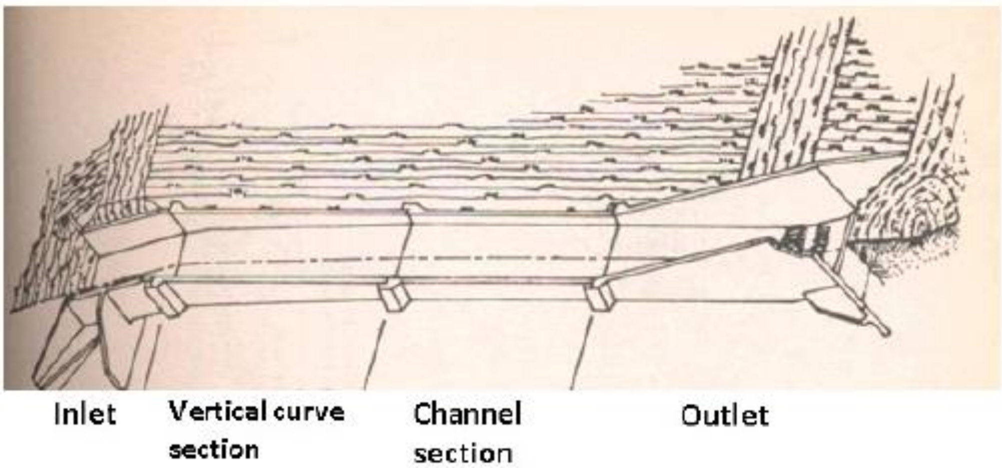
# Soil and Water Conservation Structures (SWE – 304)

- **Chute spillway, general description and its components, hydraulic design, energy dissipaters, design criteria of a SAF stilling basin and its limitations**
- **Chute Spillway and Its Uses**

Chute spillway is an open channel like structure, which is constructed on steep slope of the gully face with a suitable inlet and outlet. It usually consists of an inlet, vertical curve section, steepsloped channel and outlet. The major part of the drop in water surface takes place in a channel. Flow passes through the inlet and down the paved channel to the floor of the outlet. It handles the flow having supercritical velocity.

- **Components of Chute Spillway**

The various components of standard chute spillways are shown in Fig




- **Inlet**

The following three types of inlets are used with chute spillways:

(i) Straight inlet

(ii) Flared or side channel inlet

(iii) Box (rectangular) type inlet

The box type inlet is generally used when straight type inlet is not sufficient to handle the runoff at desire drop. The inlet section governs discharge capacity of structure. Vertical walls extending into the soil foundations under the inlet are known as cutoff walls. Their main purpose is to prevent water seepage under the structure. Similar walls, extending laterally from the inlet to prevent seepage and erosion around the ends of the structure, are called headwall extensions. These walls also protect against burrowing animals. The hydraulic design of inlet involves the design of weir length. It is determined by using the weir formula:

$$Q = \frac{2}{3} \times C_d \times \sqrt{2g} \times L \times h^{3/2}$$

Where, *Q* is the peak discharge rate, m3/s; *Cd* is the coefficient of discharge = 0.6;*L*is the weir length, m and *h* is the head of flow, m.

- **Conduit or Chute Discharge Carrier**

The conduit is the part of chute spillway which convey water from inlet to the outlet section. It can be rectangular or a trapezoidal channel. Usually the conduit section is adopted considering the dimensions of the inlet section. Sometimes, more or less same section as that of inlet is used for the conduit also. The side walls of conduit confine the flow rate and discharge distribution, too, within the conduit section. The top wall of conduit is constructed in such a way, that it may be flushed with the embankment slope. Manning's formula is used for the design of channel capacity. Design of channel crosssection is similar to the design of open channel, in which bottom width, top width, side slope and depth are determined for a given discharge rate.

- **Outlet**

Outlet section of chute spillway is located at the downstream end. It is also called as energy dissipater because, it dissipates the energy of falling water from higher to lower elevation By decreasing the velocity of flow. Thus it protects downstream area from the soil erosion. At the outlet section, energy dissipates on the concept of hydraulic jump. This hydraulic jump is the formed on the horizontal part of the basin. The Froud number (F) of incoming flow into the outlet and corresponding downstream water depth (d2) should satisfy the following equation.

$$\frac{d_2}{d_1} = \frac{1}{2}\left(\sqrt{1 + 8F^2} - 1\right)$$

Where, V1 is the sequent depth ratio that means ratio of depth of flow after hydraulic jump and before hydraulic jump.

$$\mathrm{F} = \text{Froud number} = \frac{v_1}{\sqrt{g d_1}}$$

Here,V1 is the flow velocity before occurrence of hydraulic jump and *g* is acceleration due to gravity.

Chute spillway outlet may include Chute blocks, baffle blocks, stilling basin, end sill and side (training) walls. It is preferable to keep them vertical on water side for the satisfactory formation of hydraulic jump. When the velocity at entry of stilling basin is high, chute and baffle blocks are omitted. The outlet's capacity is verified by different considerations of critical depth of flow. Straight apron can also be used for small structures. Scour at the outlet is one of the important factors leading to failure of structure. Scour may be controlled by giving proper consideration in the design to the:

1. Stability of the grade below the structure.
2. Velocities occurring in the downstream channel.
3. Tail water elevations for different flow stages.
4. Dissipation of water energy in the outlet.

Scour below drop spillways or chutes usually are reduced as the tail water elevation is increased.

- **Hydrologic Design**

The peak flood for which the chute spillway is to be designed will govern the size and capacity. It involves the estimation of runoff rate and flood volume depends on several factors associated with the runoff. The design peak runoff volume using Rational method are computed for the design rainfall intensity of 25-30 years return period.

- **Hydraulic Design of Components**

Hydraulic design involves determining the dimension of different components of structure, on the basis of expected maximum runoff rate, that has been estimated in hydrologic design phase. The dimension of structure should be able to handle design runoff.

Chute spillways are used for different purposes.. These could be as large as spillways for huge dam of river valley projects, or small size structure for gully control and conveyance of water from canals. For gully control as per the recommendation of USDA (Agr. Handbook, 135), the following four types of outlets are generally used.

1. Straight Apron
2. Cantilever
3. SAF (Saint Anthony Falls)
4. Baffle

A straight apron type of outlet is simplest of all, and its design is same as drop spillways. The cantilever type is used where channel grade and soil below the structure are unstable. The SAF

(Saint Anthony Falls) stilling basins, developed at Saint Anthony Falls hydraulics laboratory (USA) is the most common of all stilling basins widely used in several applications of chute spillways.

**Example:**

The chute spillway is to be provided with a straight inlet with peak flow discharge 3.57 $m^3/s$. The depth of flow is to have 1.28 m. What should be the weir length? (Cd = 0.6).

**Solution**:

Given:

Head = 1.28 m

Q = 3.57$m^3/s$

Cd = 0.6

The discharge over the weir is given by the equation as

$$Q = \frac{2}{3} \times C_d \times \sqrt{2g} \times L \times h^{3/2}$$

$$3.57 = \frac{2}{3} \times 0.6 \times \sqrt{2 \times 9.81} \times L \times h^{3/2}$$

L= 1.39 m **Ans.**

- **Drop inlet spillway- general description, functional use, design criteria**

The drop inlet structures are the combination of 3 major components, namely, inlet, conduit and outlet. The structural design includes the determination of specification of these components. The usual function of a drop inlet spillway is to convey a portion of the runoff through or under an embankment without erosion.

- **Inlet**

The inlet is installed having some drop which causes to flow of water from inlet to conduit. Various shapes of the inlet are used in the structures. Those include, box type, catchpit and funnel shaped. The funnel shaped also known as morning glory or glory hole are widely used in the conditions where large amount of the flow to be handled. Design of inlet includes the determination of size and selection of shape in order to receive the excess flow and transfer it to conduit. The flow carrying capacity of the inlet and conduit and outlet must align adequately for proper functioning of the drop inlet structures. The size of the inlet largely depends on the amount of excess flow to be handled, however the shape depends upon the amount of excess flow as well as site conditions.

- **Conduit**

The flow can be divided in two; first flow over weir in case of inlet and then it transforms to pipe or orifice flow in case of conduit. The flow in the conduit is governed largely by the slope of the conduit. This also influence the energy dissipated in term of head loss due to friction. The term natural slope is defined as the hydraulic slope for which the head loss due to friction is equated with the head gain due to elevation difference. These are given as

$$H_f = LK_c \frac{V^2}{2g}$$

Head loss due to friction,

In which Hf is head loss due to internal friction; L is length of the conduit, V is velocity of flow and Kc is head loss coefficient.

Natural slope (Sn) can be expressed as

$$S_n = \frac{H_f}{L} = K_c \frac{V^2}{2g}$$

Slope of pipe can be taken as the sine of elevation and length of pipe.

- **Outlet**

Different flow regimes at outlet can be expected depending upon the conditions of pipe slope and natural slope. For natural slope being greater than pipe slope and the inlet is submerged, the conduit will flow full and the capacity can be given as:

$$Q = \frac{a\sqrt{2gH}}{\sqrt{1+K_e+K_c L}}$$

In which is the area of crosssection of conduit and is the coefficient of entrance loss at inlet. For natural slope being less than the pipe slope and outlet is not submerged the flow is controlled by the inlet section of the conduit and can be given by standard orifice formula.

$$Q = aC\sqrt{2gH}$$

In which is the coefficient of discharge for the orifice.

- **Uses of Drop Inlet Spillways**

A drop inlet spillway is normally used to drop low to medium volumes of water over a sharp incline (30%). The incline height is normally greater than 1 m with no upper limit. Common functional uses are given as:

- Gully control
- Surface water inlets to open ditches and terrace inlets
- Principal spillways for farm ponds or reservoirs
- Grade stabilization of gullies
- Lower end of water disposal system
- Principal spillways for debris basins
- Used as culverts in roadway structures
- Flood prevention structures
- **Design**

**1. Hydrologic Design**

The Hydrologic design consists of knowing both the peak rate of runoff expected and also the inflow hydrograph. The hydrologic design procedure is similar as discussed in case of drop structures. The outflow will not be same as the inflow like other structures.

**2. Hydraulic Design**

It involves the design of earth dam and pipe spillway, as these two components are the main in drop inlet spillway.

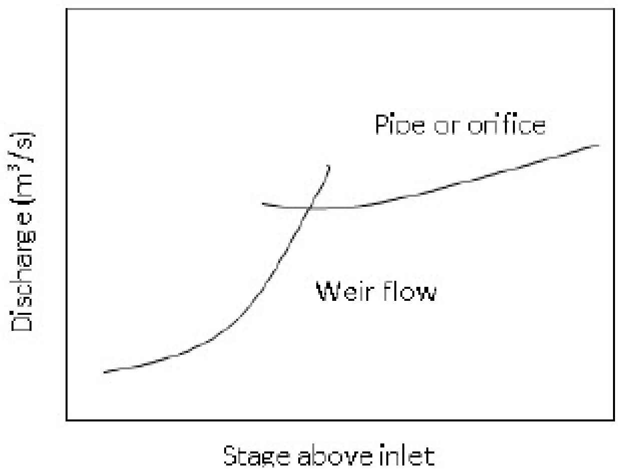
**2.1 Design of Earthen dam**

- The design of earth dam is also performed by considered all the designs steps – hydrologic, hydraulic and structural design, as in other hydraulic structures. The design of earthen dam suitable to drop inlet spillway is described as follows:
  - The upstream and downstream side slopes commonly used in earth dam are 3:1 and 2:1, respectively.

- Top width of dam varies with its height. The minimum top width should be equal to 1.8m for the height of 3.5m. When top width of dam is used as a road, then it should be kept between 2.5 and 3.0m. In addition, there should also be added 30 cm additional top width for each 60 cm dam height.
- In order to make the dam safe against overtopping, there must be added 5% of theoretical dam height or more to the dam height as a settling allowance and 60 cm as freeboard.
- Bottom width of dam is calculated on the basis of side slopes and its height. The bottom width should match the length of conduit, used.
- The side slopes of dam should be protected against erosion. This is performed by making riprap, using heavy gravels or rocks when upstream side slope is badly eroded by wave action. The downstream side slope is not affected by wave action, so vegetation can be grown to protect this side.

**2.2 Design of Pipe Spillway**

In drop inlet spillway, the pipe spillway has a vertical section towards upstream face of the dam, called riser, which is connected to the conduit passing through the dam. The top of the riser may be raised up to desired height, as per requirement for providing the grade to conduit and protecting the gully head. The flow capacity may be controlled by the inlet and conduit, both. To follow the hydraulic design of spillway, the types of flow occur in conduit should be considered. A typical discharge characteristic curve of drop inlet spillway is shown in Fig.




- **Design Problems**

- A 50cm corrugated metal pipe of 75 m length is used in construction of drop inlet spillway. Given the head is 2m, entrance loss coefficient is 0.5. Estimate the peak discharge under pipe flow.
- **Design of diversions**

Diversions are the water conveyance structures that are constructed to intercept the surface runoff and transport to the main drain.

**Design Specification for Diversion**

The design specifications involve the determination of runoff volume to be conveyed and suitable dimension of the diversion channel. Following points should be considered while designing the diversions

a) The length should not exceed 350 m.

b) Quantity of runoff should be estimated for 10 years return period for agricultural land.

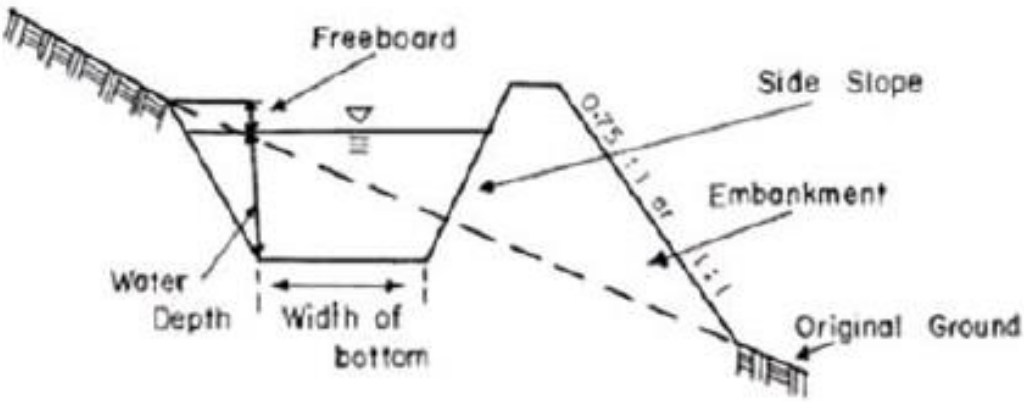
c) The maximum velocity in the channel should be limited as per Table

Table 30.1. Safe limit of flow velocity under different soil covered channel

| **Soil type** | **Safe limit (m/s)** |
|---|---|
| Sandy soil | 0.4 |
| sandy loam and silt loam | 0.6 |
| Clay loam | 0.65 |
| Clay | 0.70 |
| Gravelly soil | 1.0 |

**(Source: FAO Conservation Guide 13/3)**

A free board of 10-30 cm may be added to the depth of flow as a safeguard. Usually, the carrying capacity of the channel is higher than designed runoff to provide extra protection. The cross section is determined by the amount of runoff, designed velocity of flow and shape and side slope of the diversion and ditches. Fig. shows typical crosssection of diversion ditch. The design of ditch can be adjusted by increasing the crosssection and gradient to accommodate larger amounts of runoff. However, the velocity of the flow should not exceed the safe limits explained earlier. Another design modification is to make the ditch's side slope and gradients less steep on sites where the soils are prone to erosion.




**Design Procedure**

The design of flow channel includes determination of flow rate to be carried out by the channel; selection of suitable channel bed slope based on topography and soil type; Selection of suitable channel shape and side slope; finding cross sectional area and wetted perimeter; estimating velocity of flow using manning's formula; Validating flow velocity to be within permissible limit and finally providing free board (about 15-20% of the depth of flow) to determine total depth of channel.

**Example:** Design a grassed waterway which is to be constructed as an outlet for flow from a graded bud system. The expected runoff is 2.9cumec. The type of grass to be used is dub and needs to be maintained in excellent way. The slope of the channel is to be kept at 3.5%.

**Solution:**

The problem (waterway designed) can be solved by trial and error method,

Assume the top width (t) of the water way = 4.75 m,Depth of flow (d) = 0.45 m

For parabolic channel, cross section area (a) = 2/3 td = 1.425 $m^2$

Wetted perimeter (p) of the waterway = $t + 8d^2/3t$ = 4.86 m

Hydraulic radius (R) of the waterway = a/p = 0.293

Mean velocity by using the Manning's formula

$$v = \frac{R^{2/3} s^{1/2}}{n}$$

Where s = channel slope = 3.5/100

n = 0.04 for natural channels

Therefore, v = 2.07 m/s

Flow capacity Q of the water way = a x v = 2.95 cumec

The discharge capacity is slightly more than 2.95cumec and thus it's

acceptable. The velocity is also within the permissible limits, Hence the design

is acceptable where t = 4.75 and d = 0.45 m.

- ## Principles, farm ponds and reservoirs

Farm ponds have a significantly role in rainfed farming system where annual rainfall is more than 500 mm. It helps in mitigating the ill effect of rainfall variability as it stores water from rainfall excess and provides for utilization during prolonged dry spells by means of supplemental/protective irrigation. It also helps in presowing irrigation of rabi crop. In high rainfall semiarid regions of India, farm pond can be used for multiple uses such as protective/supplemental irrigation, fish culture, duck farming integrated with poultry.

- **Types of Farm Ponds**

1. **Embankment Type**

These type farm ponds are constructed across the stream or water course and consist of an earthen dam. Dimension of embankment are determined based on the required storage. These ponds are suitable for areas having gentle to moderately steep slope and also where stream valleys are sufficiently depressed to permit a maximum storage volume with least earth work. Given the Indian farming system, this type of pond is constructed largely at common land resources as it requires substantial land under submergence.

2. **Excavated or Dugout Ponds**

These types of farm ponds are small dug out structures with welldefined shape and size. These structures have provision for inlet and outlet. Farm ponds are constructed at lower portion of the farm and generally stored water is used for irrigation. In some places farm ponds are used for recharging groundwater. However, for recharging groundwater, high capacity structures located in the highly permeable soil are more suitable. These structures are also called percolation tank (Reddy et al. 2012).

Dugout ponds are constructed by excavating the soil from the ground and the excavated soil is used to make embankment around the pond. The pond could either be fed by surface runoff or groundwater wherever aquifers are available. The depth and size of pond depend upon the volume of water to be stored. This type of pond is more featured in individual farm. Dugout ponds can be grouped into the following four categories:

1. Excavated or dug out ponds

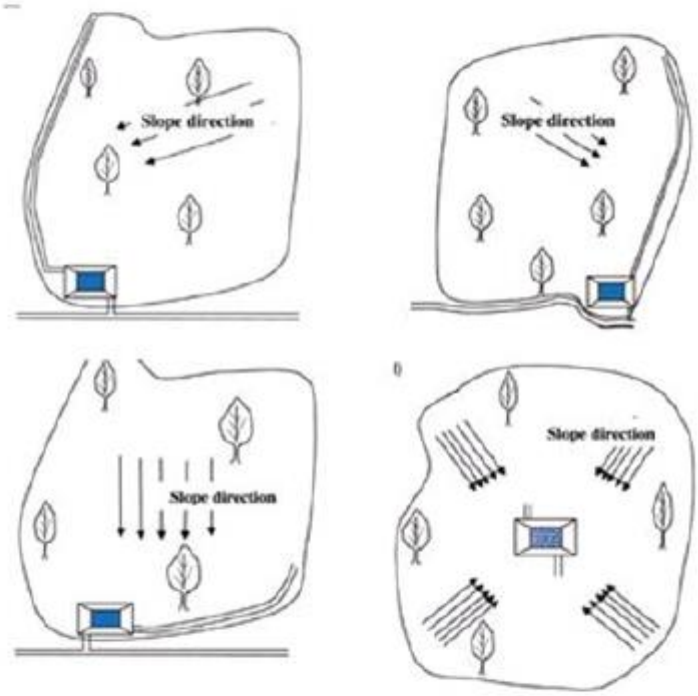
2. Surface ponds

3. Spring or creek fed ponds and

4. Off stream storage ponds

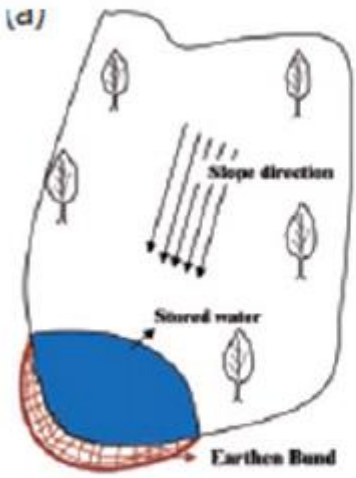
**1. Excavated or dug out ponds**

Excavated pond site should be chosen based on general slope of the field. Various locations of dugpond are illustrated in Fig. based on the prevailing land slope. If slope is towards left bottom corner of the field, a form pond must be constructed in the left corner of the plot and similarly for slope towards right bottom corner. If the slope is towards the bottom of the field, pond can be constructed at either side corner with proper field channel at the bottom of the field connecting to the inlet of the structure. If the farm area has multiple slopes in different direction, pond should be located in a portion of the area where maximum water can be drained into the structure.



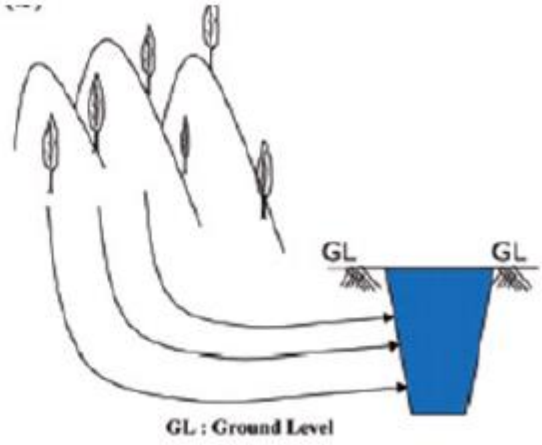

**2. Surface ponds**

When the surface runoff from a farm area is collected into a local depression or the lowest portion of the farm such that the excavation is minimum, this type of pond is called surface pond (Fig.). Surface pond is possible in the farm area with undulating topography. This type of pond does not require a formal inlet provision but it should have formal outlet provision.




**3. Spring or creek fed ponds and**

This type of pond is generally constructed at the foothills of the hilly catchments. After the soil saturation occurred due to excess rainfall, the subsurface flow of the catchment oozes up to the surface at the foothills as base flow (Fig.)

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**4. Off stream storage ponds**

This type of pond should be adopted where construction of embankment across the natural channel is not feasible or economically viable. Offstream storage ponds collect water from the stream using diversion (Fig.). In hilly catchment where, storage volume upstream of embankment of dam is not sufficient and unable to sustain the high flow velocity, these types of structure can be adopted.