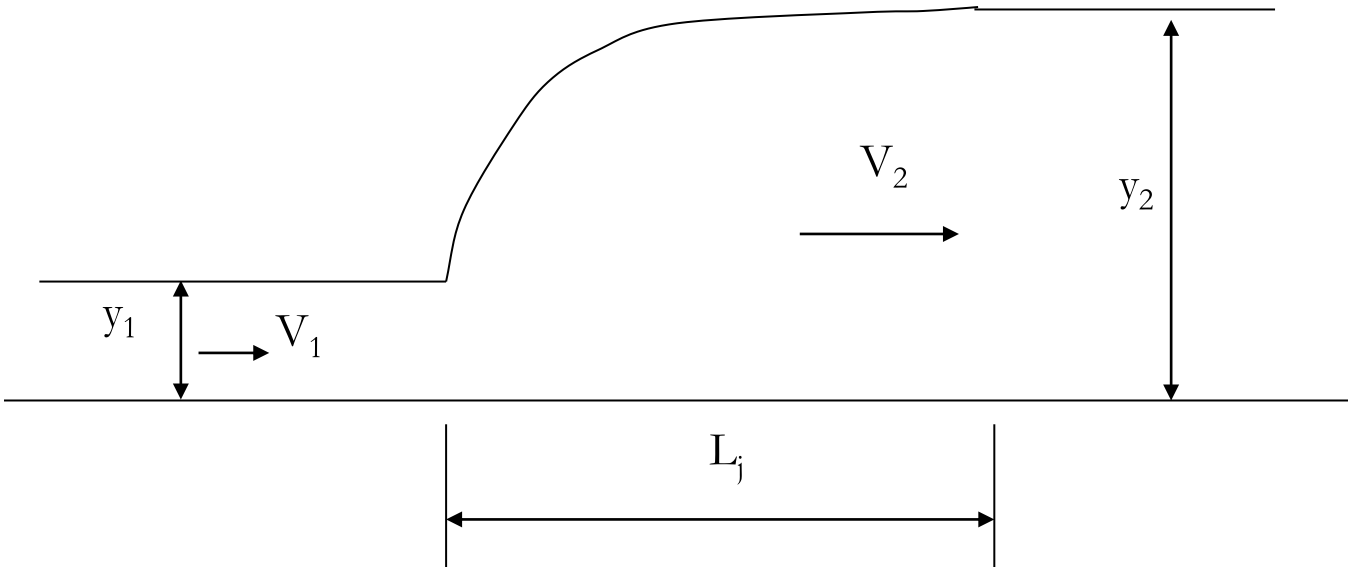
CE 3205
Water and Environmental Engineering

STILLING BASINS

Introduction

- The stilling basin is an integral part of the dam structure. It controls the velocity of falling water on the downstream side of the dam in order to prevent damage to the dam's foundation.
- The energy contained in this rushing water is dissipated in a concrete stilling basin in a phenomenon known as hydraulic jump.

Hydraulic Jump



Introduction

- Hydraulic jump is one of the most frequently encountered phenomena of rapidly varying flow. Formation of hydraulic jump is usually required for energy dissipation in stilling basins.
- US Bureau of Reclamation (USBR) types I, II, III, IV and V stilling basins have the recommended design procedures.

Importance of Stilling Basin

- The basin protects the stream-bed from the destructive energy of the hydraulic jump.
- Excess water flows from dam via a spillway. When the flow is released over the spillway structure, the potential energy is converted into kinetic energy at the toe of spillway. The flow is supercritical and has a very high velocity and hence erosive power. Therefore, this energy must be dissipated in order to prevent the possibility of severe scouring of the downstream riverbed and undermining of the foundations. The dissipation of kinetic energy can be achieved by hydraulic jumped stilling basins.

Energy Dissipaters

- Hydraulic Jump type – induce a hydraulic jump at the end of spillway to dissipate energy
- Bureau of Reclamation did extensive experimental studies to determine structure size and arrangements – empirical charts and data as design basis

Design Considerations

The design of a stilling basin structure involves

- Investigation of the river cross-section
- Determination of the water depth in the river
- Evaluation of the energy levels
- Definition of the downstream channel dimensions,
- Calculation of flow depth and finally an analysis of hydraulic jump in the stilling basin.

Design Considerations

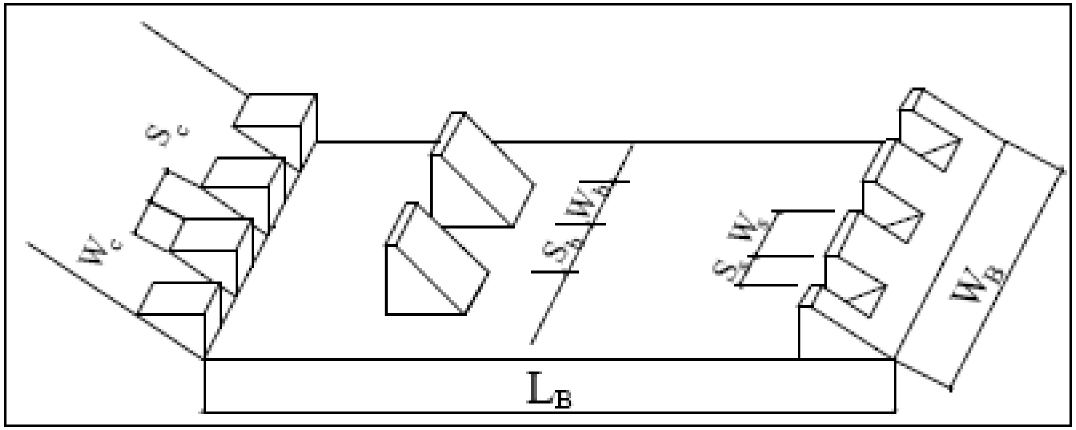
The equations that are used to determine the flow depths are non-linear and therefore required a time-consuming trial-and-error method to solve them.

However, water depths may be found by utilizing an iterative technique commonly referred to as the Newton–Raphson iteration technique, which is used to solve the system of non-linear equations.

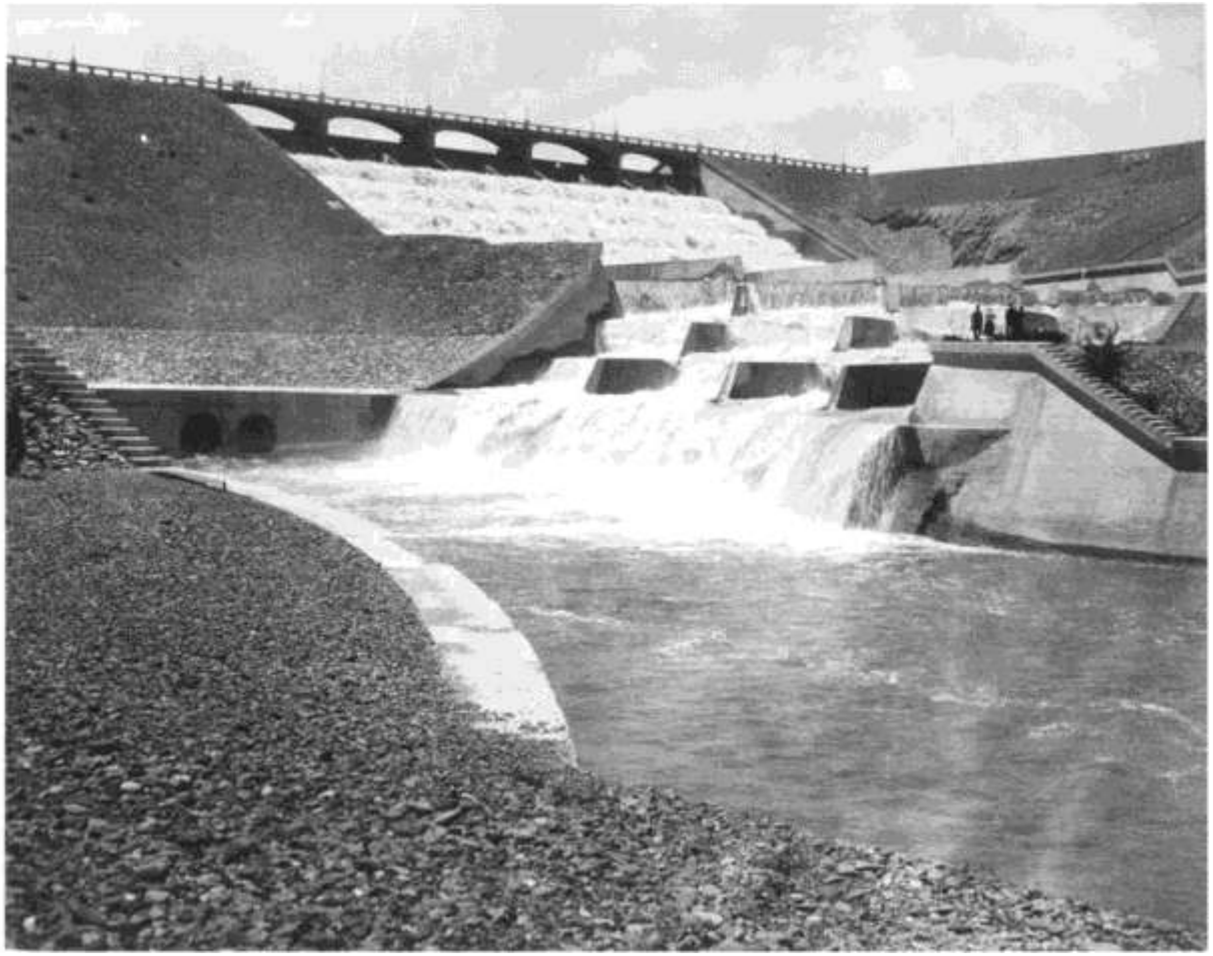
Depth of Flow Profile

- Newton-Raphson technique can be used to determine the flow profile of the hydraulic jump type stilling basin

Spillway Bukit Merah Reservoir, Perak, Malaysia



New Cronton Dam NY – Stepped Chute Spillway



Karakaya Dam

Chute Spillway

Side-Channel Spillway

Burrinjuck Dam on the Murrumbidgee River near Yass.

Hydraulic Jump Formulas

$$F_1 = v_1/(gy_1)^{1/2}$$

$$q = v_1 y_1$$

$$y_2 = (y_1/2)\,[(1 + 8F_1^2)^{1/2} - 1]$$

$$v_2 = q/y_2$$

$$F_2 = v_2/(gy_2)^{1/2}$$

Headloss Across the Jump

$$h_L = y_1 + V_1^2/2g - (y_2 + V_2^2/2g)$$

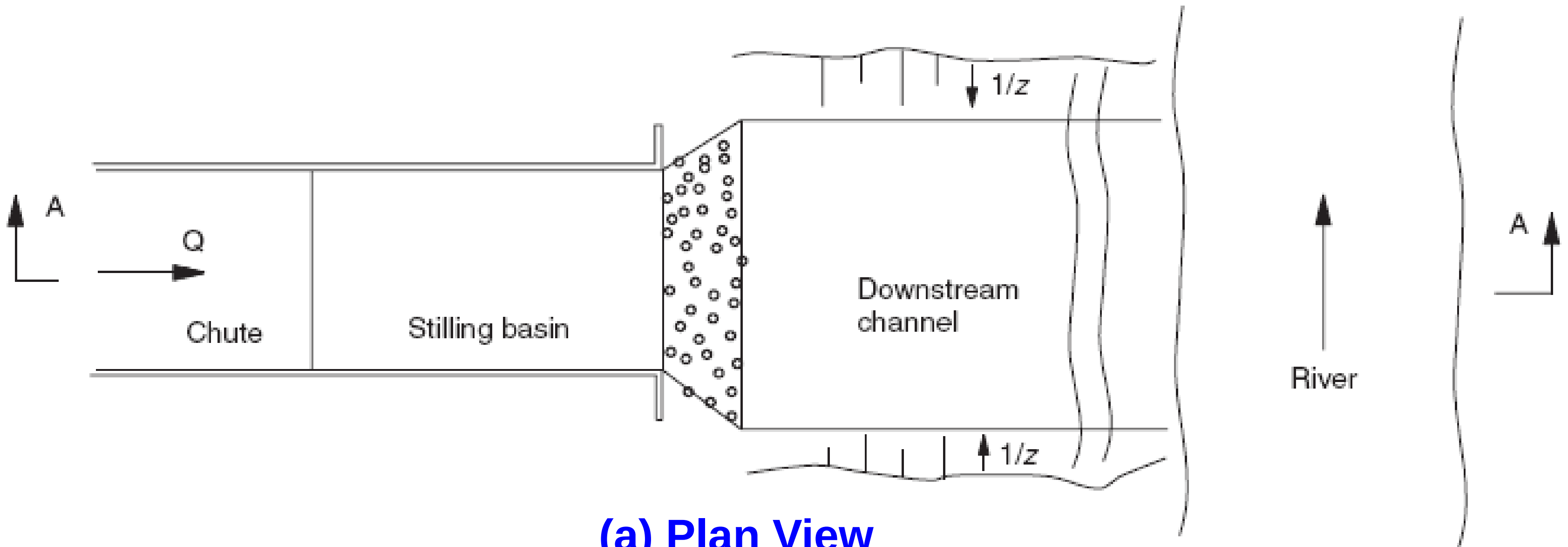
Flow in the Channel

The uniform flow in a channel is frequently determined by the use of a resistance equation such as the Manning equation, which defines cross-sectional average velocity [$V = (1/n)R^{2/3}s^{1/2}$] together with the continuity equation $Q = VA$.

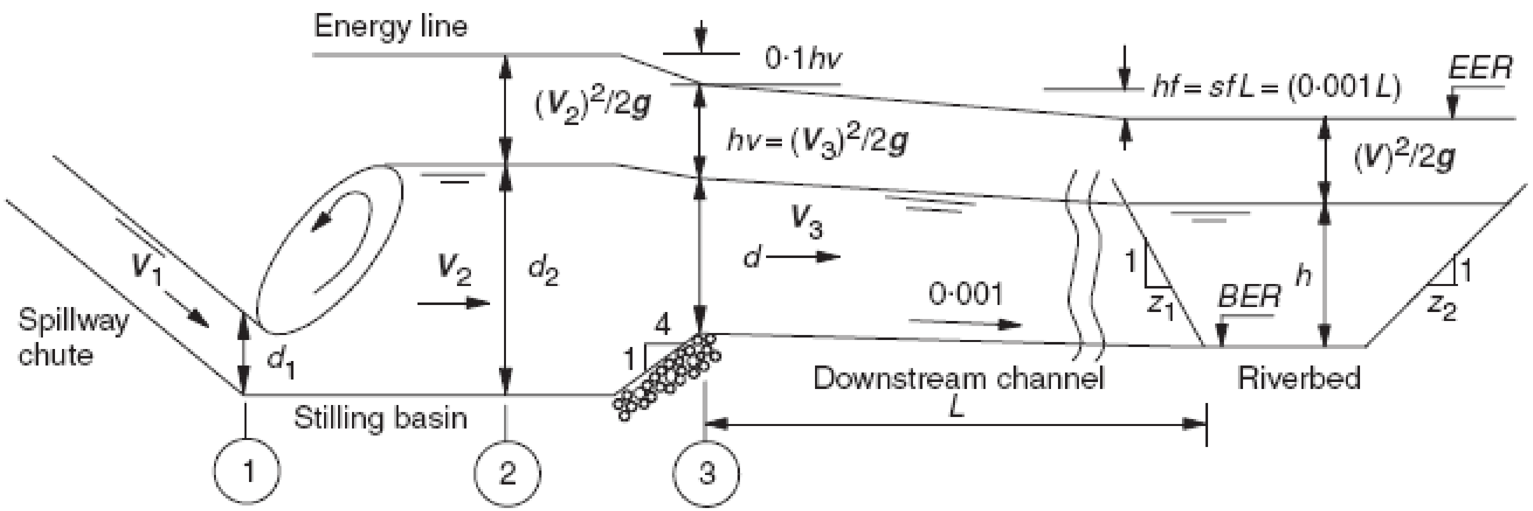
I	$$Q = \left(\frac{1}{n}R^{2/3}s^{1/2}\right)A$$

where Q is the flow discharge (m^3/s); A is the cross-sectional area of the river (m^2); n is Manning's coefficient of roughness; R is the hydraulic radius (i.e. ratio of flow area to wetted perimeter, A/P) (m); and s is the mean longitudinal slope of the riverbed.

General Profile of the Stilling Basin



(a) Plan View



(b) Longitudinal Cross-section

Stilling Basin

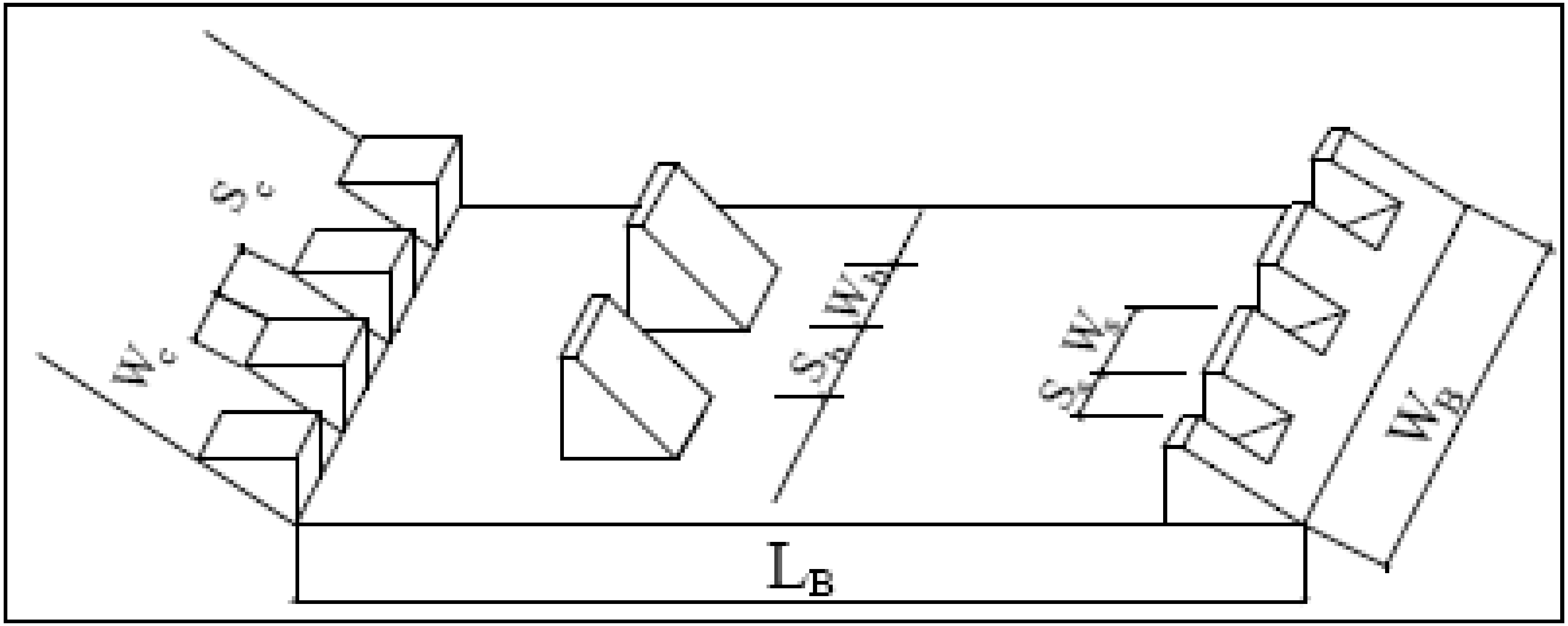
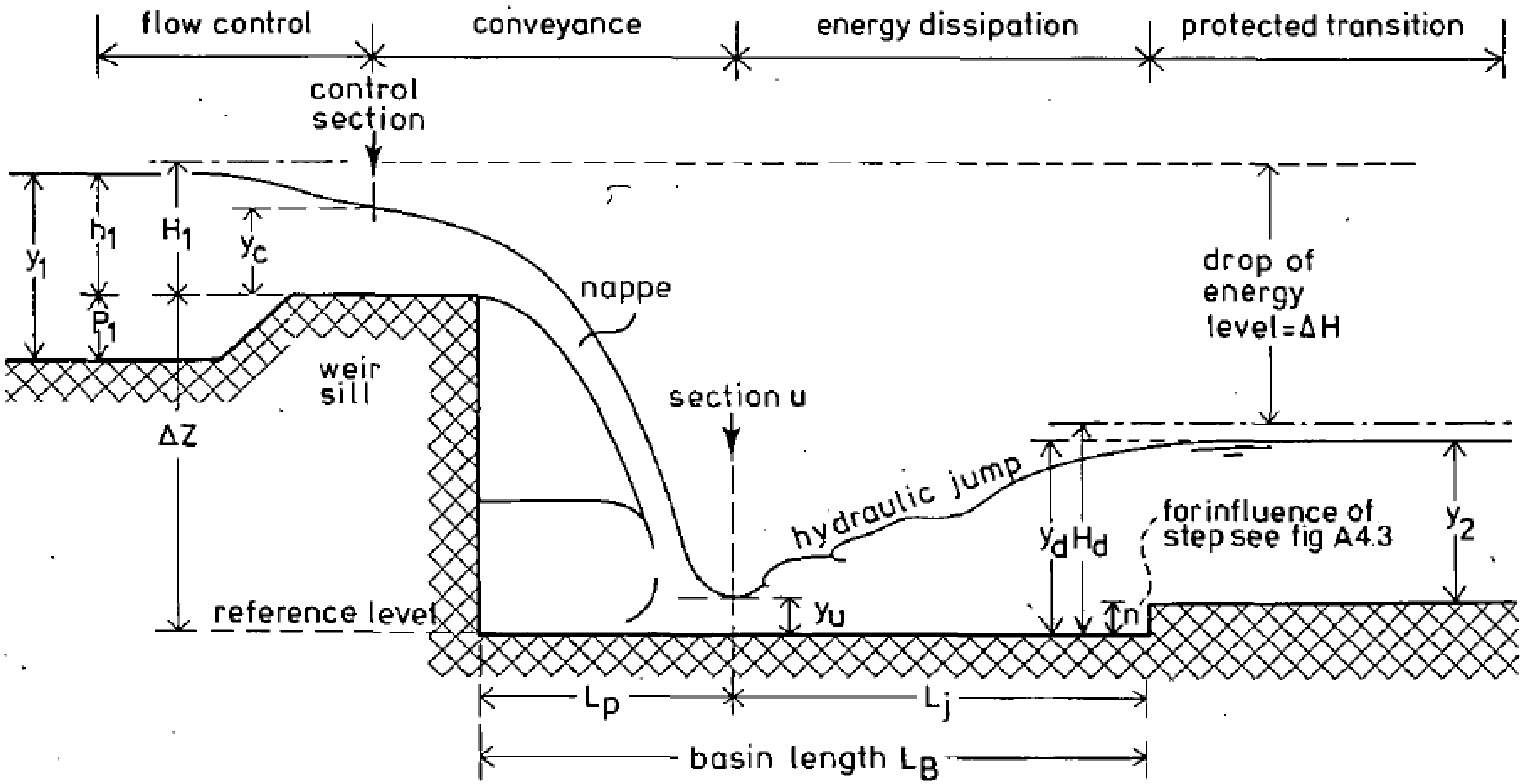
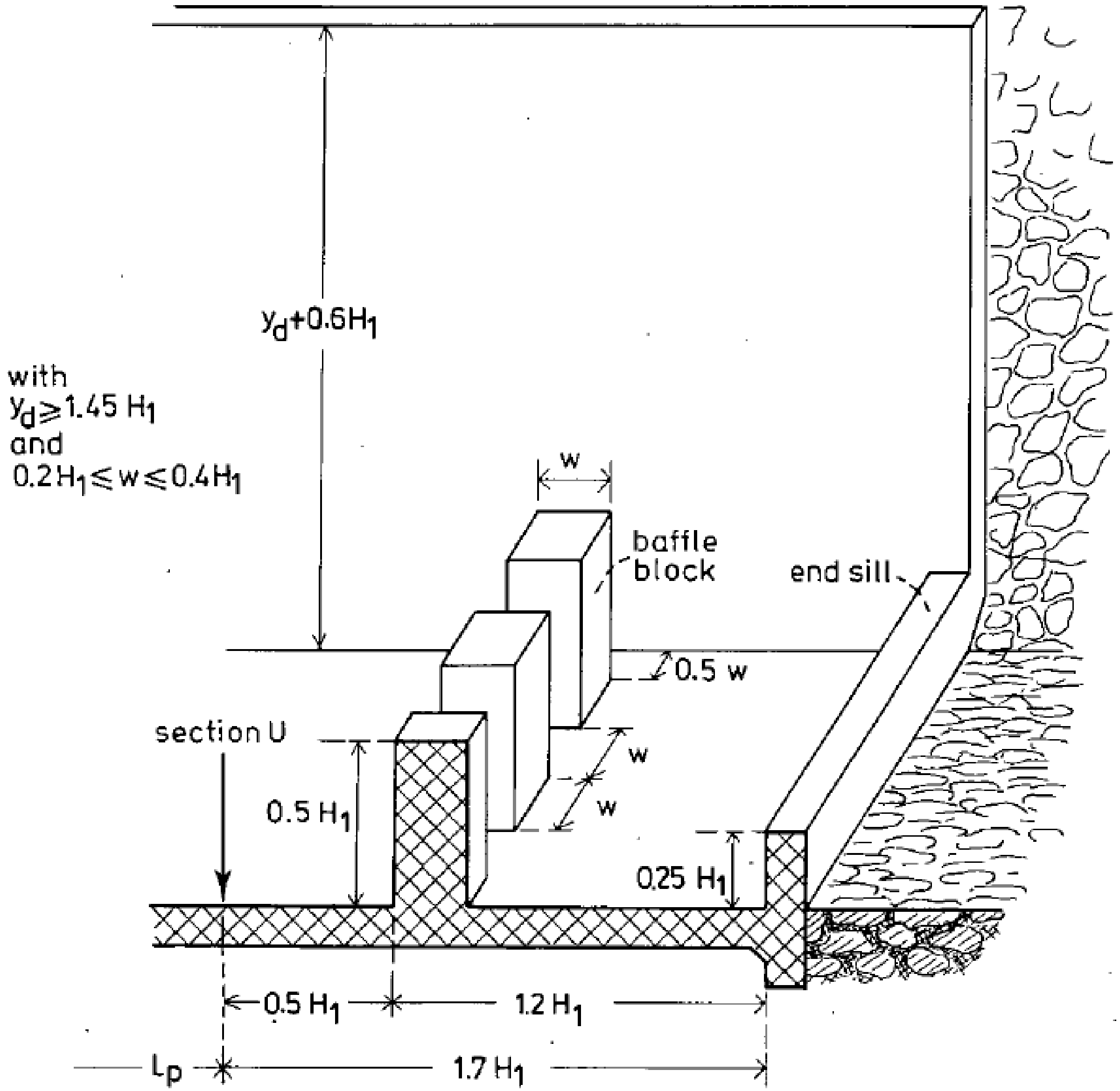


Figure 1: Baffle blocks, end Sills and Chute blocks

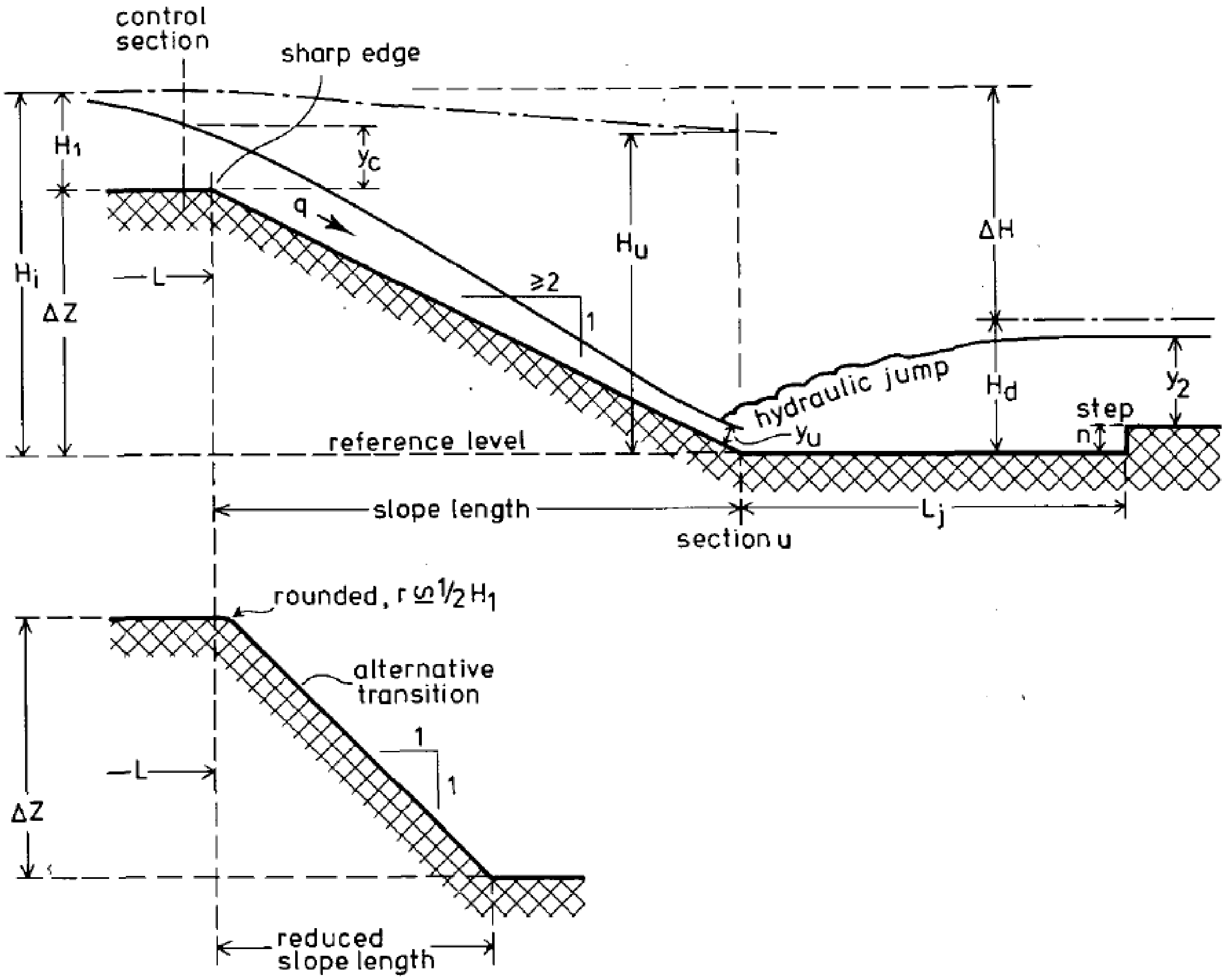
Straight Drop Structures



Straight Drop Structures



Inclined Drops or Chutes



Hydraulic Jump Energy Dissipater

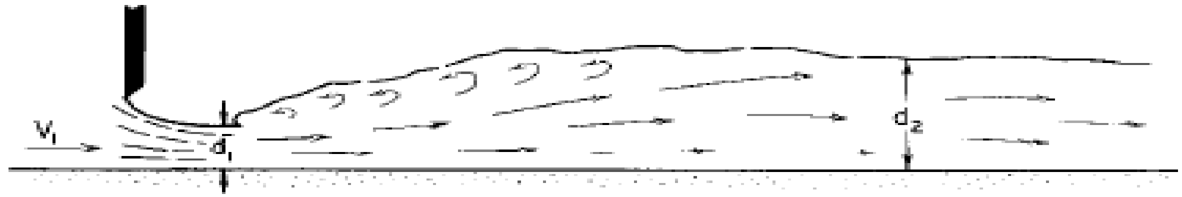
- Froude number

  $Fr = V/(gy)^{1/2}$

- $Fr > 1$ – supercritical flow
  $Fr < 1$ – subcritical flow

- Transition from supercritical to subcritical on a mild slope – hydraulic jump

Characteristics of Hydraulic Jump



F_1 BETWEEN 1.7 and 2.5
FORM A–PREJUMP STAGE

F_1 BETWEEN 2.5 and 4.5
FORM B–TRANSITION STAGE

F_1 BETWEEN 4.5 and 9.0
FORM C–RANGE OF WELL–BALANCED JUMPS

F_1 GREATER THAN 9.0
FORM D–EFFECTIVE JUMP BUT ROUGH
SURFACE DOWNSTREAM

Hydraulic Jump

- Jump in horizontal rectangular channel

  $y_2/y_1 = ½ ((1+8Fr_1^2)^{1/2} - 1)$

  $y_1/y_2 = ½ ((1+8Fr_2^2)^{1/2} - 1)$
- Loss of energy

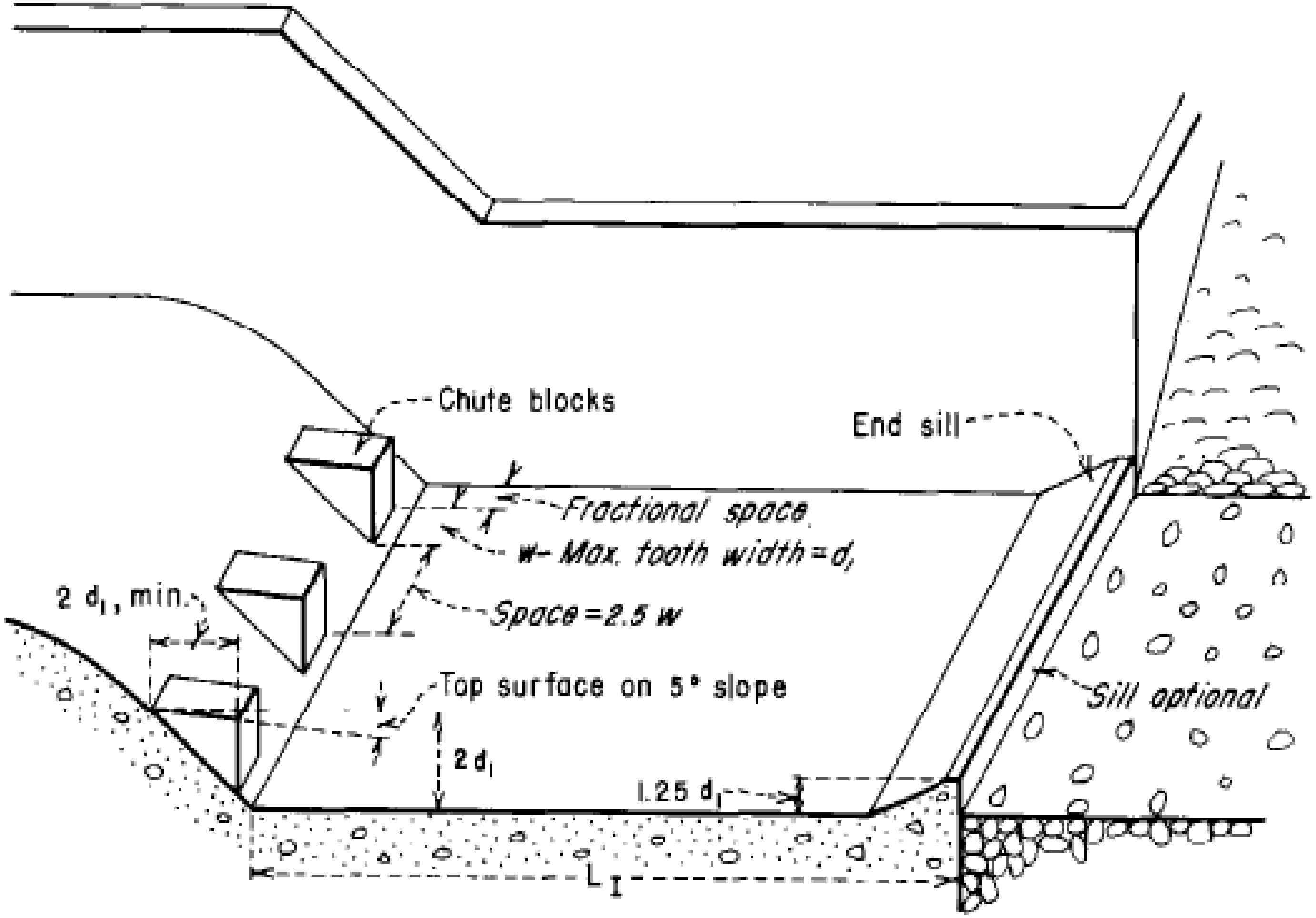
  $\Delta E = E_1 - E_2 = (y_2 - y_1)^3 / (4y_1y_2)$
- Length of jump

  $L_j \cong 6y_2$

Hydraulic Jump

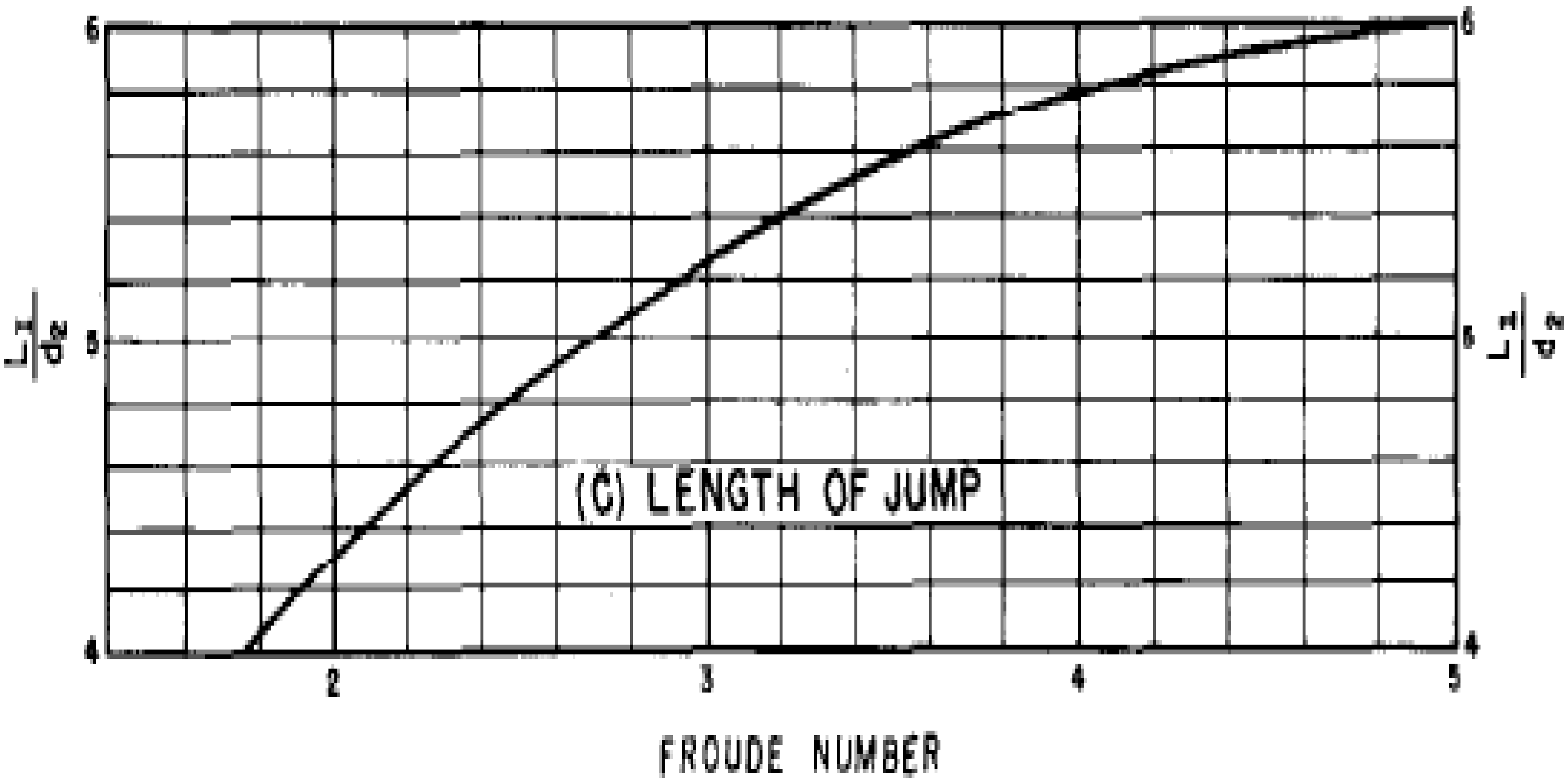
- Design guidelines
  - Provide a basin to contain the jump
  - Stabilize the jump in the basin: tailwater control
  - Minimize the length of the basin
- to increase performance of the basin
  - Add chute blocks, baffle piers and end sills to increase energy loss – Bureau of Reclamation types of stilling basin

Type IV Stilling Basin: 2.5<Fr<4.5



(A) TYPE IV BASIN DIMENSIONS

Stilling Basin – 2.5<Fr<4.5



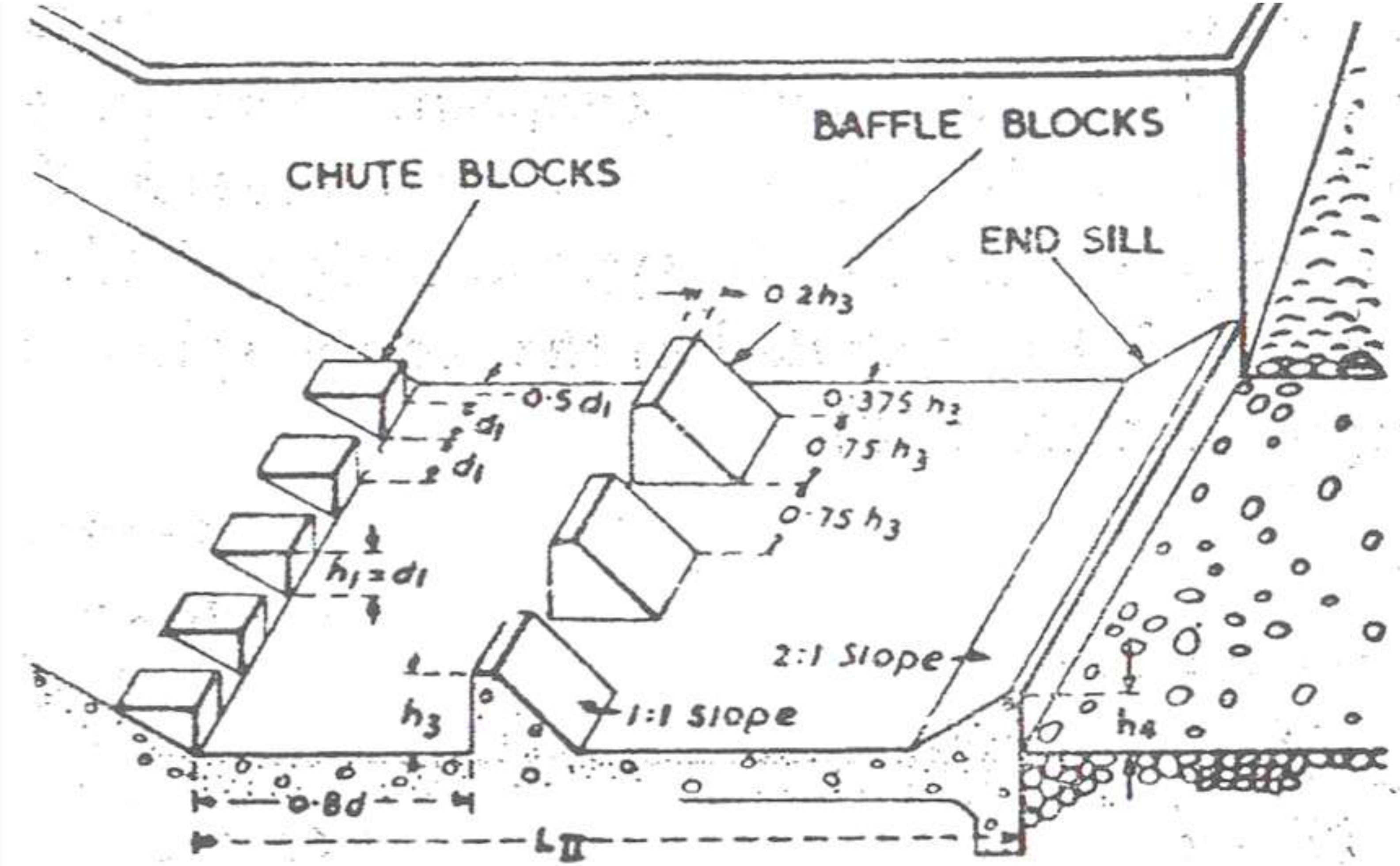
Type IV Stilling Basin – 2.5<Fr<4.5

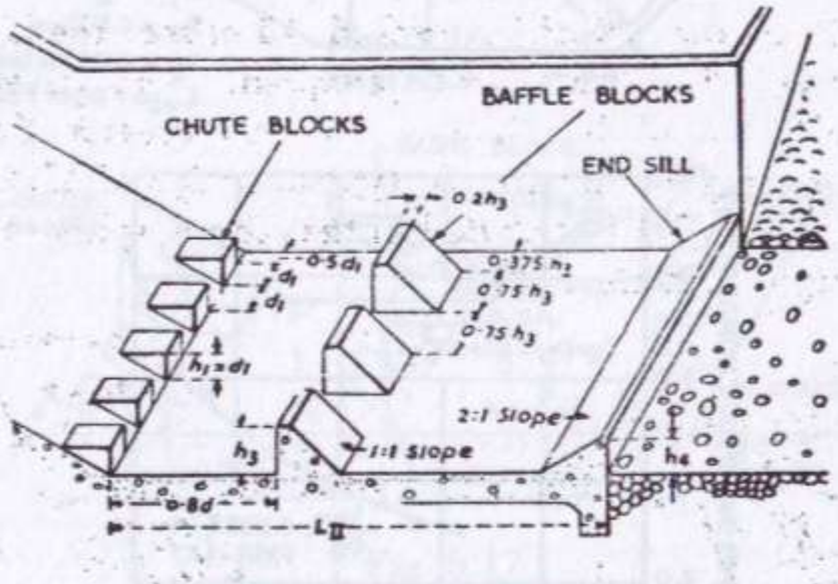
- Energy loss in this Froude number range is less than 50%
- To increase energy loss and shorten the basin length, an alternative design may be used to drop the basin level and increase tailwater depth

Stilling Basin – Fr>4.5

- When Fr > 4.5, but V < 60 ft/sec, use Type III basin
- Type III – chute blocks, baffle blocks and end sill
- Reason for requiring V<60 fps – to avoid cavitation damage to the concrete surface and limit impact force to the blocks

Type III Stilling Basin: Fr>4.5





TYPE II BASIN DIMENSIONS

Fig. 3.22 USBR Stilling Basin II

Length of Basin (L) :

Froude Number (F_1)	5	6	8	10	12	14	16
L/D_2	2.3	2.5	2.6	2.7	2.8	2.8	2.8

Baffle Block Height (h_3) :

F_1	5	6	8	10	12	14	16
h_3/D_1	1.5	1.7	2.0	2.3	2.7	3.0	3.3

End sill height (h_4)

F_1	5	6	8	10	12	14	16
h_4/D_1	1.2	1.3	1.5	1.6	1.7	1.8	1.9

Type III Stilling Basin – Fr>4.5

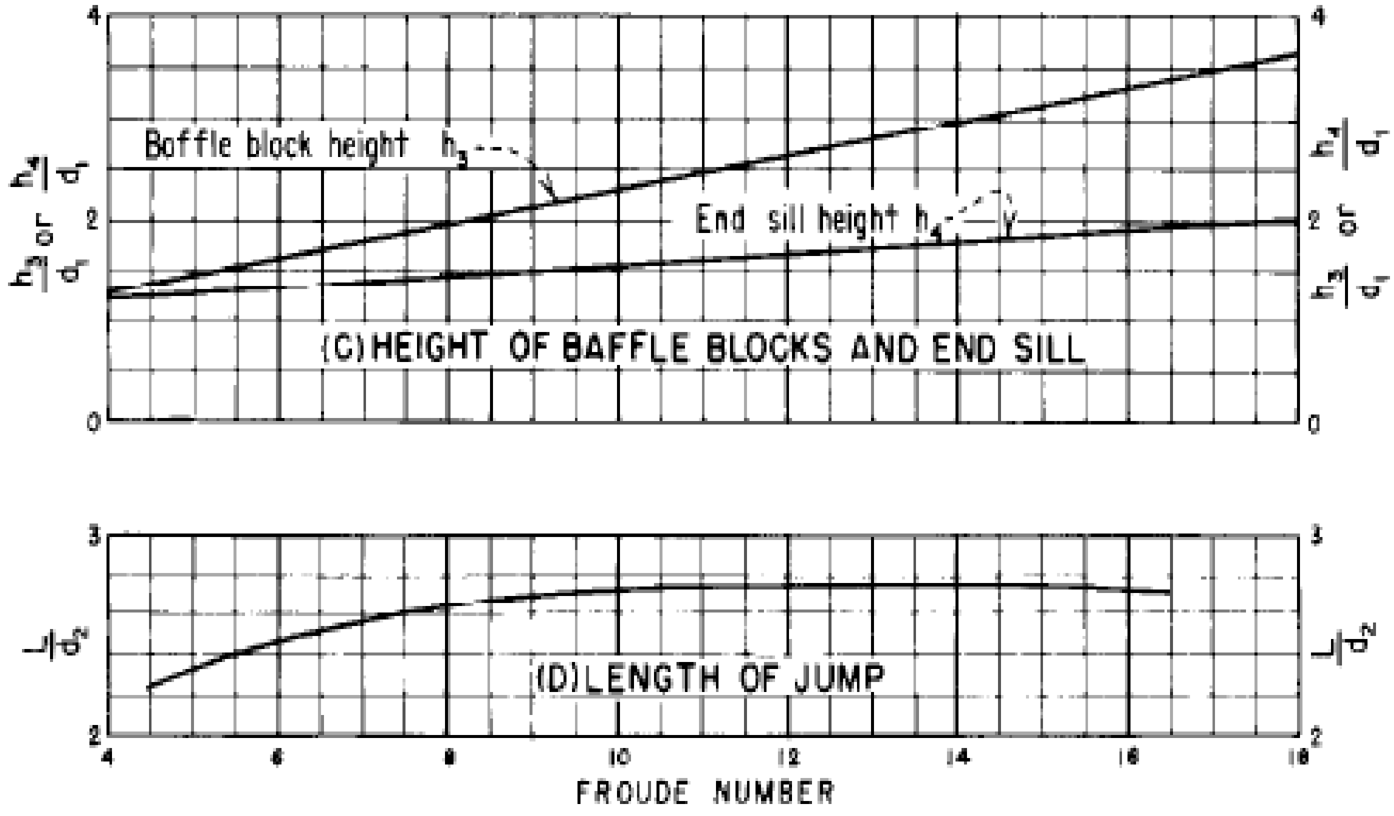


Figure 9-41.—Stilling basin characteristics for Froude numbers above 4.5 where incoming velocity, $V_1 \leq$ 60 ft/s. 288–D–2426.

Type III Stilling Basin: Fr>4.5

- Calculate impact force on baffle blocks:

$F = 2\,\gamma\,A\,(d_1 + hv_1)$

where F = force in lbs

γ = unit weight of water in kg/m^3

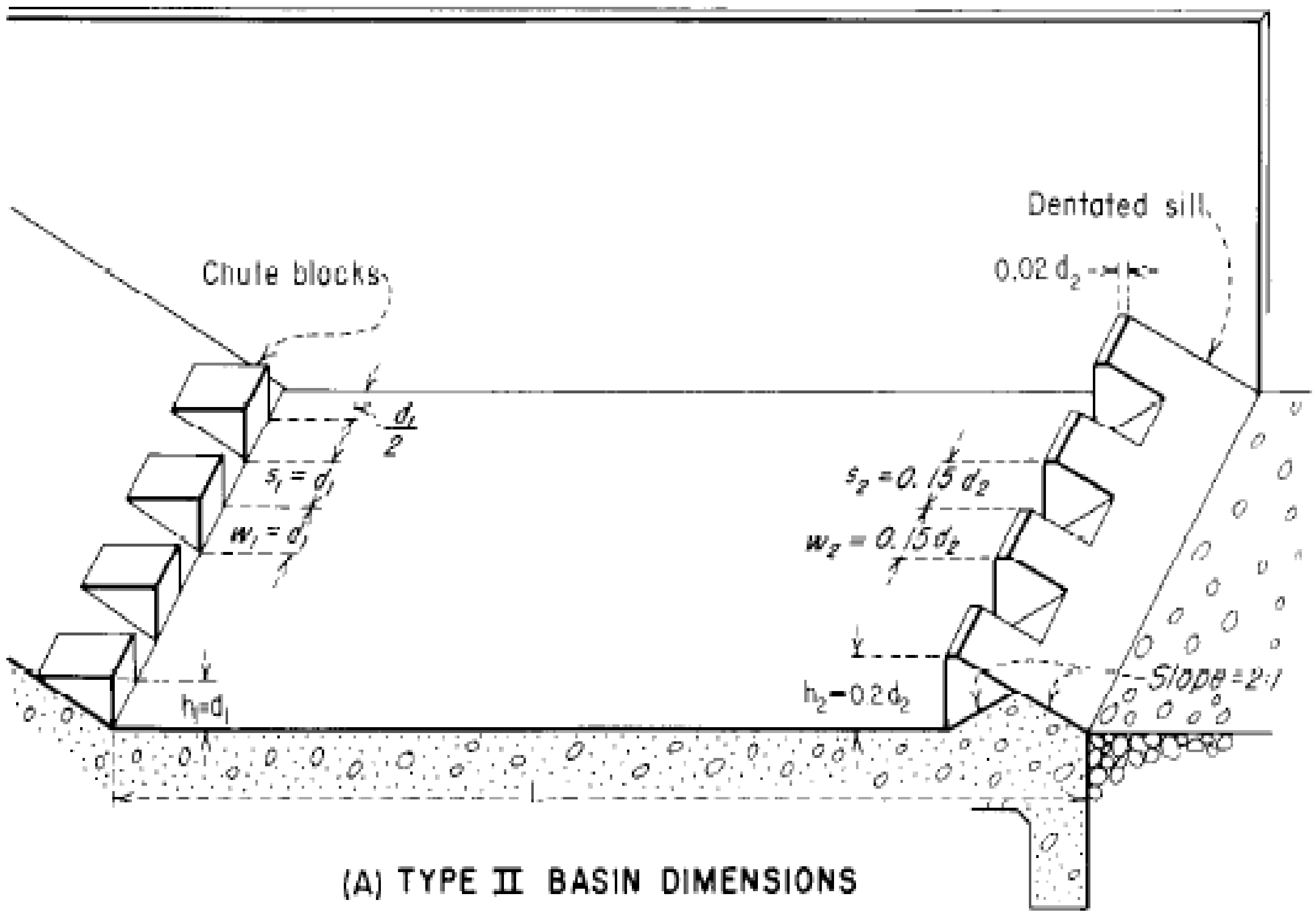
A = area of upstream face of blocks in m^2

(d_1+hv_1) = specific energy of flow entering the basin in m.

Type II Stilling Basin – Fr>4.5

- When Fr > 4.5 and V > 20 m/sec, use Type II stilling basin
- Because baffle blocks are not used, maintain a tailwater depth 5% higher than required as safety factor to stabilize the jump

Type II Stilling Basin: Fr>4.5



(A) TYPE II BASIN DIMENSIONS

Problem

- A rectangular irrigation canal 10 m wide carries a flow of 30 m^3/s at a depth of 1.50 m. A drop structure is required, at which the bed of the downstream canal is 2.5 m lower than the bed of the upstream canal. Sketch and carry out a hydraulic design for a simple stilling basin that ensures that the hydraulic jump is contained at the foot of the spillway.

Thank You