Planning and Design of Drainage in Hilly Area
A Conceptual Guideline

Urbanization need not be Unfortunate Reality Built Against Nature

Urbanization can also be Unique Rationally Built Admirable Nature
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Hilly urban areas of Northeastern part of India are facing multiple hazards in the form of flood, landslide, soil erosion, subsidence and poor-water-quality-issues because of inadequate drainage system. In fact, in some cities unplanned development has created a situation of virtually having no drainage system to drain out the storm water. Many a time drains are constructed in an erroneous way because of lack of proper understanding about the need of safe drainage of both surface and sub-surface flow. Although, standard text book contains design procedure for various components of a drainage systems, a holistic planning and concept of total design is necessary for design of a sustainable drainage system. Therefore, this conceptual guideline for planning and design of drainage system in hilly terrain is prepared, so that a drainage engineer can design the system by considering all important aspects. This guideline provides steps to be adopted for planning drainage system for different kind of hilly urbanizations and also provide design steps for some complex components like step chutes with some typical examples. For design of other standard components a beginner can refer standard text books after making detail planning by following this guideline.

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## CONTENTS

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Introduction to urban expansion in hilly area and drainage concerns</td>
<td>3</td>
</tr>
<tr>
<td>2 Drainage considerations in case of expansion from plains to hill</td>
<td>4</td>
</tr>
<tr>
<td>3 Drainage consideration in case of expansion from ridge to valley</td>
<td>5</td>
</tr>
<tr>
<td>3.1 Consideration for Primary Valley Line</td>
<td>5</td>
</tr>
<tr>
<td>3.2 Consideration for a Secondary Steep Valley Line</td>
<td>6</td>
</tr>
<tr>
<td>4 Some issues that need special consideration for hilly area</td>
<td>18</td>
</tr>
<tr>
<td>4.1 Design consideration of drainage channels, internal common drains</td>
<td>18</td>
</tr>
<tr>
<td>and roadside drains</td>
<td></td>
</tr>
<tr>
<td>4.2 Choice of channel section</td>
<td>20</td>
</tr>
<tr>
<td>4.3 Methodology to design the most efficient channel section</td>
<td>20</td>
</tr>
<tr>
<td>4.4 Need of compound channel section</td>
<td>22</td>
</tr>
<tr>
<td>4.5 Considerations for Culvert</td>
<td>23</td>
</tr>
<tr>
<td>4.6 Desilting mechanisms such as Silt traps and Silt fence</td>
<td>23</td>
</tr>
<tr>
<td>4.6.1 Silt Trap</td>
<td>23</td>
</tr>
<tr>
<td>4.6.2 Silt Fence</td>
<td>24</td>
</tr>
<tr>
<td>4.7 Weep holes</td>
<td>24</td>
</tr>
<tr>
<td>4.8 Consideration for pavement drainage</td>
<td>25</td>
</tr>
<tr>
<td>References and suggested readings</td>
<td>26</td>
</tr>
</tbody>
</table>
Planning and Design of Drainage in Hilly Area: 
A Conceptual Guideline

1. INTRODUCTION TO URBAN EXPANSION IN HILLY AREA AND DRAINAGE CONCERNS

Drainage of a hilly urban area needs to be planned for future giving due emphasis to its expansion pattern. Depending on origin of the residential development and culture of the community, expansion in the hills may take place in two distinct patterns. When people, traditionally living in plains of river valley, starts residing in the hills because of non-availability of affordable land in the plains, then urbanization expands towards hill starting from the plain area. If such expansions take place in an unplanned manner through indiscriminate cutting of the hills it induces several problems in the drainage. Toe cutting made in the process of unplanned expansion adversely affects the slope stability and the retaining wall constructed as remedial measures may in turn adversely affect the subsurface drainage if sufficient weep holes are not provided or if the permeability aspect of the retaining wall is not addressed properly. This increases the slope instability during rainy season. Similarly the exposition of land surface because of vertical and horizontal cutting aggravates the surface erosion process by many folds. Deposition of such eroded sediment inflicts serious problem in the drainage system in the area located downstream of it.

In contrary to the people residing in the river valley area, people of hilly area generally prefer to live in the ridges of the hills. Therefore, the urbanization starts from a relatively flat area available along the ridge line and gradually expands towards the valley. During the process of expanding towards the prime valley line many a time people encroach into the secondary transverse valley line blocking the natural waterways. Obstruction to natural drainage may affect the slope stability adversely with varying severity depending on the geology of the formation. Care should be taken to keep these natural secondary valley lines clear so that natural drainage is not obstructed.

Irrespective of the expansion pattern, because of urbanization in the hilly area, imperviousness of the surface increases and thus leads to high runoff generation. Safe drainage of such high runoff to the ultimate outlet (river or water bodies in the form of lake) always remains a challenging task. Design discharge need to be calculated taking in to consideration the future possible development in the area. Discharge may increase with time primarily due to three factors: 1) increase in building density and paved area, 2) increase in rainfall intensity because of impact climate change, and 3) increase of per capita water utilization because of improved life style and better water supply. Considering these factors, it is advisable to go for an appropriate design of the drainage system, so that system remains sufficient to meet the increasing future demand at least for the next 50 years.

For more detail contact Civil Engineering Department, IIT Guwahati, Email: aks@iitg.ernet.in
Rapid urbanization has led to a considerable stress on the environment. Lack of judicious planning has given rise to a number of problems and their ill-effects experienced have been considerably profound. Some of the hazards that have surfaced over the recent times primarily because of the inadequate drainage system are stated below.

- Flooding, water logging
- Hill slope Erosion
- Landslide and Subsidence
- Traffic problem
- Health hazard

2. **DRAINAGE CONSIDERATION IN CASE OF EXPANSION FROM PLAINS TO HILLS**

In this section some of the general principles are laid down. For detail design of various components one can refer standard text book.

i) Cutting of hills in any form (both horizontal and vertical/inclined) and exposition of bare land should be avoided to the extent possible to resist surface erosion, which affect the drainage system located at downstream.

ii) To avoid hill cutting in a new propose development, the road systems should be first planned and developed. Houses on stilt can then be constructed by providing approach to the individual houses from upstream side of the hill ground in natural slope. Care should be taken while aligning the road to have minimum cutting and necessary measures for stability of road side slope should also be taken up.

iii) In case of a road passing through downstream face of a plot, stilt house can be constructed with approach stair located in the front of the house.

iv) In cases, where vertical cutting is unavoidable, house may be constructed in different layers with floors of different rooms at different level. This will help reducing the height of vertical cutting. Such houses can have internal steps to connect different floors.

v) Height or depth of permissible vertical cut should not only be decided based on the cohesive property of the soil, but also by considering behaviour of the soil in saturated un-drained condition or under seepage condition, i.e., by considering seepage pressure.

vi) For safe drainage of such housing area catch drain (in the form of contour drain/graded drain) should be constructed on upstream of the built-up area to divert the upstream storm water runoff away from the housing area. Upstream face of such contour drain
should be made permeable by providing weep hole and the downstream face and the base should be made impermeable.

vii) Provision of adequately sized pervious drain in the form of grass waterway or boulder waterway should be provided to carry the diverted water downhill safely. The pervious drain running downhill should preferably be placed along a natural drainage line wherever possible.

viii) For these manmade drains, constructed across the slope to carry water downhill, both the vertical sides should be made permeable by providing weep holes or flexible gabion structure depending on the size of the drain. Basically, the bed and sides should be protected against erosion of flowing water while maintaining free sub-surface drainage to avoid failure of vertical sides.

ix) Size of the grass waterway or boulder waterway should be calculated by considering contributing area of the entire watershed and also by considering the fact that time of concentration will change (generally reduce) with increase of drainage density because of artificial drains. Future landuse pattern and management measures should also be considered for calculating design peak discharge.

X) Detail procedure for calculating design discharge is given under section 3.2 of this report.

3. DRAINAGE CONSIDERATION IN CASE OF EXPANSION RIDGE TO VALLEY

3.1 Consideration for Primary Valley Line (generally 2\textsuperscript{nd}, 3\textsuperscript{rd} or higher order drainage line)

With increase in discharge, the regime state of a primary valley line gets disturbed and the primary valley line starts undercutting to achieve a new regime state. This may lead to failure of a small portion of slope close to the stream. Such small toe failure may add instability to a critically stable slope. By the term \textit{critically stable slope} we are referring to those hill slopes which, because of saturation during the rainy season, remains marginally stable under the overburden of traffic and building load. Therefore proper measures should be taken to drain out the increased discharge through the natural primary valley line. Following approach is suggested:

i) The bank line of such channel should be protected by retaining wall made of rock block or gabion box depending on the steepness of the side slope.

ii) Sufficient weep holes should be provided in case of concrete/masonry retaining wall.

iii) Width of such lined channel should never be reduced from its existing natural width.
iv) For a channel carrying debris and having moderate slope (say $10^\circ < S_b < 30^\circ$) intermediate sill projecting from the bed can be constructed to reduce the flow velocity. Deposition of debris on upstream of such sill will gradually convert the channel into a stable stepped channel.

v) For a channel having thick natural cover of boulder (which is found in most of the natural channel) no additional measures is necessary for protecting against scouring.

vi) In absence of a boulder bed in a moderate slope discrete concrete block may be placed to prevent scouring under the impact of high stream flow velocity while keeping the bed permeable to allow infiltration.

vii) In case of a steep channel (say $S_b > 30^\circ$) drop structure with a stilling basin needs to be constructed. Drop height $(H)$ required can be calculated by using the relation.

$$H = (S_n - S_b)L$$

Where $S_n$ = existing bed slope, $S_b$ = proposed permissible bed slope and $L$ = length of the slope. $S_n$ can be calculated by using Manning’s formula based on the permissible velocity.

### 3.2 Consideration for a Secondary Steep Valley Line (generally 1st or 2nd order drainage line)

These valley lines are generally of very steep slope ranging from $30^\circ$ to $60^\circ$ and of narrow width ranging from 0.50m to 2.00m. As the slope approaches $90^\circ$ the waterway gets converted to waterfalls. Water, in such channels, flow with very high velocity. High kinetic energy of such flow can cause severe scouring at unprotected downhill portion. Scouring caused at toe of the slope by such flow may promote land slip. In hilly area it becomes difficult to get sufficient space for construction of a stilling basin to dissipate such high kinetic energy. Therefore, for long slope, where reduction of slope is not possible and where dissipation of energy by providing a stilling basin at downstream of the drop structure is not practically feasible, stepped chute can be used to dissipate a major part of the energy. Such stepped chute can be followed by a small scale stilling basin to dissipate the remaining energy before releasing the water in to the primary valley or to another steep channel reach. Inadequate design of such steep drainage line may cause serious damage to the roads and culvert which they cross on their way downhill. Therefore, such channels need to be designed by applying state-of the art knowledge and considering future extreme discharge condition. The design discharge may be estimated based on the observed historical rainfall record, possible extent of urbanization and impact of climate change. Of course due consideration should also be given to the economy of the country while deciding design discharge. Following are some of the important aspects that need to be considered for design of such steep narrow channel.
i) Watershed delineation should be done with utmost care to have the drainage area up to inlet of the channel and Rational method, though simple, can be used for estimating the design discharge, provide the watershed area does not exceed 200 acre. In case of large watershed it should be subdivided into sub-watersheds of smaller area. As the surface flow will continue to add to the drainage channel downstream, design discharge for all critical sections need to be calculated accordingly. Rainfall intensity to be used for design purpose need to be estimated by referring region specific I-D curve. An example is provided to illustrate watershed delineation as shown in Figure 1.

![Figure 1: Delineation of a hilly area to the sub-watershed level](image)

ii) Based on the record of continuous automatic rainfall recorder, intensity-duration frequency curve need to be prepared. Many a time because of steep slope of the terrain and because of quick drainage of water over a paved area and through a lined drainage network, time of concentration become very small (say about 5minutes or even less). Erroneous extrapolation of I-D-F curve for such small duration may give extraordinarily high intensity, which may not have practical significance. Therefore, I-D-F curve derived from a reliable automatic rainfall recorder should be used. Computation of discharge for a hilly area of Guwahati is presented below as an example.
Calculation of peak discharge

The peak discharge from an area is calculated by using the Rational Method:

\[ Q = \frac{CIA}{3600000} \]  

Where, \( Q \) = peak discharge (cumec), \( C \) = Runoff Coefficient (dimensional less), \( I \) = Rainfall Intensity (mm/hr) corresponding to duration = time of concentration, \( A \) = Area (sq m).

An example problem for discharge calculation

A micro watershed in Guwahati, a city located in the North-eastern part of India was selected. Watershed delineation and stream digitization were carried out in Arc Swat using the ASTER Digital Elevation Model (DEM) Data and a sub watershed of 0.17 sq km was considered for the model application. The slope map was developed using 3D analyst of ArcGIS 9.3 and topographic information like area, slope, landuse and suitable EMP area were extracted. The soil map for the area has been collected from Assam Remote Sensing Application Centre (ARSAC) and the soil types for the plots are determined from the map. The study area is shown in Figure 2.

Runoff Coefficient (C): The runoff coefficients for various land cover are considered based on available literatures (Sarma et al 2005; Iowa Storm water Management Manual, 2008) and are given in table below. For calculating the C value for a heterogeneous land cover, weighted C value \( (C_{\text{weighted}}) \) should be used.
Table 1: C factor for different land covers

<table>
<thead>
<tr>
<th>Land Cover</th>
<th>Runoff Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>High density built up area</td>
<td>0.9</td>
</tr>
<tr>
<td>Built up area with rainwater harvesting system</td>
<td>0.5</td>
</tr>
<tr>
<td>Medium Residential</td>
<td>0.40</td>
</tr>
<tr>
<td>Low Residential</td>
<td>0.22</td>
</tr>
<tr>
<td>Forest</td>
<td>0.2</td>
</tr>
<tr>
<td>Barren land</td>
<td>0.5</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.2</td>
</tr>
<tr>
<td>Garden</td>
<td>0.3</td>
</tr>
<tr>
<td>Pond, lake</td>
<td>0</td>
</tr>
</tbody>
</table>

Rainfall intensity: To determine the rainfall intensity that generates peak flow in the plots, time of concentration for each of the plot is first determined by using the Kirpich formula. Then by taking the duration = time of concentration, the intensity of the designed rainfall is determine by using the intensity duration curve developed by Sarma et al. (2004) for the area under study.

\[ I = 51.307e^{-0.2179D} \]  \hspace{2cm} (2)

Where \( I \) = Intensity (mm per hr); \( D \) = duration (hr)

Table 2: Summary of the plots

<table>
<thead>
<tr>
<th>Plot</th>
<th>Area (Sq m)</th>
<th>Length of main channel</th>
<th>Slope</th>
<th>Calculated time of concentration (min) using Kirpich formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55665</td>
<td>256.80</td>
<td>16.32</td>
<td>0.19</td>
</tr>
<tr>
<td>2</td>
<td>73971</td>
<td>265.58</td>
<td>20.68</td>
<td>0.18</td>
</tr>
<tr>
<td>3</td>
<td>42154</td>
<td>360.14</td>
<td>15.27</td>
<td>0.25</td>
</tr>
<tr>
<td>4</td>
<td>2742</td>
<td>85.21</td>
<td>2.5</td>
<td>0.17</td>
</tr>
</tbody>
</table>

By using equation 2, the intensities of the design rainfall for the plots are obtained as 50 mm/hr.
Table 3: Calculation of peak discharge for different scenarios for the four plots

<table>
<thead>
<tr>
<th>Plots</th>
<th>Discharge (Case A)(^*) (in Cumec)</th>
<th>Discharge (Case B)(^**) (in Cumec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.15</td>
<td>0.54</td>
</tr>
<tr>
<td>2</td>
<td>0.21</td>
<td>0.72</td>
</tr>
<tr>
<td>3</td>
<td>0.12</td>
<td>0.41</td>
</tr>
<tr>
<td>4</td>
<td>0.01</td>
<td>0.03</td>
</tr>
</tbody>
</table>

\(^*\) Plots with natural land cover only (mix forest) (with \(C_{\text{weighted}} = 0.2\))

\(^**\) Plots with dense residential area (with \(C_{\text{weighted}} = 0.7\))

iii) A long steep slope needs to be broken up by introduction of contour drain and stilling basin so that the total drop (\(H_r\)) does not become too high. In absence of an accepted national guideline and also considering possibility of various site specific constraints, a slope length in the order of 20m to 30m can be used for practical purpose. More the length and steepness larger will be the size of stilling basin at downstream of the section. In an existing urban set-up the road side drain on the hill side can be developed to serve the purpose of the contour drain. Even in a proposed urban development, road side drain can be used to collect water from the upper catchment.

iv) The size of the contour drain can be designed by considering flow volume generated from the upstream catchment and considering a negligible channel slope to carry that discharge. To avoid clogging of these contour drains by sediment or other debris, upstream flow should be allowed to enter these drains through a sediment and debris trap. Provision of cleaning of these drains should also be kept as extreme rainfall beyond the designed one can cause clogging of the drain with higher sediment yield.

v) In case of non availability of land, stilling basin can be designed inside the culvert of a wide road to dissipate the kinetic energy of water when it crosses the road through a nearly horizontal culvert of sufficient length (length equal to base length of the road). However, preferably a stilling basin just at downstream of the slope and upstream of the road should be constructed. Thus the water from the road culvert will be approaching downstream steep channel as a subcritical flow and will emerge in to the stepped chute by forming a draw down profile. Thus the depth at upstream of the stepped chute can be considered to be critical depth or brink depth and the energy can
be calculated accordingly. Potential energy component of the total head being very high at inlet of the stepped chute with respect to the outlet, minor error in calculation of depth at inlet of the stepped chute is acceptable as specific energy at inlet is generally not more than 5% to 10% of the total energy head at upstream with respect to the outlet of the stepped chute.

vi) Though different investigators (Moore (1943), White (1943), Rand (1955), Gill (1979), Chamani (1955), Chanson et al. (2002), Rajaratnam and Chamani (1995), Chinnarasri and Wongwis (2006), Chamani et al. (2008)) have forwarded several conceptual models for flow process over a drop structure and stepped chute, a purely analytical model for determining energy loss in a stepped chute are yet to be established. Energy losses in stepped chute can basically be considered to be contributed by the several processes such as:

a. Direct impact of vertically falling water with the channel bed,

b. Turbulent mixing of water jet with the pool of water accumulated at each of the drop,

c. Frictional loss because of flow over rough surface,

d. Generation of a shear layer between the water jet and the rotating pool,

e. Momentum transfer between skimming jet and rotating pool.

f. Air entrainment and mixed air-water flow

g. Formation of full or partial hydraulic jump.

vii) As analytical computation of energy losses in most of the above processes are difficult, empirical relationship developed based on experimental studies are generally used for computing relative energy loss, i.e., ratio of energy loss ($E_\text{i}$) to the energy at upstream of the stepped chute ($E_\text{0}$).

viii) With the increase of relative critical depth, i.e., ratio of critical depth ($d_c$) to step height ($h$), the flow pattern changes from i) free falling nappe with air pocket, to ii) Nappe with flow recirculation in pool, and then to iii) skimming flow supported over circulating pool (Chinnarasri and Wongwis 2006). As these relationships were derived empirically, their validity is also limited within a upper and lower bound of length-height ($l/h$) ratio of the steps. Depending on the flow type some of the energy loss
processes mentioned above becomes dominant. Therefore, different relationships need to be used for computing relative energy loss.

ix) Experimental study (Chinnarasri and Wongwises 2006) has also confirmed that step with small upward inclination (10° to 30°) or a sill at the end of each step can increase energy dissipation in the stepped chute. Number of steps also influences the energy loss.

x) Based on the above following steps are suggested for design of a stepped chute:

a. Determine the design discharge by rational formula considering future development and climate change. Based on the study carried out by Vinnarasi and Sarma(2012), Deka and Sarma (2010) and Kumar and Sarma (2010) on impact of climate change on rainfall of Brahmaputra Basin, an increase of intensity by 20% may be considered logical. Generally two years return period is used unless there remains a serious threat to some important structure.

b. As the formula for stepped chute are developed for a subcritical flow approach, uniform flow and critical flow for the computed discharge can be computed and compared to ensure that the approaching flow in subcritical ($y_c > y$). Alternatively Froud's number can be computed to ensure that $Fr < 1$. In case this condition is not satisfied stilling basin at upstream of the stepped chute can be modified to achieve this.

c. Consider width of the channel depending on the width of the natural drainage line and steepness of the side slope. Increase of width beyond natural available width may call for construction of higher and stronger side wall.

d. Provide weep holes in the side wall so that high seepage pressure may not cause damage to the side wall of the drain.

e. Consider a trial step size, i.e., length ($l$) and height ($h$) of the steps within the limit for which the experimental observation are considered valid.

f. Calculate relative critical depth ($d_c/h$) and compare the same with the limiting values of relative critical depths that indicate the type of flow, i.e., to know if the flow is of nappe type, skimming type or in transition.

g. Compute relative energy loss using appropriate equation or the equations of the given below:

\[ E_L / E_0 = \left( \frac{dc}{h} \right)^\zeta \]  

For more detail contact Civil Engineering Department, IIT Guwahati, Email: aks@iitg.ernet.in
where \( \eta \) and \( \zeta \) can be computed by applying equation given by Chinnarasri and Wongwises 2006 for different step geometry. Initially horizontal step may be tried. Care must be taken about the scale factor to ensure applicability of the equation in the prototype. In case the flow is expected to be of skimming type more emphasis should be given on the scale effect. Pegram et al. (1999) gave that the result of model can be applied with confidence if the scale is not more than 1:20 of the experimental set up. In case of larger scale more conservative design will have to be adopted to compensate for the uncertainty of the scale effect. Experimental setup of Chinnarasri and Wongwises 2006 had a maximum \( H \) (total head) of 2.12m and step height of 0.106m for a slope of 45°. Therefore, these formula or graph can conveniently be applied for a prototype having \( H \) in the order of 40m and step height in the order of 2m.

h. Another approach of determining energy loss is by computing \( E/H \) as a function of non-dimensional drop number \( (q^2/gH) \). (Chinnarasri and Wongwises (2004).

i. It is suggested that Energy loss may be computed by both the approach and the lower value should be adopted to be on conservative side.

j. Flow velocity at outlet of the stepped chute can be computed approximately by using the non dimensional relationship given by Chinnarasri and Wongwises (2004) between drop number and \( V/(gH)^{1/2} \).

k. Alternatively downstream depth \( (d_f) \) can be calculated by using the non-dimensional relationship between \( d_f/h \) and \( d_f/h \) as given by Chamani et al. 2008 provided value of \( d_f/h < 0.8 \)

l. In case the design velocity is found within permissible limit, the trial design is considered okay.

m. In case the design velocity is higher than the permissible velocity then different step geometry (inclined step with sill) and different type of stilling basins can be tried. Attempt can also be made to increase relative energy loss by increasing number of steps.

n. Based on the available energy at downstream of the stepped chute, an energy dissipater in the form of stilling basin need to be designed. A simple expanding stilling basin with a sill at the end may also become sufficient depending on the residual energy.

o. In case of not obtaining a safe design, one may try to divide the accumulated flow in two or more part by adjusting slope of the upstream contour drain and more than one stepped chute can be provided to carry the accumulated upstream flow downhill safely.
An example showing preliminary design of a stepped chute to be provided in an actual site in Kohima, Nagaland is presented below to show how the hydraulic design of a stepped chute can be carried out. Discharge computation has not been shown, as standard established procedure as indicated above can be used for the purpose. Design has been done for the portion between two road levels.

**Example problem of stepped chute**

A drain need to be designed for carrying discharges as shown in the Figure 3 through a channel whose longitudinal profile is shown in the Figure-3. This site was surveyed by Urban Development Department of Nagaland in presence of Prof. A.K.Sarma of IIT Guwahati, and Mr. V. Chourasia and Mr. D. Chand of MoUD during 13th May to 15th May 2011.

![Figure 3: Longitudinal Profile of the Example Site](image)

A typical section showing different components needed to carry the flow safely is shown in the Figure 4.

![Figure 4: Typical Components of the Drainage System for Secondary Drains](image)
Step 1: Checking approaching flow condition

\( y_n \) is calculated by approximate formula given by Das and Barr. Bed slope of the culvert crossing the road both before the stepped chute and after the stepped chute has been assumed as 0.005, as this will be almost horizontal. As the drain and the culvert bed and surface will be made of stone masonry, Manning’s roughness coefficient (\( n \)) has been considered as 0.025. Based on the site condition width \( B \) of the rectangular channel has been considered as 1.00m.

<table>
<thead>
<tr>
<th>Table 4: Calculation of different parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>3.23</td>
</tr>
<tr>
<td>4.33</td>
</tr>
</tbody>
</table>

As \( Fr \leq 1 \) the flow is subcritical thus the results of experimental study carried out by different investigators as mentioned earlier are valid and the flow will get released to the stepped chute located downstream with critical depth.

![FIGURE 4 (a) : SKIMMING (HOR) FIGURE 4 (b) : SKIMMING (INCL) FIGURE 4 (c) : SKIMMING (HOR + SILL)](image)

Step 2: Calculation of Total Energy (\( E_0 \)) before entering the stepped chute

Total Energy just at upstream of the chute = \( E_0 \) = \( H_t \) + \( y_c \) + \( V_c^2 \)/2\( g \). In the present case it is 11.67m for the first stepped chute.

Step 3: Trial step dimension and checking of flow regime

Trial step dimension has been assumed as 1m x 1m. Thus \( l/h \) is 1.00 and as given by Chinnarasri and Wongwises (2004)-
For $0.10 = h/l = 1.73$, the minimum critical flow depth required for the onset of skimming flow on horizontal and inclined steps is

$$\frac{d_c}{h} = (0.844 + 0.003\theta) \left(\frac{h}{l}\right)^{-0.153 + 0.0040} \quad (4)$$

Where, $h$ is the step height and, $l$ is the horizontal length and $\theta$ is the inclination of the step.

The maximum critical flow depth for the nappe flow regime is

$$\frac{d_c}{h} = 0.927 - 0.005\theta - 0.388 \quad (5)$$

For $h/l = 1.00$ skimming flow initiates in a horizontal stepped chute for $d_c/h = 0.844$, therefore the flow in the chute will be skimming flow and the curve or equations need to be used accordingly. Skimming flow over horizontal, inclined and horizontal with sill are shown in Figure 4a, 4b and 4c.

**Step 4:** Calculation of Independent Non-Dimensional terms

Following non-dimensional terms are calculated:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Expression</th>
<th>Value for the first Chute</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Drop Number:</td>
<td>$q^2/gH_t^3$</td>
<td>1020.05 (Approx 1000)</td>
</tr>
<tr>
<td>2. Relative critical depth:</td>
<td>$d_c/h$</td>
<td>1.02</td>
</tr>
<tr>
<td>3. Slope:</td>
<td>$\tan^{-1}\left(\frac{(R L_1 - R L_2) / \text{Distance}}{x \times 360/3.1416}\right)$</td>
<td>26.88° (Approx. 30°)</td>
</tr>
</tbody>
</table>

**Step 5:** Derivation of required parameters from Graph (Chinnarasri and Wongwises 2004) and calculation of remaining energy at bottom

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value for the first Chute</th>
<th>Remaining energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. $E_u/E_o$</td>
<td>0.72</td>
<td>3.27m</td>
</tr>
<tr>
<td>2. $E_t/H_t$</td>
<td>0.70</td>
<td>4.57m</td>
</tr>
<tr>
<td>3. $V_t/(gH_t)^{1/2}$</td>
<td>0.82</td>
<td>4.43m</td>
</tr>
</tbody>
</table>

Thus remaining energy at bottom of the first chute from 14.64m (drop from culvert is neglected) to 4.54m can be considered as 4.5m.
Step 6: Depth and froud number at outlet of first chute

Empirical formula available cannot be applied with confidence, as $d_h > 0.8$. Therefore, this depth has been calculated based on $V$ and unit discharge $q$. These values have been found as:

$Y_1 = 0.4$ and $Fr_1 = 4.15$ which corresponds to formation of an oscillating jump.

$Y_2 = 2.13$ for a free jump which required an approximate length of 12m and at downstream of jump velocity $V_2$ will become 1.52. However, in the present site it will be difficult to get a length of 12m formation of the jump. Stilling basin with sill will also require more length then available.

Therefore, bed with has been increased to 1.5 and 2.0m respectively and trial calculations has been made. It has been found that with a width of 1.5m residual energy drops down to 4.0m and with 2.0m bed width it drops down to 3.6m and tail water depth of free jump become 1.5m with a velocity of 1.1m

Based on the result obtained above, 2.00m width has been suggested if site condition permits and a small stilling basin of 2m length with sill height of 1m is suggested which will force a submerged hydraulic jump and water will emerge with permissible energy and velocity. The sill can also be made folding type to make the channel efficient and self cleansing during low flow period.

In case providing 2m width become difficult due to practical constraints, 1.5m width channel with inclined steps (angle 20°) can be provided.

Step 7: Design of lower portion of drain having slope 0.3

Next series of stepped chute from RL of 4.5m to zero level for a length of (17.5-2)m can be designed to have permissible velocity and froud’s number by providing necessary numbers of step and drop height to moderate slope. For the discharge of 4.33 for this section and with bed width 2m, it was found that a slope of 0.01 is sufficient to have permissible velocity.

<p>| Table 5: Calculation of permissible slope |</p>
<table>
<thead>
<tr>
<th>Q</th>
<th>B</th>
<th>$n$</th>
<th>$S_b$</th>
<th>$y_0$</th>
<th>$V$</th>
<th>$y_c$</th>
<th>Fr</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.33</td>
<td>2</td>
<td>0.025</td>
<td>0.01</td>
<td>0.90</td>
<td>2.41</td>
<td>0.78</td>
<td>0.81</td>
</tr>
</tbody>
</table>

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Table 6: Calculation for drop height and length

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing slope $S_0$</td>
<td>0.3</td>
</tr>
<tr>
<td>Proposed new slope $S_n$</td>
<td>0.01</td>
</tr>
<tr>
<td>Proposed length $L$</td>
<td>3.4</td>
</tr>
<tr>
<td>drop height $H=(S_0-S_n) L$</td>
<td>0.986</td>
</tr>
</tbody>
</table>

Therefore, a drop of 1m at centre of length 3.5m will make the flow safe with velocity <2.5m

For safety this flow need to be passed through another wide stilling basin before entering into the road side drain at lower level. This will take care of probable increase of rain fall intensity due to climate change and increase of discharge due to extensive urbanization.

Following the same procedure next level of Stepped chute can be designed.

4. SOME ISSUES THAT NEED SPECIAL CONSIDERATION FOR HILLY AREA

Some of the issues that need careful consideration in design of various components of drainage system in hilly area are presented in this section. For detail design of these components standard books may be followed.

4.1 Design consideration of drainage channels, internal common drains and roadside drains

- Design of individual plot should be responsibility of individual. Though detail design may not be required to fix the size, detail planning of layout is required to ensure that water from one plot does not overflow to the nearby downstream plot. In case of difficulties, an internal common drain passing through various plots may be provided with mutual agreement of all individual owners.

- Internal common drains and roadside drains have to be designed in order to handle the peak runoff adequately. In case of a common system of waste water and storm water the drain should be planned as cover drain with cleaning provision.

- All these drain can be designed by following principle of most efficient channel section, provided property boundary does not put any constraint in adopting such efficient section. The geometric elements of most hydraulically efficient sections for different type of channels are given in a tabular form in Table 7.

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Table 7: Geometric elements of most hydraulically efficient sections without freeboard

<table>
<thead>
<tr>
<th>Cross-Section</th>
<th>Area (A)</th>
<th>Wetted Perimeter (P)</th>
<th>Hydraulic Radius (R)</th>
<th>Top width (B)</th>
<th>Hydraulic Depth (D)</th>
<th>$AR^{2/3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangle</td>
<td>$2y^2$</td>
<td>$4y$</td>
<td>$\frac{y}{2}$</td>
<td>$2y$</td>
<td>$y$</td>
<td>$(2y^8)^{1/3}$</td>
</tr>
<tr>
<td>Trapezoidal</td>
<td>$\sqrt{3}y^2$</td>
<td>$2\sqrt{3}y$</td>
<td>$\frac{y}{2}$</td>
<td>$\frac{4}{3}\sqrt{3}y$</td>
<td>$\frac{4}{3}y$</td>
<td>$\sqrt{3}(\frac{y^8}{4})^{1/3}$</td>
</tr>
<tr>
<td>Semicircle</td>
<td>$\frac{\pi}{2}y^2$</td>
<td>$\pi y$</td>
<td>$\frac{y}{2}$</td>
<td>$2y$</td>
<td>$\frac{\pi}{4}y$</td>
<td>$\frac{\pi}{2}(2y^8)^{1/3}$</td>
</tr>
</tbody>
</table>

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4.2 Choice of channel section

The primary factors that govern the selection of channel geometry are:

- Soil type (stability considerations); preferably inclined section in unstable soil conditions.
- Ease for maintenance.
- Range of seasonal variation of peak discharge and minimum discharge.
- Availability of construction material

4.3 Methodology to design the most efficient channel section:

Step 1: Computation of contributing area from delineated watersheds.

Step 2: Computation of the peak discharge using the rational method.

Step 3: Choice of channel geometry and construction material.

Step 4: Mathematical computation of the dimensions of the most efficient section.

An example of mathematical computation of the dimensions of a channel section for rectangular geometry:

FIGURE 5: A RECTANGULAR SECTION
Discharge in a particular channel is given by,

\[ Q = \frac{1}{n} AR^{2/3} S^{1/2} \]  

(6)

From Manning's equation

\[ V = \frac{1}{n} R^{2/3} S^{1/2} \]  

(7)

Where,

\begin{align*}
V & = \text{velocity of flow (m/s)} \\
n & = \text{Manning's coefficient} \\
R & = \text{hydraulic radius (m)} \\
s & = \text{sewer gradient}
\end{align*}

For most efficient rectangular section:

\[ \text{Area}(A) = 2y^2 \]
\[ AR^{2/3} = (2y^{8/3})^{2/3} \]
\[ y = \frac{B}{2}. \]  

(8)

Therefore, width (B) of the most efficient rectangular channel section for a particular drainage area contributing a peak discharge (Q) to the channel is given by the following relation,

\[ B = 2(0.793 nQ/\sqrt{s})^{3/4} \]  

(9)

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4.4 Need of Compound Channel Section

In areas like northeaster part of India, where difference between lean period flow and monsoon flow is quite high, it is always advantageous to go for a compound channel to meet requirement of both the seasons. Monsoon period needs large capacity channel, which leads to a wide channel in case of conventional shape like rectangular or trapezoidal. On the other hand during the lean period it is usually observed that, in such wide channels section, silting occurs due to low velocity of flow. Deposition of debris generated from urban areas also gets deposited in such wide channel. Therefore, to have self cleansing velocity during lean period, a smaller section can be kept in the lower portion of the channel by designing the channel as two stage compound section.

Different geometry can be adopted for the secondary section which is intended to address the lean period flow. Figure 6 and 7 shows two typical possible sections (Dimensions are not in true proportion)

![Diagram of Compound Section with Primary Rectangular Section and Secondary Circular Section](image1)

**FIGURE 6 : COMPOUND SECTION WITH PRIMARY RECTANGULAR SECTION AND SECONDARY CIRCULAR SECTION**

![Diagram of Two Stage Compound Trapezoidal Section](image2)

**FIGURE 7 : TWO STAGE COMPOUND TRAPEZOIDAL SECTION**

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4.5 Considerations for Culvert

Inadequate culvert causes major problems in the drainage of hill. Many a time, heavy flow coming down from the uphill cannot drain efficiently across a road because of inadequate size and positioning of the culvert. This makes the water to flow over the roads and causes problem to the traffic. Stagnant water in a sag portion of road many a time induces failure of the downstream slope, as the saturated slope gets subjected to vehicular load.

4.6 Desilting Mechanisms such as Silt Traps and Silt Fence

4.6.1 Silt Trap

Silt Trap is an extremely important component in a hilly urban drainage system, as lots of sediment gets released from a hilly watershed because of disturbances caused by human activities. Inclusion of released silt into the drains and deposition of the same may lead to serious problem in the entire drainage system. Settling basin that prevents water-borne soil from entering a drainage system should therefore be provided at upstream of all major drains and necessary infrastructure for periodical mechanized cleaning of these silt trap should also be taken up as an integrated component of drainage system.

Consideration for size of Silt Trap

For designing dimension (length, depth and width) of silt trap a proper particle size analysis of the sediment need to be carried out apart from considering volume to be trap. Volumetric Capacity also depends on frequency of cleaning. Thus economic analysis considering both installation and maintenance cost should be carried out for optimal design of the silt trap. Other restrictions like property line etc. also need to be considered while designing the size of sediment trap.

Consideration for shape of Silt Trap

The shape of the sediment control device is also important. The longer the flow path of a particle through a device, the better is the chances of being captured. In addition, longer devices provide more area for deposition away from the turbulence of the inlet and outlet. A length to width ratio of 10:1 is recommended. The minimum length to width ratio should be 2:1.
4.6.2 Silt Fence

Surface water carries lots of sediment from construction site and other deforested areas located uphills. Such sediment entering into the drains reduces efficiency of the drainage system. Silt Fence is a low cost temporary measure that can prevent sediment entering into the drainage system while allowing sediment-free water to pass through it. Depending on the gradation and size of the suspended silt, different types of screen need to be used.

4.7 Weep Holes

Weep holes (Figure 8) in sufficient number must be provided to release the subsurface water so as to avoid generation of high lateral seepage pressure on the wall. Depending on the soil type, a filter layer consisting of sand and pebbles may be provided on upstream face of the retaining wall to eliminate scope of weep hole getting clogged by finer fraction of soil. Weep hole should be provided in a staggered manner for uniform distribution of the same over the wall surface.
Governing factors for number and size of weep holes:

- Soil properties: Porosity, water content, etc.
- Intensity of rainfall.

4.8 Consideration for pavement drainage

Drainage aspects of hilly road should be given due emphasis, as insufficient drainage may lead to two basic problems. First, pitched pavements are likely to get damaged and washed away by water during rainy season, if drainage is not proper. This is particularly because the subgrade of the road gets damaged with deposition and infiltration of water into it. Secondly, hydroplaning, a common phenomenon observed when a thin film of water that increases in thickness as it flows to the edge of the pavement is of major concern, as because it leads to the loss of traction of vehicle. Depth of water on pavement depends on the factors such as length of flow path, surface texture, surface slope, and rainfall intensity. All these factors should be considered for design of longitudinal and transverse pavement slope, curb and gutter, and in the design of inlet to the roadside drain. Depending on rate of flowing water and existence of debris and sediment different kind of inlet such as, grate inlets, curb-opening inlets and combined inlets can be used. For actual design of these items more details of these aspects should be studied by the designer.

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References and suggested readings


