Figure 6.14 shows the stone crates manufactured from MS angles. Since their specific gravity is lower than concrete blocks, they need to be of larger dimensions.

For the present project, surface protection works with CC blocks are proposed. As an alternative, the patented method of protection using gabions may be considered.

![Image: Steel Frame Crates and Stones (in process of fabrication)]

Figure 6.14: Steel Frame Crates and Stones (in process of fabrication)

6.5 Filter Material

The fundamental purpose of a filter is to facilitate the passage of water from the surface to the bed of the bank or bed, at the same time preventing movement of the subsoil. Filters provided below the protective surface are of two types, graded filter and geo-fabric filter.

Graded filters are traditionally used below revetment and protection works. The material used in the granular graded filters is normally durable. The filter material has good surface contact with both the sub-soil and the protection works. Under gradually changing conditions of water level and slow movement of ground water, the graded filter may be “self healing”.

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Graded filters require strict quality control in design and execution. Procurement of suitable material, and maintaining the desired uniformity can be a problem. The quality of the final product is not certain. Graded filters of greater thickness show a spreading effect, causing damage to the protection works on top.

The design of a graded filter depends upon many factors, which are site specific. The designer has latitude in the design of the graded filter, e.g. the total filter, permeability of individual layers, etc. The IS code No 9429 is followed for the design of graded filters. Given a high degree of flexibility available in the design, the designer can tackle each case separately.

Difficulties in procurement of suitable material, high quality control for the filter material, difficulties in placement at site, extreme care and strict supervision required during construction, etc are the main difficulties in providing a graded filter.

6.5.1 Geofabric filter

Geotextiles are textile fabrics made up of polymers, and are permeable to water. The fine holes or pores in the geotextile allow the fluid to flow through the material. Due to the high tensile and warp strength of the geotextile, the geofabric filter has an advantage in case of uneven settlement of small magnitudes. However, in case of significant settlement, damage to the filter is certain, and difficult to repair.

Comparatively, the design and construction of geotextile filters are simpler. The concept of geotextile filters is relatively new. Various materials are used and processes followed in manufacturing geotextiles, resulting in a range of physical, hydraulic and mechanical properties.

The mechanical properties of geofabric filters are durability, tensile strength, puncture strength, tear strength and frictional properties, etc. Durability aspects are deterioration due to oxidation, chemical attack by acids and alkaline materials found in soil and water, etc. The hydraulic properties of the geotextile influence its ability to function as a filter or drain. The most important hydraulic properties are the size and distribution of pores and water permeability. Ease of laying the filter at site and its effective and efficient performance over a long period are the most important advantages, which make geotextiles the most suitable as filter material below the CC blocks.

6.6 Design Parameters

Figure 6.15 shows a typical layout of the bank protection works for the project, showing the key components. This section deals with the design and sizing of the different component of the bank protection work.
6.6.1 Thickness of Pitching

The literature gives many relations for the design parameters using the hydraulic parameters as the basic input. These are evolved either theoretically or statistically. Normally, the relations are applicable for the conditions for which they are evolved, e.g. for the upper reaches in mountain, sub-mountain, alluvial plains, lower reaches, etc.

As the design velocities are high, the corresponding weight of the stones is high. Concrete blocks of suitable size are proposed. Taking the specific gravity of concrete as 2.4, the equivalent size of the CC cube is calculated, and this is taken as the thickness of pitching. Computations are made for the three sets of design parameters indicated in section 6.1.1 on hydraulic design parameters. The results are shown in table 6.2.

Figure 6.15: Layout of typical Bank Protection Works

From the above relations the results applying the BIS code are higher and those computed by Pillarczyk relation are on the lower side. The results of Isbash relation lie between the two. The Isbash relation is theoretical and found satisfactory over a wide range of velocities and specific gravities.

As large size stones are required for the protection works, concrete cubes are proposed for the protection works. To maintain uniformity and ease of construction, only three sizes of CC cubes are proposed. The sizes determined are shown in the last row of table 6.2.
As a first step, the depth of scour is calculated based on the intensity of discharge using various relations given by the BIS code 8408, as followed by Indian Railways. Further computations are made to determine the width of aprons in the same reaches. Table 6.3 shows the depth of scour and corresponding width of aprons.

Table 6.3: Depth of Scour below HFL and Width of Apron (m)

<table>
<thead>
<tr>
<th>Relation</th>
<th>Depth of Scour</th>
<th>Width of Apron</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reaches along left bank</td>
<td>Reaches along right bank</td>
</tr>
<tr>
<td></td>
<td>(chainage m)</td>
<td>(chainage m)</td>
</tr>
<tr>
<td></td>
<td>0 to 1867</td>
<td>1867 to 6412</td>
</tr>
<tr>
<td>Isbash</td>
<td>6.19</td>
<td>6.6</td>
</tr>
<tr>
<td>BIS No 8408</td>
<td>4.6</td>
<td>5.2</td>
</tr>
<tr>
<td>Komura</td>
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<td>0.62</td>
</tr>
<tr>
<td>Lacey</td>
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</tr>
<tr>
<td>Pillarczyk</td>
<td>0.48</td>
<td>0.53</td>
</tr>
<tr>
<td>Inglis</td>
<td>1.08</td>
<td></td>
</tr>
</tbody>
</table>

To maintain uniformity and ease of construction, three apron widths are proposed, as shown in the last row of table 6.3. These can be suitably adjusted to accommodate the actual number of CC blocks.
The top level of the CC block aprons should be at LWL (discussed earlier in this section). The river bed has to be excavated to lay the apron. As far as possible, the apron should be laid on a horizontal bed.

6.6.3 Geofabric Filter

Important sub-parameters required for the design are the type of filter, and cushions above and below the filter. These are discussed below.

6.6.3.1 Cushion

The riverbed material is relatively coarse and does not contain finer material such as silt. The cohesion of the bed material is nearly zero. The cushion material over the filter cloth will help avoid damage to the filter cloth during construction. It is suggested that a mixture of coarse and medium sand of grain size 0.15 to 0.3mm, and thickness 8 to 10cm is provided above and below the filter cloth. The cushion material is required to absorb any shock and stress during construction. Once the top protective layer is in position, the cushion does not have a role.

6.6.3.2 Pore size of filter cloth

D10 of the bed material ranges between 0.2 and 0.4mm in all the samples. A geofabric with a pore size (D50) of 0.15mm will be sufficient avoid dislodging of finer particles. Detailed design is normally required when the base soil is made up of fine sand or clay. In the present case, the bed and bank material contains mainly coarse to very coarse material.

6.6.3.3 Toe wall

Provision of a toe wall between the slope pitching and aprons is required. In the present case, the toe wall can be made up of concrete blocks. The size of the blocks should be the same as that used for the slope pitching and aprons at that section (see Figure 6.15).

The toe wall should be constructed with three layers of CC blocks. The top layer should be of one block, the second layer of two blocks and the third layer of three blocks. The blocks may be keyed for firm connection between the blocks. This will help avoid sliding due to side thrust. While no separate foundations are proposed below the toe wall, a filter layer may be provided below the toe wall.

6.6.3.4 Special Locations

The above discussion and the proposed parameters are for the overall protection works. Separate considerations are required at specific locations, as below:

6.6.3.5 Treatment for drains

All existing hill slope streams should be channelled across the reclaimed land to allow the water and sediment to pass to the river. The side slopes of the drainage channels should be pitched with
concrete blocks of size 0.5m. Aprons of width 2m should be provided. If the gap between the aprons on both sides, ie the unprotected bed width of the drain, is less than 2m, the whole bed width should be protected. The streams running down the hill slopes are steep, and sufficient additional cross section area should be provided for the flow through the reclaimed land.

The top level of the drainage channel protection works should be such that the high discharge of the drains will not spill on to the reclaimed ground. A freeboard of 1m should also be provided for this protection.

6.6.3.6 Curvatures at corners

Sharp bends in the alignment of protection works should be avoided, as these would be a source of eddies causing damage to the protection works, resulting in higher maintenance costs. A radius of curvature of at least 30m should be provided where the drainage channels discharge to the river, and at acute bends or sharp corners at any other location.

6.6.3.7 Transitions

The purpose of a transition is to avoid any kink in the stream flow due to the protection works. This would be a source of eddies and subsequent damage to the protection works.

Transitions should be provided at the upstream and downstream limits of the protection works on both banks. The width of the aprons should be reduced at a rate of 1:8 in plan upstream and 1:10 downstream. The ends of the protection works should be anchored to the banks. The anchor should be of the same design as that of the toe wall, and aligned along the sloping bank. CC blocks of 0.5m may be used for this purpose.

A similar transition should be provided wherever the width of the apron changes within the protection works. The size of the CC blocks should be same as that provided at that location.

Connecting different filling levels: over the length of the reclamation, fill levels may be different in the parts of the same sector. At such locations, a minimum slope of 1:3 should be maintained to connect the different levels. This slope is consistent with the properties of the soil.

6.6.3.8 Sewage Treatment Plant

The protection works continue downstream of the Dhote Khola to protect the sewage treatment plant, following the above design considerations.

6.7 Conclusion on Flood Protection and River Training Work

It is very much essential that river training measures carried out should be simultaneously with the land reclamation plan including excavation of the river bed and revetment of the structure.

The mathematical model studies of the complex morphological processes in the river have provided the key hydraulic parameters for the design of the flood and bank protection works. These parameters
are water levels, flow velocities and bed levels resulting from potential scour through the protected reach from Phuentsholing upstream.

Different means of flood and bank protection works were considered, ie a series of groynes or spurs jutting into the river from each bank, a smooth pitched revetment along both banks, and a combination of groynes and revetments. The revetment is favoured as it gives a smooth streamlined flow conditions, and the width occupied by the river channel is considerably less.

The volume of material excavated from the river bed to form the new river channel, approximately 300m wide by 2m deep, will be placed behind the bank protection works. A small quantity of additional material will be imported to raise the level to the top of the bank, making the land behind the embankment more or less plane, and safe from flooding.

The embankment works protect the river banks from erosion and constrain the river within the protected banks, given also that constraining the river width increases the flood flow velocities. Basically the works have to resist high flow velocities, and prevent undermining by scour in the river bed. Various protection forms were considered: large natural stone blocks, smaller stones in wire mesh boxes (gabions) and large concrete blocks. The latter were selected as they can be formed on site from local aggregate, present a relatively smooth surface to the river flow, and are resistant to abrasion which can cause gabions to collapse.

The blocks are placed at a 1:3 vertical:horizontal slope along the river bank, and to a width up to 7m from each bank over the river bed, corresponding to the maximum scour depths predicted by the mathematical model. Where deep scour holes develop, the blocks fall into the holes and prevent further deepening and undermining of the bank protection works. The size of the concrete cube blocks varies from 0.5 to 0.7m, depending on the predicted velocities at that section of the bank.

Special consideration is given in the design to the transitions from natural to protected bank upstream and downstream, where an erosive attack from the river can outflank the protection, and to conveyance of flood flows from the drains running down to the river from the hill slopes behind the protected area.