Hydraulics of Open Channels, Rivers and Dams

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Hydraulics of Open channels, Rivers and Dams

- ✓ Uniform flow-Selection of Manning’ s friction coefficient for natural streams
- ✓ Compound Channels-Discharge Capacity
- ✓ Hydraulics of Culverts
- ✓ Dams-Design of Spillways

Uniform flow

α) $\frac{\partial h}{\partial x} = 0 \quad h = \sigma\tau\alpha\theta\varepsilon\rho\acute{o}, \quad \frac{\partial U}{\partial x} = \frac{\partial Q}{\partial x} = 0,$

β) $S_f = S_{\varepsilon\varepsilon} = S_o = S$

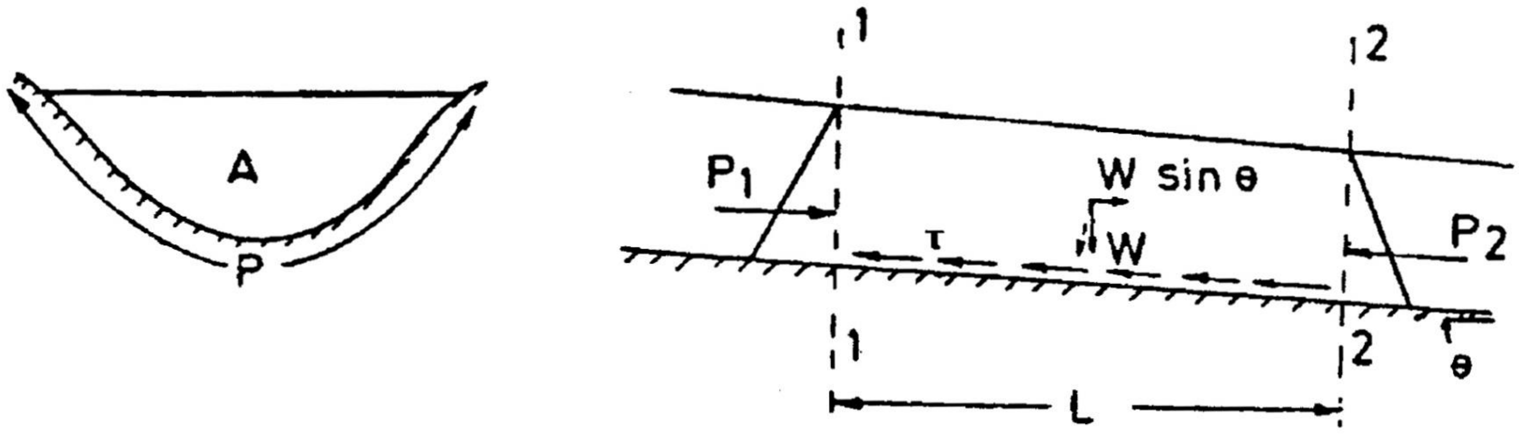


Figure: Characteristics of control volume

$\Sigma F = m\gamma$ Για $\gamma = 0 \rightarrow \Sigma F = 0$

$F_1 + W_{\sin\theta} - F_2 - F_f = 0$ (1)

$F_1 = F_2$ $W_{\sin\theta} = \gamma\, ALS$

$W = \gamma AL$ $F_f = \tau_o PL = KV^2 PL$ (Chezy)

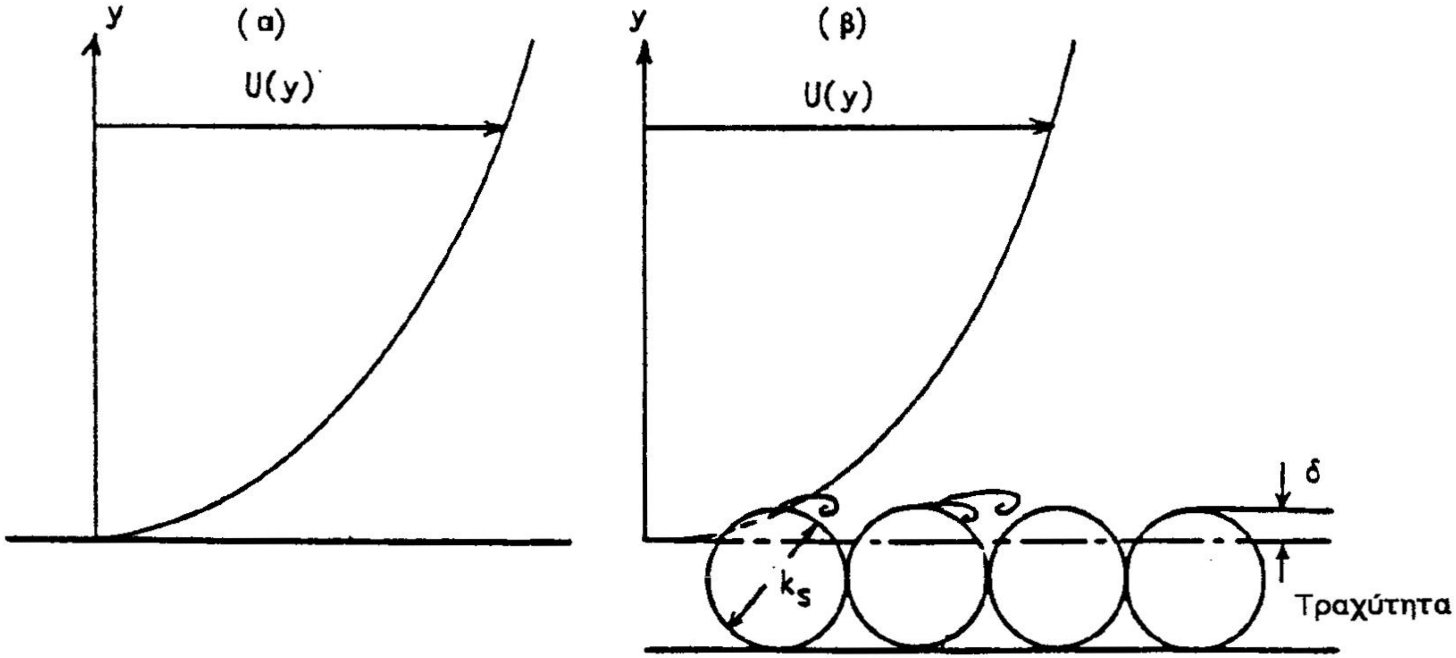
$\sin\theta = S_o$ τ_o = boundary shear stress, P = wetted perimeter

$$\gamma ALS = KV^2 PL \;\Rightarrow\; V = \sqrt{\left(\frac{\gamma}{K}\right)\left(\frac{A}{P}\right)S_o} = C\sqrt{RS_o}$$

C = Chezy coefficient

R = hydraulic radius (A/P)

Flow over smooth and rough bed



(α) Smooth Bed ***(β) Rough Bed***

Uniform flow

R. Manning (1889) found $C = \dfrac{R^{1/6}}{n}$

and hence $U = \dfrac{1}{n} R^{2/3} S^{1/2}$

where n = Manning coefficient (with dimensions $TL^{-1/3}$)

Manning’s n for natural channels

Type of Channel and Description	Minimum	Normal	Maximum
A. *Natural Streams*			
1. Main Channels			
a. Clean, straight, full, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	0.030	0.035	0.040
c. Clean, winding, some pools and shoals	0.033	0.040	0.045
d. Same as above, but some weeds and stones	0.035	0.045	0.050
e. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. Same as "d" but more stones	0.045	0.050	0.060
g. Sluggish reaches, weedy. deep pools	0.050	0.070	0.080
h. Very weedy reaches, deep pools, or floodways with heavy stands of timber and brush	0.070	0.100	0.150

Manning's n for natural channels

Type of Channel and Description	Minimum	Normal	Maximum
2. Flood Plains			
a. Pasture no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
2. Same as above, but heavy sprouts	0.050	0.060	0.080
3. Heavy stand of timber, few down trees, little undergrowth, flow below branches	0.080	0.100	0.120
4. Same as above, but with flow into branches	0.100	0.120	0.160
5. Dense willows, summer, straight	0.110	0.150	0.200

Manning's n for natural channels

Type of Channel and Description	Minimum	Normal	Maximum
B. *Lined or Built-Up Channels*			
1. Concrete			
a. Trowel finish	0.011	0.013	0.015
b. Float Finish	0.013	0.015	0.016
c. Finished, with gravel bottom	0.015	0.017	0.020
d. Unfinished	0.014	0.017	0.020
e. Gunite, good section	0.016	0.019	0.023
f. Gunite, wavy section	0.018	0.022	0.025
g. On good excavated rock	0.017	0.020	
h. On irregular excavated rock	0.022	0.027	
2. Concrete bottom float finished with sides of:			
a. Dressed stone in mortar	0.015	0.017	0.020
b. Random stone in mortar	0.017	0.020	0.024
c. Cement rubble masonry, plastered	0.016	0.020	0.024
d. Cement rubble masonry	0.020	0.025	0.030
e. Dry rubble on riprap	0.020	0.030	0.035
3. Gravel bottom with sides of:			
a. Formed concrete	0.017	0.020	0.025
b. Random stone in mortar	0.020	0.023	0.026
c. Dry rubble or riprap	0.023	0.033	0.036

Selection of n for natural streams

Important factors for the selection of n:

(α) the type and the material size of the bed and the sides of a channel,

(β) the channel shape (geometry) in case that n is used in the energy equation for gradually varied flow.

Selection methods

(α) Field measurements Field measurements of discharge, flow depth and geometric characteristics of the cross sections.

VERY EXPENSIVE!!!!!

Selection of n for natural streams

(β) **"Photographic Method"** Various sources (e.g. Book by Chow, 1959), where there are photos of rivers with the respective n values.

- Photos in Black and White!!!!!
- Rivers in USA

- Similar method in UK

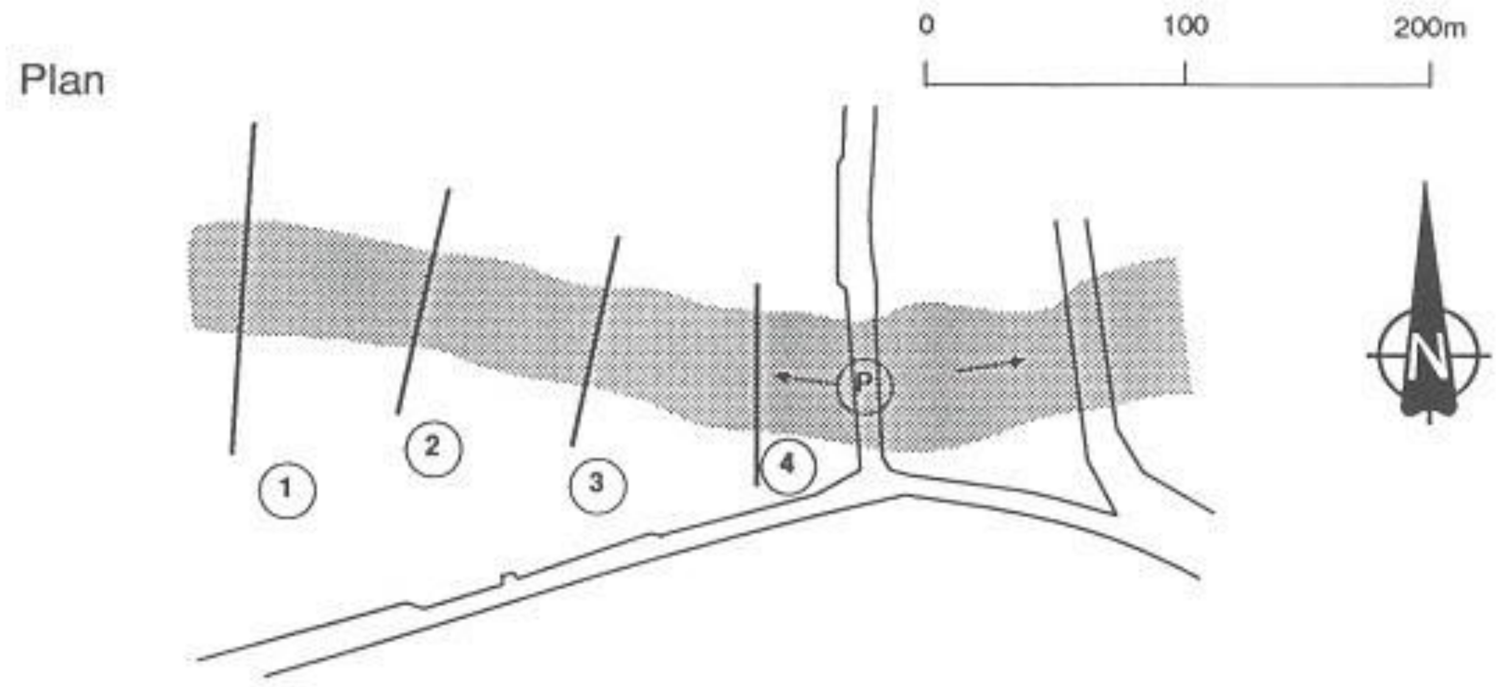
River Vyrnwy at Llanymynech

Bankfull hydraulic and geometric characteristics

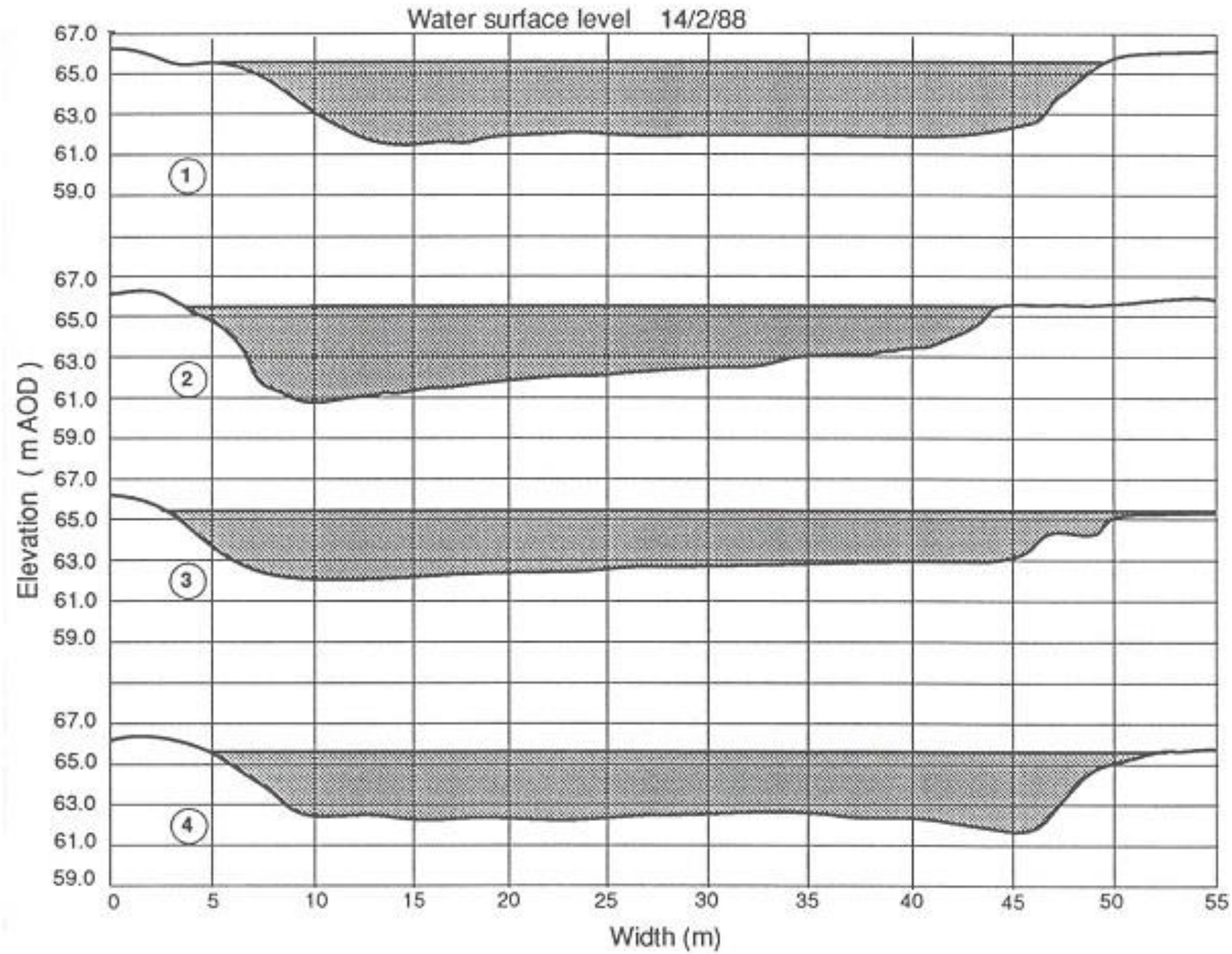
Manning's n roughness coefficient = 0.026
Discharge = 167.7m^3/s
Water surface slope = 0.000372 (1:2688)
Average cross sectional area = 131.6m^2
Average flow width = 46.4m
Average hydraulic radius = 2.25m

Description of channel

Bed material unknown. Right bank grass covered with scattered mature alders. Left bank lined with alder and willow. Left flood plain sown with crops, right flood plain is short grass pasture.

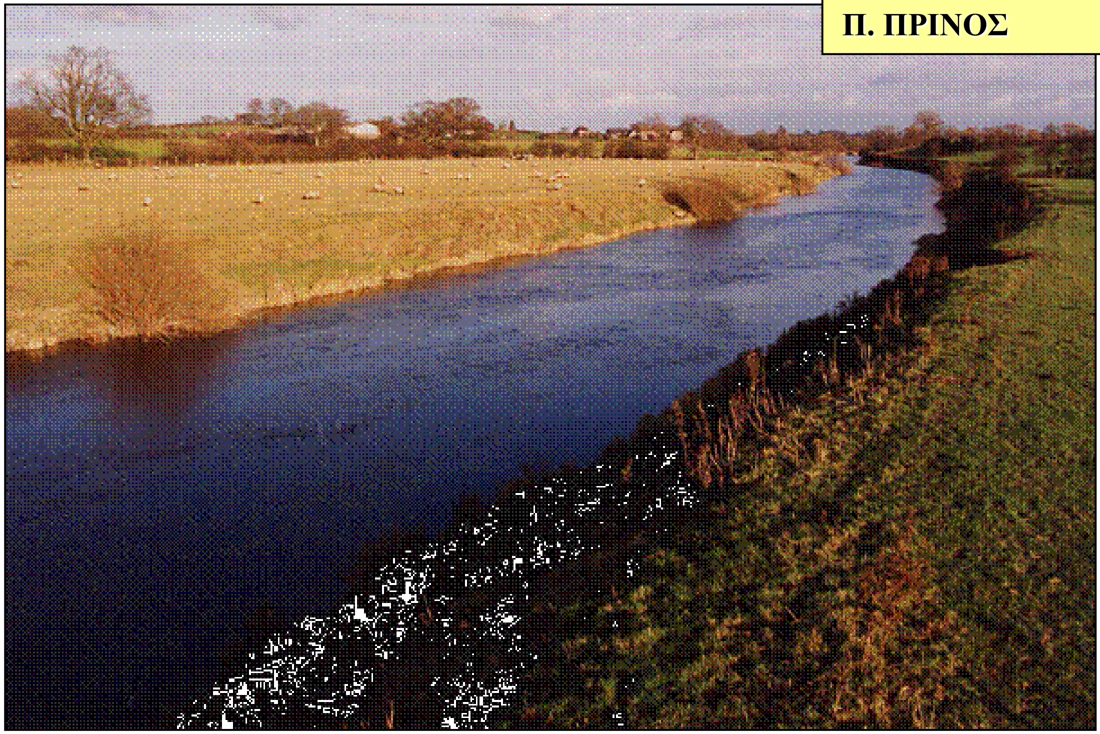


Plan sections, River Vyrnwy at Llanymynech



Cross sections, River Vyrnwy at Llanymynech

River Severn at Montford



Bankfull hydraulic
and geometric characteristics

Manning's n roughness coefficient = 0.028

Discharge = 151m^3/s

Water surface slope = 0.000186 (1:5376)

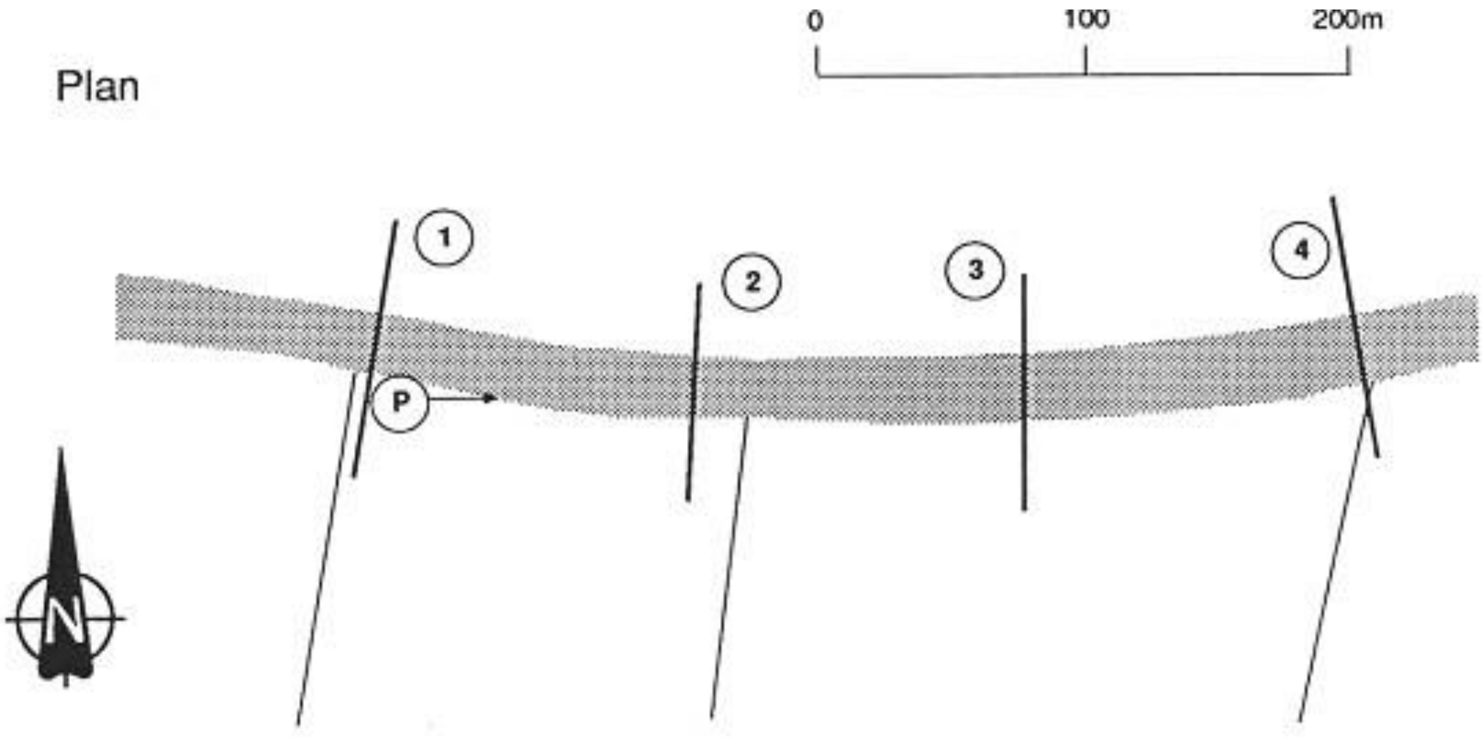
Average cross sectional area = 139m^2

Average flow width = 39.9m

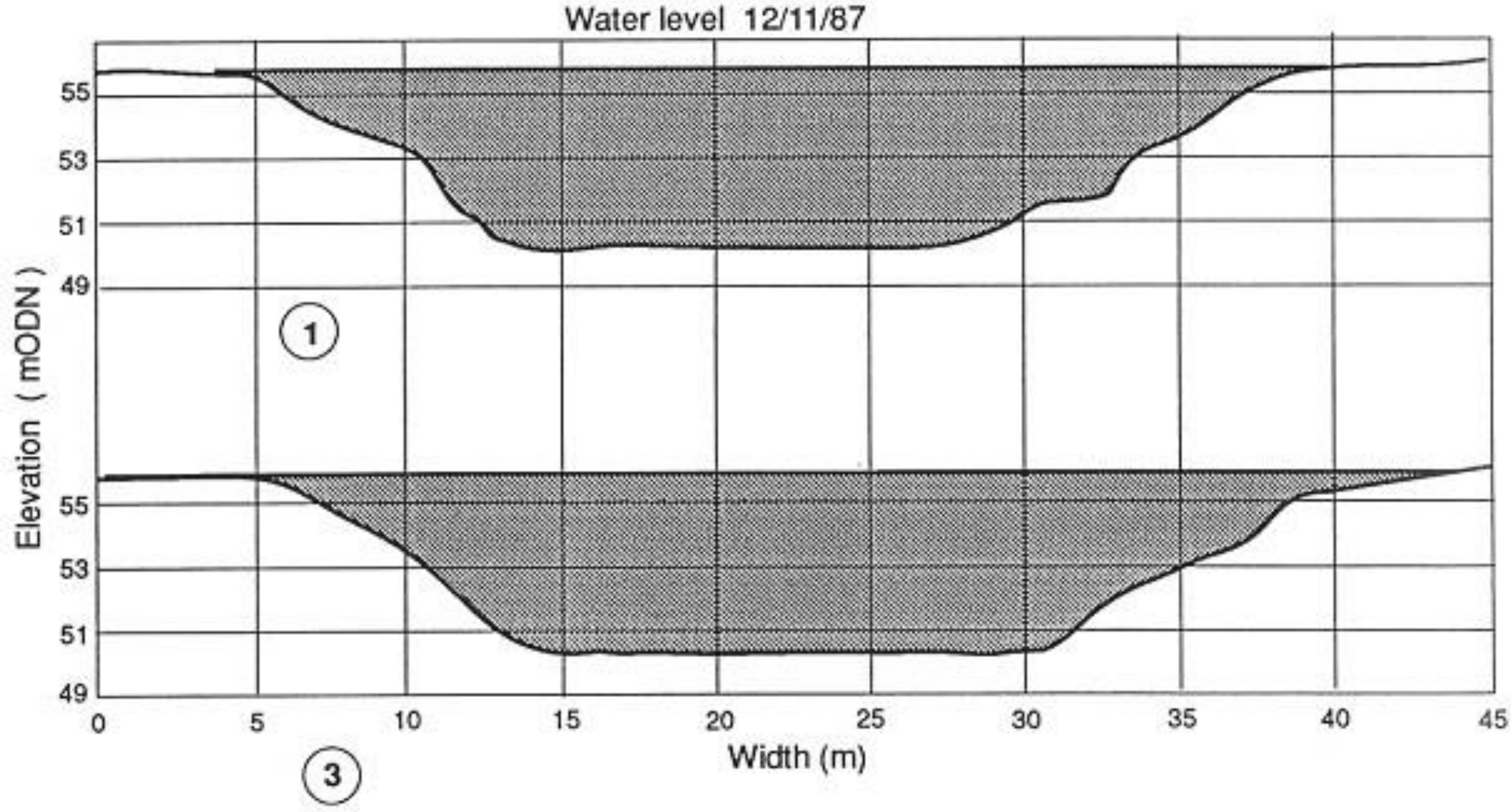
Average hydraulic radius = 3.31m

Description of channel

Bed material unknown. Left and right banks grass with occasional small willow trees. Flood plains of short grass pasture with hawthorn hedgerows and fences.



Cross sections



Cross sections, **River Severn at Montford**

River Manifold at Ilam

Bankfull hydraulic and geometric characteristics

Manning's n roughness coefficient = 0.042

Discharge = 52.8m^3/s

Water surface slope = 0.001977 (1:506)

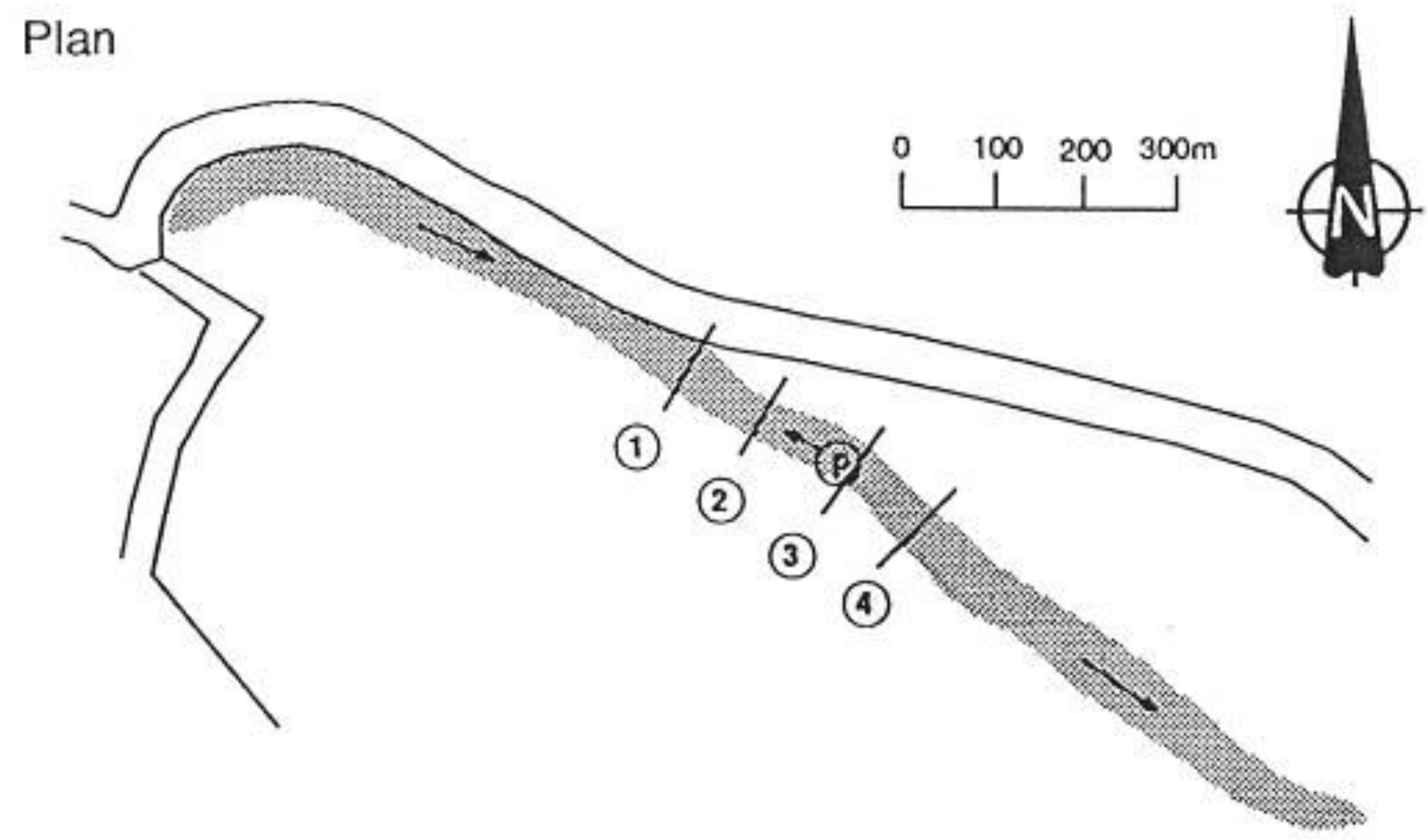
Average cross sectional area = 35.6m^2

Average flow width = 21m

Average hydraulic radius = 1.64m

Description of channel

Bed material is gravel and boulders. Bank vegetation of alder, ash, hazel, beech, sycamore and hawthorn traces with grass, scattered undergrowth of bramble. Flood plains of short grass pasture with hedgerows and wire fencing.



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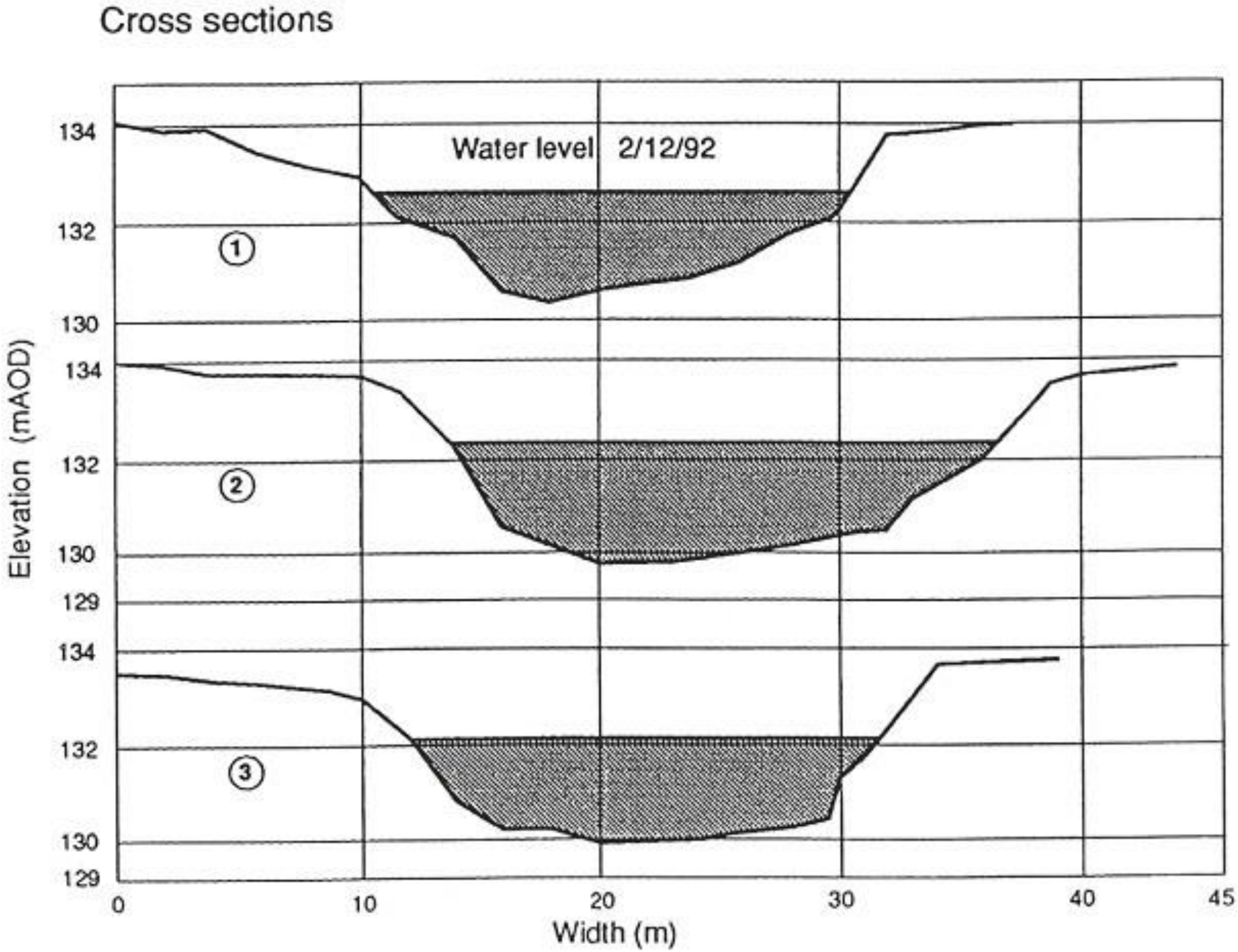
Π. ΠΡΙΝΟΣ



Cross sections, **River Manifold at Ilam**

River Tanat at Llanyblodwel

Bankfull hydraulic and geometric characteristics

Manning's n roughness coefficient = 0.052

Discharge = 54.8m^3/s

Water surface slope = 0.00298 (1:336)

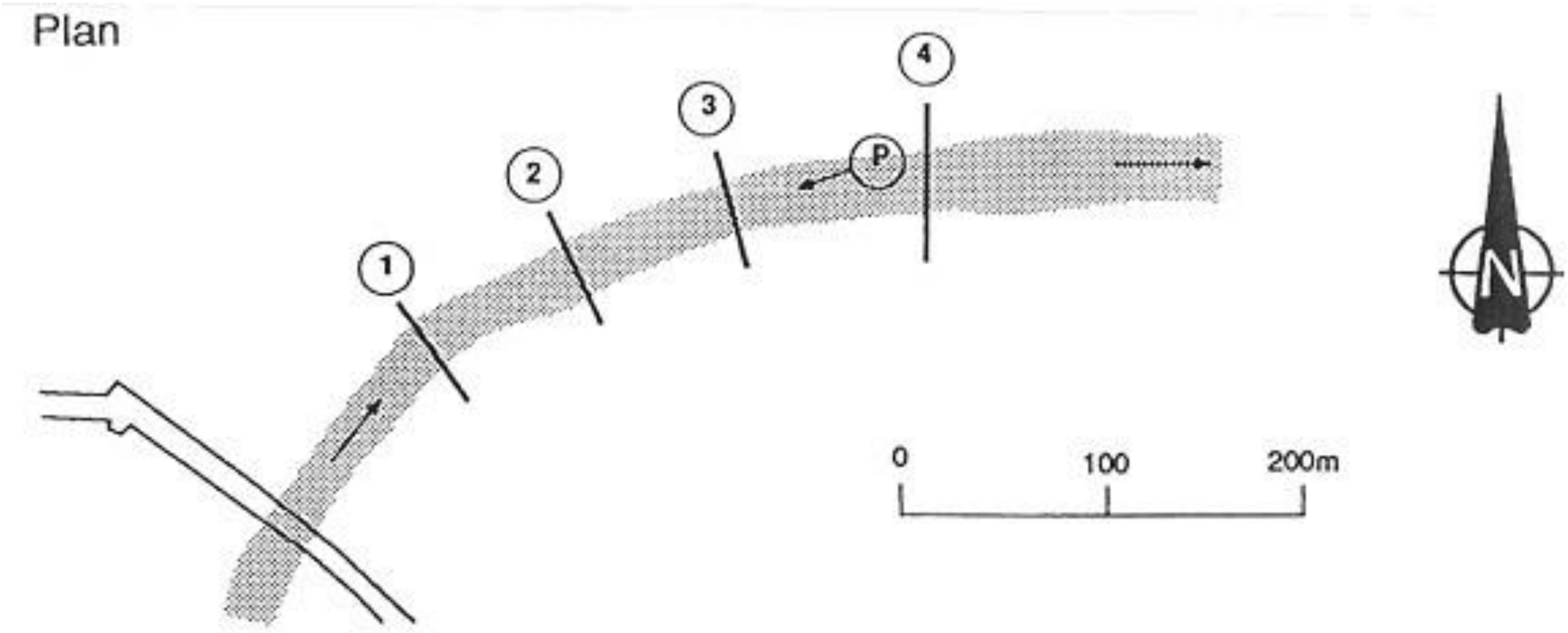
Average cross sectional area = 40.4m^2

Average flow width = 26.7m

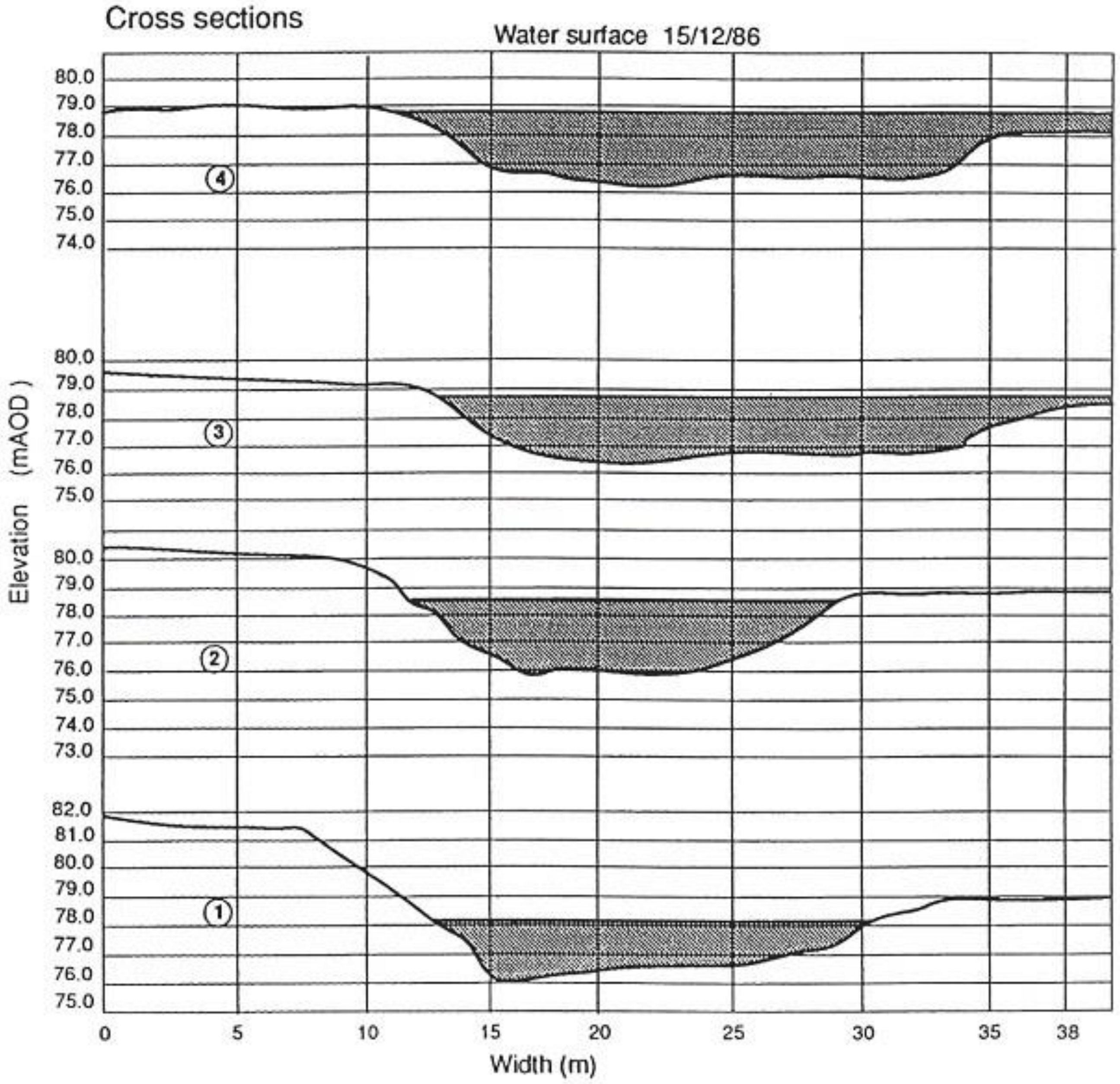
Average hydraulic radius = 1.45m

Description of channel

Bed gravel and boulders. Banks lined with mature alders, ash and willow, undergrowth of bramble, nettle, wild rose and rank grass. Left flood plain is sown with crops, right flood plain is short grass pasture. Field boundaries delimited by hedgerows.

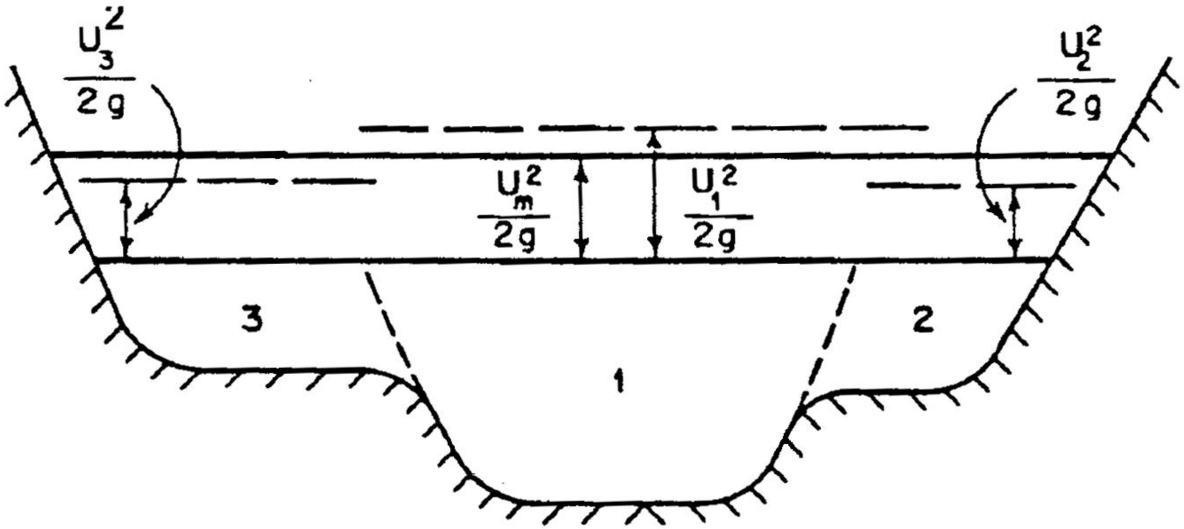


Plan sections, **River Tanat at Llanyblodwel**



Cross sections,
River Tanat at Llanyblodwel

COMPOUND CHANNELS



Cross Section of a compound channel

Calculation methods for the discharge capacity

(1) "Single Channel" Method

(2) "Separate Channels" Method

(1) "Single Channel" Method

The whole compound section is taken as a single cross-section

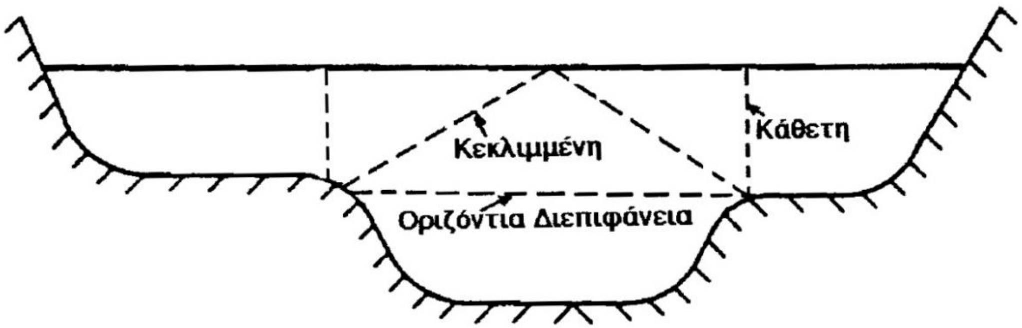
$$Q_t = \frac{1}{n} A_t R_t^{2/3} S_t^{1/2}$$

Where the subscript t refers to the total discharge, total area of cross-section etc.

(2) “Separate Channels” Method

The total discharge is determined by summing up the discharges of the various sub-sections.

$$Q_t = \sum_{i=1}^{N} \frac{1}{\eta_i} A_i \; R_i^{2/3} S_i^{1/2}$$



The interface used for subdividing the compound cross-section may be vertical, inclined or horizontal.

HYDRAULICS OF CULVERTS

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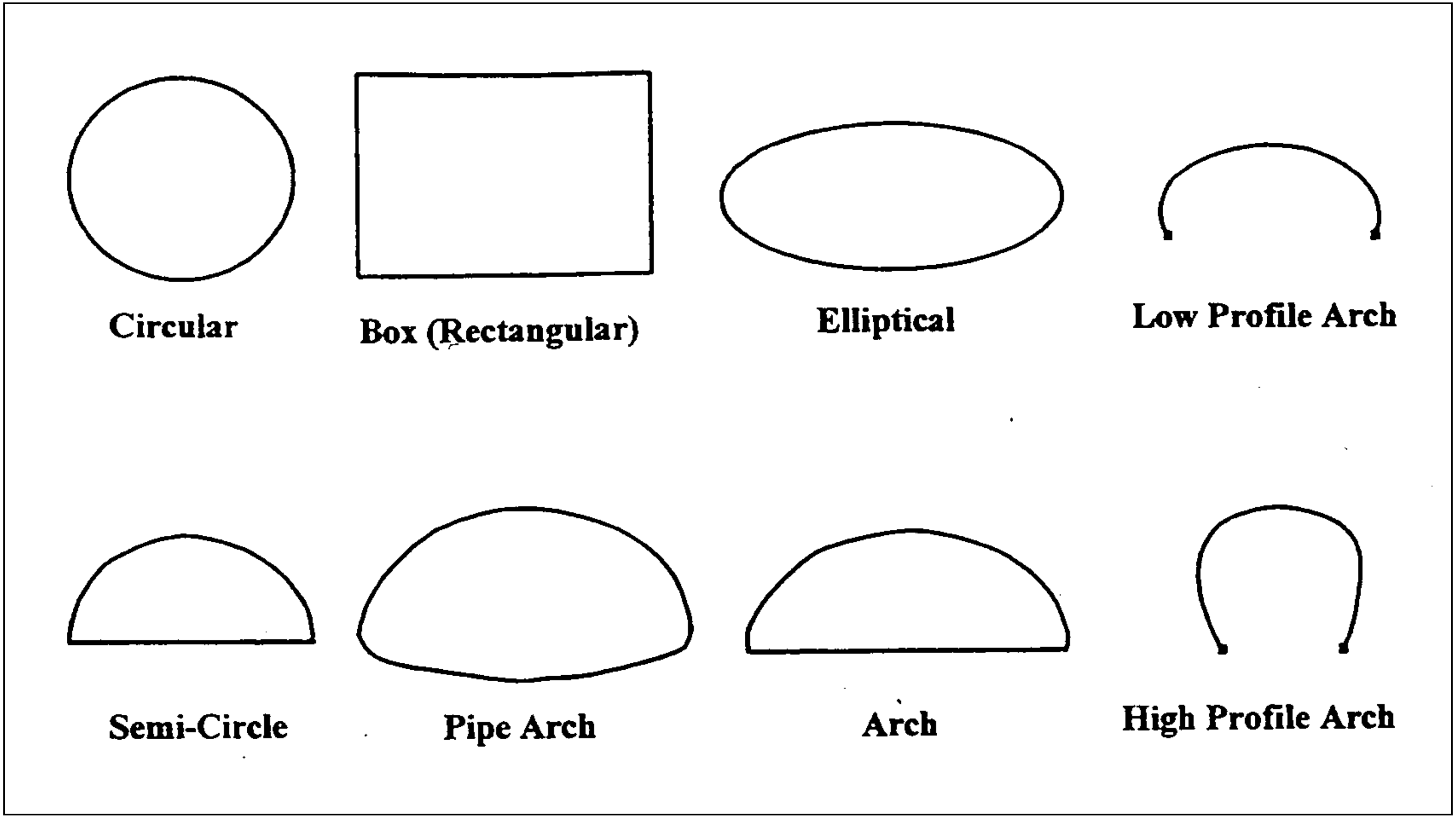
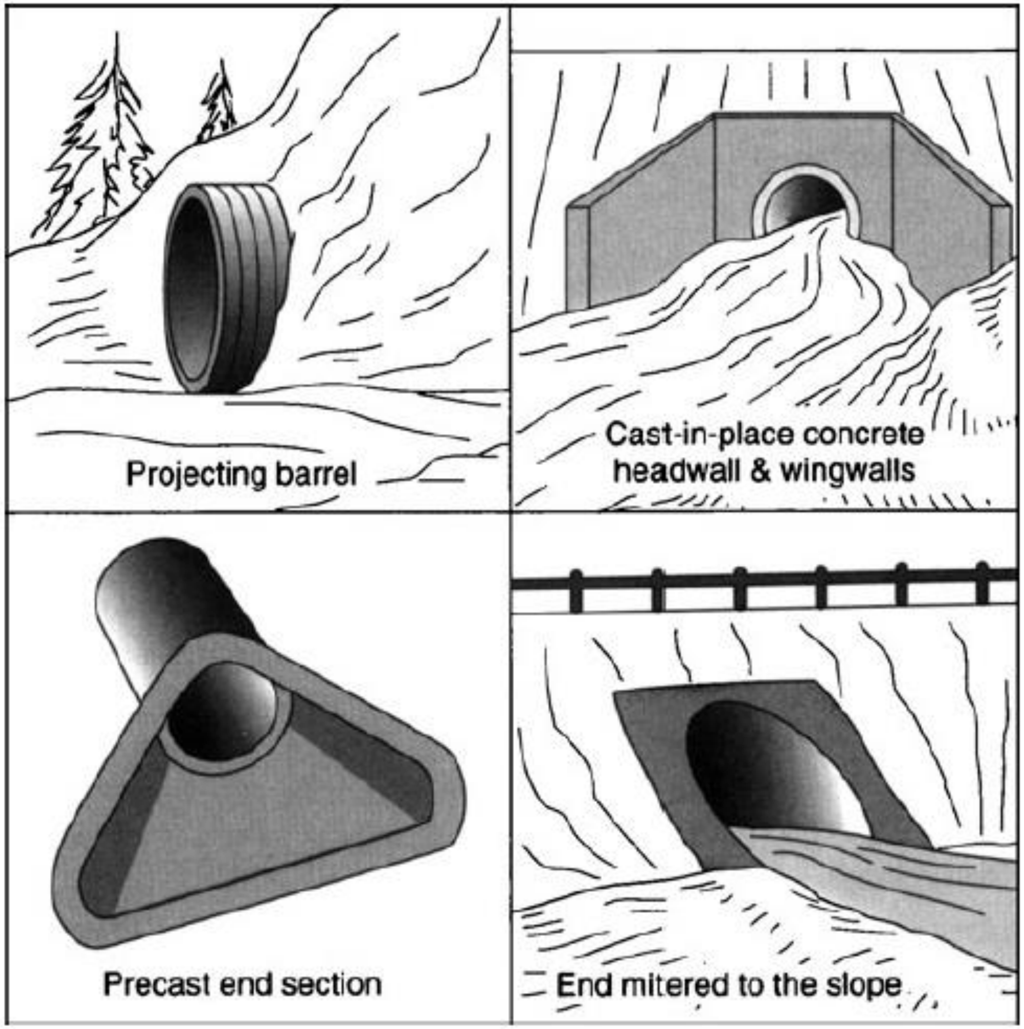


HYDRAULICS OF CULVERTS

Culverts of rectangular c/s

Arch Metallic culverts

Types of Inlets



Typical Culvert Profile

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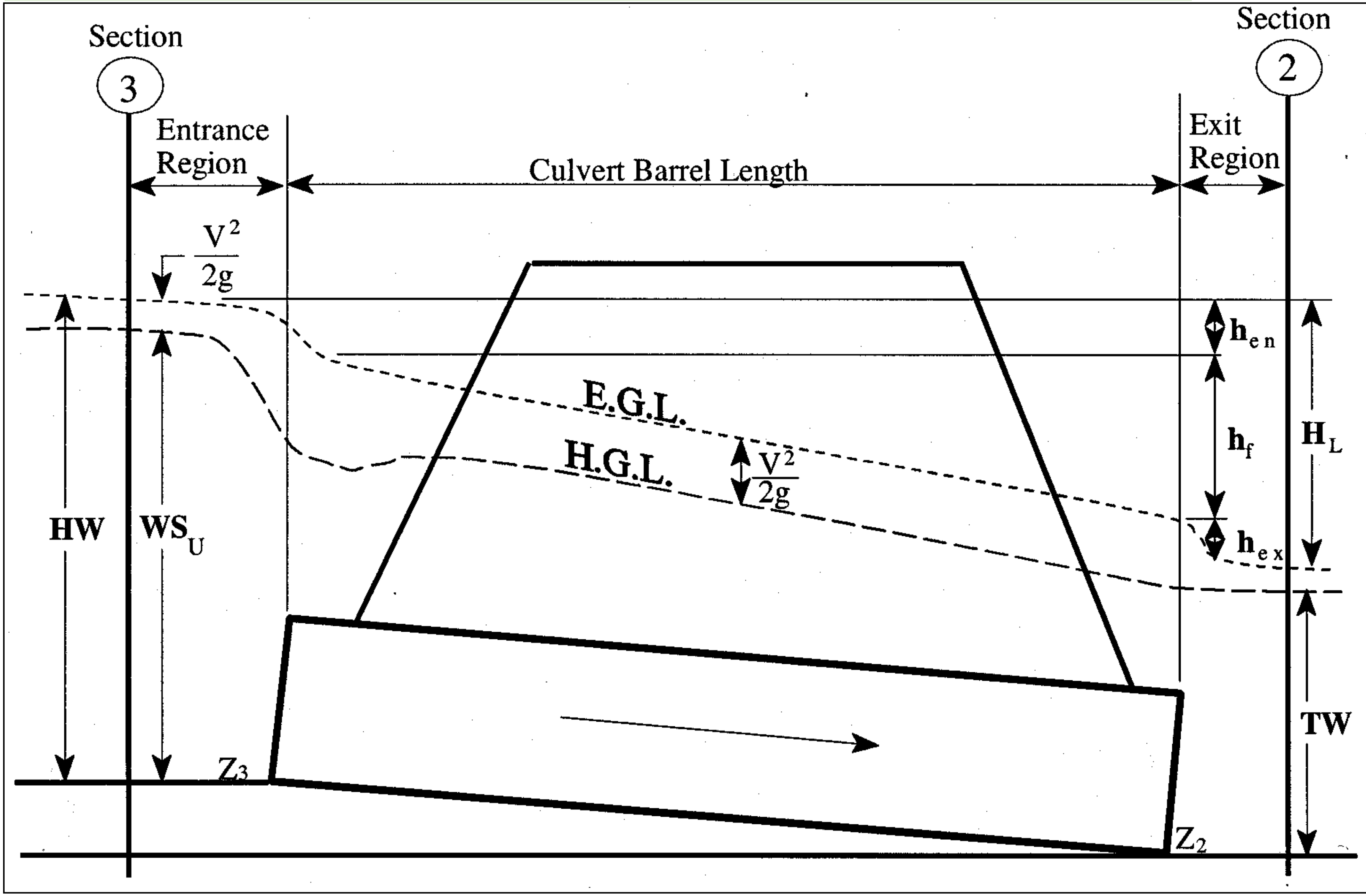


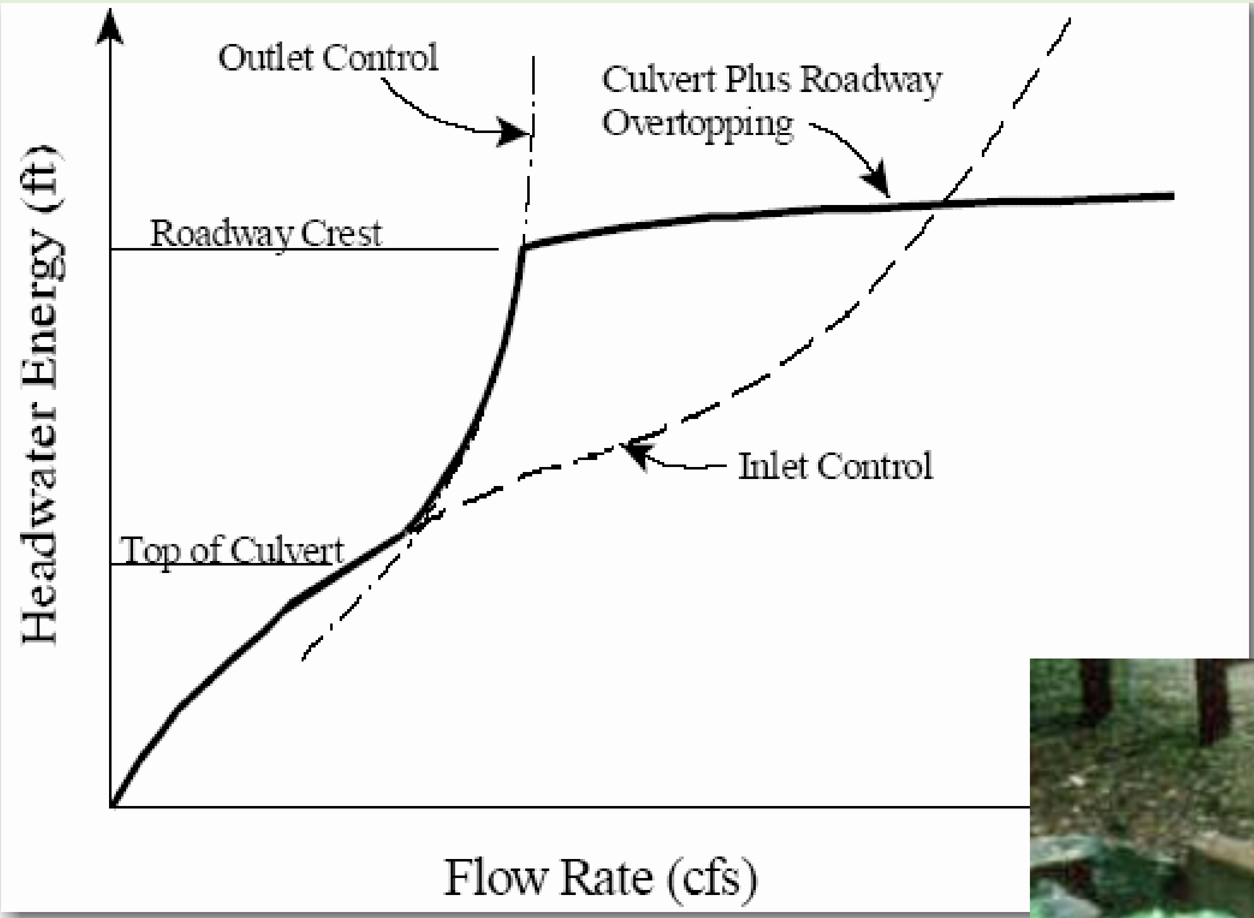
“Inlet control” and “Outlet control”?

For a given flow profile, what physical features of the culvert dominate flow capacity?

1. **Features of the culvert entrance?**
INLET CONTROL

2. **Features at the downstream end?**
OUTLET CONTROL

Culvert Rating Curve



As a general rule inlet controls at the lower flows and outlet control takes over for the higher flows.

Higher tailwater not caused by flow through the culvert can alter this curve. Once overtopping of the road embankment begins, a large increase in flow can occur with a small increase in the headwater.

Culvert Hydraulics - Inlet Control

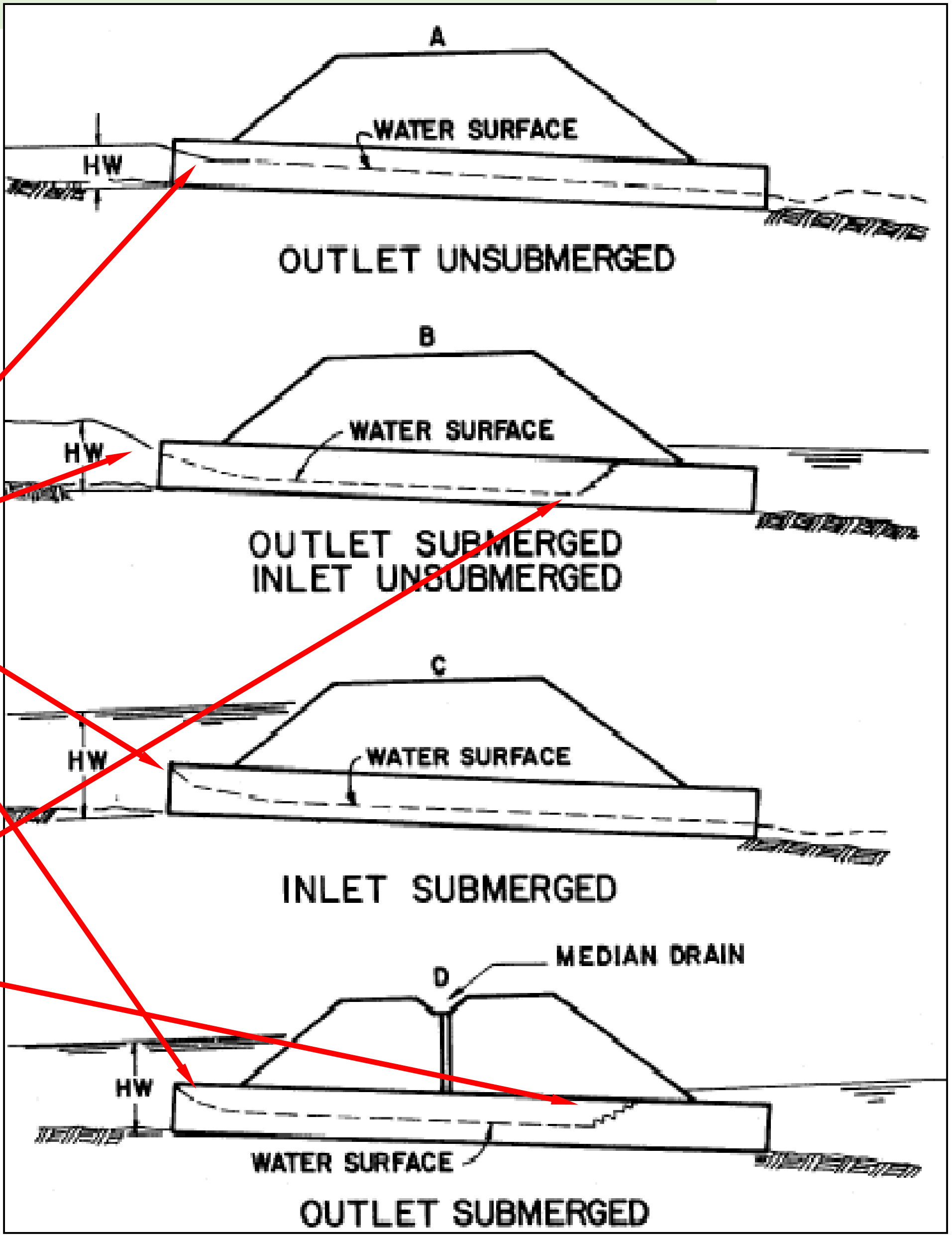
- Occurs when flow capacity of the culvert entrance is less than the flow capacity of the culvert barrel.
- Depends primarily on the geometry of the culvert entrance. Sharp entrance has less capacity.
- Control section is just inside the entrance.
- Flow passes through critical depth at this location or just downstream of this location.
- Headwater is calculated assuming the entrance acts as a weir or as a sluice gate.
- Usually occurs during lower flows.

Inlet control

Flow is less than the barrel capacity because inlet features cause too much energy loss.

Flow passes through critical depth near the inlet. (This is the control section.)

Hydraulic jump occurs in the barrel if downstream slope is subcritical



Culvert Hydraulics - Outlet Control

Occurs when flow capacity is controlled by the tailwater conditions or the flow capacity of the culvert barrel.

Entrance, exit, and friction losses are computed in determining controlling headwater elevation.

Bernoulli equation is used to compute the change in energy through the culvert.

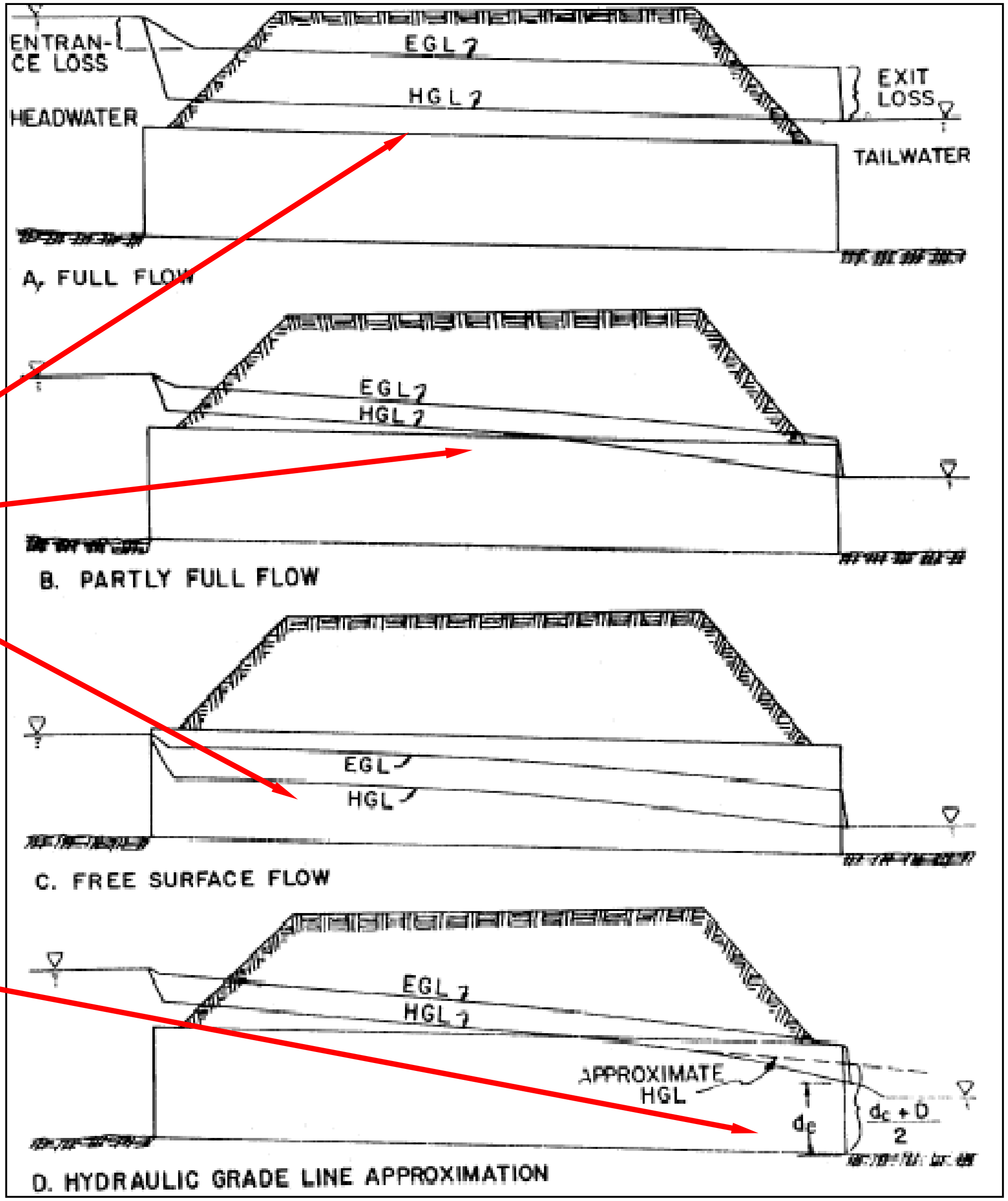
$$h_f = L\left[\frac{Qn}{AR^{2/3}}\right]^2$$

Outlet control

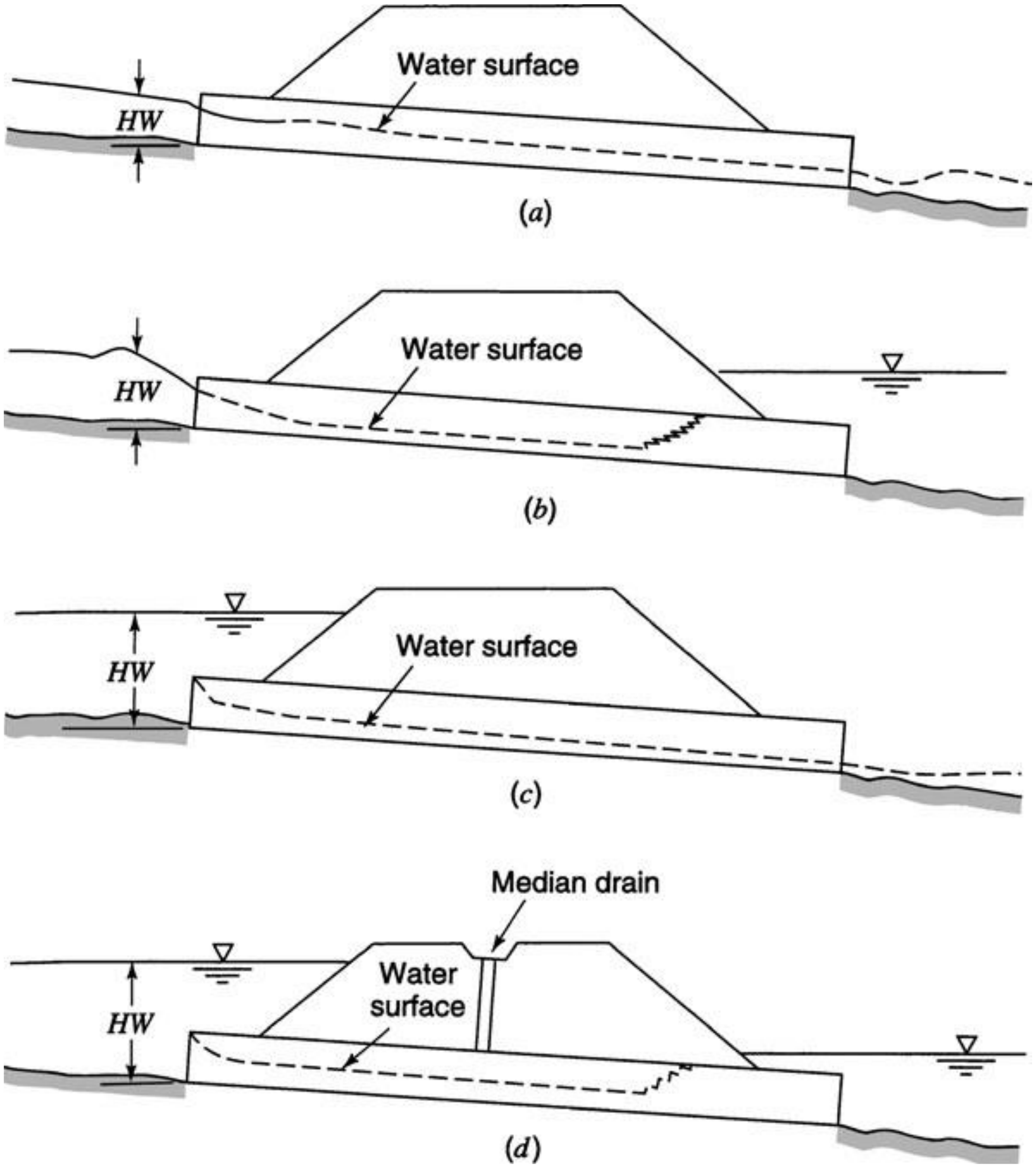
Barrel capacity can be reached and flow limited only by downstream tailwater.

Flow is generally subcritical and controlled by barrel friction unless...

...tailwater is low enough due to a downstream supercritical slope. Then flow passes through critical near the outlet (the control section).



Inlet Control



Types of inlet control.

(a) Outlet and inlet unsubmerged;

(b) Outlet submerged, inlet unsubmerged

(c) Inlet submerged and outlet unsubmerged

(d) Outlet and inlet submerged

Inlet-Control Design Equations

A culvert under inlet-control conditions performs as an orifice when the inlet is submerged and as a weir when it is unsubmerged.

The (submerged) orifice discharge equation is computed using

$$\frac{HW}{D} = C\left[\frac{Q}{AD^{0.5}}\right]^2 + Y - Z \quad \text{for} \quad \frac{Q}{\left(AD^{0.5}\right)} \geq 4.0$$

where HW is the headwater depth above the inlet control section invert (ft), D is the interior height of the culvert barrel (ft), Q is the discharge (ft^3/s), A is the full cross-sectional area of the culvert barrel in (ft^2), S_0 is the culvert barrel slope (ft/ft), C and Y are constants (Table), and Z is the slope correction factor where $Z = -0.5S_0$ in general and $Z = +0.7S_0$ for mitered inlets.

The (unsubmerged) weir discharge equation is (Form 1):

$$\frac{HW}{D} = \frac{E_c}{D} + K\left[\frac{Q}{AD^{0.5}}\right]^M + Z \quad \text{for} \quad \frac{Q}{\left(AD^{0.5}\right)} \leq 3.5$$

Where E_c is the specific head at critical depth and K and M are constants (Table).

Outlet-Control Design Equations

A culvert under outlet-control conditions has either subcritical flow or full-culvert flow, so that outlet-control flow conditions can be calculated using an energy balance. For the condition of full culvert flow, considering entrance loss h_e, friction loss (using Manning's equation) h_f, and exit loss h_0, the total head loss H is

$$H = h_e + h_o + h_f \Rightarrow H = \left(1 + k_e + \frac{10n^2L}{R^{1.33}}\right)\frac{U^2}{2g}$$

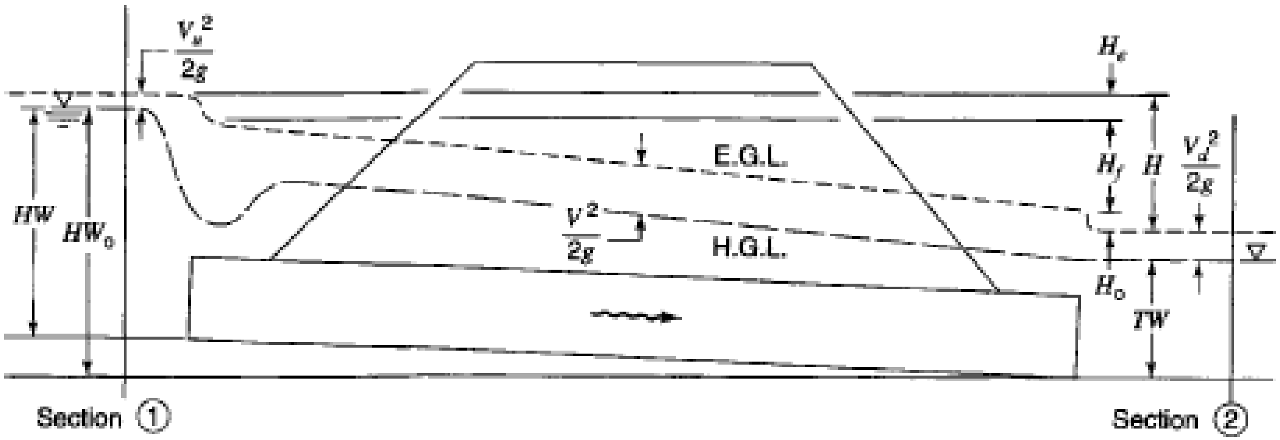
where k_e is the entrance loss coefficient, n is Manning's roughness coefficient, R is the hydraulic radius of the full-culvert barrel, V is the velocity and L is the culvert length . Other losses such as bend losses H_b, junction losses H_j, and grate losses H_g can also be added to the equation.

Table 16.2.2 lists common values of Manning's n values for culverts.

Table 16.2.3 lists entrance loss coefficients for outlet control, full or part full flow.

Outlet-Control Design Equations

Figure illustrates the energy and hydraulic grade lines for full flow in a culvert.
Equating the total energy at section 1 (upstream) and section 2 (downstream) gives



$$HW_0 + \frac{U_u^2}{2g} = TW + \frac{U_d^2}{2g} + h_e + h_o + h_f \Rightarrow HW_0 = TW + h_e + h_o + h_f$$

(for negligible velocity heads)

Manning n values for culverts

Type of conduit	Wall description	Manning *n*
Concrete pipe	Smooth walls	0.010–0.013
Concrete boxes	Smooth walls	0.012–0.015
Corrugated metal pipes and boxes, annular or helical pipe (Manning *n* varies with barrel size)	2 2/3" by 1/2" corrugations	0.022–0.027
	6" by 1" corrugations	0.022–0.025
	5" by 1" corrugations	0.025–0.026
	3" by 1" corrugations	0.027–0.028
	6" by 2" structural plate corrugations	0.033–0.035
	9" by 2 1/2" structural plate corrugations	0.033–0.037
Corrugated metal pipes, helical corrugations, full circular flow	2 2/3" by 1/2" corrugations	0.012–0.024
Spiral rib metal pipe	Smooth walls	0.012–0.013

*Note: The values indicated in this table are recommended Manning *n* design values. Actual field values for older existing pipelines may vary depending on the effects of abrasion, corrosion, deflection, and joint conditions. Concrete pipe with poor joints and deteriorated walls may have *n* values of 0.014 to 0.018. Corrugated metal pipe with joint and wall problems may also have higher *n* values, and in addition may experience shape changes that could adversely affect the general hydraulic characteristics of the pipeline.

Source: Normann et al. (1985).

Entrance Loss Coeff. for outlet control

Table 16.2.3 Entrance Loss Coefficients for Outlet Control, Full or Partly Full $H_e = K_e[V^2/2g]$

Type of structure and design of entrance	Coefficient K_e
Pipe, concrete	
Mitered to conform to fill slope	0.7
*End section conforming to fill slope	0.5
Projecting from fill, square cut end	0.5
Headwall or headwall and wingwalls	
Square-edge	0.5
Rounded (radius = 1/12D)	0.2
Socket end of pipe (groove-end)	0.2
Projecting from fill, socket end (groove-end)	0.2
Beveled edges, 33.7° or 45° bevels	0.2
Side- or slope-tapered inlet	0.2
Pipe or pipe-arch, corrugated metal	
Projecting from fill (no headwall)	0.9
Mitered to conform to fill slope, paved or unpaved slope	0.7
Headwall or headwall and wingwalls square-edge	0.5
*End section conforming to fill slope	0.5
Beveled edges, 33.7° or 45° bevels	0.2
Side- or slope-tapered inlet	0.2
Box, reinforced concrete	
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Wingwalls at 10° to 25° or 30° to 75° to barrel	
Square-edged at crown	0.5
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of 1/12 barrel dimension, or beveled edges on 3 sides	0.2

Design of Culverts

The hydrologic analysis for culverts involves estimation of the design flow rate based upon the climatological and watershed characteristics.

This section concentrates on the use of performance curves for the design process.

Performance curves are relationships of the flow rate versus the headwater depth or elevation for different culvert designs, including the inlet configuration.

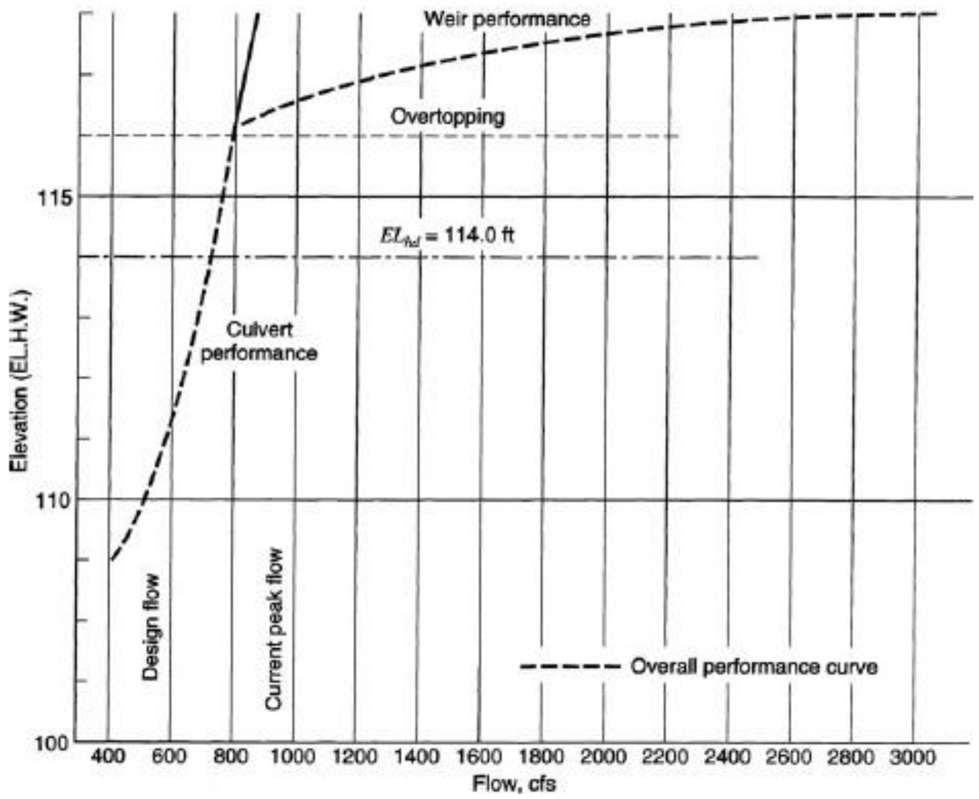
Both inlet and outlet performance curves are developed.

An overall performance curve can be developed using the following procedure (Norman et al., 1985):

1. Select a range of flow rates and determine the corresponding headwater elevation for the culvert. The flow rate should cover a range of flows of interest above and below the design discharge. Both inlet and outlet control headwater are computed.
2. Combine the inlet- and outlet-control performance curves into a single curve.
3. For roadway overtopping (culvert headwater elevation > roadway crest), compute the equivalent upstream water depth above the roadway crest for each flow rate using the weir equation

Design of Culverts

4. Add the culvert flow and roadway overtopping flow for the corresponding headwater elevations to obtain the overall culvert performance curve. The following Figure shows a culvert performance curve with roadway overtopping, showing the outlet-control portion and the inlet-control portion.

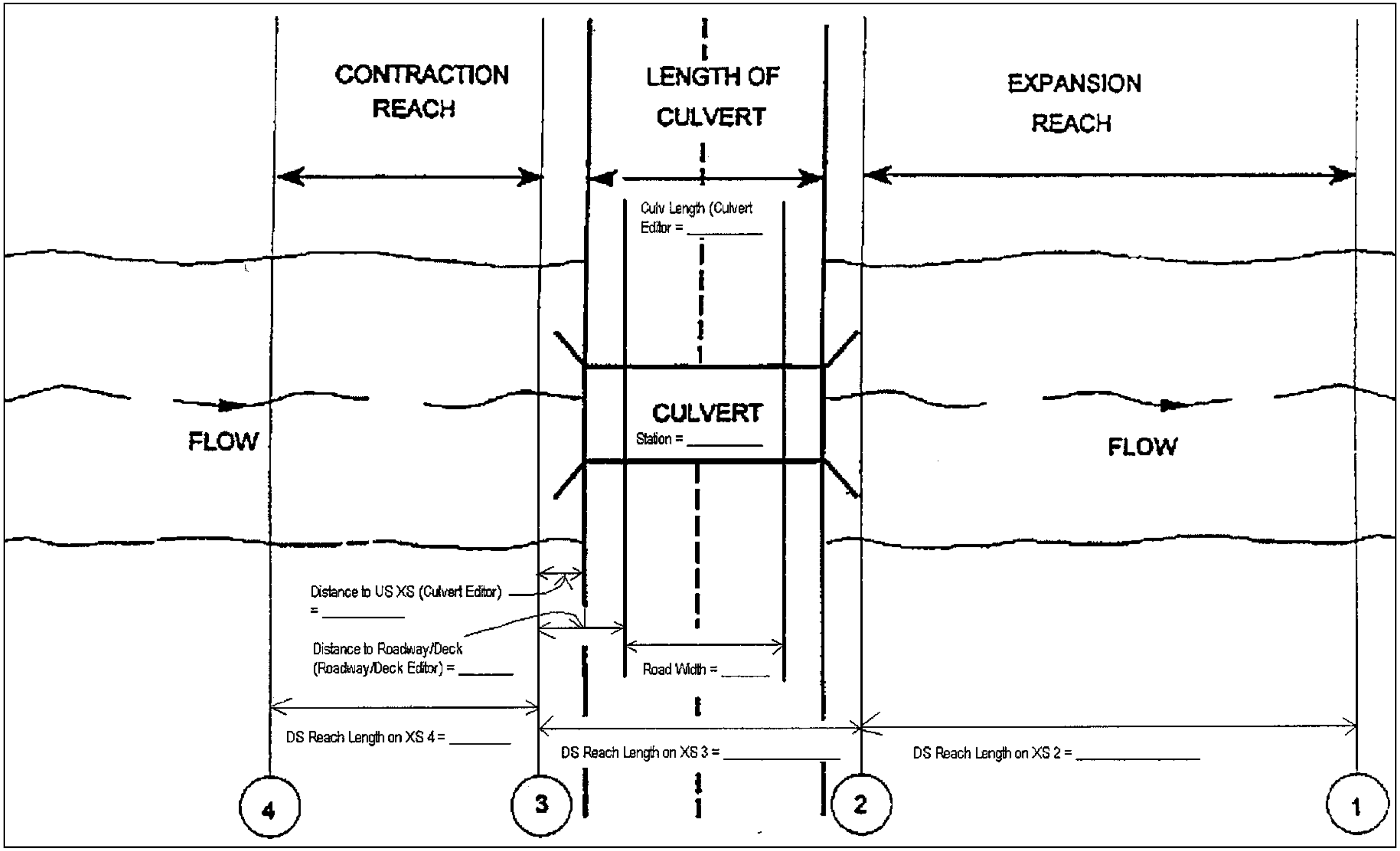


Inlet and Outlet Control *(details)*

1. For a given flow rate, HEC-RAS calculates the required upstream energy head for the two cases, inlet or outlet control, assuming first one then another.
2. In general, whichever requires the higher head will be the controlling scenario.
3. The energy head under outlet control is a function of barrel characteristics (size, shape, length, roughness) as well as inlet geometry and tailwater conditions.
4. The energy head under inlet control is not a function of barrel characteristics, but entirely inlet geometry.
5. HecRas calculates energy head assuming the inlet acts like a sluice gate or weir.
6. If the inlet control energy head is higher, HecRas double-checks to see if an hydraulic jump occurs in barrel. If so, orifice flow is assumed. This is an outlet control scenario.

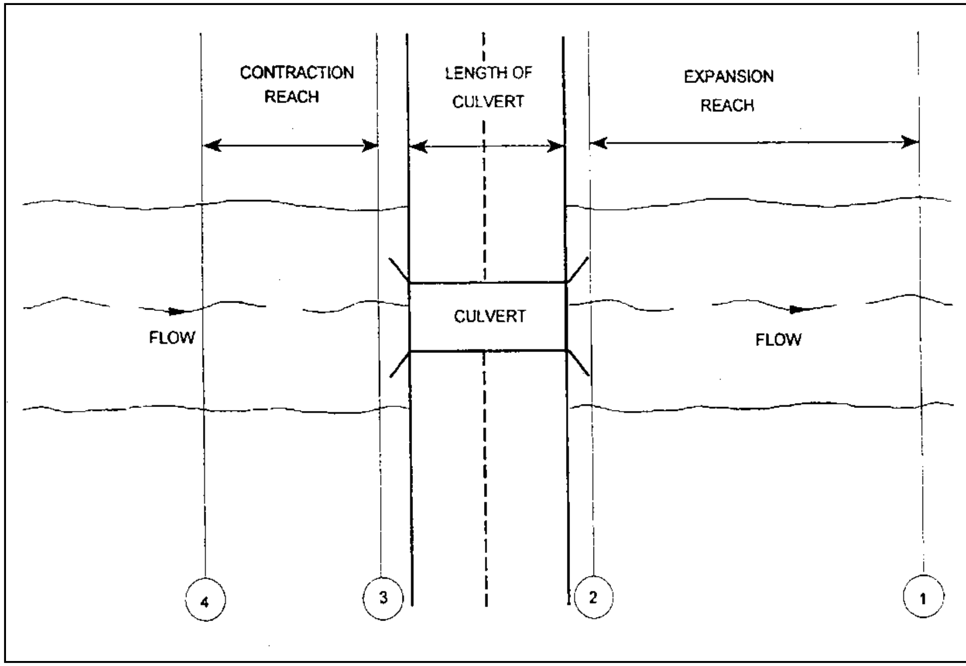
Cross Section Locations

The culvert must be bounded by two established cross sections (2 and 3) as well as sections that represent full channel flow (1 and 4).



Cross Section Locations (4 of them)

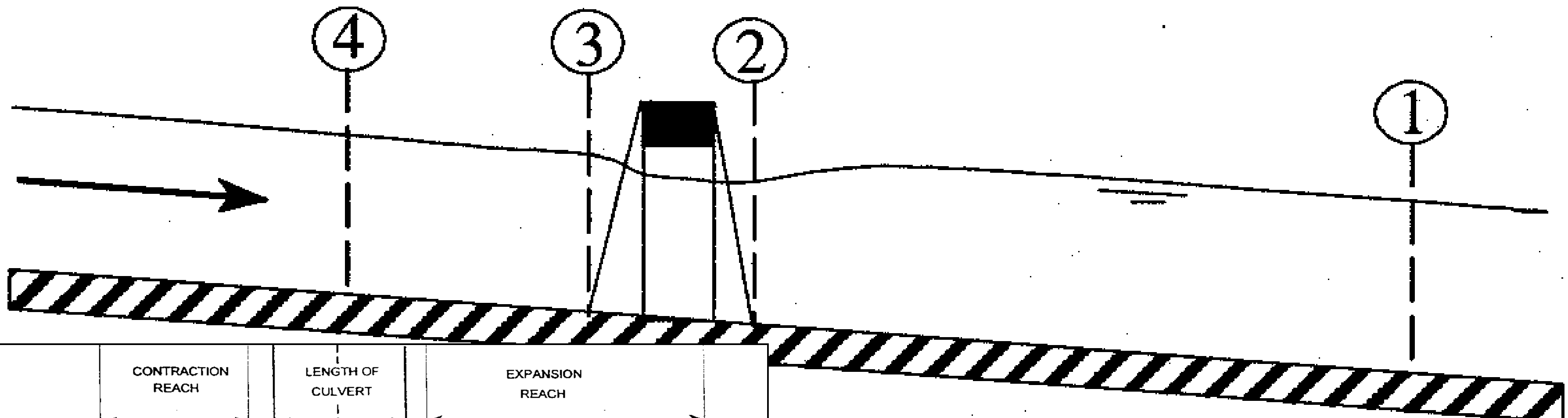
1 – flow fully expanded downstream of culvert
2 – Just downstream of culvert outlet
3 – Just upstream of culvert inlet
4 – flow full expanded upstream of culvert

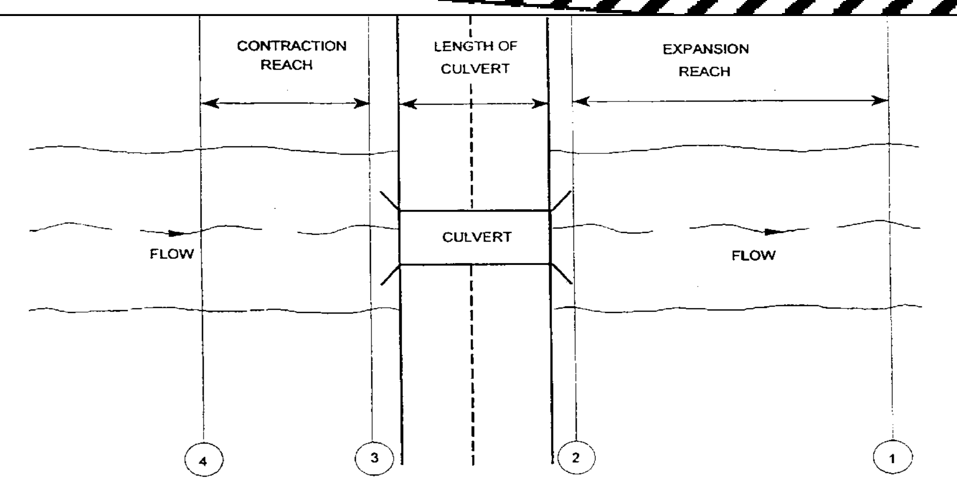


Specify contraction & expansion coefficients.

There is a possible range of values. Use larger values is a very abrupt transition

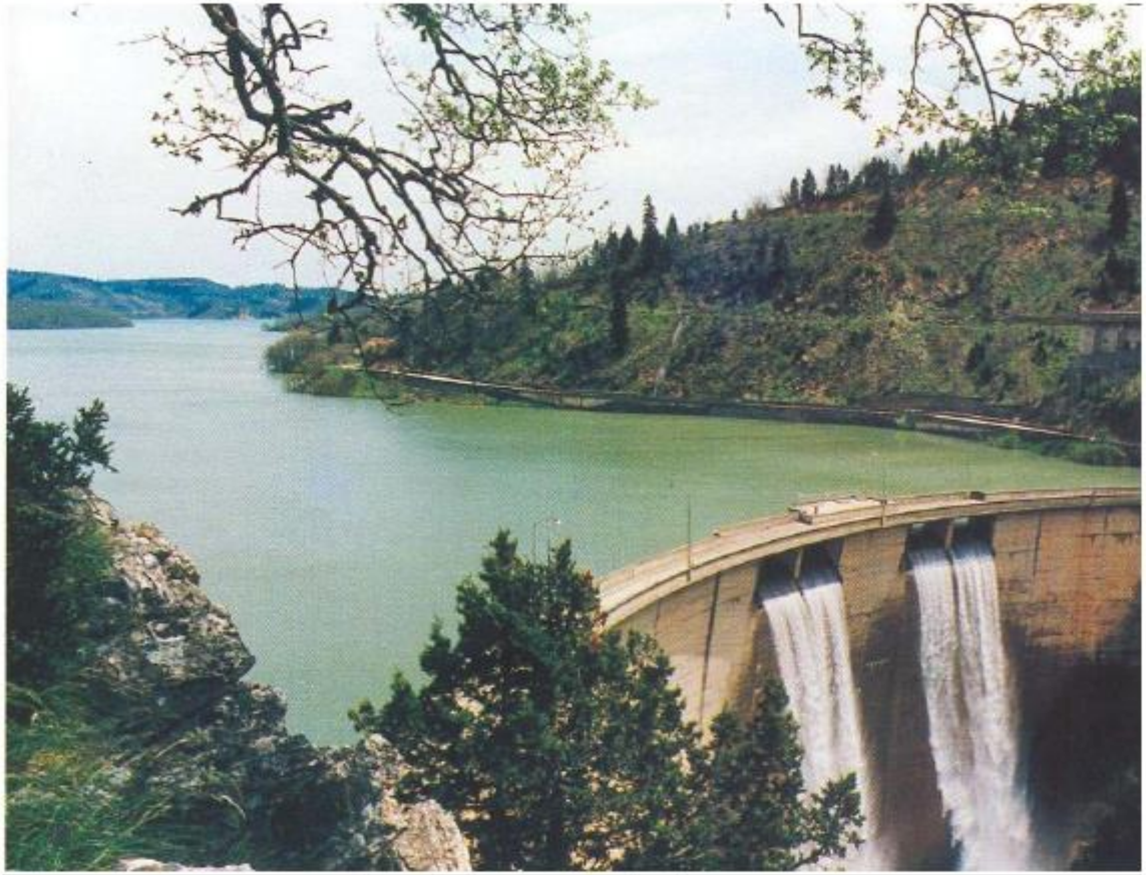
	Exp.	Contr.
section 4 (furthest u.s.)	0.5 (to 0.8)	0.3 (to 0.6)
section 3	0.5 (to 0.8)	0.3 (to 0.6)
section 2	0.5 (to 0.8)	0.3 (to 0.6)
section 1(furthest d.s.)	0.3	0.1





DAMS-DESIGN OF SPILLWAYS

Ταυρωπός (Πλαστήρας)



Γενική άποψη του Φράγματος

Κρεμαστά

Θυροφράγματα και διώρυγα πτώσης από κατάντη (πλημμύρα 12/2005)

<u>Καστράκι</u>

Γενική άποψη του Υπερχειλιστή σε λειτουργία (πλημμύρα 12/2005)

Κατασκευή εισόδου Υπερχειλιστή (L=120 m)

Θησαυρός

Οι τρεις διώρυγες του Εκχειστή από κατάντη
(πλημμύρα σχεδιασμού 7.500 m^3/sec)

Πλατανόβρυση

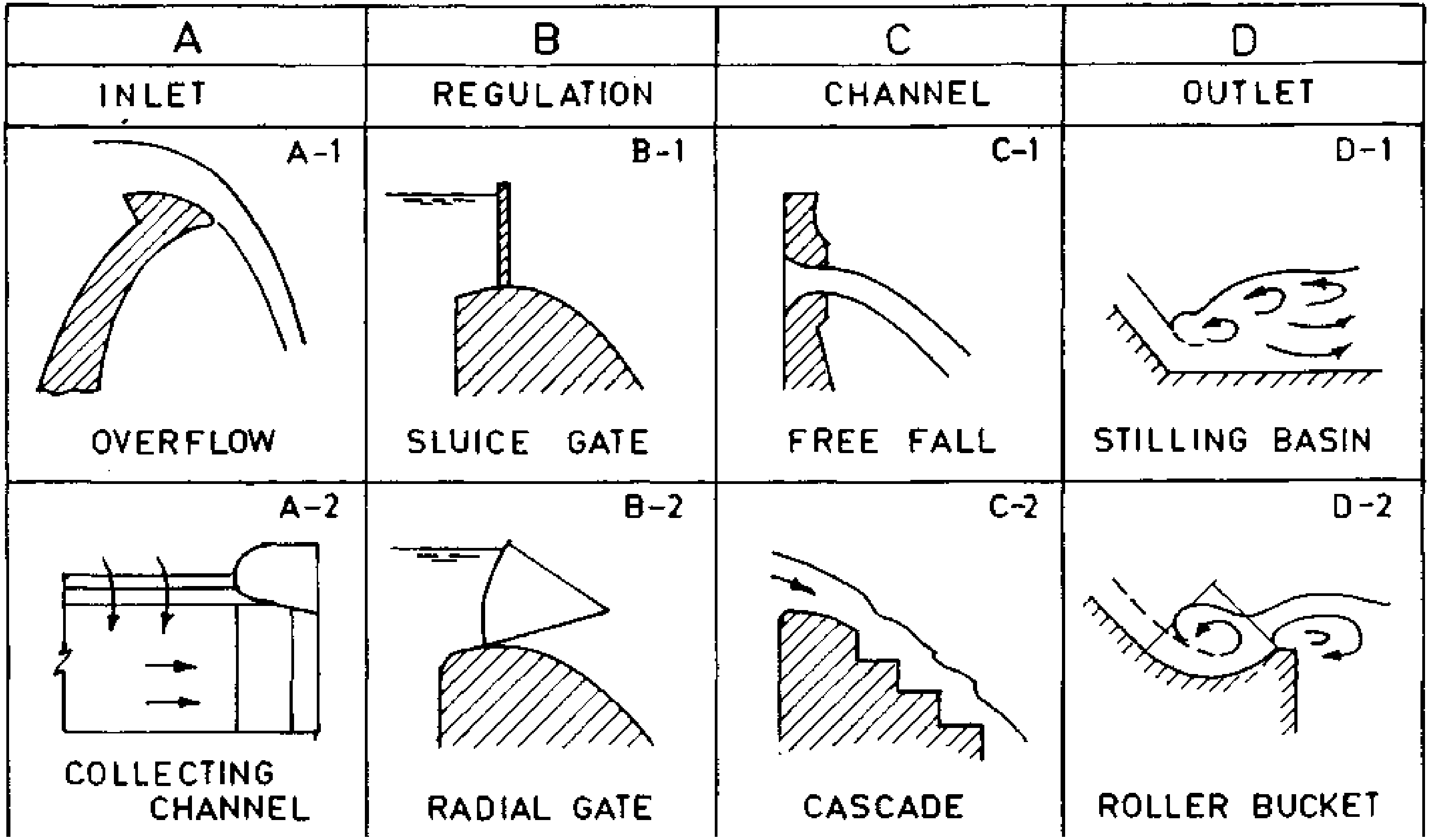
Ο Εκχειλιστής επί του Φράγματος (πλημμύρα σχεδιασμού 5.300 m^3/sec)
Δοκιμαστική λειτουργία του ενός από τα πέντε θυροφράγματα (Q=150 m^3/sec)

Itaipou (σύνορα Παραγουάης-Ουρουγουάης)

Μια πραγματικά μεγάλη πλημμύρα…

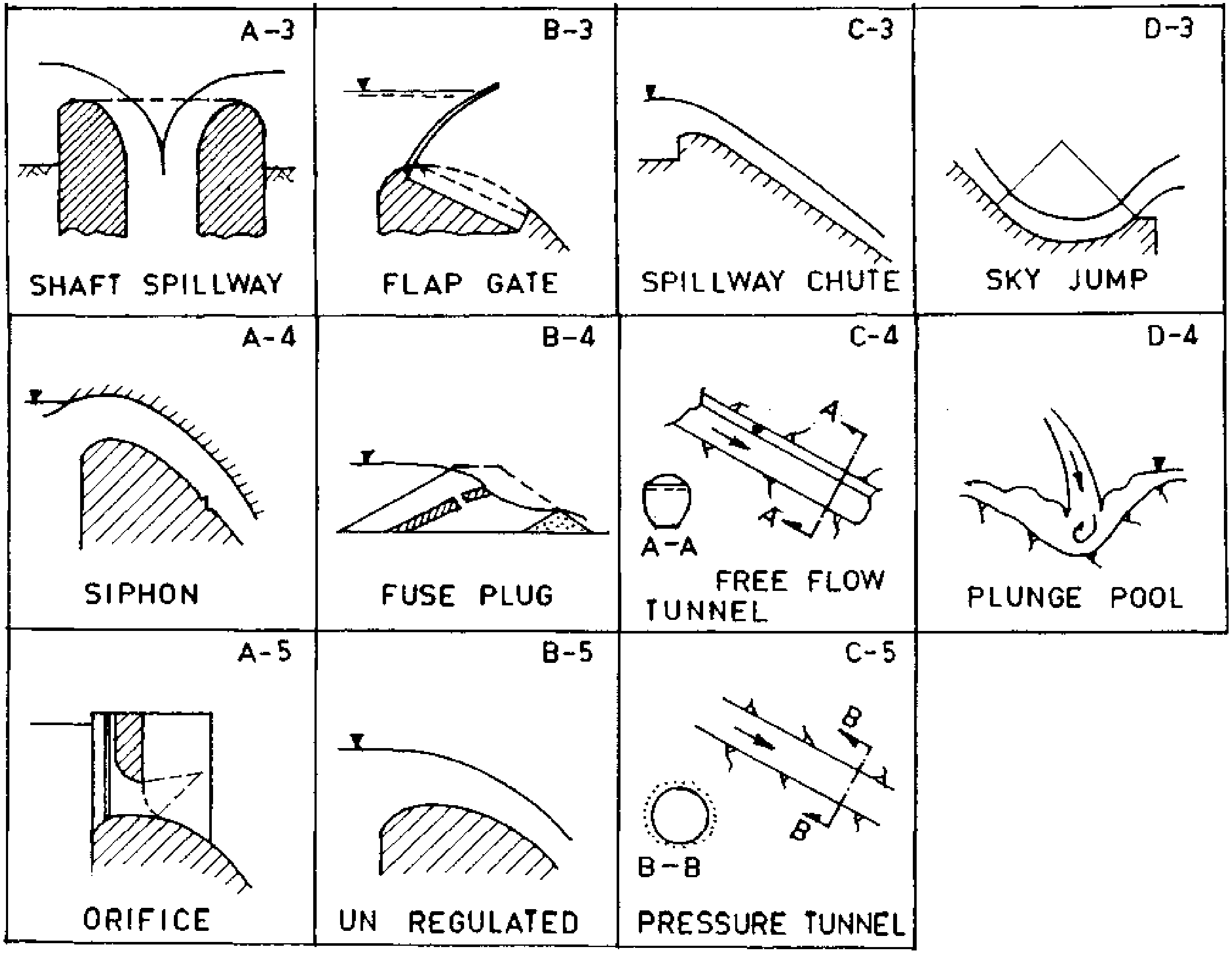
SPILLWAYS

INLET-REGULATION-CHANNEL-OUTLET



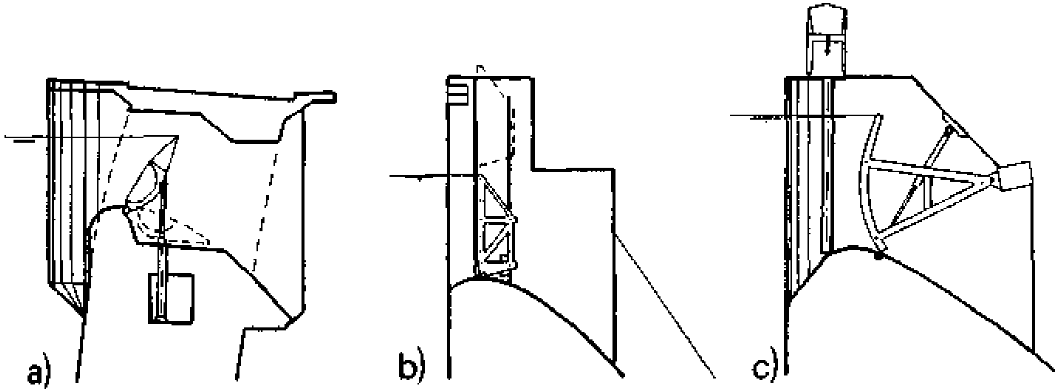
SPILWAYS

INLET-REGULATION-CHANNEL-OUTLET

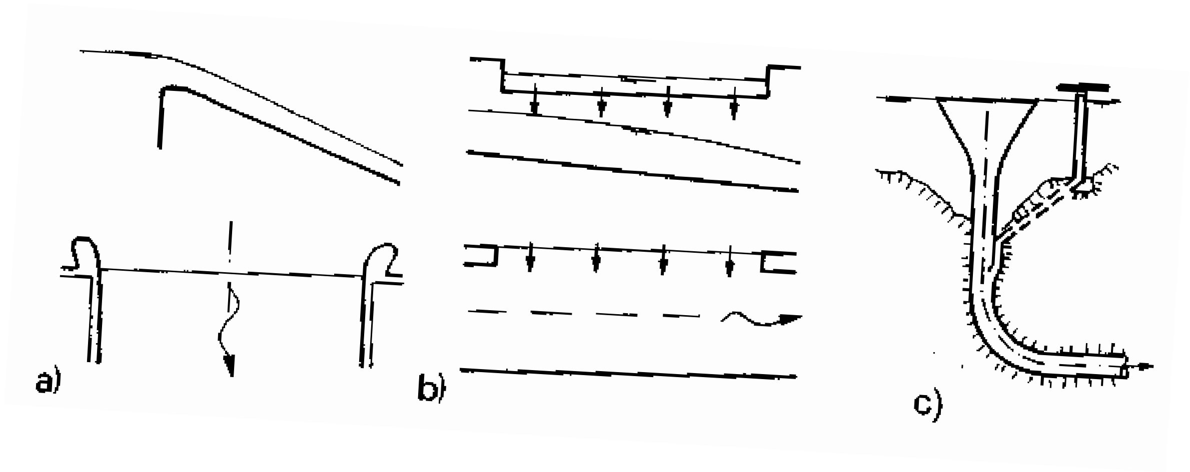


TYPES OF GATES AND SPILLWAYS-

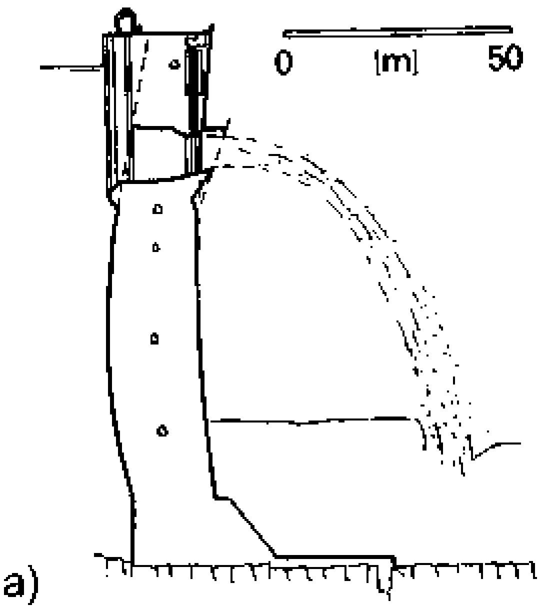
ΑΠΘ ΠΟΛ. ΜΗΧ.
Π.ΠΡΙΝΟΣ



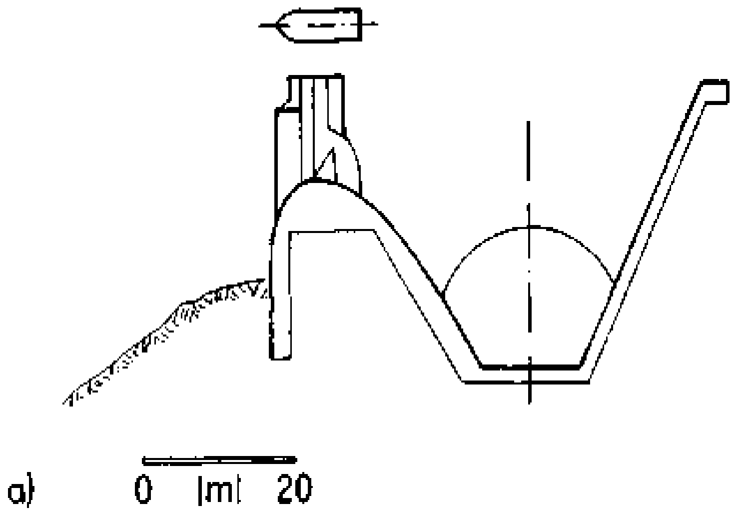
Flap Vertical Radial Gate



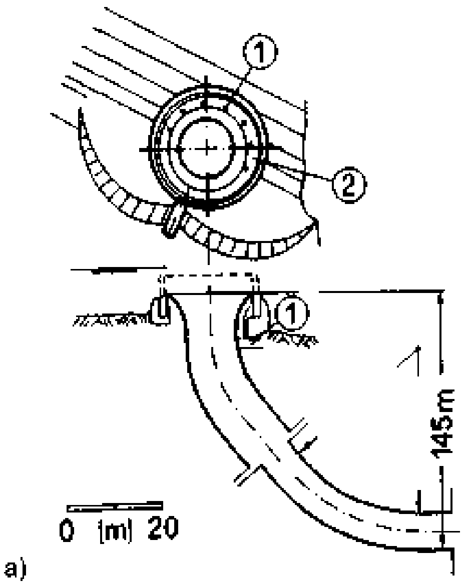
Frontal Side Funnel Spillway



Υπερχείλιση μέσω Οπής

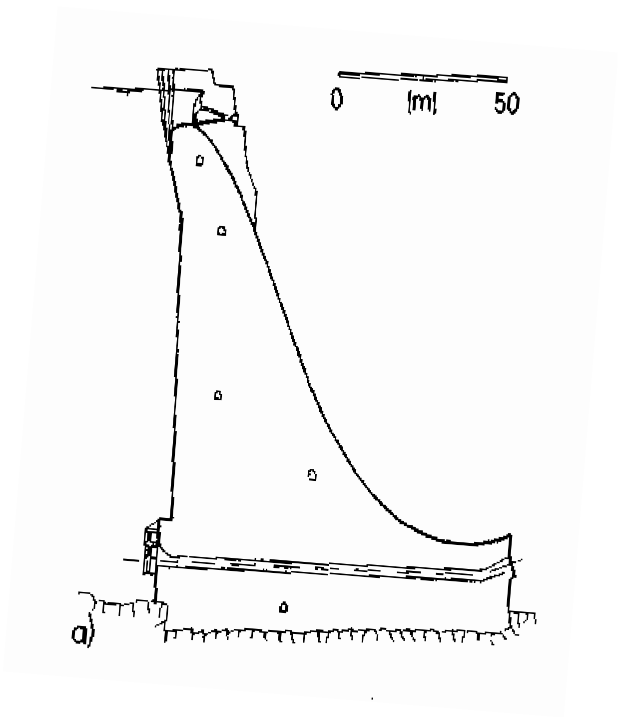


Πλευρικός Υπερχειλιστής

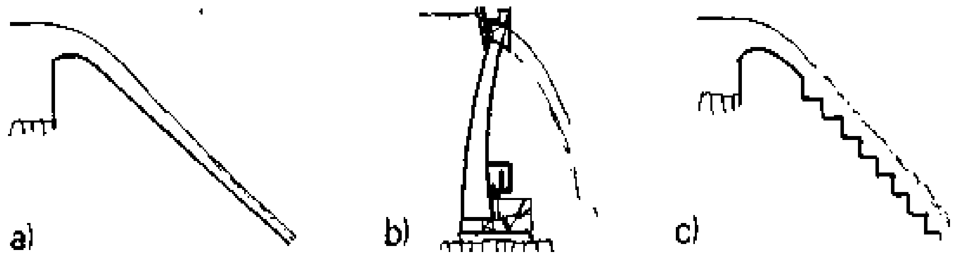


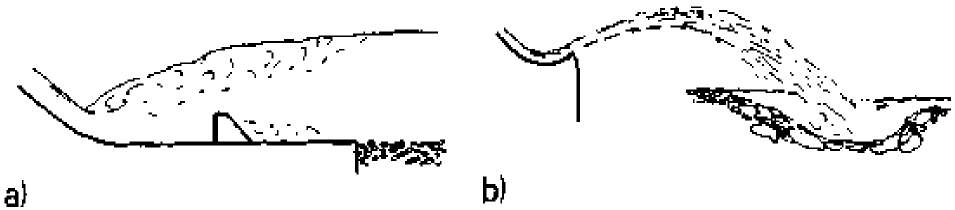
Χοάνη

Frontal Spillway



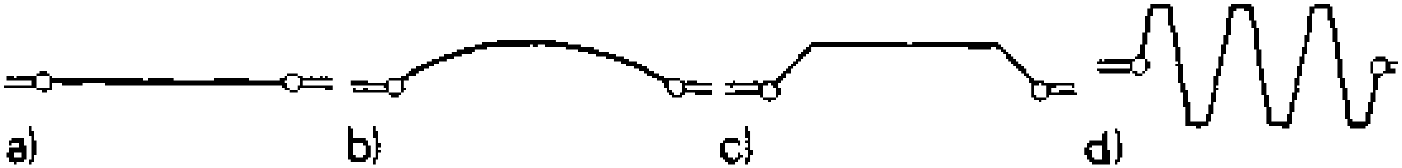
Types of Spillways



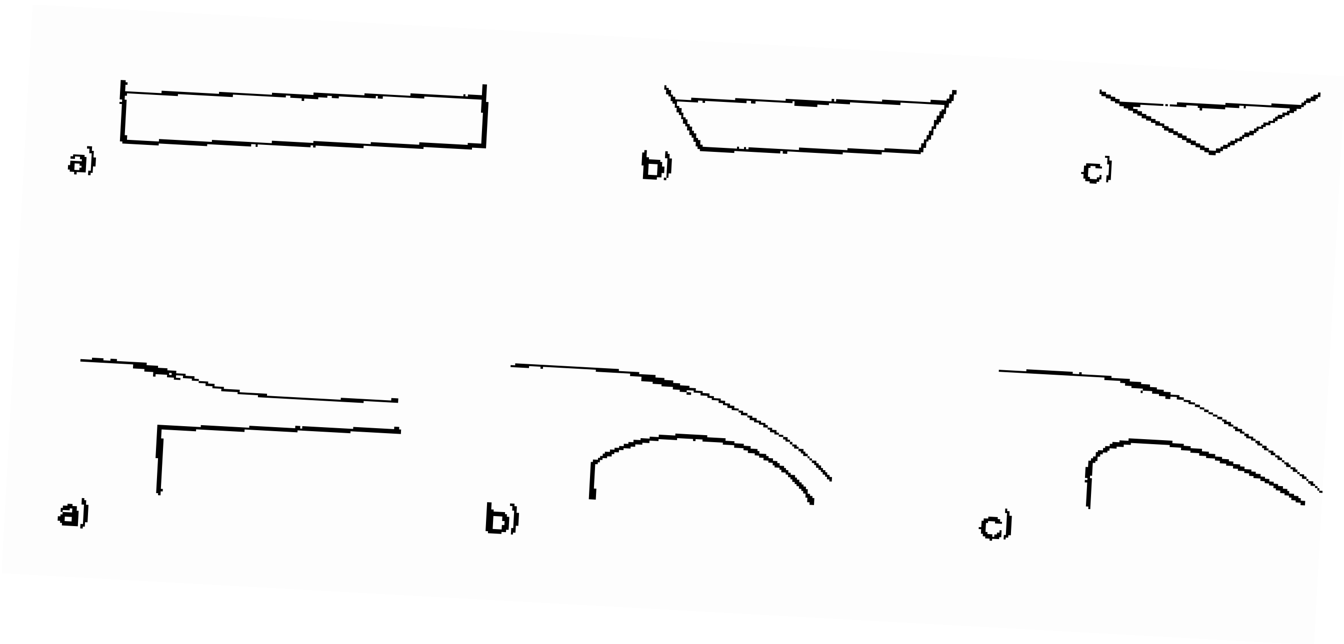


Energy Dissipation

TYPES OF CRESTS



Plan view



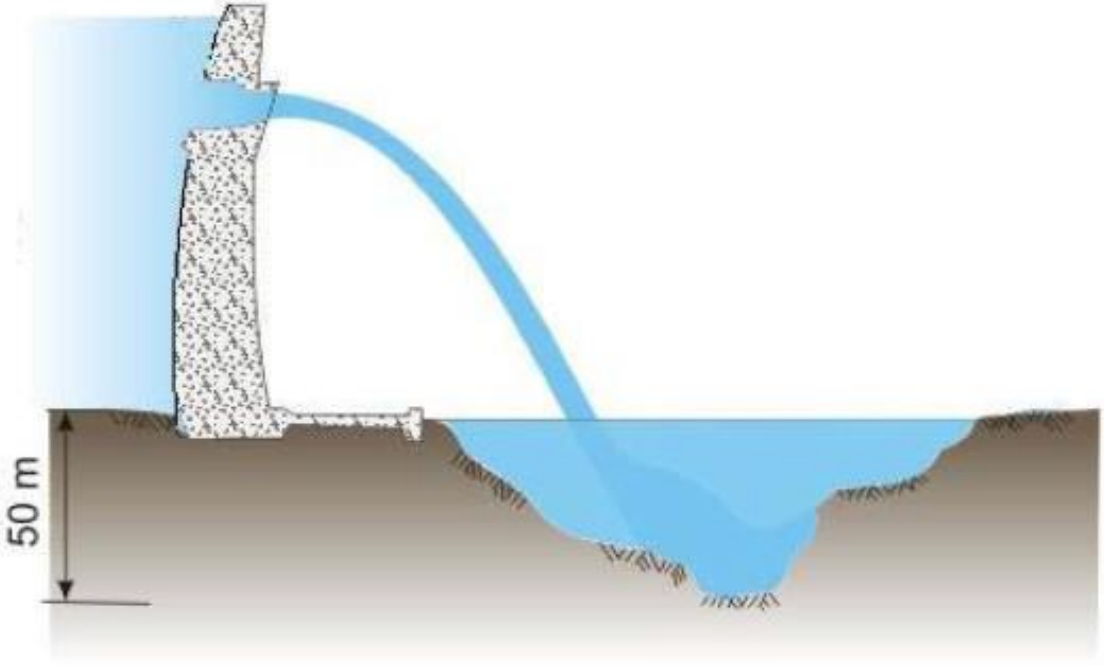
Cross Section

Side View

SPILLWAYS

- Free Fall Spillways
- Ogee Spillways
- Side Spillways
- Morning Glory Spillways

FREE FALL



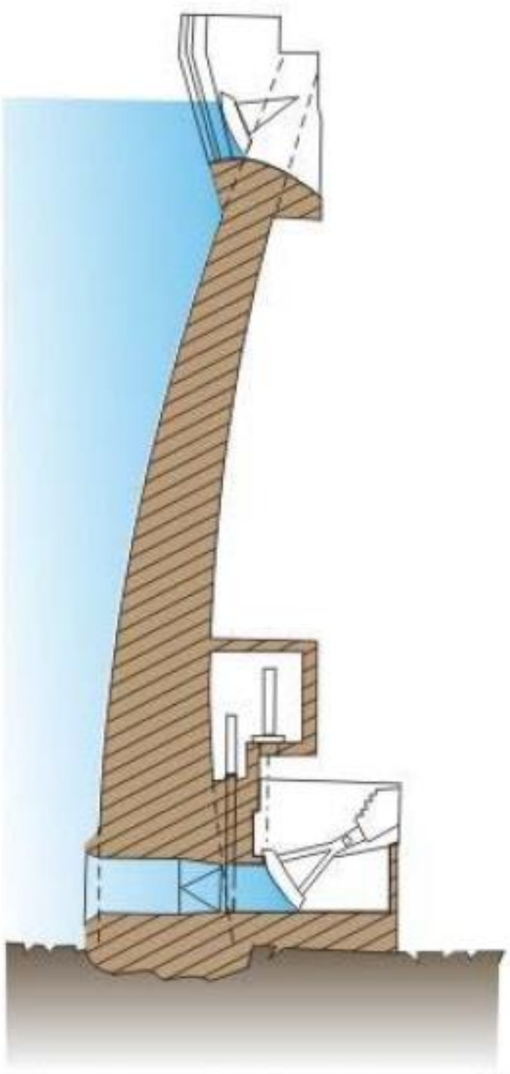
Free overfall (straight drop) spillways allow the flow to drop freely from the crest (see Figure 17.3.1). These types of spillways are characterized by the following (U.S. Bureau of Reclamation, 1987):

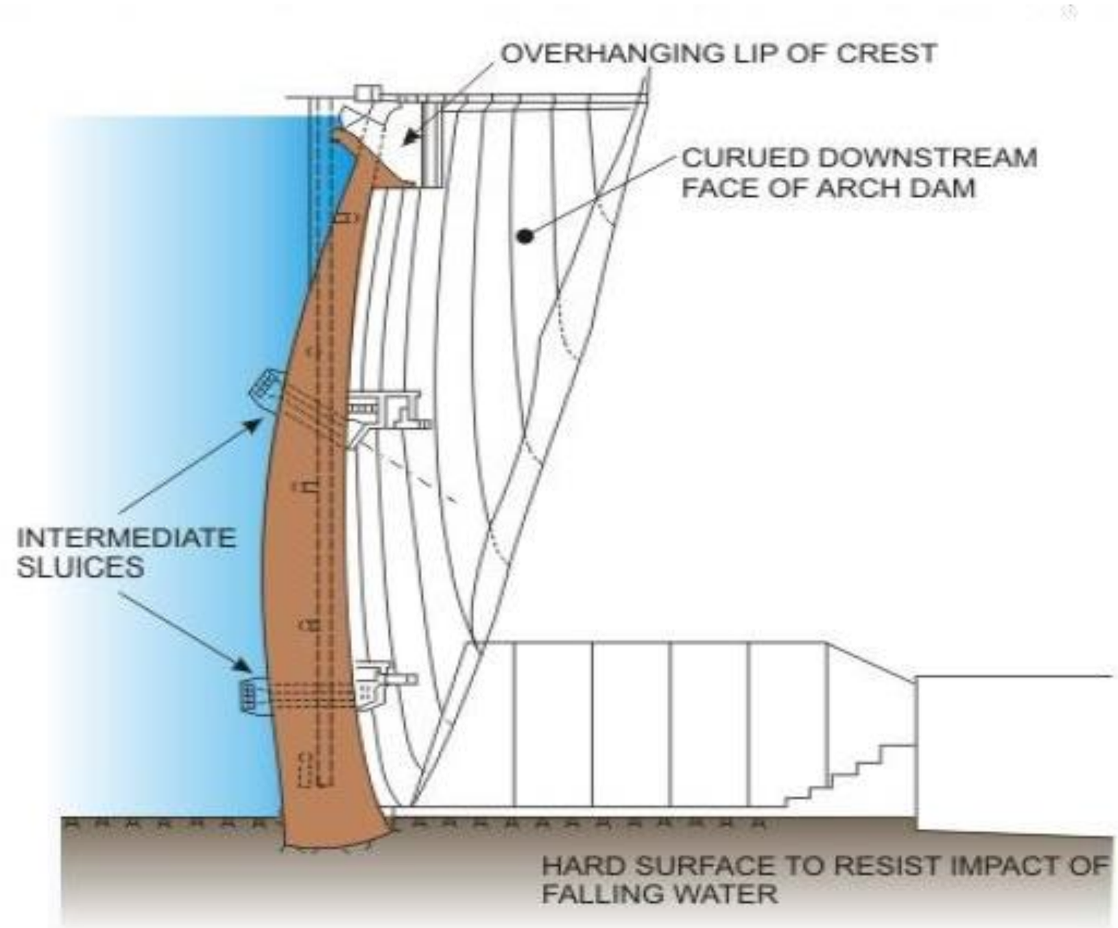
- Suited to a thin arch or crest that has a nearly vertical downstream face.
- Flows may be free discharge or may be supported along a narrow section of the crest.
- In many cases the crest is extended in the form of an overhanging lip to direct small discharge away from the face of the overfall section.
- The underside of the nappe is ventilated to prevent a pulsating and fluctuating jet.
- A deep plunge pool will develop at the base of the overfall as a result of scour if artificial protection is not provided.
- A hydraulic jump can form on flat aprons if the tailwater has sufficient depth.
- The major hydraulic problems with free overfall spillways are the characteristics of the control and the dissipation of flow in the downstream basin.
- Flow in the downstream basin can be dissipated by three basic approaches (U.S. Bureau of Reclamation, 1987):

by a hydraulic jump
by impact and turbulence induced by impact blocks
by a slotted grating dissipator installed immediately downstream from the control.

The hydraulic control of free-overfall spillways can be sharp-crested to provide a fully contracted

FREE FALL




OVERHANGING LIP OF CREST
CURUED DOWNSTREAM FACE OF ARCH DAM
INTERMEDIATE SLUICES
HARD SURFACE TO RESIST IMPACT OF FALLING WATER

Crest Characteristics

The hydraulic control of free-overfall spillways can be (a) sharp-crested to provide a fully contracted vertical jet, (b) broad-crested to cause a fully suppressed jet, or (c) even shaped to increase crest efficiency.

The discharge for these types of spillways is of the form)

$$Q = CLH_e^{3/2} \quad \text{(Στο σύστημα μονάδων BG)}$$

Q= παροχή (cfs), C=συντελεστής παροχής ($f^{0.5}/s$), L=μήκος στέψης (f)

H_e=φορτίο (=H+$\frac{U_a^2}{2g}$), H=ύψος νερού πάνω απο την στέψη (f)

Crest Characteristics

- When crest pier and abutment are shaped to cause side contraction of the flow, the effective crest length L is less than the net crest length.

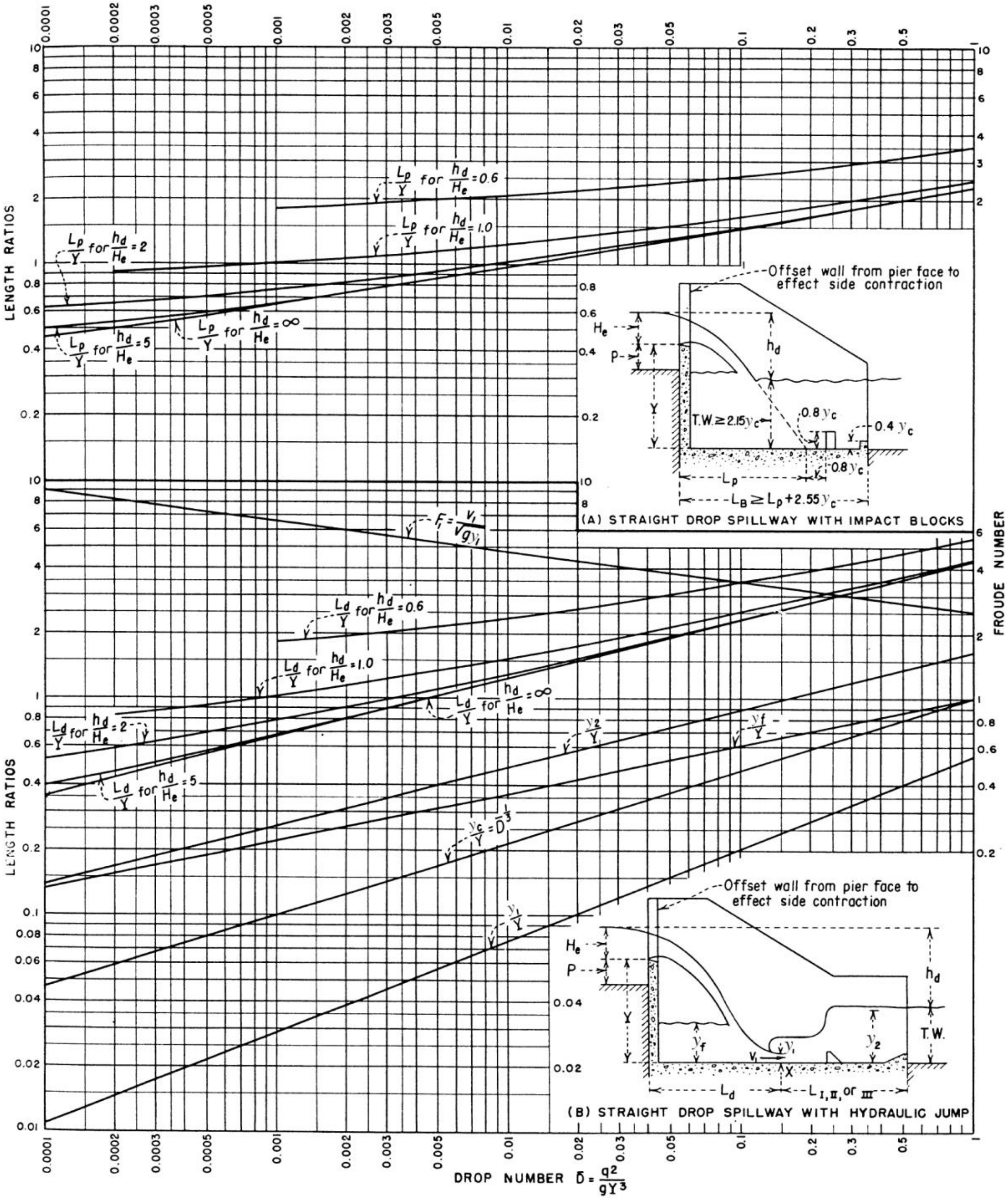
$$L = L' - 2(NK_p + K_a)H_e$$

L'=net length of the crest, N=number of piers,

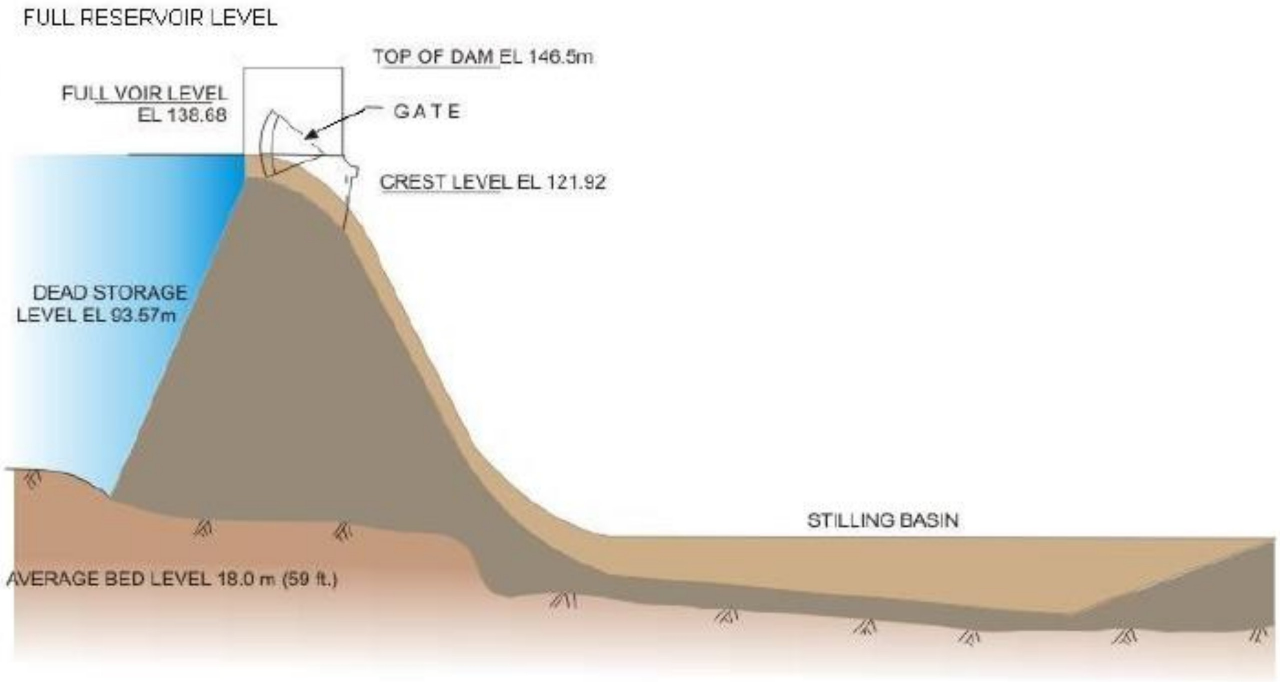
K_a =abutment contraction coeff. (=0.2)

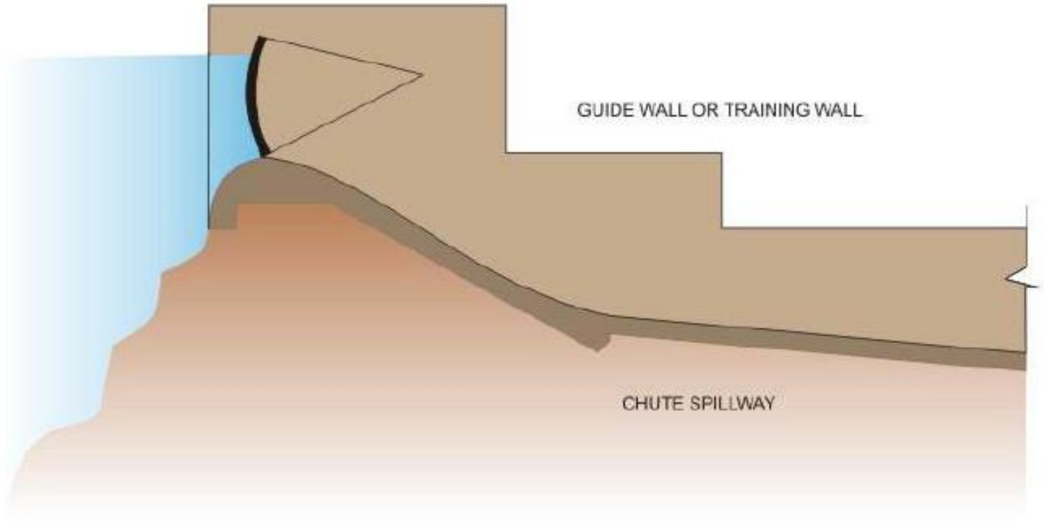
K_p =pier contraction coeff. (=0.01-0.02 dependent on the shape)

FREE FALL Hydraulic Characteristics

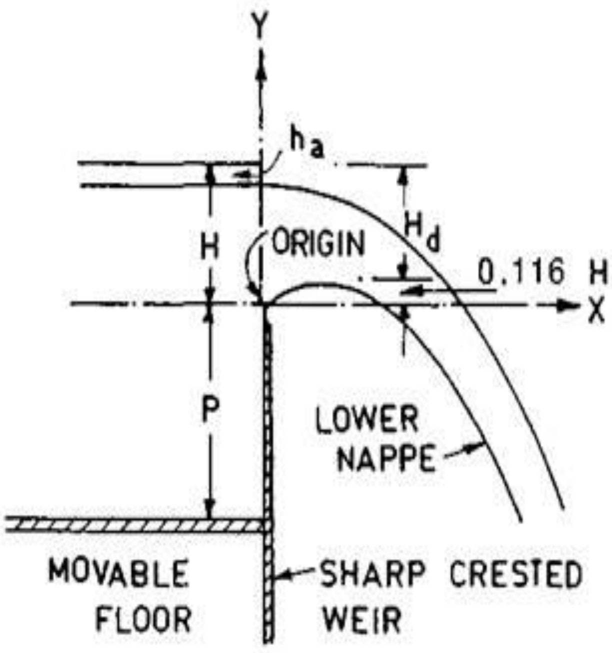


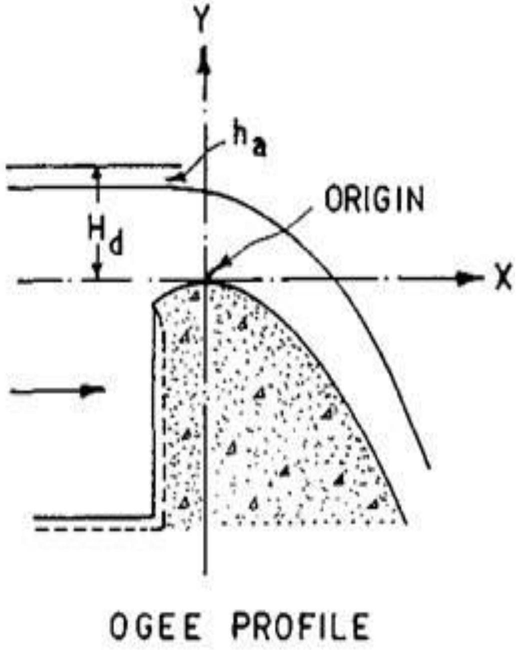
Ogee Spillways





Ogee Spillways





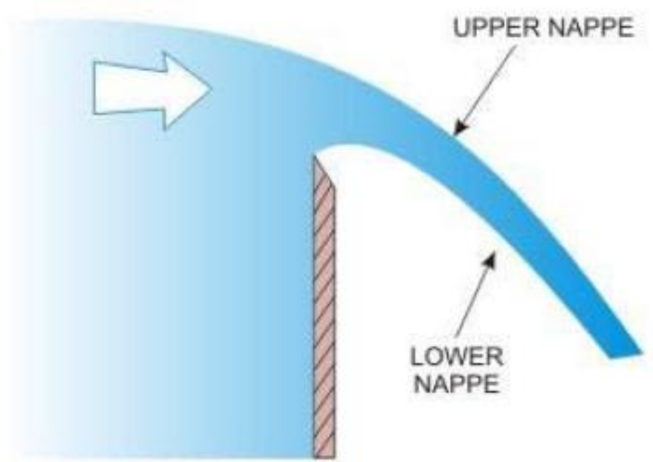
Σχήματος S σε προφίλ

Με η χωρίς θυρίδα

Σε φράγματα βαρύτητας

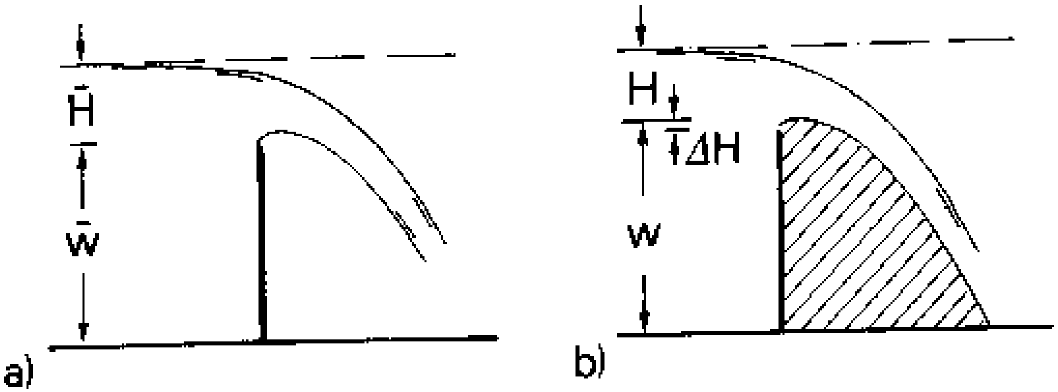
Κατανομή πίεσης στην στέψη σχεδόν ατμοσφαιρική.

Για παροχές μικρότερες της παροχής σχεδιασμού οι πιέσεις στον υπερχειλιστή μεγαλύτερες από την ατμοσφαιρική (υπερπιέσεις) ενώ για μεγαλύτερες παροχές έχουμε υποπιέσεις.

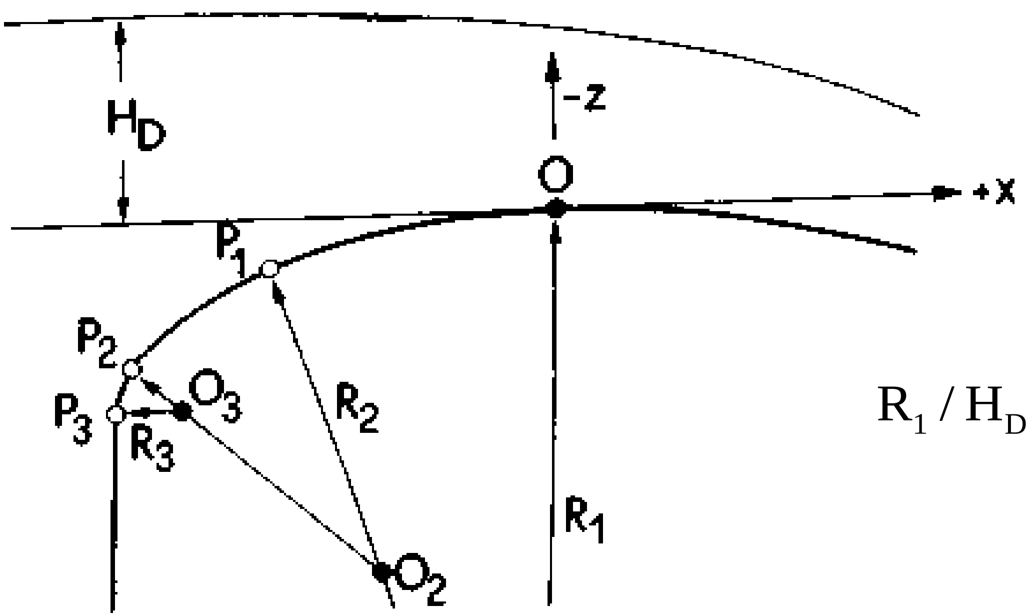


Το σχήμα της στέψης σημαντικό για την κατανομή της πίεσης στο τοίχωμα του υπερχειλιστή

Design of Crest



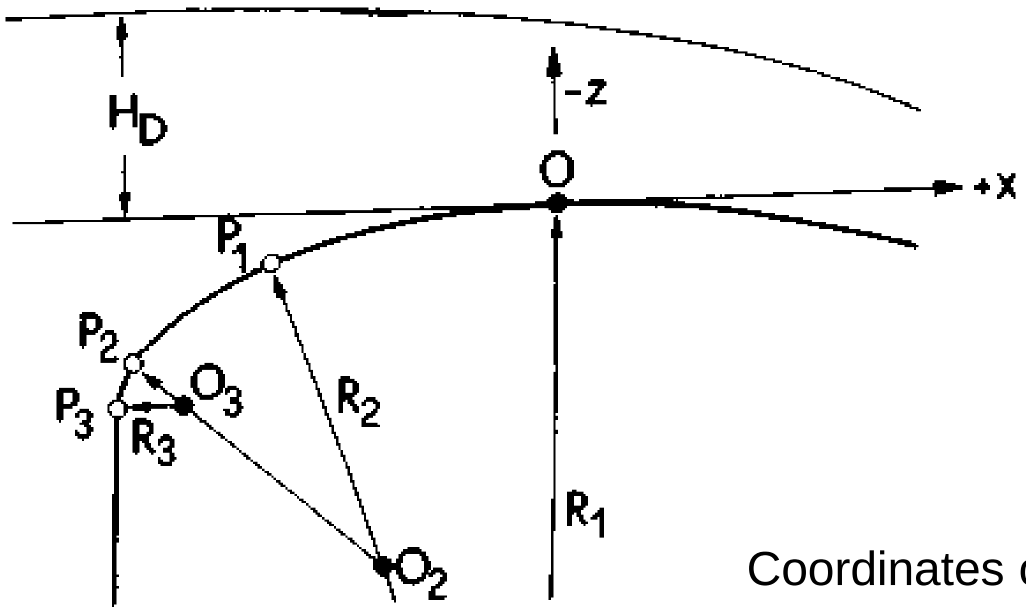
The shape of the crest is important for the variation of pressure along the bottom of the spillway



Design based on the Design Head H_D

$$R_1 / H_D = 0.50,\ R_2 / H_D = 0.20,\ R_3 / H_D = 0.04.$$

Ogee Spillways



Coordinates of O_i and P_i

Σημείο	O_1	O_2	O_3	P_1	P_2	P_3
x/H_D	0.0	-0.105	-0.242	-0.175	-0.276	-0.2818
z/H_D	0.500	0.219	0.136	0.0032	0.115	0.1360

Ogee-USBR

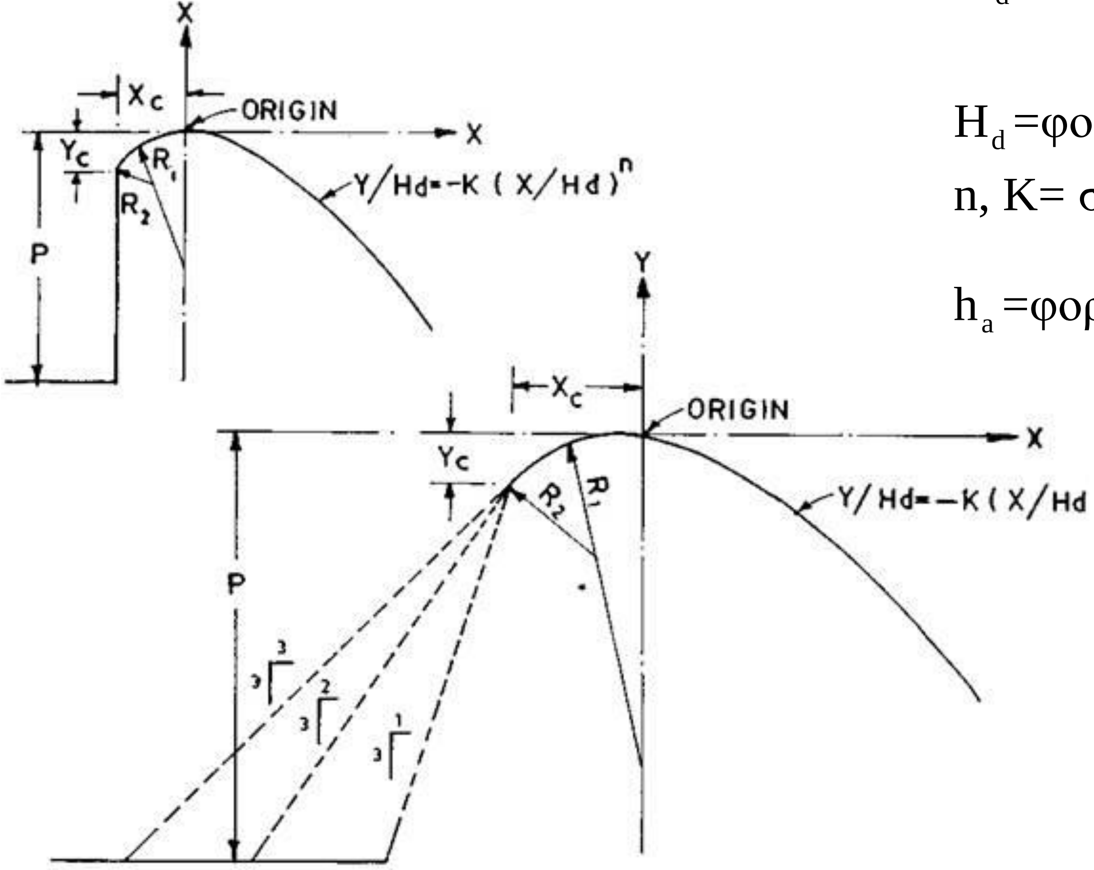
Εξίσωση προφιλ για x>0

$$\frac{y}{H_d} = -K\left(\frac{x}{H_d}\right)^n$$

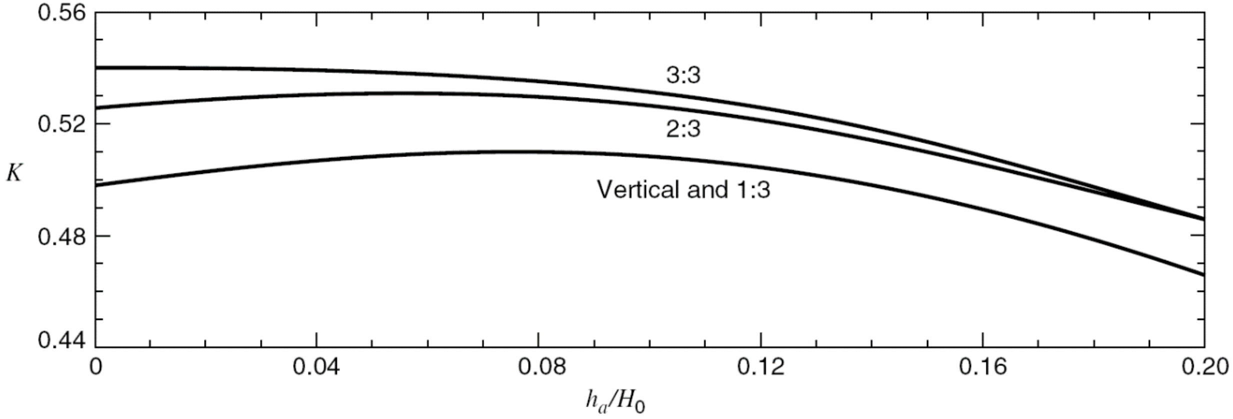
H_d =φορτίο σχεδιασμού

n, K= συναρτήσεις του h_a/H_d (βλέπε σχήμα)

h_a =φορτίο ταχύτητας $\left(=\frac{U_a^2}{2g}\right)$

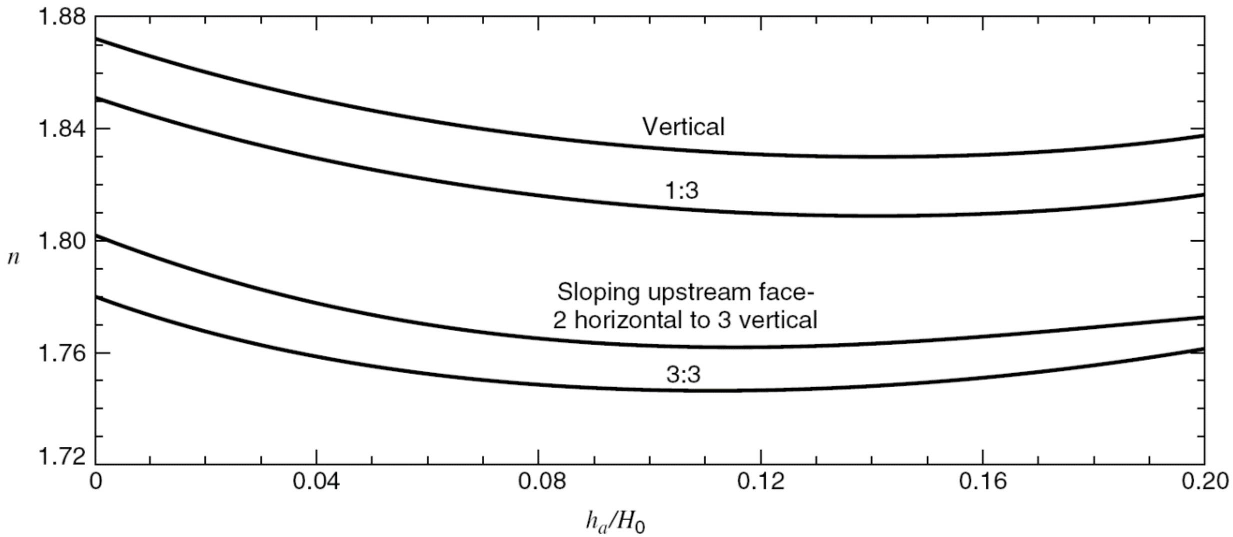


Σταθερές K, n για τον υπολογισμό του προφίλ του υπερχειλιστή



(*b*)

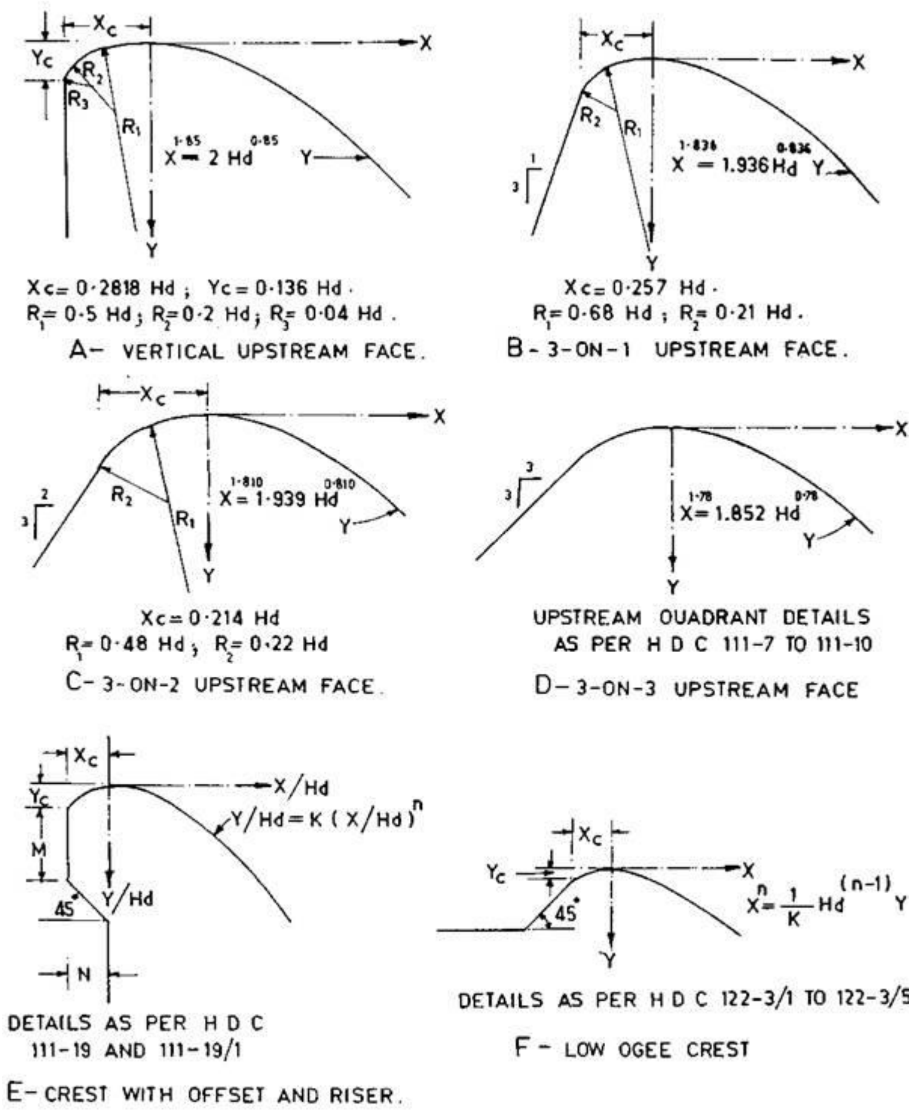
Τιμές του K



(*c*)

Τιμές του n

Ogee- WES



Εξίσωση προφιλ για x>0

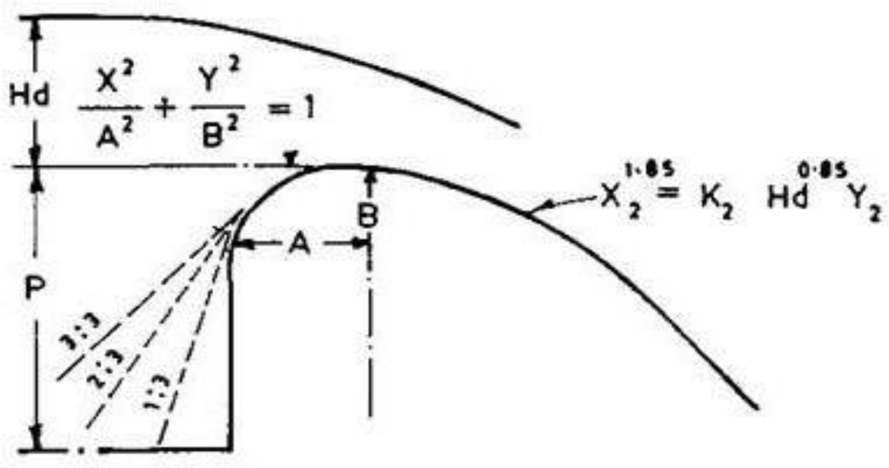
$$X^{n} = K H_{d}^{n-1} Y$$

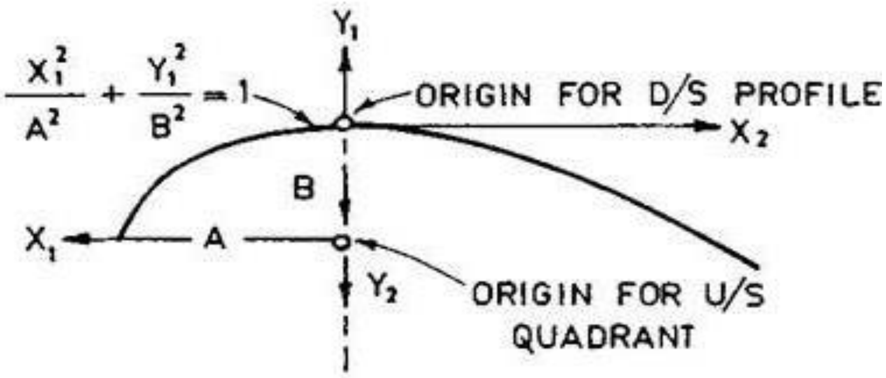
H_d =φορτίο σχεδιασμού

n, K= συναρτήσεις του h_a / H_d (βλέπε σχήμα)

h_a =φορτίο ταχύτητας $\left(=\frac{U_a^2}{2g}\right)$

Ogee- Murphy





Εξίσωση προφιλ για x<0

$$\frac{X^2}{A^2} + \frac{Y^2}{B^2} = 1$$

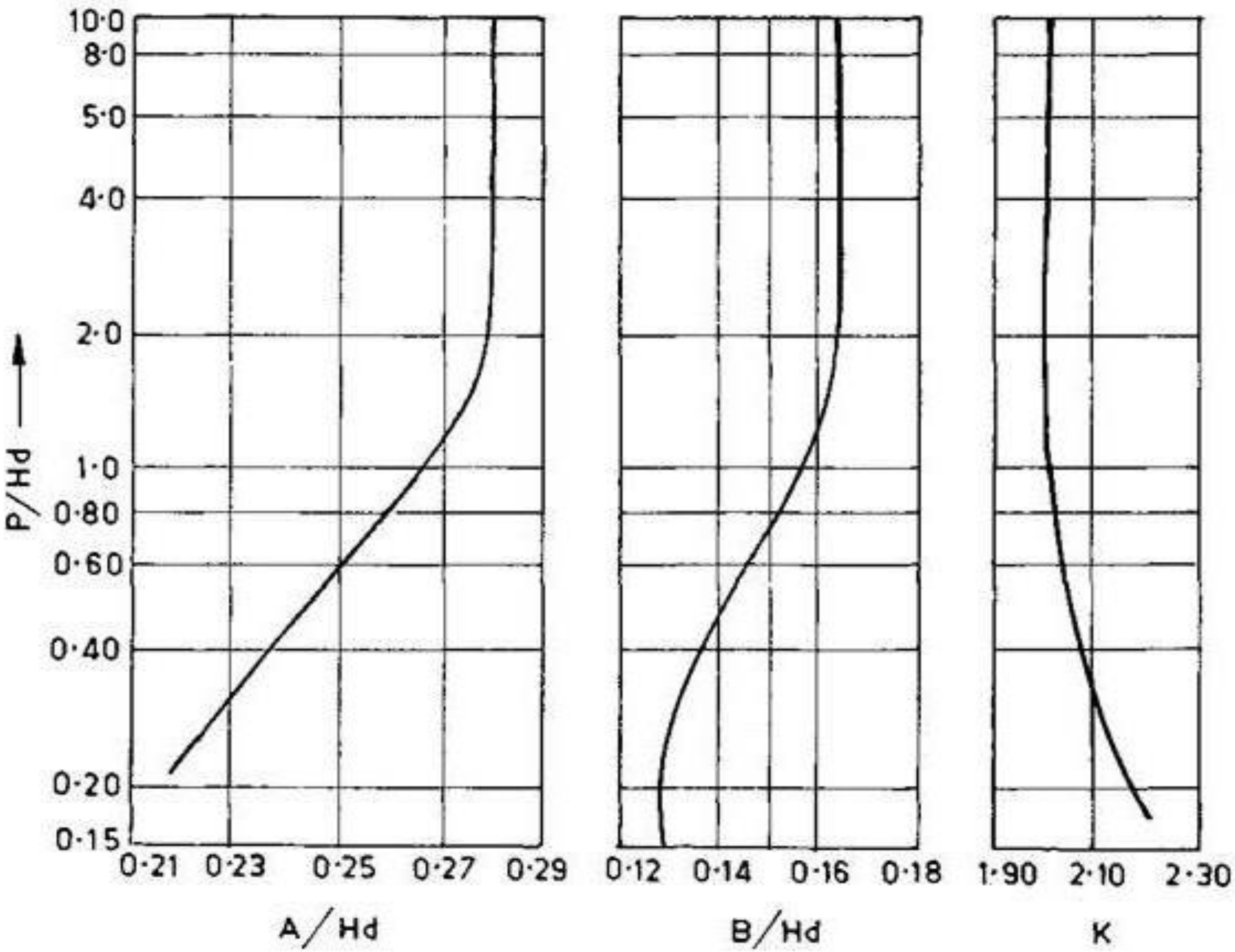
Εξίσωση προφιλ για x>0

$$X^{1.85} = KH_d^{0.85}Y$$

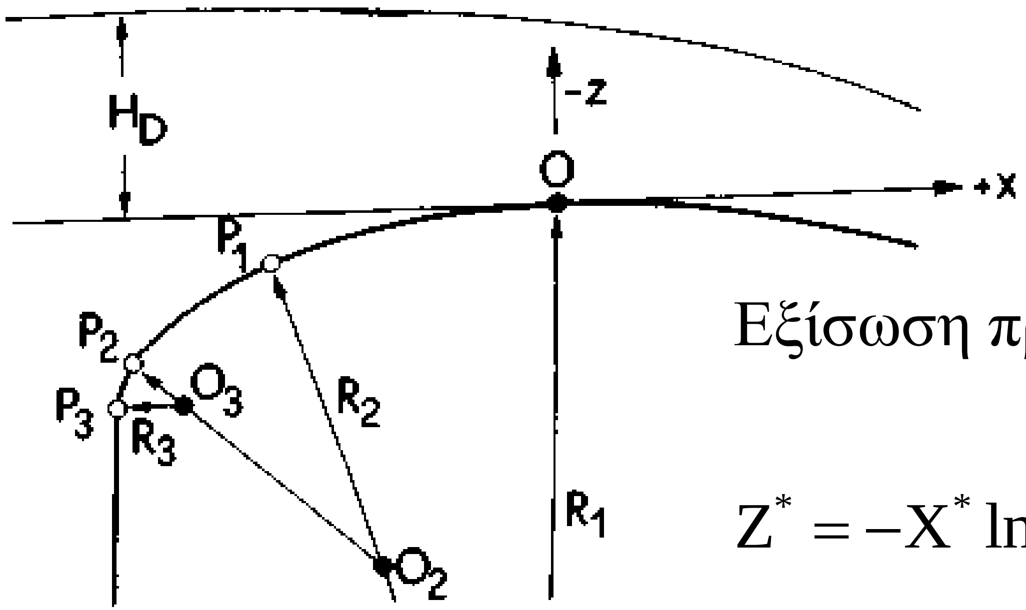
H_d =φορτίο σχεδιασμού,

K= συνάρτηση του P/H_d (βλέπε σχήμα)

Ogee- Murphy


10·0
8·0
5·0
4·0
2·0
1·0
0·80
0·60
0·40
0·20
0·15
P/Hd
0·21
0·23
0·25
0·27
0·29
A/Hd
0·12
0·14
0·16
0·18
B/Hd
1·90
2·10
2·30
K

Ogee- Hager



Εξίσωση προφιλ για X^*>-0.2818

$$Z^* = -X^* \ln X^*$$

οπου

$$X^* = 1.3055\left(\frac{x}{H_d} + 0.2818\right)$$

$$Z^* = 2.7050\left(\frac{z}{H_d} + 0.136\right)$$

Discharge for Ogee Spillway

Based on Discharge for sharp crested weir

$$Q = C_d \frac{2}{3} L \sqrt{2gH^3} \quad \text{(In Europe)}$$

Q= Discharge, C_d =discharge coeff. (C_d =$C_c C_v$, C_c =contraction coeff. C_v =velocity coeff.), L=crest length, H=water height over the crest

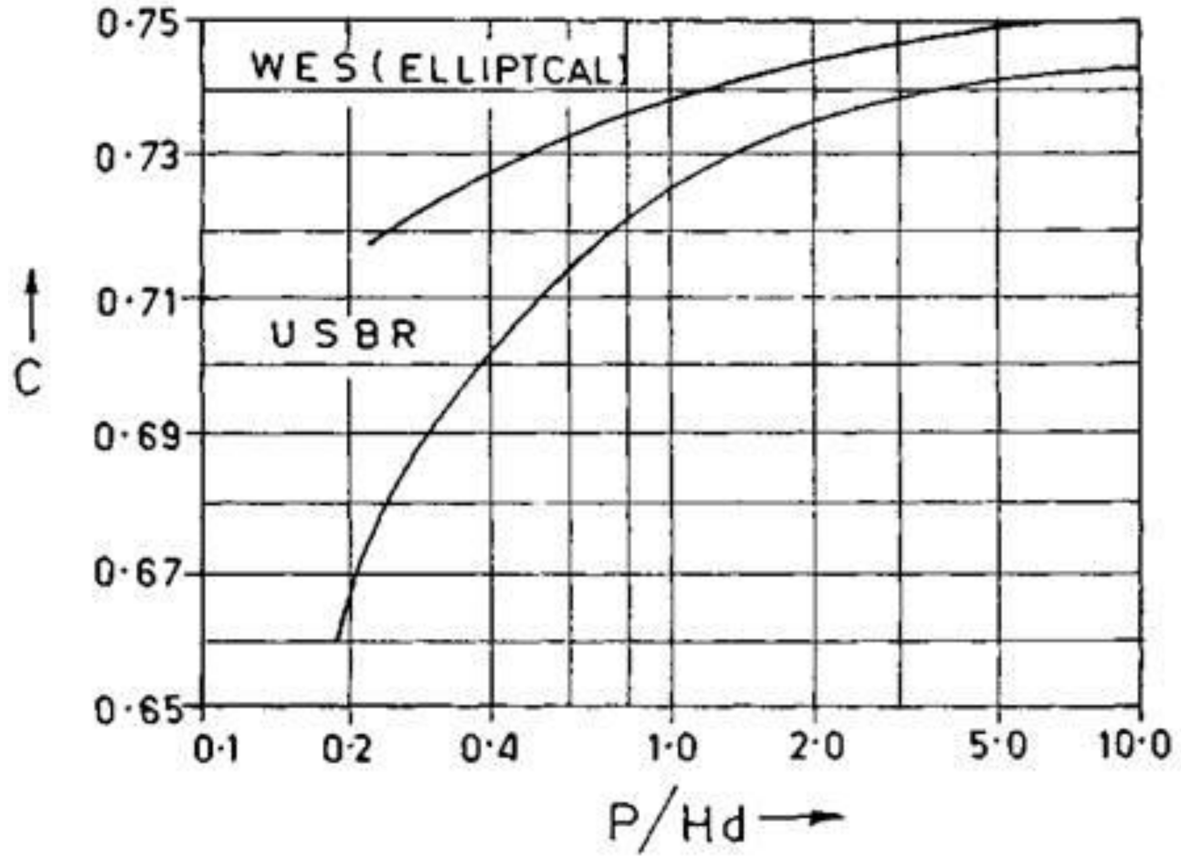
$$Q = C \frac{2}{3} L \sqrt{2gH_o{}^3}$$

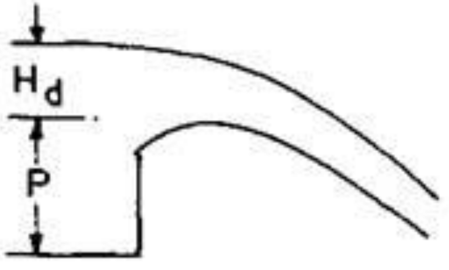
Q= discharge, C=discharge coeff. (dimensionless, 0.578-0.75)

L=crest length, H_o = characteristic water height over the crest

The coefficient C is dimensionless

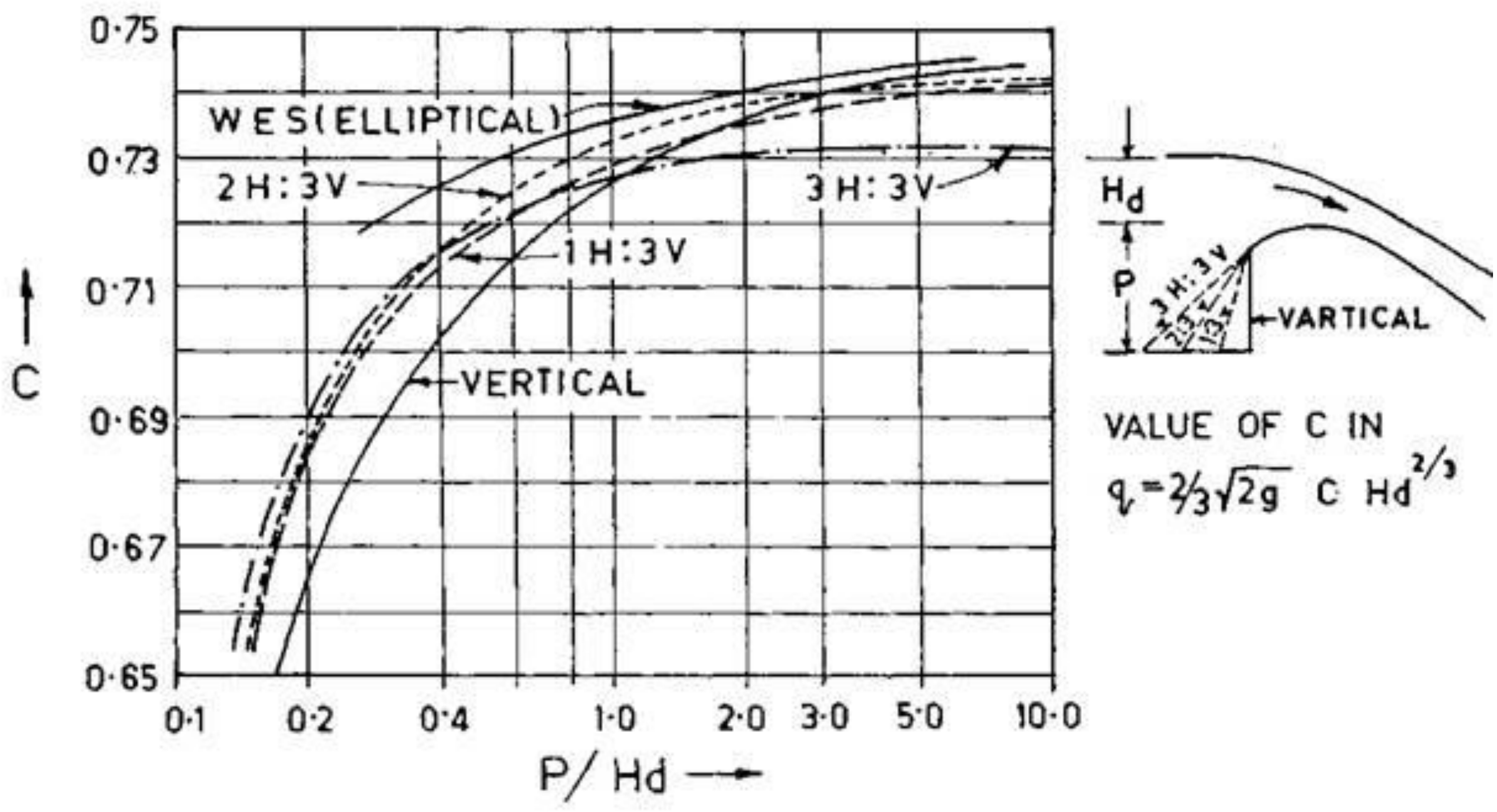
Effect of H_d on C



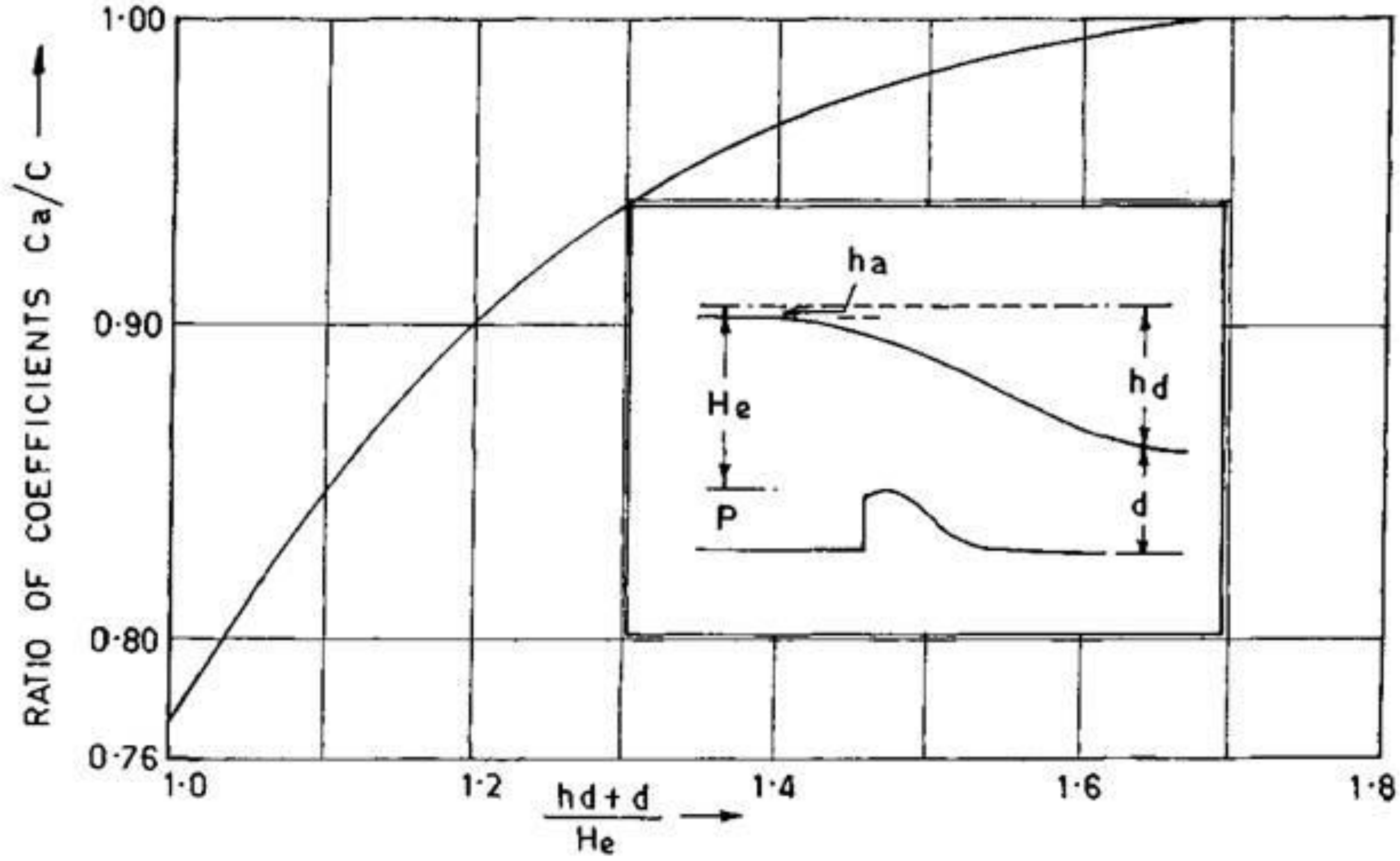


$$Q = \frac{2}{3} \sqrt{2g}\ C\ Hd^{3/2}$$

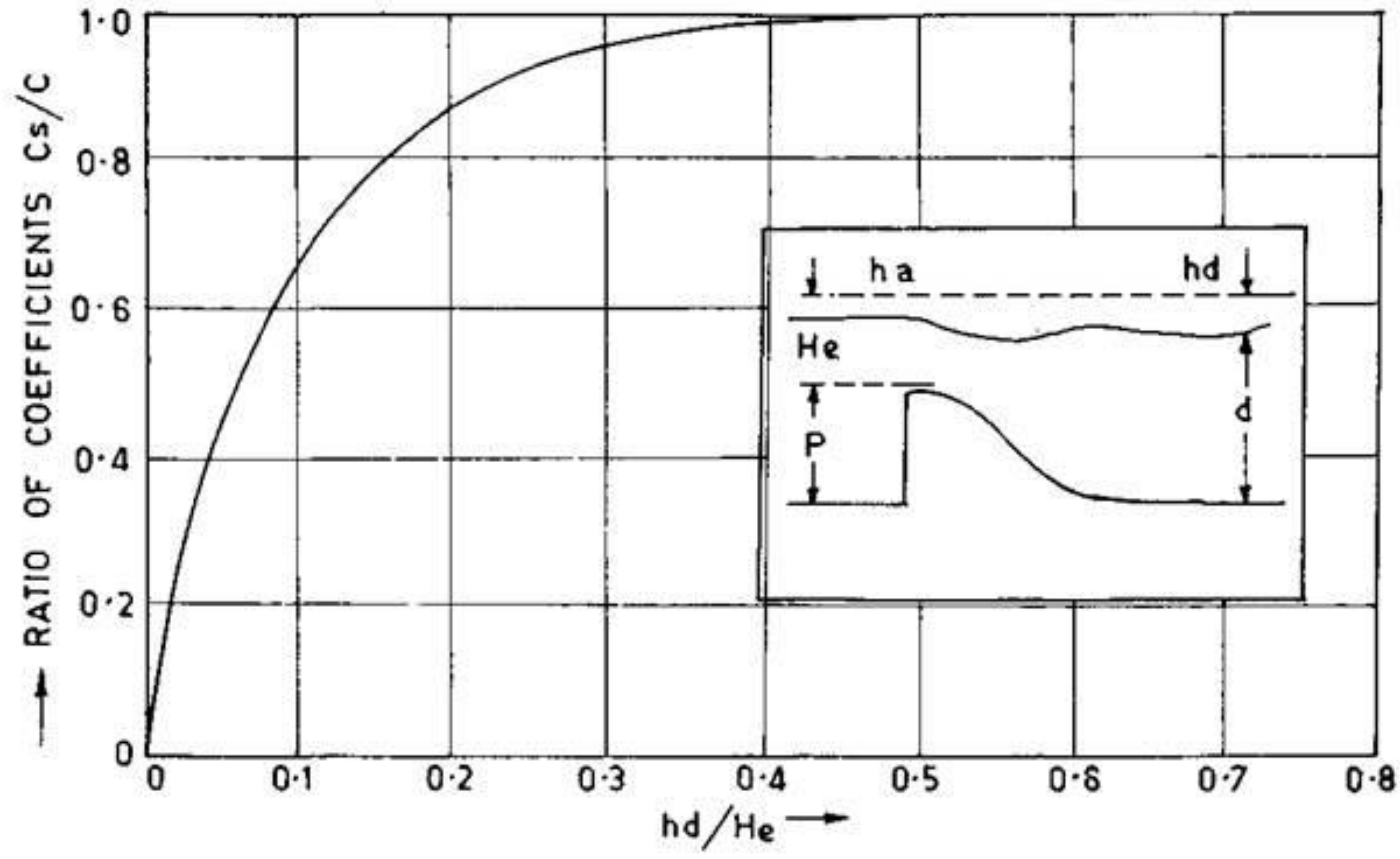
Effect of face inclination on C



Effect of P on C



Effect of h_d on C

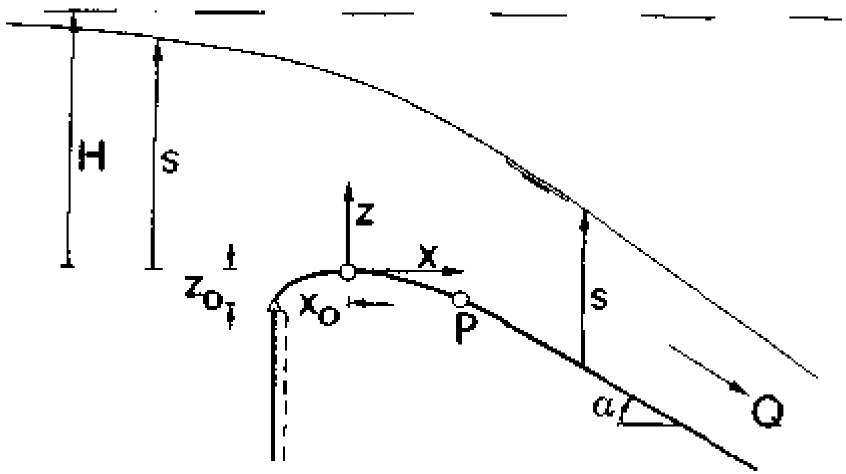


Determination of flow depth s

Σχεδιασμός για x>0

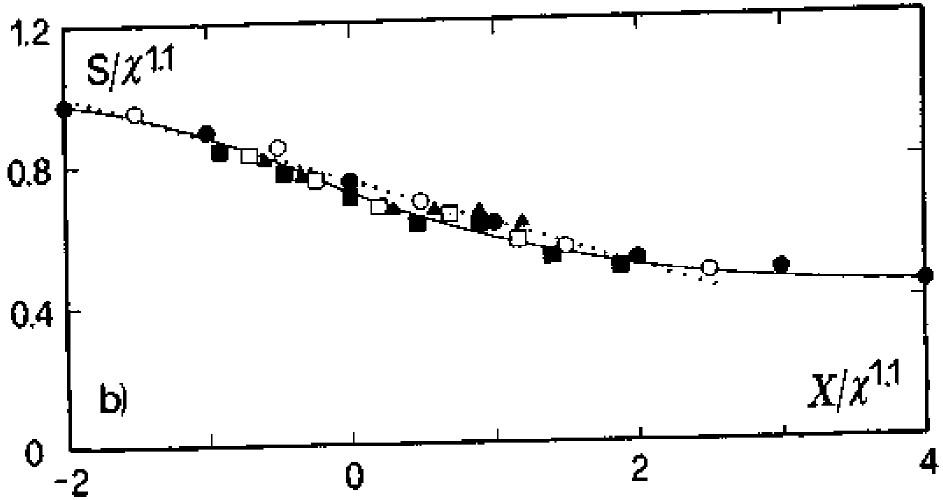
$$z / H_D = 0.50\ (x / H_D)^{1.85}$$

Προφίλ ελεύθερης επιφάνειας



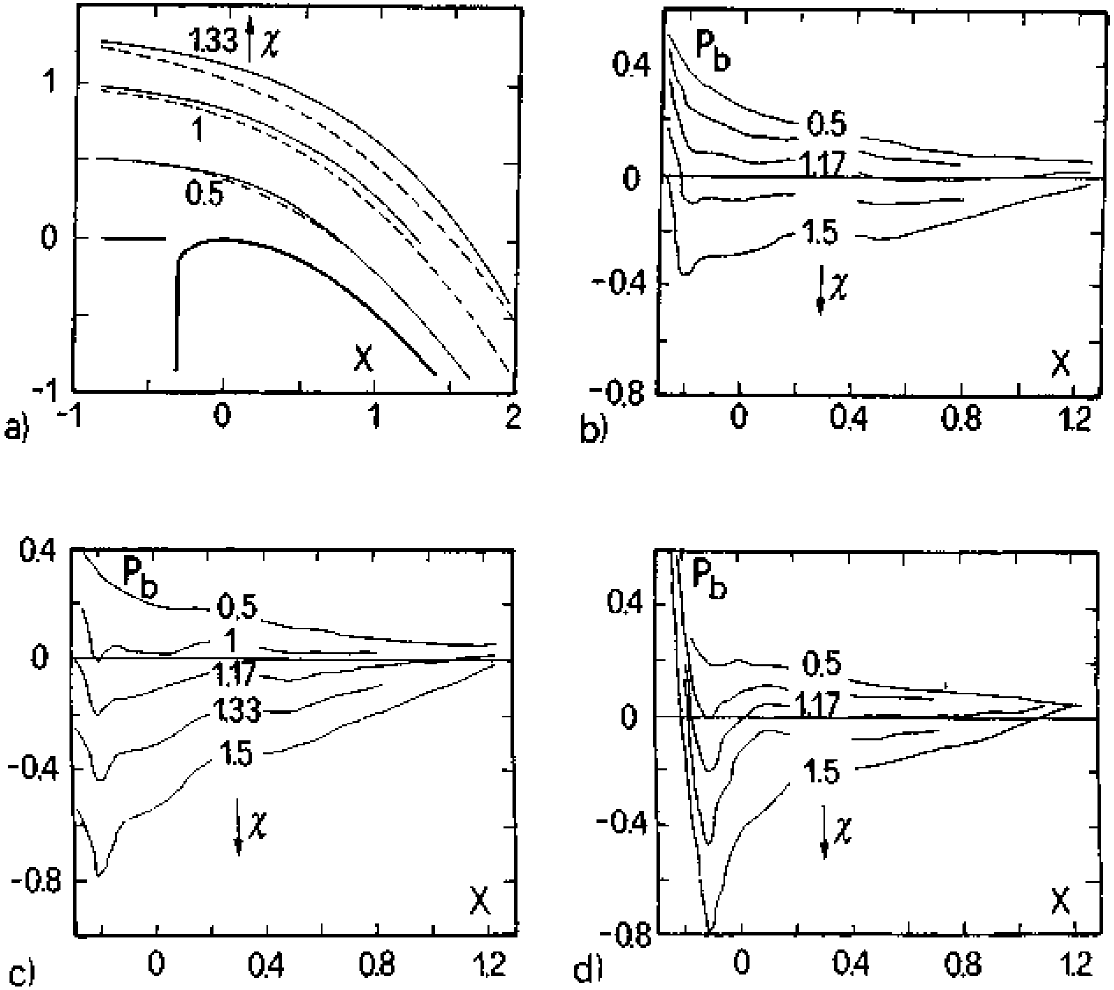
$$S = 0.75(x_1^{1.1} - (\frac{1}{6} x_2))$$

$$S = s / H_D,\ x_1 = H / H_D,\ \ x_2 = x / H_D$$



Free surface profile

Flow Profile and Pressure Variation



(α) Προφίλ ελεύθερης επιφάνειας (με και χωρίς βάθρα)

(b), (c), (d) Κατανομή πίεσης στο τοίχωμα του υπερχειλιστή

(b) χωρίς βάθρα

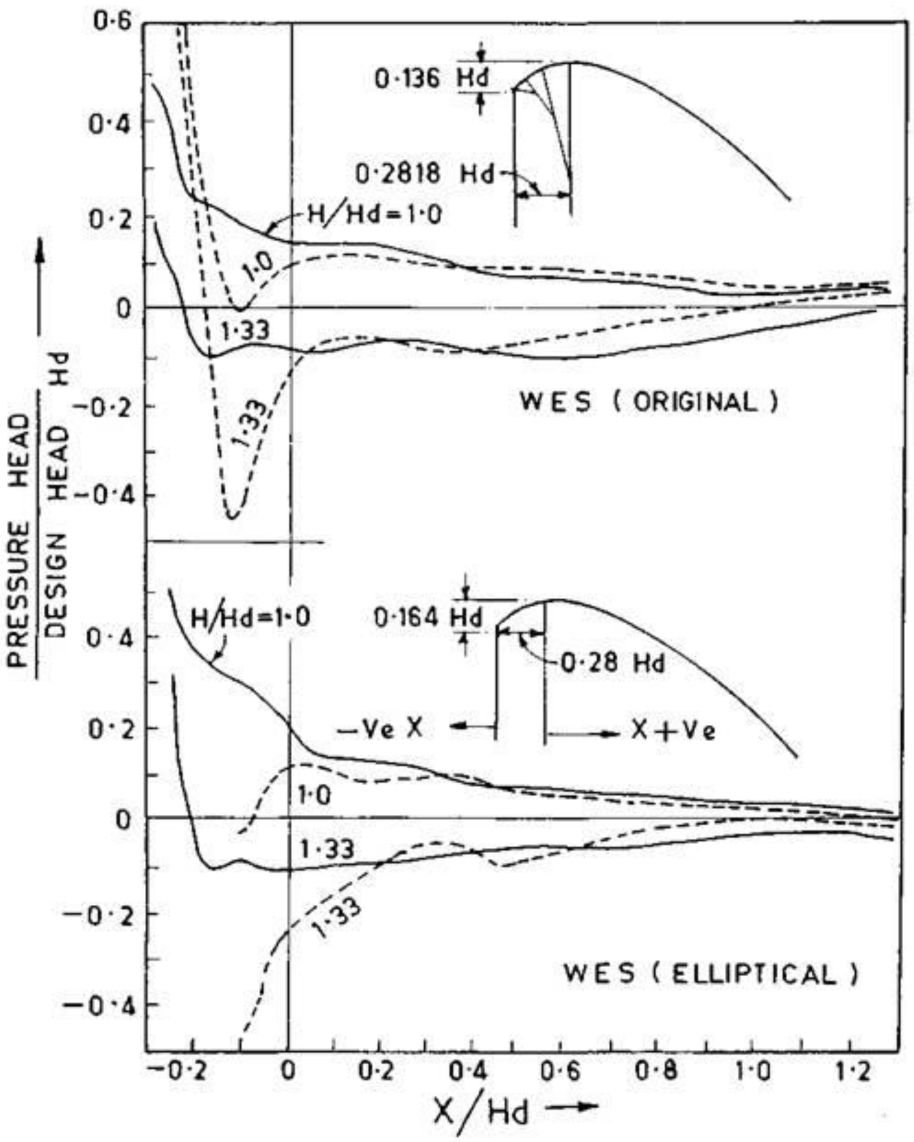
(c) μεταξύ των βάθρων

(d) κατά μήκος των βάθρων

$$P_b = p_b / (\rho g H_D) \quad \sim \quad X = x / H_D$$

για διάφορα $\chi = H/H_D$

Pressure variation along the spillway crest

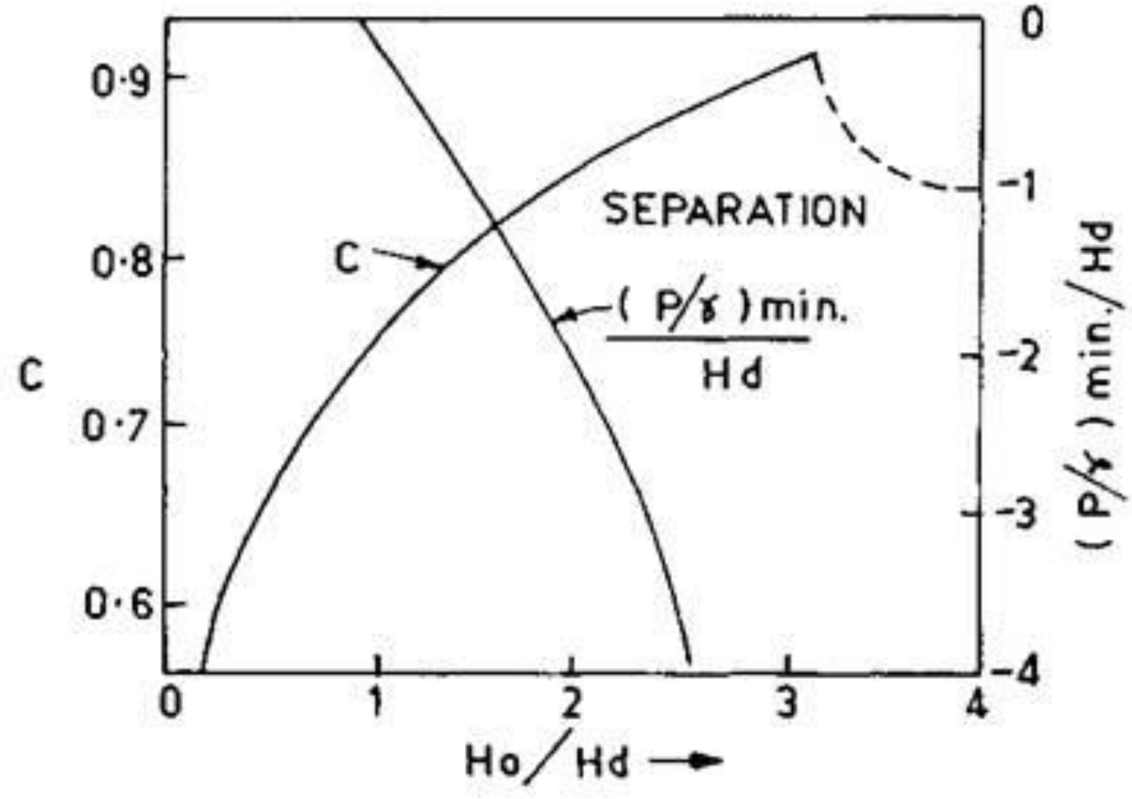


Η κατανομή της πίεσης στο τοίχωμα είναι σημαντική γιατί δείχνει αν υπάρχει κίνδυνος σπηλαίωσης και αν υπάρχει αποκόλληση της ροής λόγω των βάθρων.

The minimum pressure is for $X/H_D<0$

Θpositive pressures for $H/H_D<1.0$

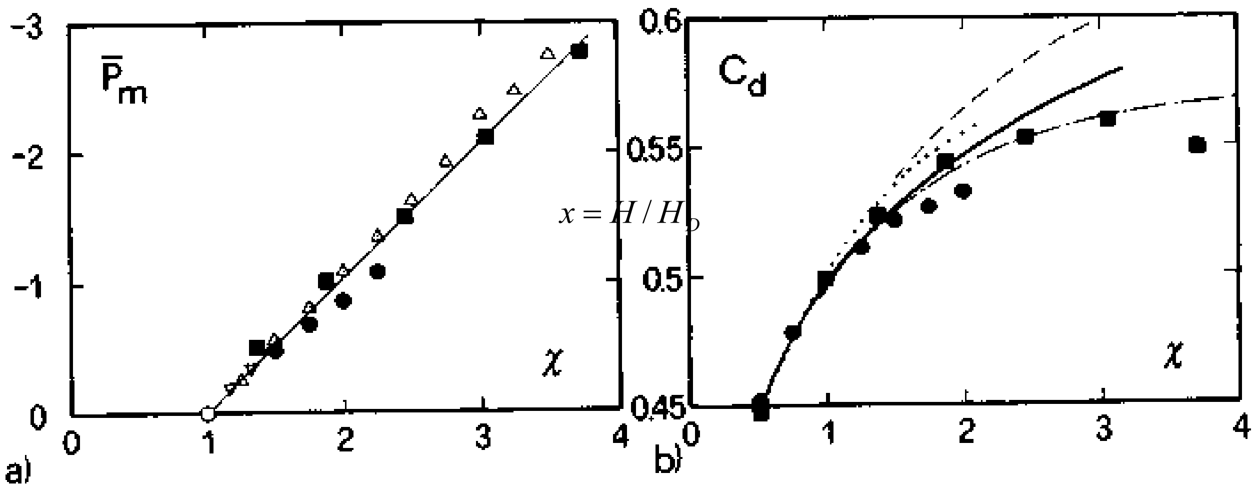
Variation of C with crest pressure



Variation of Pressure and C_d with the head H

$$Q = C_d L (2gH^3)^{1/2}$$

$$C_d = \frac{2}{3\sqrt{3}}\left[1 + \frac{4\chi}{9+5\chi}\right]$$



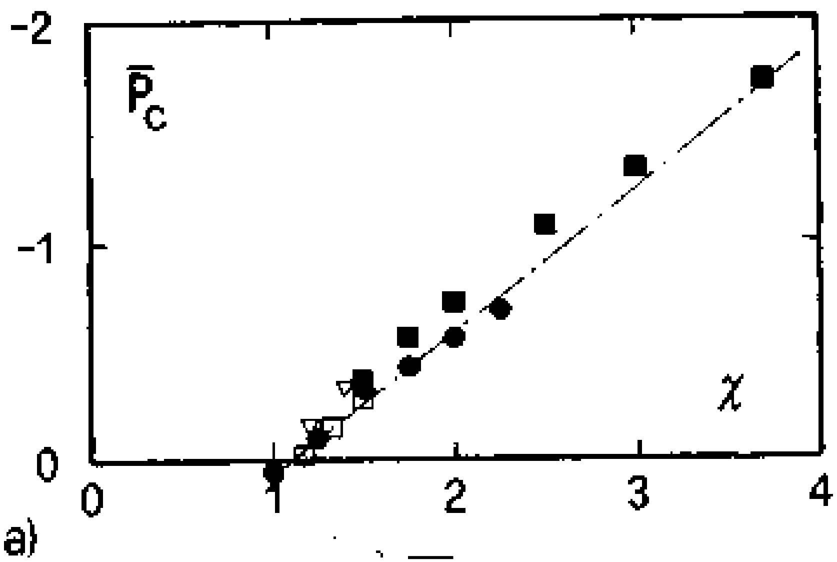
Ελάχιστη πίεση στο τοίχωμα για διάφορα χ

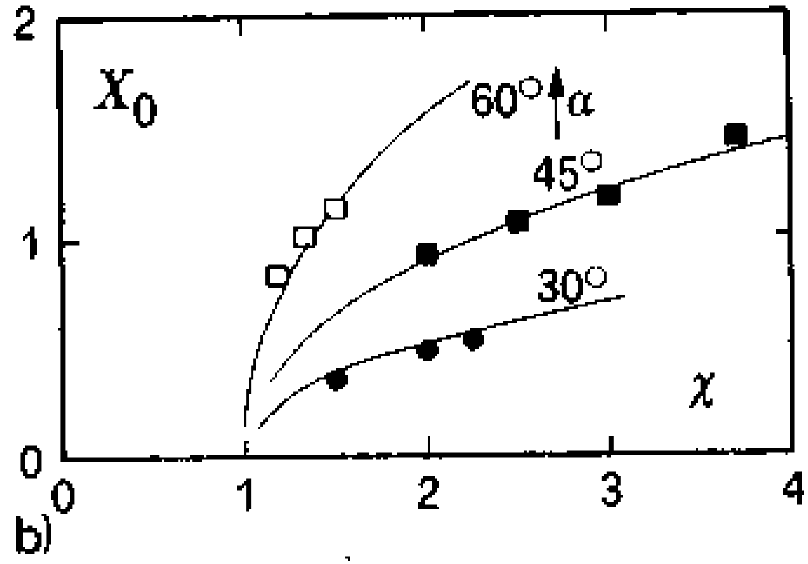
$$(\bar{P}_m = \frac{P_{min}}{\rho g H})$$

Μεταβολή Συντελεστή παροχής C_d με το χ

$$\chi = H / H_D$$

Variation of crest pressure with H/H_D





Πίεση στέψης $\overline{P}_c(x)$ για διάφορα χ (=H/H_D)

$$\overline{P}_c = \frac{P_c}{\rho g H}$$

$$\overline{P}_c = \frac{2}{3}\overline{P}_m$$

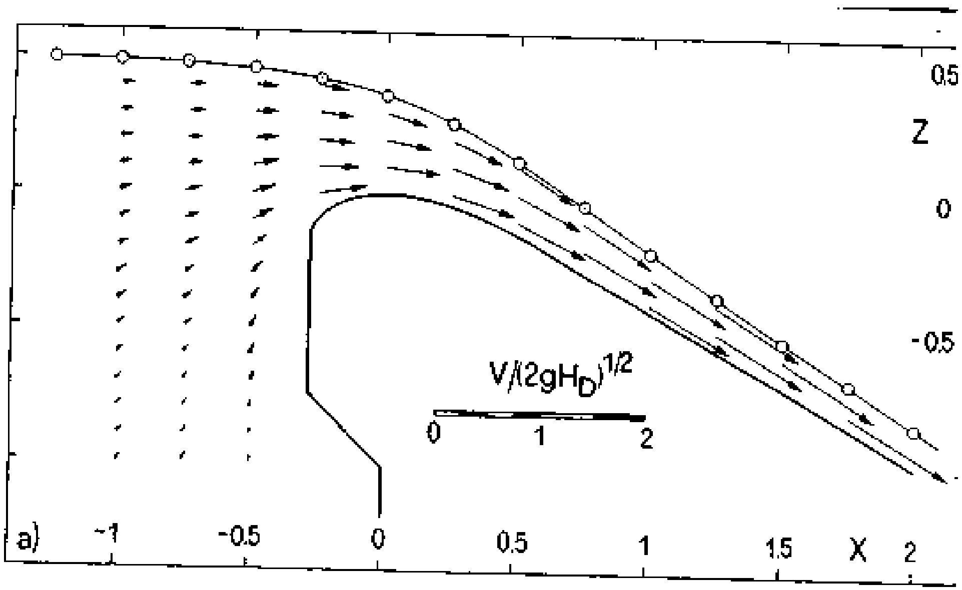
Θέση ατμοσφαιρικής πίεσης

στο τοίχωμα X_o

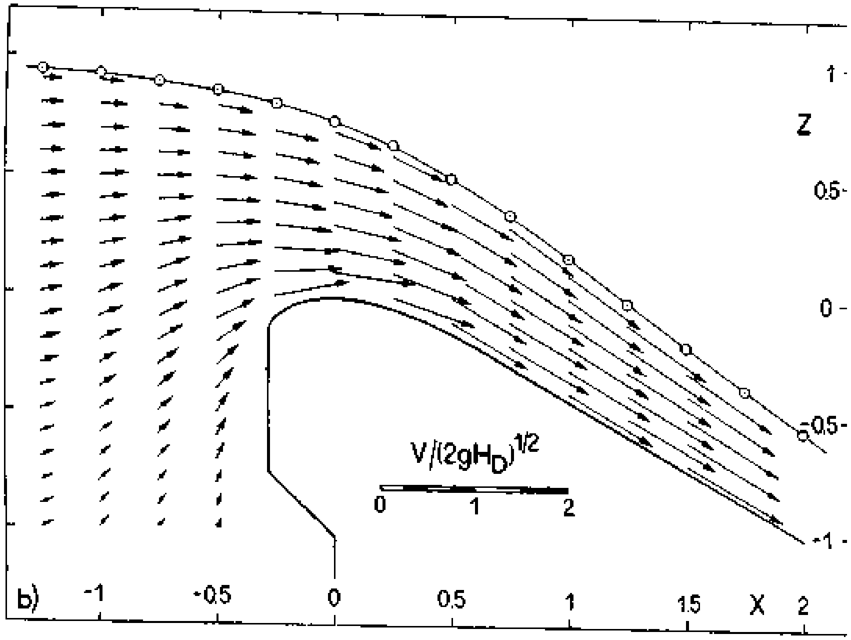
$$X_o = \frac{X_o}{H_D} = 0.9\tan\alpha(x-1)^{0.43}$$

Μεταβάλλεται με το χ (=H/H_D) αλλά και με την γωνία α (γωνία chute)

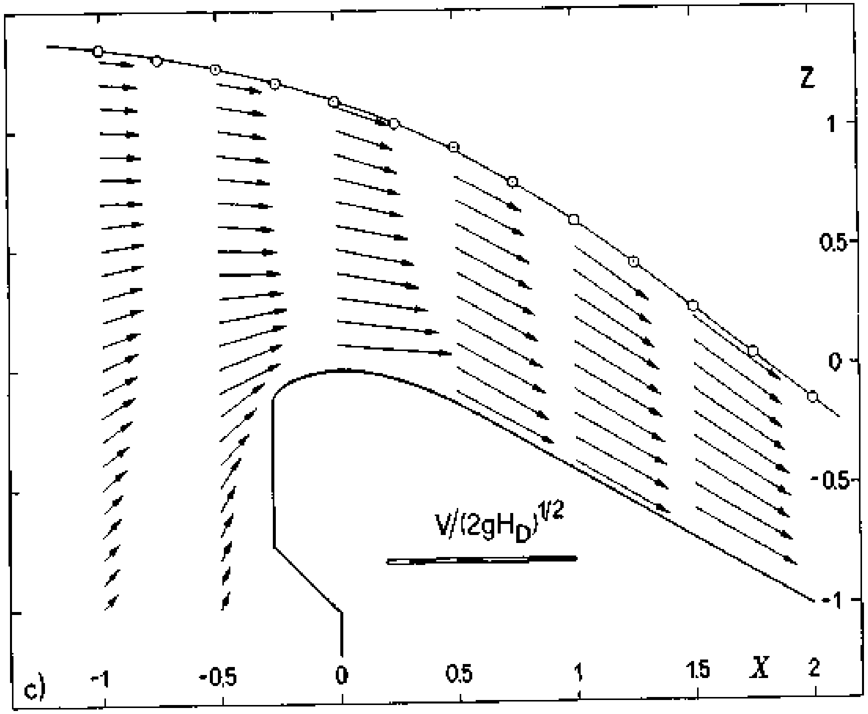
Μεταβολή της ταχύτητας $\frac{v}{(2gH_D)^{1/2}}$ στο X και Z ($X=x/H_D$, $Z=z/H_D$)



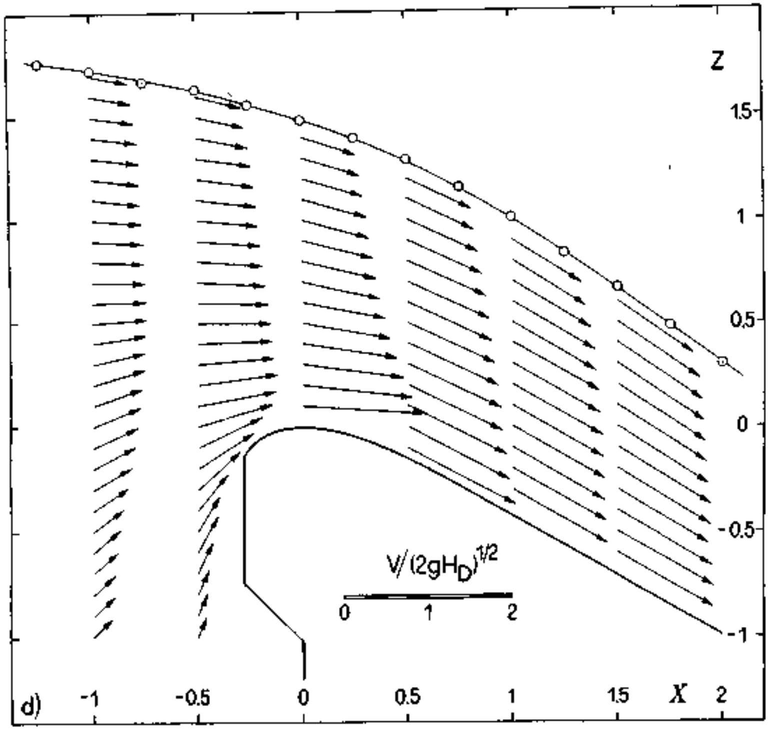
για $H/H_D=0.5$



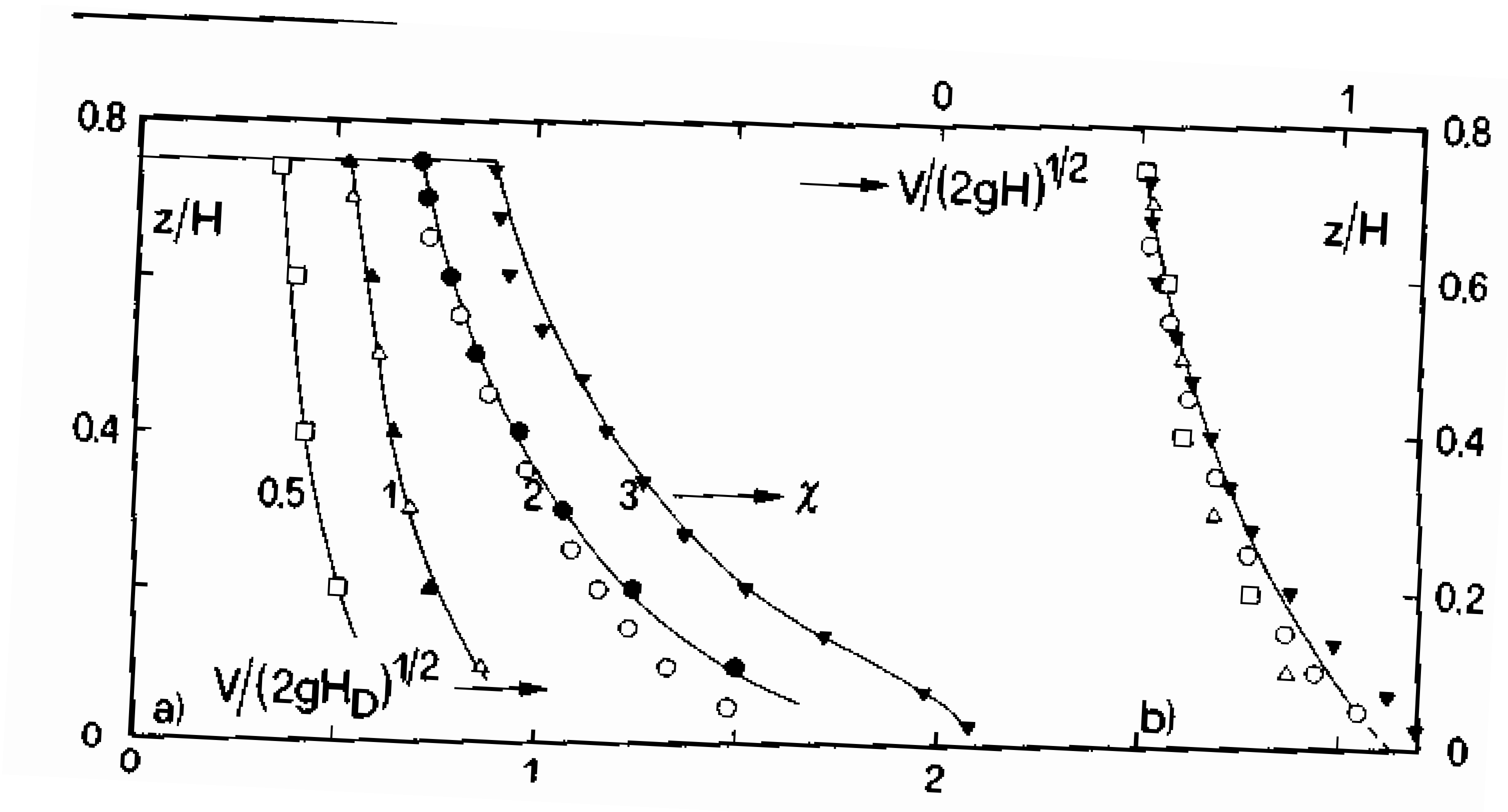
για $H/H_D=1.0$


Z
1
0.5
0
-0.5
-1
V/(2gH_D)^1/2
c)
-1
-0.5
0
0.5
1
1.5
X
2

$$H / H_D = 1.5$$


Z
1.5
1
0.5
0
-0.5
-1
V/(2gH_D)^1/2
0
1
2
d)
-1
-0.5
0
0.5
1
1.5
X
2

$$H / H_D = 2.0$$



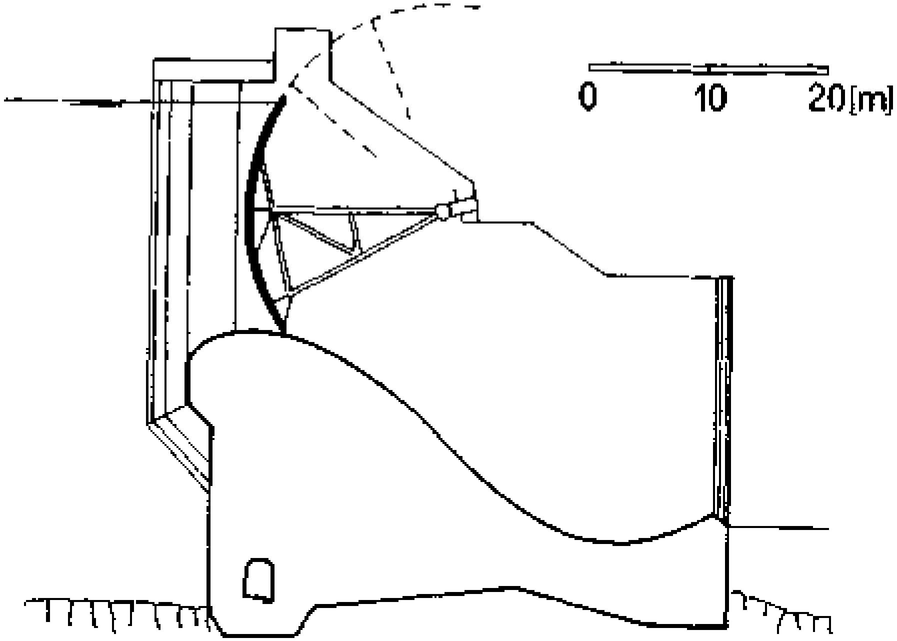
Κατανομή της ταχύτητας στην στέψη για διάφορα $\chi \ (= H / H_D)$.

$$\frac{V_c}{(2gH_D)^{1/2}} \qquad \qquad \frac{V_c}{(2gH)^{1/2}}$$

GATES

Απλές και αξιόπιστες στην λειτουργία τους

Εύκολες στην συντήρησή τους



(α) Χαρακτηριστικά παροχής

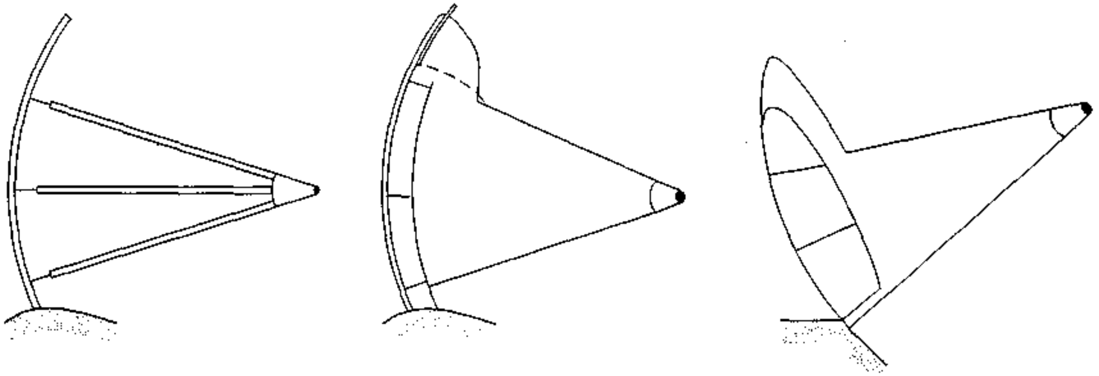
(β) Πίεση στην στέψη

(γ) Vibrations

Θυρίδες (Gates) στην στέψη υπερχειλιστών

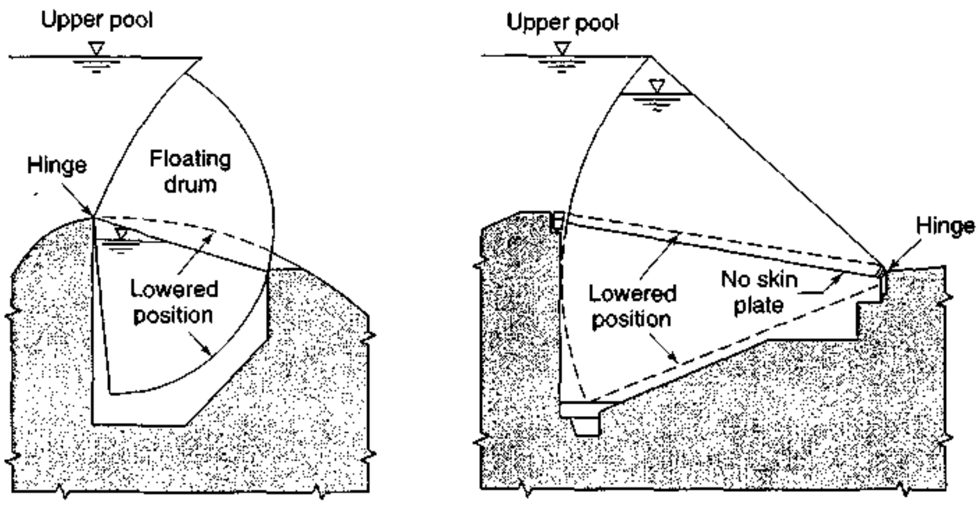
Ακτινικές Θυρίδες (Tainter)

Κλασσική | Με καπάκι | Καταδυόμενη



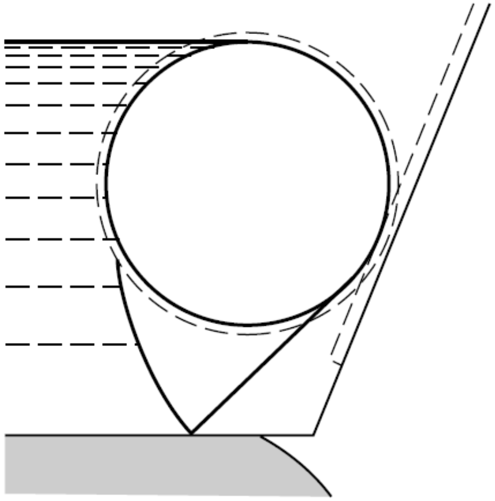
(a) (b) (c)

Θυρίδες Drum

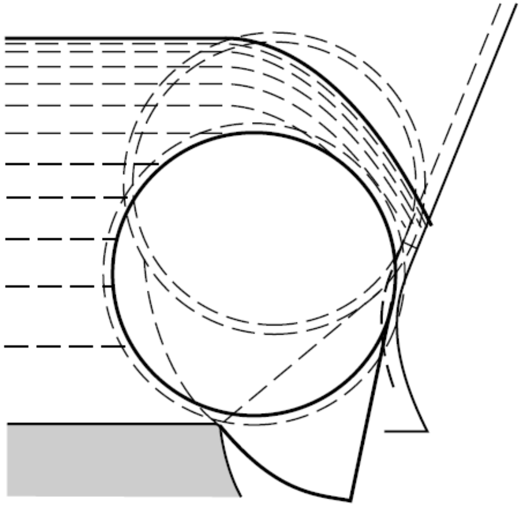


(a) (b)

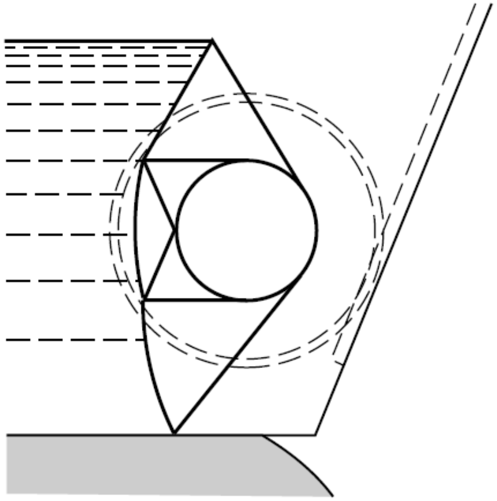
Κυλιόμενες Θυρίδες
Σιδερένιοι κύλινδροι μεταξύ των βάθρων με κεκλιμμένη σχάρα κατά μήκος της οποίας η θυρίδα μετακινείται με αλυσίδα.



Standard gate

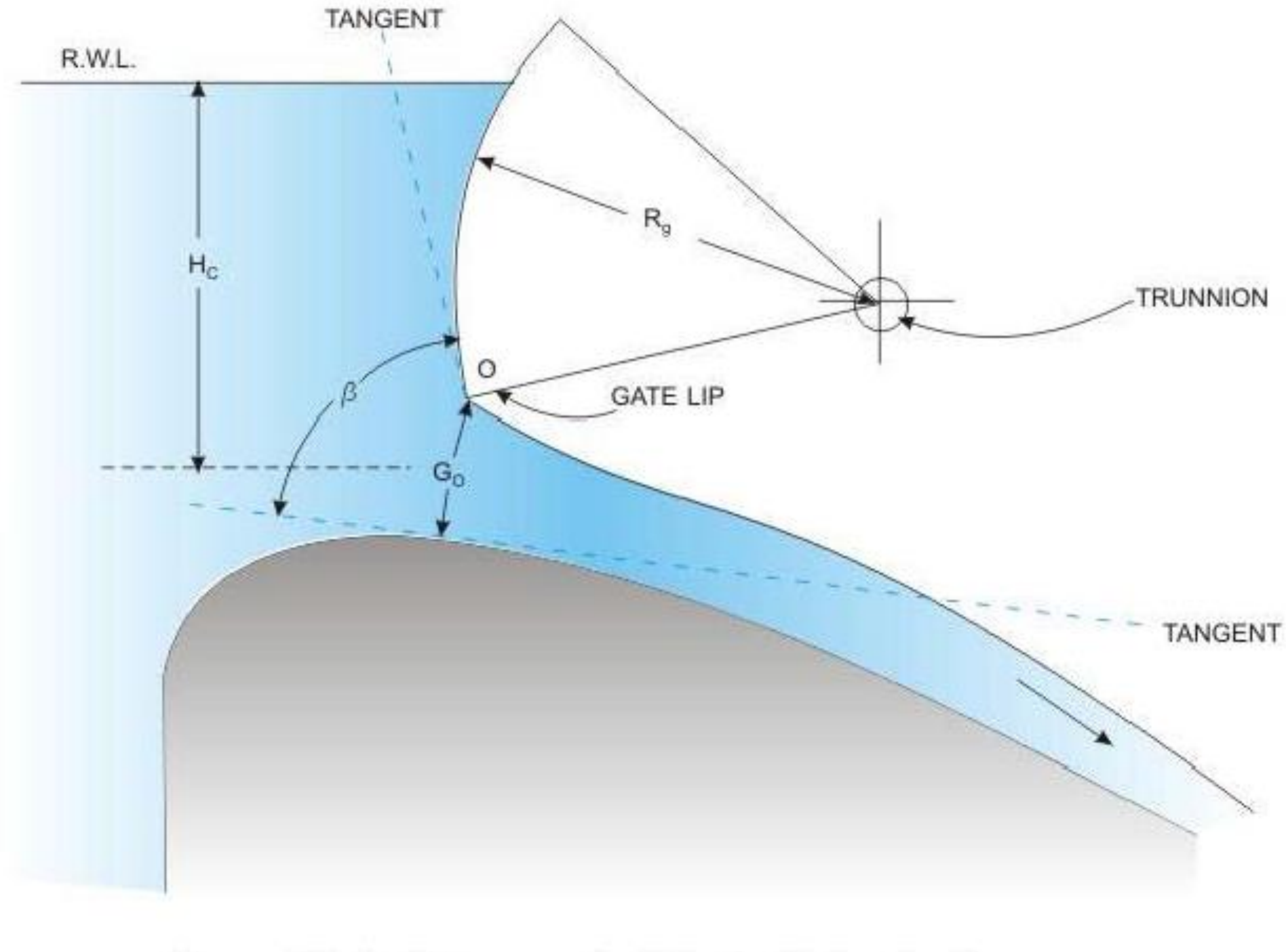


Submergible gate



Small roller with sheilds

Ακτινική θυρίδα (Tainter)

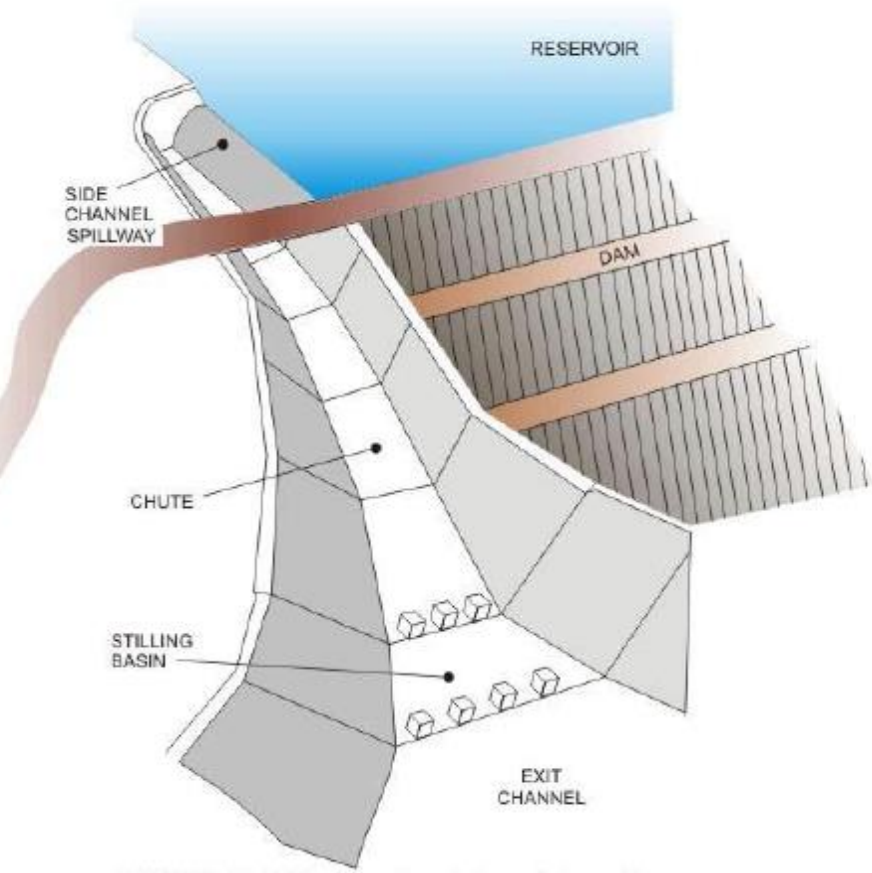


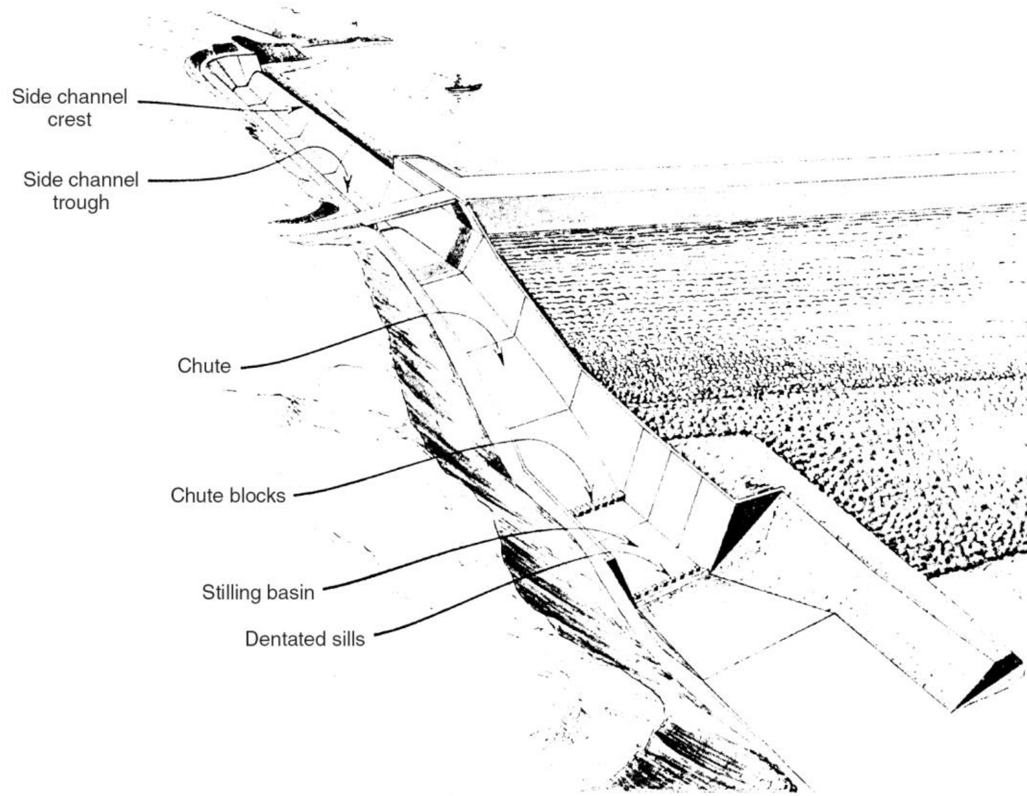
Ανατρεπόμενα Θυρόφραγμα-Raygate

Φωτό 1: ΥΗΕ Καστρακίου ποτ. Αχελώος. (ο υπερχειλι

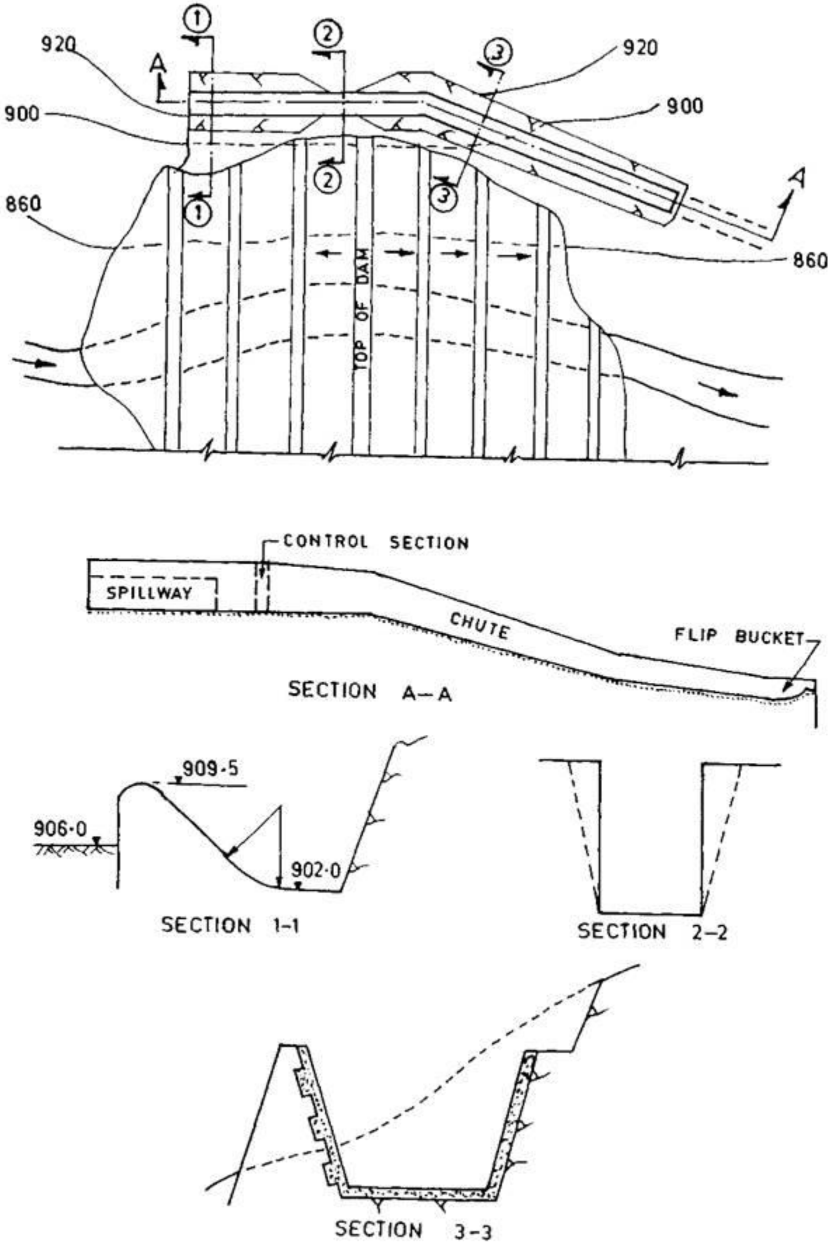
Σχ. 5: Πλευρική όψη από κατάντη της στέψης του υπερχειλιστή Καστρακίου, με τα Raygates τοποθε

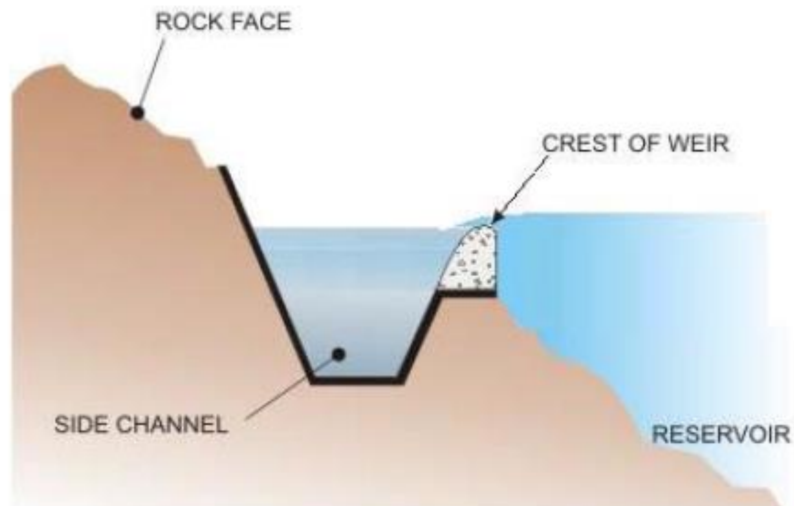
Side-Channel Spillways

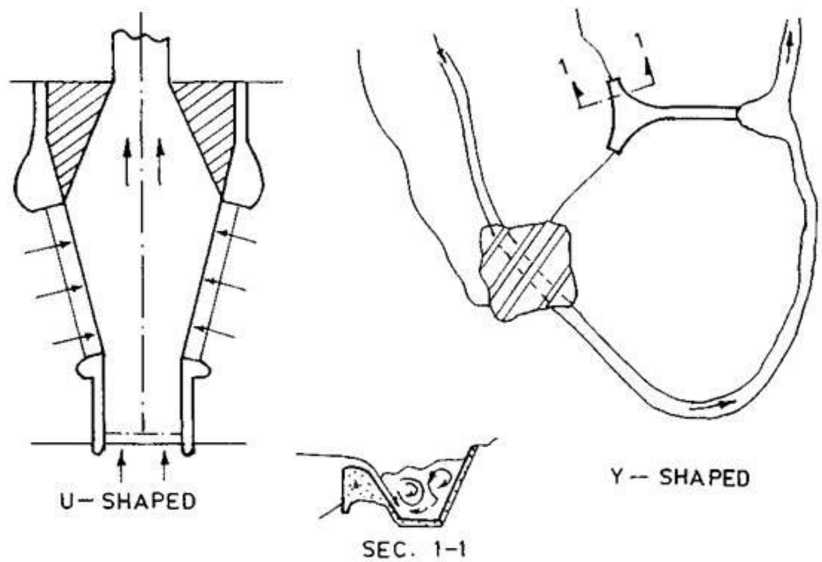




Πλευρικός Υπερχειλιστής



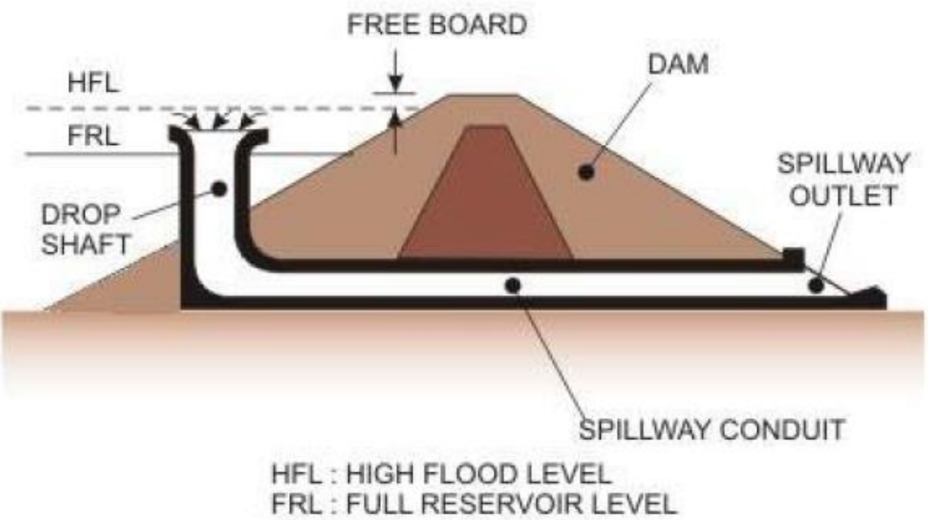


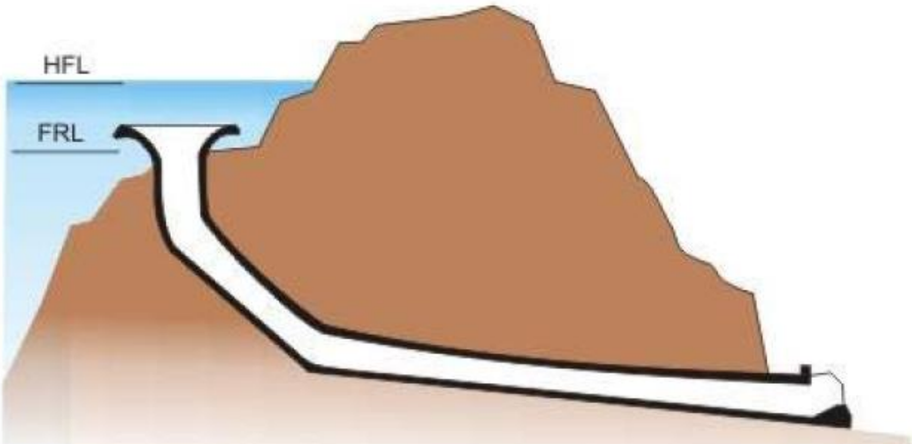


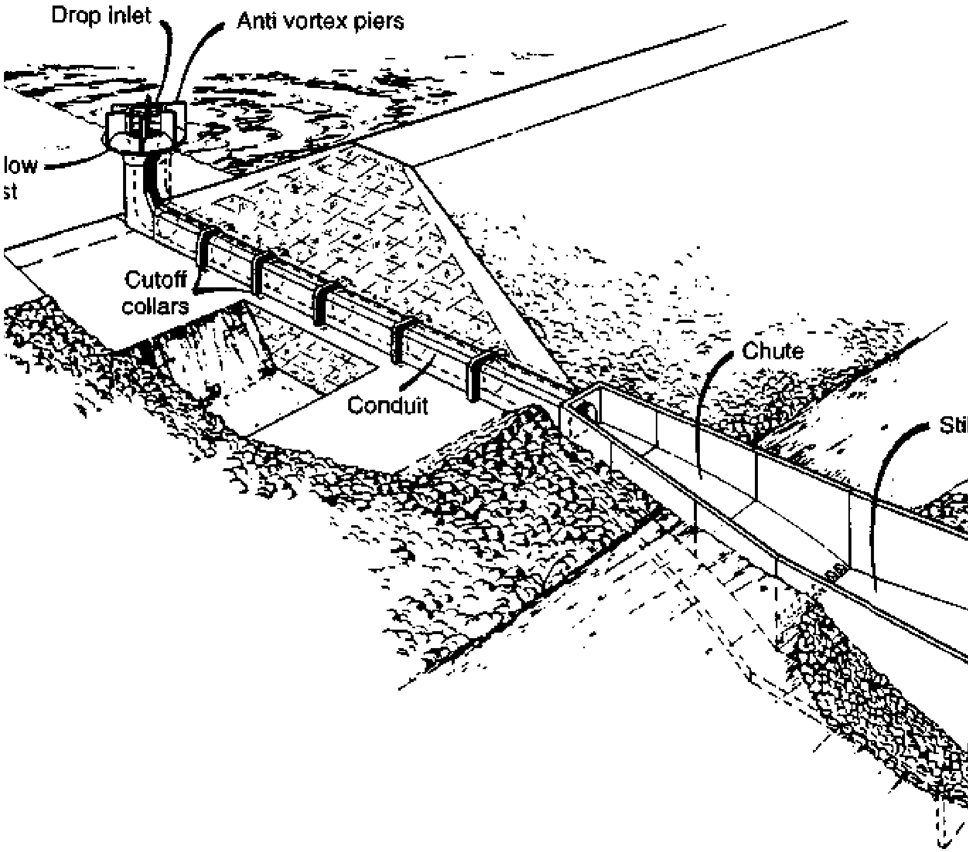
SIDE CHANNEL SPILLWAY

Morning Glory Spillway

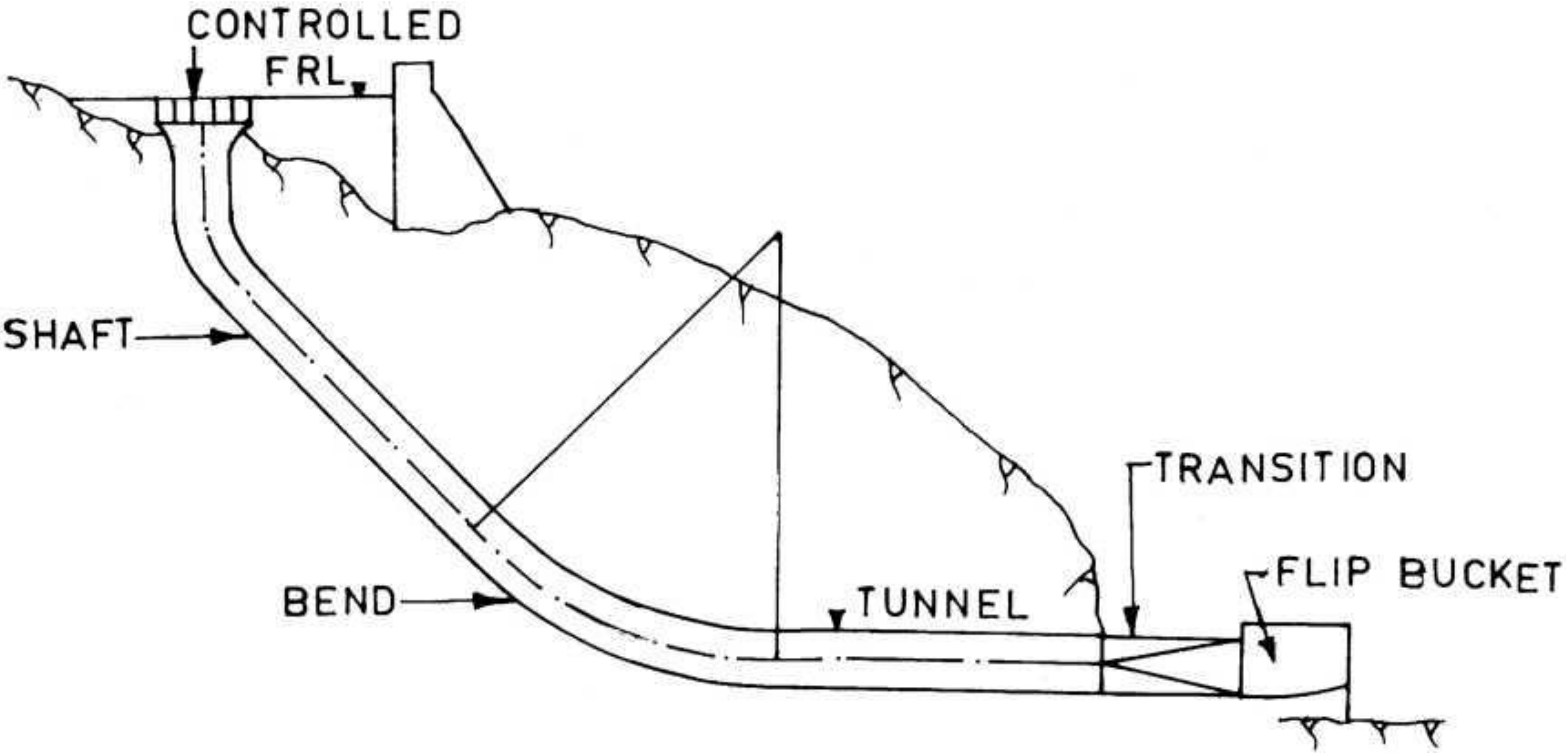
Περιλαμβάνουν (α) εκχειλιστή , (β) Κατακόρυφη Σύνδεση, (γ) Κλειστό Αγωγό



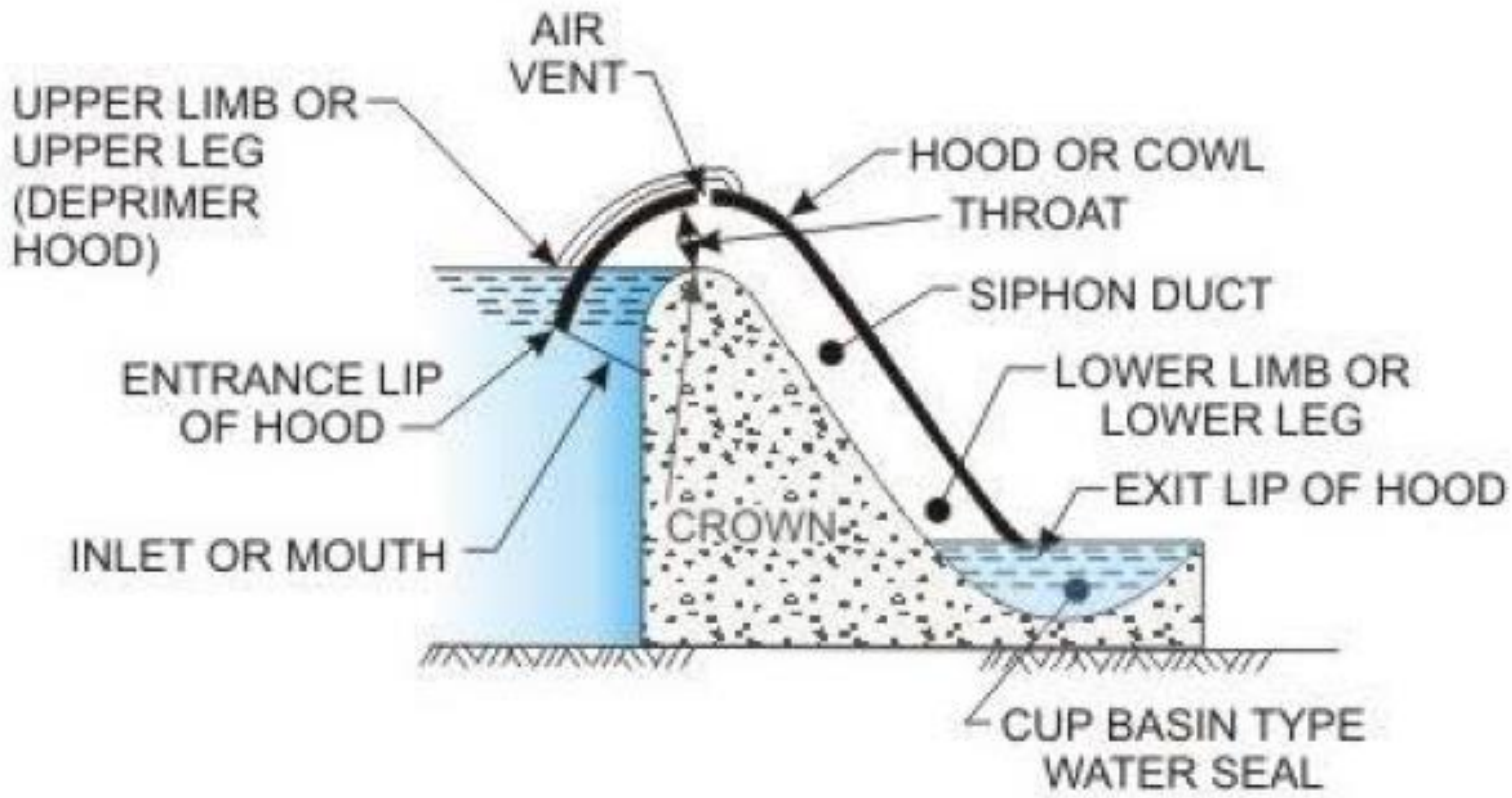




Morning Glory Spillways



Siphon Spillway



Siphon Spillway