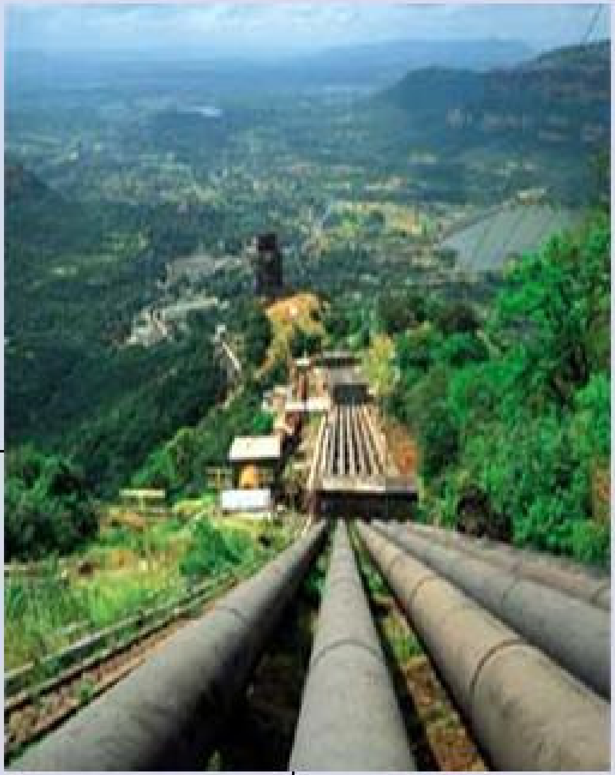
DESIGN OF PENSTOCKS



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Introduction

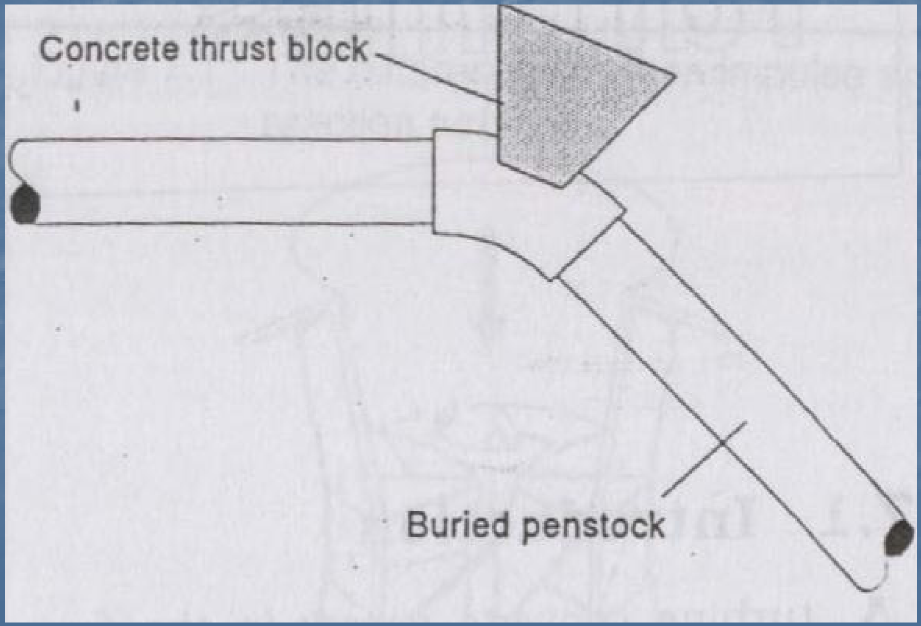
- From the forbay tank down to the turbine water is conveyed through the penstock.

Major components

- Forbay
- Penstock value
- Vent pipe
- Support pier

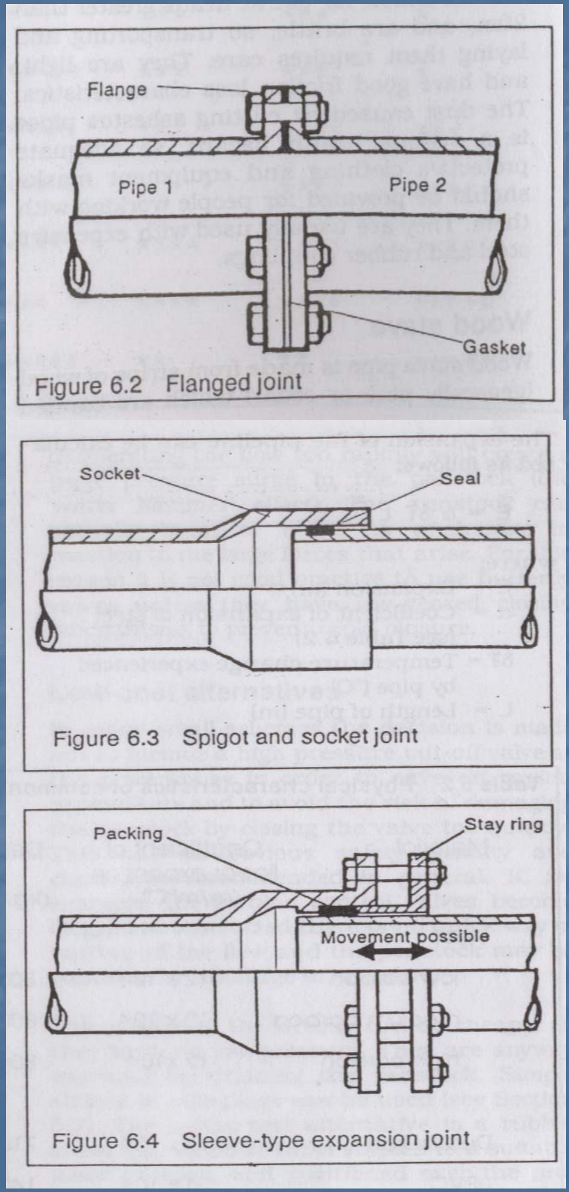
Components.....

- **Anchors**
- **Drain valve**
- **Air bleed value**
- **Bends**
- **Thrust block**

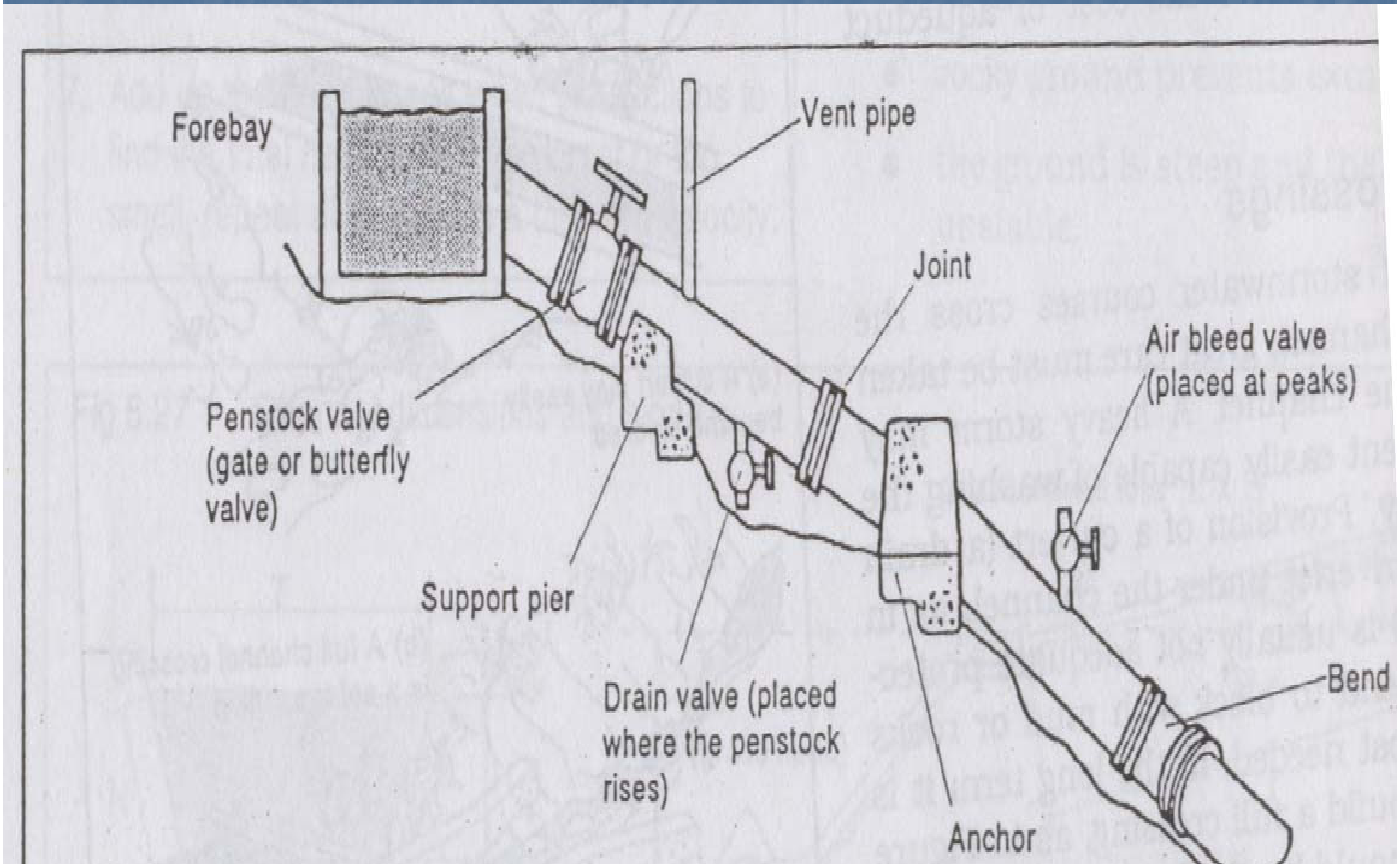


Major components (joint types)

- flanged
- Socket
- Sleeve type



Components of penstock



Material used for construction…

- Mild steel
- uPVC (unplastizied polyvinyl chloride)
- HDPE (high density polyethylene)
- Ductile iron
- Prestressed concrete
- GRP (glass reinforced plastic)

Important factors to be considered when selecting material ……………….

- Design Pressure
- Surface Roughness
- Weight of material
- Ease of transportation
- Method of jointing
- Cost of material etc

Constraints in deciding diameter

- Price
- Head loss

Compromise: **Minimum cost (smallest diameter)**

or

Minimum head loss ? (acceptable head loss)

Major contributions to head loss, h_f

* **Friction** **(due to surface roughness)**

$$h_f = ½ . V^2 . L.f \ / \ g.D$$ ← **Darcy's equation**

V – flow velocity

L – penstock length

D –diameter

f -- friction constant ← **from moody chart**

Major contributions to head loss, h_f

- **Turbulence (caused by due to bends ,inlet, valves ,reductions etc)**

$$h_f = \sum K_i . V_i^2 / 2.g$$

K_i = turbulence loss coefficient

Calculation of head loss & diameter

- **CASE STUDY:- A steel penstock ,500 m long has a design flow of 0.42 m^3/s and a gross head of 220 m. Calculate and diameter and wall thickness. head loss < 2% of gross head.**

- **Select diameter as , D =300 mm**
- **Flow velocity V = 4.Q / pi .D^2**

= 5.9 m/s

Renolds no = V.D x 10^6

= 1.8x 10^6

- Surface roughness of mild steel is, f = 0.3

So , K/D = 0.3/300 = $1x\ 10^{-3}$

from Moody chart f = 0.005,

From Darcy's eq^n ,

$$h_f = ½ \times 5.9^2 \times 500 \times 0.0046 / 9.81 \times 0.25$$
$$= 15.0 \text{ m}$$

in our case gross head = 220 m

H_f = (15 / 220)x 100 =6.8 %

Calculation of diameter is an iterative process ,

increase D by 10 mm ,

now V = 5.5 m/s

K/D = 0.3/310 = 9.6×10^{-4}

Re = V X D = 5.5 X .310 = 1.7×10^{6}

corresponding f = 0.005

h_f = 12.7 m

h_f = 5.77 %

Results of 15 iterations

iterations	Diameter (mm)	hf / (m)	V /(m/s)	%hf
1	300	15	5.9	6.82
2	310	12.7	5.5	5.77
3	315	11.8	5.3	5.36
4	320	10.8	5.22	4.91
5	325	10	5	4.55
6	330	9.3	4.9	4.23
7	335	8.2	4.7	3.73
8	340	7.7	4.6	3.50
9	350	6.6	4.3	3.00
10	355	6.2	4.2	2.82
11	360	5.7	4.1	2.59
12	365	5.4	4	2.45
13	370	5	3.9	2.27
14	375	4.7	3.8	2.14
15	380	4.3	3.7	1.95

Constraints in deciding wall thickness

- Cost
- Strength (withstanding pressure)

<u>Compromize:</u> **Minimum cost**

or

Minimum strength ?

Calculation of wall thickness

- **Wall should be thick enough to withstand the maximum water pressure**

- **Maximum pressure = static + surge**

- **Surge pressure :- worst possible case (instantanious closure of valve)**

Surge pressure , h_{surge}

- **$h_{surge} = C.V / g$**
  - V – flow velocity
  - C – velocity of pressure wave
- **$C = 1/ [\rho (1/k+D/E.t)]^{½}$**
  - D – diameter
  - t – Wall thickness
  - E- Young's modulus of elasticity
  - K – Bulk modulus of water
  - ρ – density of water

- **Thickness ,**

  $t_{min} = \rho.g.h_{max}.D/\ (2.\sigma_T\ /S)$

  - σ_T – ultimate tensile strength
  - S - safety factor typically 3

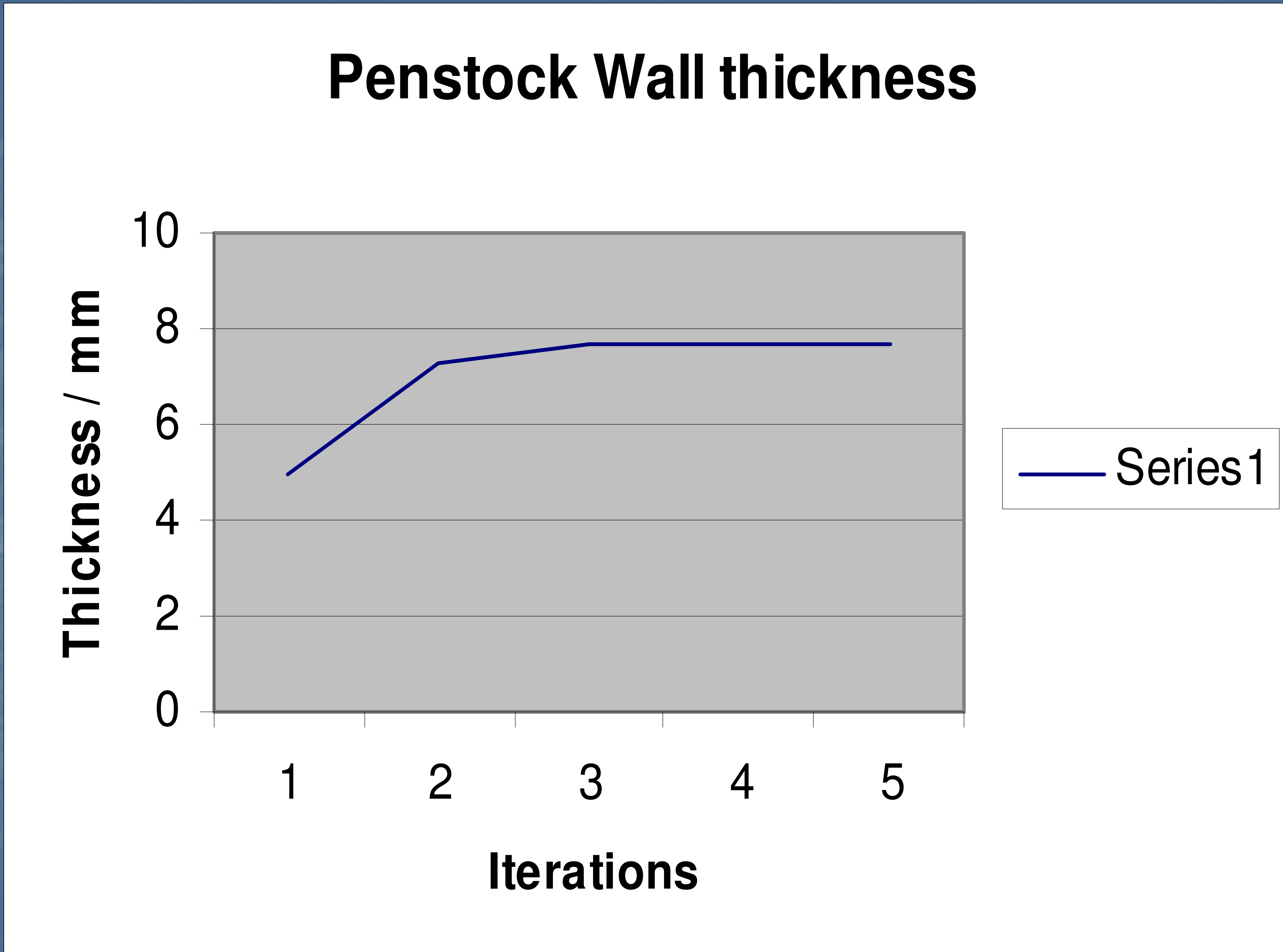
Procedure: this is an iterative process

1. Estimate t
2. Calculate C, h_{max} , t_{min}
3. Compare t with t_{min}
4. If $t < t_{min}$ increase t
5. if $t > t_{min}$ reduce t close to t_{min}
6. Repeat 2 and 3

Calculation of penstock wall Thickness

Let us select t as 5 mm , D = 380 mm

- Iteration 1 ▶
- Iteration 2 ▶
- Iteration 3 ▶
- Iteration 4 ▶


Penstock Wall thickness
Thickness / mm
10
8
6
4
2
0
1
2
3
4
5
Iterations
Series1

References :

- **Micro hydro power** –Adam Harvey ,Andrew Brown , Rod Edward , VAris Bokalders

Thank You !

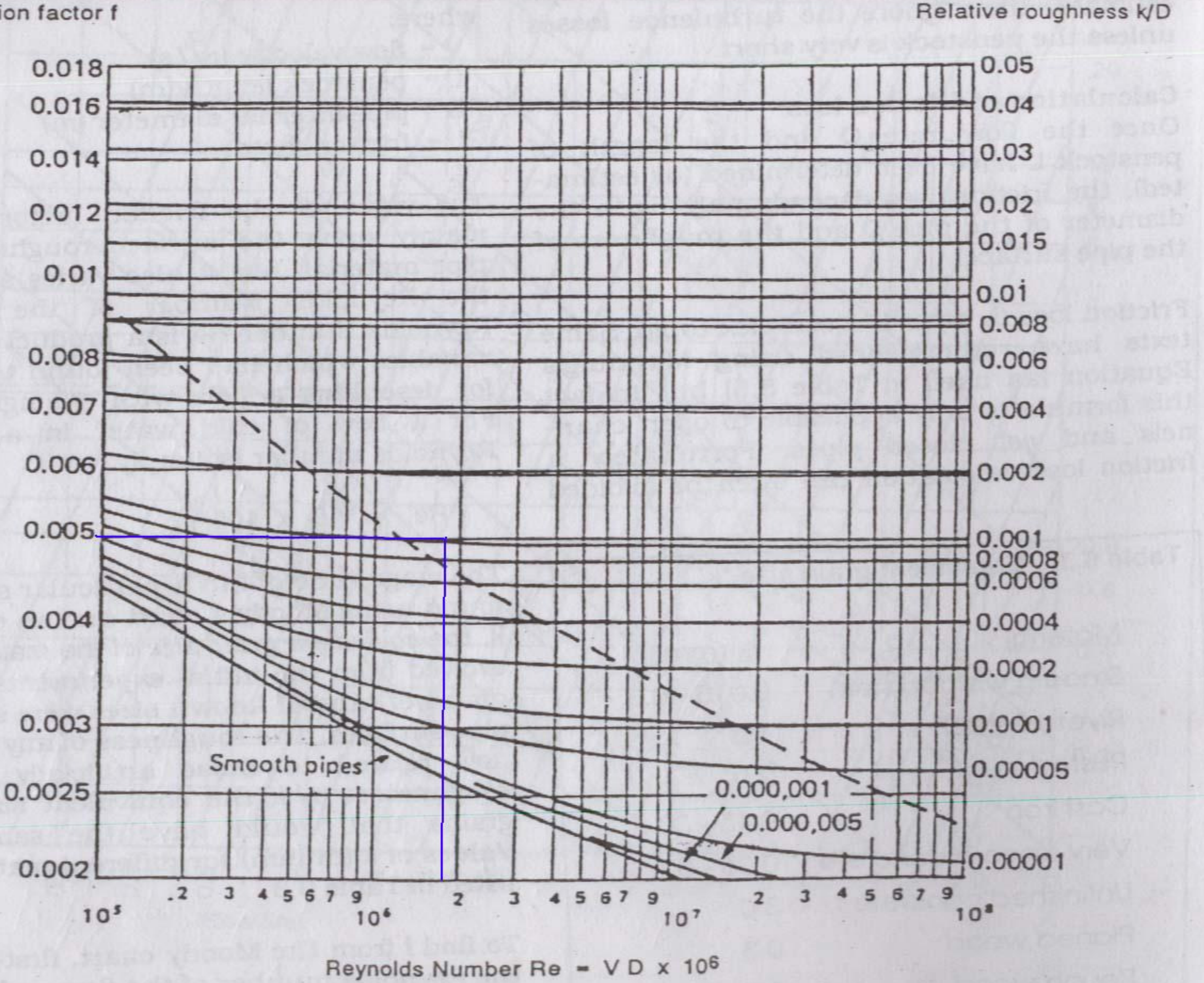
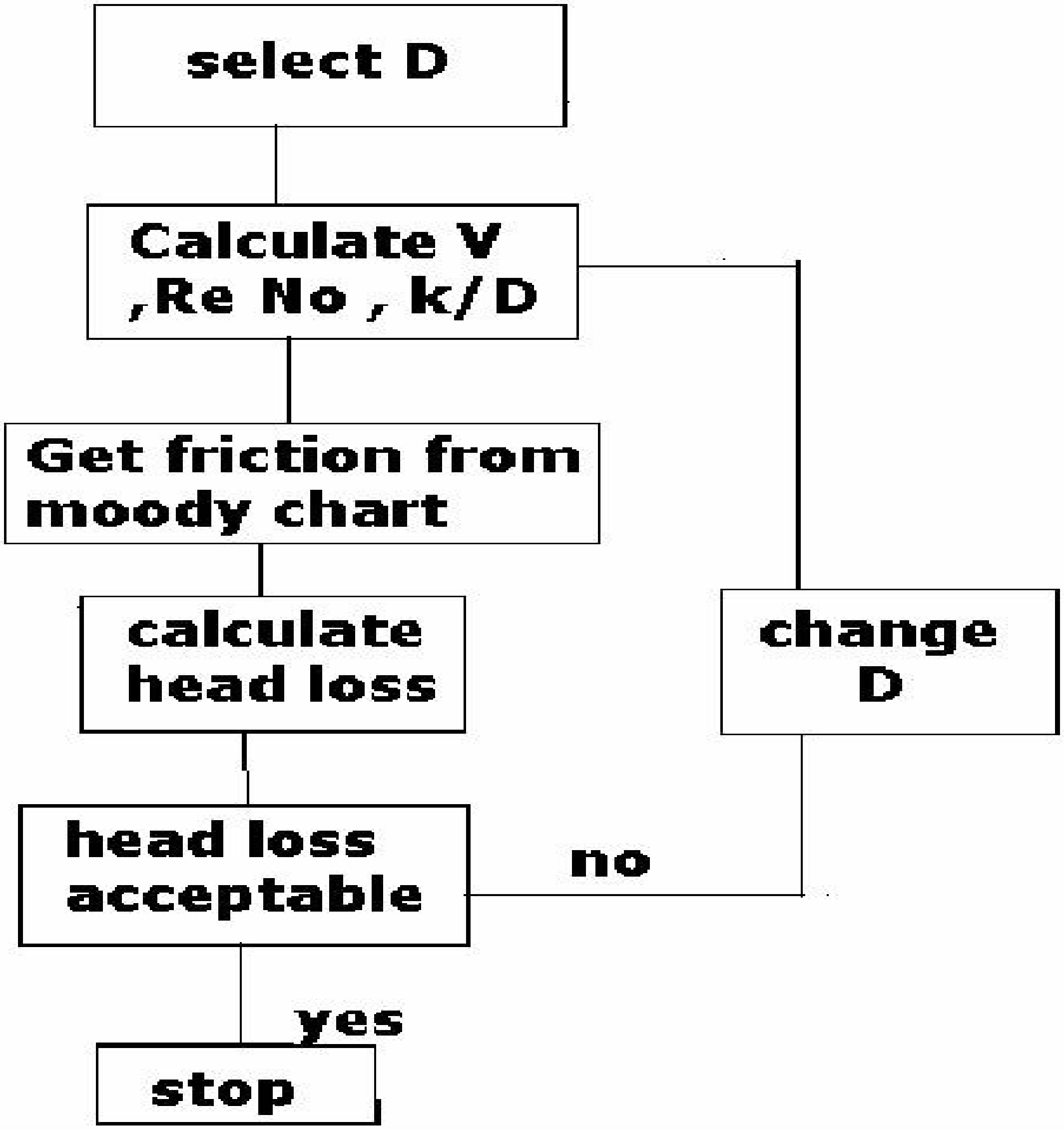


Figure 6.8 Moody's chart for finding the friction factor f of pipes


select D
Calculate V ,Re No , k/D
Get friction from moody chart
calculate head loss
head loss acceptable
no
change D
yes
stop

Results of iterations

1

Wall Thickness	t =	5.00	mm
Diameter	D =	380	mm
Velocity	V =	3.70	m/s
Surge wave velocity	C =	1088.93	m/s
h serge	=	410.71	m
P max =hstatic+hserge		626.41	m
t min		7.30	mm

2

Wall Thickness	t =	7.30	mm
Diameter	D =	380	mm
Velocity	V =	3.70	m/s
Surge wave velocity	C =	1172.29	m/s
h serge	=	442.15	m
P max =hstatic+hserge		657.85	m
t min		7.66	mm

3

Wall Thickness	t =	7.66	mm
Diameter	D =	380	mm
Velocity	V =	3.70	m/s
Surge wave velocity	C =	1181.93	m/s
h serge	=	445.78	m
P max =hstatic+hserge		661.48	m
t min		7.71	mm

4

Wall Thickness	t =	7.71	mm
Diameter	D =	380	mm
Velocity	V =	3.70	m/s
Surge wave velocity	C =	1183.21	m/s
h serge	=	446.27	m
P max =hstatic+hserge		661.97	m
t min		7.71	mm