MANUAL ON DESIGN FABRICATION ERECTION AND MAINTENANCE OF STEEL PENSTOCKS

HYDEL CIVIL DESIGN DIRECTORATE-I
CENTRAL WATER COMMISSION
NEW DELHI

MANUAL ON DESIGN FABRICATION ERECTION AND MAINTENANCE OF STEEL PENSTOCKS

Prepared by -

E. DIVATIA
A.S. CHELVARAJ
G.N. MURTHY

Sri K. Madhavan, gave his valuable suggestions and guidance in the preparation of this Manual.

FOREWORD

Penstocks form a very important component of Hydro-Electric Projects specially in high head plants. These have to be designed to withstand high hydraulic pressure under static as well as transient conditions. There has been considerable advancement in the development of special types of steel to be used, the design criteria to be adopted, fabrication and erection practices. In order to achieve the maximum economy in the cost of penstocks, it is found essential to adopt the latest practices in design, fabrication and testing. At present this information is scattered in various articles on the subject. It is necessary to compile all the data and criteria available, so that they can be adopted giving due consideration to the material readily available in the country.

Central Water and Power Commission which is engaged for the past twenty-five years on the designs of penstocks/pressure shafts has attempted to collect the recent practices adopted in the design of penstocks. This manual covers all aspects involved in planning, design, fabrication and erection of welded steel penstocks. It also deals with the design of components like bends, bifurcation and other accessories viz., manhole etc. The matter presented is based on the design practice followed in CW&PC and supplemented with extensive study of the relevant literature on the recent trends.

I am sure that this manual will meet the long felt need of the Hydraulic engineers concerned with the design, fabrication and erection of penstocks.

(Y.K. Murthy)
Chairman, CW&PC.

New Delhi
Dated the 6th March, 1974

C O N T E N T S

Sl.No.	Subject	Page No.

.

LIST OF FIGURES

1. INTRODUCTION

1.1 This manual presents general information and gives principal guideline regarding criteria for hydraulic and structural design of steel penstocks for hydro-electric power plant and steel pipe lines for pumping plants taking into account the current development in the high strength steel plates, advancement in welding technique and modern methods of analysis. Considerable information on the subject is available in the literatures published on the subject and codes on the penstock design is also prepared by various countries like France, Italy, Russia, ASME Pressure Vessel Code. I.S.I. is also attempting to prepare the code on the subject. The various design criteria presented here are based on the information collected from various codes and experience gained by Central Water & Power Commission in penstock design and construction during the last two decades.

The manual also deals with general methods of fabrication, erection and maintenance of pipelines.

1.2 TYPES OF STEEL PIPELINES

1.2.1 Steel pipelines dealt with in this manual are closed steel conduits, which convey water under pressure. The various types of closed conduit which can be designed as per the guidelines underlined in this manual are described as follows:

(a) Penstocks: Which convey water from reservoir or forebay to turbine of Hydro-Electric Plant. Various types of penstock installations are described in Chapter 2.

(b) Discharge lines: Which convey water from pumping plants to reservoirs at higher elevation. For reversible pump turbine installation penstocks serve as discharge lines and vice-versa.

(c) Outlet pipes: Sometimes pipes are installed to release water from reservoir for irrigation or other purpose. These are embedded in concrete or masonry dam or laid in a tunnel below earthen dam.

(d) Pipe Syphon: Conveys water across a depression, valley or nalla. These are laid in the depression or nalla beds connecting the two ends of canal or tunnel on either bank of the nalla.

1.2.2. The hydraulic and structural design criteria for all the four types discussed above are identical.

These pipes are constructed of wood staves, reinforced concrete, prestressed concrete or steel. To have maximum hydraulic efficiency and structural safety against pressure fluctuations, steel is considered as best material for penstock because of high strength and flexibility. In this manual, design of only welded steel pipelines with special reference to their use for hydro-electric projects is presented.

2. GENERAL

2.1 TYPE OF PENSTOCKS

Depending upon the method of fabrication the penstocks are classified as under:

2.1.1 Riveted or flange bolted Penstocks

Riveted penstocks were in vogue in India during 1940 to 1950 when the present welding technique was not developed fully. Due to the difficulty of welding and stress relieving of thick plates in field, it was a practice to use riveted circumferential joints, which involved three to four rows of rivets for high head plants like Mahatma Gandhi Hydro-Electric (Mysore) and Barapani Hydel (Assam) involving more material, and the total weight of the pipes is more by 8 to 10% than welded pipes and also gives higher hydraulic losses which made them uneconomical and now riveted pipes are obsolete. Photo 1 shows a pipe line with riveted girth joints.

Flange bolted pipes are only used for small diameter pipes if site condition render field welding and rivetting difficulty.

2.1.2. Welded Penstocks

With the advancement in welding technique and development of higher heads, all welded steel penstocks are mostly used. The pipes are formed by butt welding the longitudinal and circumferential joints. The main advantage of this type over riveted penstocks are (i) Lower Weight (ii) Lesser Hydraulic Losses and (iii) Ease of Fabrication and Erection.

Most of the penstocks recently designed for Hydro-Electric Project in India are of all welded type.

2.1.3 With the advancement in designs, higher and higher heads with larger capacity of power station are developed for power development. As the head increases so also the thickness and various difficulties are faced in rolling and welding of thick plates. This difficulty is overcome by the development of high tensile steel multi-layered penstocks and banded or hooped penstock.

2.1.4 Multilayered Penstock

This consists of several layers of thin steel plates wrapped around the pre-fabricated central core pipe by a special wrapping machine. The internal pressure is resisted by the interaction of layers. It is claimed that this type of design gives a saving of about 10 to 15% in material. But the cost of fabrication and installation is expected to be high. The use of thin plates eliminates the stress relieving.

2.1.5 Banded or Hooped Penstocks

In this type the bands or hoops are slipped over thin walled penstock pipe by cold process or hot process. These bands or hoops induce prestress in the pipe as a result of which high operating heads can be carried by comparatively thin pipes. The banded pipes are designed for equal stress in the hoop and in the pipe under maximum operating pressure. Inspite of saving in material the banded pipes are more expensive, mainly because of special fabrication process. This type is adopted for Jogindernagar Penstocks.

2.2 The various types of penstock installations generally adopted for a hydro-electric project or a pumped storage scheme are further classified into following categories: -

a) Surface Penstocks: Where steel conduit or pipe is laid exposed and is supported above ground by saddle supports or ring girder supports.

b) Embedded Penstocks: The steel conduit is embedded in large mass of dam concrete serving as watertight membrane.

c) Buried Penstocks: The conduit is laid in open trenches and backfilled with earth.

d) In Tunnel: Conduits are placed in open tunnel and the pipe is either supported in similar manner as surface penstocks or backfilled with concrete. In the latter case, the conduit is called pressure shaft.

The type of installation generally adopted depends upon the layout.

2.3 LAYOUT OF PENSTOCKS

2.3.1 The layout and arrangement of penstock depends upon the type of development, site conditions, topography and relative location of dam and power plant.

2.3.2 In case of "concentrated fall development", the powerhouse is located close to the dam.

2.3.2.1 When the power house is located at the toe of dam, the penstocks are generally short and embedded in dam concrete or masonry as in case of Gandhisagar Dam Project (Fig.2).

2.3.2.2. Sometimes, the penstocks are partly embedded in dam and partly supported on the downstream slope of dam by rocker supports to facilitate construction of dam earlier to erection of Penstocks as for Nagarjunasagar Dam Project (Fig.3).

2.3.2.3 When Power House is located a little further away from the dam and depending upon the utility of space between dam and powerhouse the penstocks are encased in concrete before burying in earth as for Jawahar Sagar Dam Project, where the space between power house and dam is utilised as switchyard (Fig.4).

2.3.2.4 Advantage is also taken of diversion tunnel, when power house is situated at the outfall of diversion tunnel. The steel conduit is placed in the tunnel after diversion is complete and tunnel intake is plugged as in case of Pong Dam Project (Fig.5).

2.3.2.5 For a head development, where underground power house is located just below reservoirs, the steel conduits are placed in tunnel shafts and backfilled with concrete as in the case of Koyna Stage III Project.

2.3.3 In case of medium and high head penstocks, the water is conducted from dam or diversion structure across river by open channel or tunnel upto forebay or surge shaft at a suitable point and from there it is carried by surface penstocks as in case of Upper Sileru Project and Balimela Project (Fig 6 & 7).

Sometimes, depending upon the topography a combination of surface penstock and penstock in tunnel is used as in case of Baira-Siul Project, Beas-Sutlej link Project and Lower Sileru Project (Fig.8).

2.3.4 For very high heads, it is generally preferred to lay the penstocks in tunnel shafts and backfill with concrete as this arrangement enables to transfer part of internal hydraulic pressure to surrounding rock. Idikki Project, Koyna Project and Yamuna Projects are examples (Fig. 9).

2.3.5 However, surface penstocks have also been used for high heads and these require high tensile strength steel like T_1 steel or Luken 36 steel as in case of Sharavathi Project, Sabrigiri Project and Kundah Project.

2.4 The attached statement (Appendix I) gives the particulars of penstocks used on various projects in India.

3. HYDRAULIC DESIGN

3.1 GENERAL

3.1.1 The Hydraulic design of a penstock involves determination of Hydraulic losses in a pipe line, pressure rise or pressure drop due to turbine or pump operation and ascertaining of most economic diameter of penstock on the basis of available data. These are discussed as below. Sometimes studies are required to be made to ascertain the necessity or desirability of providing surge tank or pressure relief device in the penstock.

3.2 HYDRAULIC LOSSES

For a penstock alignment, it is rarely possible to provide a straight uniform alignment and normally the flow in a pipe encounters a variety of deviations like partial obstacles, change in section, branches, bends etc. which impose additional losses other than the frictional resistance. The various hydraulic losses which occur from penstock intake to power house are classified as follows

i) Entrance losses
ii) Friction loss in pipe
iii) Conduit losses other than friction loss.

These losses are expressed in terms of coefficient to be applied to the velocity head at the section in question.

3.2.1 <u>Entrance losses</u>

3.2.1.1 Entrance losses include trash rack loss and entrance loss.

3.2.1.2 Trash rack losses: The penstock opening is protected from floating debris entering into it by trash rack structure at intake. The head loss through trash rack varies according to velocity of flow through it. The velocity of flow is restricted to 3 fps with 50% clogged area. The loss through trash rack can be expressed as:

$$h_t = \frac{Kv^2}{2g} \quad \ldots \quad \ldots. \quad \ldots. \quad \ldots.\ldots. \quad (1)$$

Where K = a loss coefficient

v = velocity through rack limited to a maximum of 3 fps.

The value of 'K' depends upon the ratio of net to gross area at rack section and on the shape of bars. The waterways experiment station, USA has published a chart, which shows the variation of K with A_r for different shaped bars, where A_r is the ratio of area of bars to area of section. Refer Fig. 10.

3.2.1.3 Entrance losses

The magnitude of entrance losses depends upon the shape of entrance. The entrance is given a bellmouth shape and proportioned as shown in Fig.11 for smooth entry.

The hydraulic losses are estimated as:

$$h_e = Kv^2 / 2g. \qquad \ldots \qquad (2)$$

Where the magnitude of 'K' depends upon the geometry of entrance. Representative values are as follows:-

S. No.	Type of entrance	Value of 'K'
1.	Sharp Cornered	0.5
2.	Slightly rounded	0.23
3.	Bell-mouthed	0.05 to 0.1

3.2.2 Friction Losses

Head loss in straight pipes may be estimated by any one of the several formulae. Scobey's and Darcy's formula are recommended.

Scobey's Formula: $$h_f = \frac{K_s\ v^{1.9}}{D^{1.1}} \quad \ldots. \quad \ldots.. \quad \ldots.. \qquad (3)$$

Where h_f = Friction loss per 1000 ft.

K_s = A loss coefficient depending upon the pipe material and interior condition of pipe. Recommended value for designs is 0.34 for all types of installation.

v = Velocity through pipe

D = Dia. of pipe

From Fig.12, the losses can be directly found for pipe of any diameter.

Darcy's formula : $$h_f = \frac{fL\ v^2}{2gd} \qquad \ldots (4)$$

Where h_f = Friction loss through pipe

L = Length of pipe

v = Velocity through pipe

D = Diameter of pipe

f = A loss coefficient depending upon type and condition of pipe and Reynolds Number – Recommended value is 0.014. It can be obtained from chart on Fig.13.

3.2.3 Conduit losses other than friction loss

In a penstock, other conduit losses include losses due to bends, expansion or contraction, obstruction caused by valve passes and losses in penstock branches and wyes.

3.2.3.1 Bend loss

The bend losses depend upon the shape of bend, deflection angle and ratio of radius of bend to diameter of pipe. The bend loss can be calculated from:

$$h_b = \xi \frac{v^2}{2_g} \qquad \ldots (5)$$

Where

h_b = Head Loss resulting from bend

ξ = Bend loss coefficient which can be estimated from charts in Fig.14 for various R/D ratio and deflection angle.

v = velocity in pipe

3.2.3.2 Loss due to expansion & contraction

a) Head loss due to gradual expansion may be estimated as:

$$h_e = K\frac{(v_1 - v_2)^2}{2g} \quad \ldots \quad \ldots. \quad \ldots \quad (6)$$

This excludes the friction loss in the expansion section.

Where

v_1 = Velocity at upstream end

v_2 = Velocity at downstream end

K = A loss coefficient depending upon the cone angle is generally given by

$$K = (1 - \frac{a_1}{a_2}) \text{ Sin } \theta \qquad \ldots. (7)$$

Where

a_1 = Area on upstream

a_2 = Area on downstream

θ = One half of the flare angle.
A taper of 1 in 10 is recommended.

b) Head loss in reducer piece may be estimated as:

$$h_r = \frac{0.25\,v^2}{2_g} \qquad \ldots. (8)$$

v = velocity at d/s end

3.2.3.3 Losses in valve passages

Various types of valves are provided on a penstock and discharge lines to check the flow. These are circular gate valves, needle valves and butterfly valve. All the valves, even under fully opened position, present obstacle to flow in the form of disc thickness.

a) Circular gate valve

Fig.15 gives the loss in terms of a modified discharge coefficient. The equation used is:

$$Q = C_d D^2 \text{ x } \sqrt{g\Delta H} \quad ... \quad (9)$$

Where

Q = Discharge in cfs.

C_d = Discharge coefficient

D = Valve diameter in ft.

ΔH = Pressure drop across the valve in ft.

b) Needle valve or Howell Bunger valve

Needle valve or Howell Bunger valve is provided in the penstock for bypassing the regulated discharge whenever required. Fig.16 gives the value of loss coefficient for relative linear travel.

c) Butterfly valve

Butterfly valves are frequently used in penstock as service or emergency gates with the provision for automatic closure in the event of power failure. The value of loss coefficient can be obtained from Fig.17.

3.2.4 Losses in penstock branches and Wyes

It is not essential that each unit of a power plant is provided with individual penstocks. Often one single penstock feed more than two units. The number and size of penstock is fixed on economic consideration as described in Article 3.4.

Depending upon the number of units a single penstock feeds, the penstock branching is defined as Bifurcation – when feeding two units, Trifurcation – when feeding three units and Manifold – when feeding more than three units.

The hydraulic losses at wyes are governed by angle of bifurcation, ratio of cross sectional area and type and shape of bifurcation. The hydraulic phenomenon in a branch pipe corresponds to that due to change in direction, change in shape or sudden expansion and losses caused by obstruction, such as tie rods or sickle.

The various types of wyes and branches generally adopted are:-

a) Wyes with sharp transition.
b) Wyes with conical transition.
c) Wyes with tie rods.
d) Wyes with sickle.
e) Spherical type of bifurcation.

Extensive studies and model tests are conducted to determine the head losses in various types of wyes and branches. These model tests are conducted for wyes with bifurcation angles 30^o, 45^o, 60^o and 90^o. For the hydraulic loss to be minimum it is recommended to keep the angle of bifurcation between 45^o to 60^o. The losses are more when one or more of pipes are closed.

The head loss coefficient for wyes with various types of transition is given in Fig.18.

The head loss coefficient largely increases due to presence of a tie rod. The model test results with and without tie rod conducted by Hydraulic laboratory unit of Columbia is shown in Fig.19.

The head loss in a spherical wye increases rapidly with increasing diameter of the wye. The results of model test conducted by Hydraulic laboratory unit of Columbia is shown in Fig. 20.

The head losses for wyes with sickel is very high due to the obstruction caused by sickle plate. The loss can be reduced by improving flow condition and reducing approach velocity by proper shaping of the wye. Escher Wyes has done a lot of experiments in this regard. Fig.21 gives losses in a Wye with sickle.

The loss coefficient for a trifurcation can be given as :-

$$K = \frac{Q_2}{Q_m} \text{ Sin } \theta_2 + \frac{Q_3^2}{Q_m} \text{ Sin } \theta_3 + \text{Entry loss coefficient} \;....(10)$$

Where

Q_m = Discharge through main pipe.

Q_2 and Q_3 = Discharge through branches

θ_2 and θ_3 = The horizontal angle of take-off

The above formula cannot be used for evaluating loss coefficient when one or more branches are closed. The losses will be higher.

3.3 PRESSURE RISE AND PRESSURE DROP

3.3.1 Water hammer phenomenon is caused by the rapid movement of turbine gates. Due to rapid opening and closing of the turbine gate the rate of flow in a conduit is changed rapidly and this intertia effect in turn develops a series of positive and negative pressure waves along the pipe line. The pressure wave velocity `a' is a function of diameter (d) and thickness (t) of pipe and is given in fps units by –

$$a = \frac{4660}{\sqrt{1 + \frac{d}{100t}}} \quad \ldots (11)$$

Fig.22 gives wave velocity for various ratio of pipe diameter to thickness. The maximum pressure rise occurs at the end of first time interval $\frac{2L}{a}$ the intensity is given by:

$$\xi_m = \frac{\ell}{2\theta} + \sqrt{\left[\left(\frac{\ell}{2\theta}\right)^2 + 1\right]} \quad \ldots (12a)$$

and the pressure drop at the instant t_r =t/T = 1 is given by:-

$$\xi_m = \frac{-\ell}{2\theta} + \sqrt{\left[\left(\frac{\ell}{2\theta}\right)^2 + 1\right]} \quad \ldots (12b)$$

where $\ell = \frac{av_o}{2gh_o,}$, $\theta = \frac{\gamma}{T}$

$\xi_m = \frac{h}{h_o}$, $T = \frac{2L}{a}$

For instantaneous closure, the pressure rise is given by.

$$h = \frac{av_o}{g} \qquad \ldots(12c)$$

Where

h = maximum pressure rise.
a = wave velocity of pressure wave as determined above
v = velocity of flow at that instant
g = acceleration due to gravity
ho = static head, γ = time of closure or opening
L = Length of pipe.

3.3.2 Pressure Rise Computation

For preliminary designs, the maximum pressure rise and drop due to water hammer can be estimated from the Allievi's charts shown in Fig. 23 and 24.

It is recommended that accurate determination of pressure rise along the penstock or pump discharge line shall be made by the solution of characteristic equations of water hammer.

The various operating conditions for which the water hammer pressure is to be evaluated are enumerated in Article 4.3.

3.3.3 Pressure Rise Gradient

The pressure rise due to water hammer is measured above static water level in reservoir or surge tank and it is assumed to vary uniformly along penstock, from maximum at turbine end to zero at intake for a turbine penstock installation without surge tank.

For a penstock turbine installation with surge tank, the water hammer gradient varies along the penstock as shown in Fig. 25.

3.4 ECONOMIC STUDIES OF PENSTOCK

3.4.1 Number of penstock

In a Hydro-Electric Project, the power potential to be developed, number and size of units to be installed in a power house is determined after water power studies taking into consideration the hydrological data and head available for power generation. Sometimes, for large diameter, it is more economical to use as many penstock lines as the number of units, but the general practice is to use single penstock to feed more than one unit by proper bifurcations and/manifolds. The number of penstocks to be provided for any particular installation depends upon:-

a) Spacing and size of units.
b) Location of take-off of penstocks.
c) Size easy for handling, fabrication, transportation and erection of pipes.
d) Head losses occurring at the manifold versus losses in single line.
e) Cost of civil works like number of piers, anchor blocks etc.
f) Flexibility in the operation.
g) Thickness of liner not exceeding 50 mm.

The number of penstocks should be determined by economical analysis.

A comparison of single penstock to multi-penstock for identical velocity or identical head loss condition can be summarised as follows.

Items	**Single penstock**	**'n' number of penstocks**	
		Identical Velocity	**Identical head loss**
Discharge	Q	Q/n	Q/n
Diameter	d	d/n	$d/n^{2/5}$
Velocity	v	v	$v/n^{1/5}$
Head loss	h	$hn^{1/2}$	h
Wall thickness	S	$S/n^{1/2}$	$S/n^{2/5}$
Total weight	G	G	$G/n^{1/5}$

The diameter of pipe to be adopted for a single line or a number of lines is to be determined by economic diameter studies.

3.4.2 Economic diameter Studies

The economic diameter of penstock is the diameter for which the annual cost, which includes the cost of power lost due to friction and charges for amortization of construction cost, maintenance operation etc. is minimum.

The economic diameter can be evaluated initially by an empirical formula such as :

$$D = \left(\frac{P}{H}\right)^{0.466} \qquad \ldots (13)$$

Where

D = Diameter of pipe

P = Rated H.P.

H = Rated Head

The economic diameter is calculated by evaluating annual power loss and annual cost for maintenance etc. and equating first derivative with respect to D to Zero. The steps involved are as follows:-

The annual loss of power due to friction:

$$P_f = Q \text{ x } h_f \text{ x } \frac{62.5}{550} \text{ x } e \text{ x } 0.746 \text{ x } 8760 \text{ x } f \qquad \ldots (14)$$

The annual cost of power lost, putting

$$h_f = \frac{K_s\ Q^{1.9}}{631.93\ D^{4.9}}$$

$$E_f = P_f b = \frac{1.17631\, K_s\ Q^{2.9}\ efb}{D^{4.9}} \qquad \ldots (15)$$

The annual cost of penstock

$$E_p = \frac{334\ HD^2\ ap\ \text{x}\, (1+i)}{S_g\ \text{x}\ e_j} \qquad \text{Per ft. length of penstock} \ldots (16)$$

Total annual cost

$$E_f + E_p = E \qquad \ldots (17)$$

For the total annual cost `E’ to be minimum.

$$\frac{dE_p}{dD} + \frac{dE_f}{dD} = 0,$$ solving and simplifying, the diameter of penstock is given by

$$D = 0.50218 \text{ x } \sqrt[6.9]{\frac{k_s \ Q^{2.9} \ e.f.b.S_g.e_j}{a.H.p^{(1+i)}}} \qquad .... \qquad (18)$$

D = Diameter of penstock
H = Head on penstock including water hammer.
Q = Discharge through penstock.
e = Overall efficiency of plant.
f = Loss factor corresponding to load factor as per Fig. 26.
b = Cost of power per kWh.
K_s = Loss coefficient is Scobey's Formula considering total loss expressed as pipe friction.
e_j = Joint efficiency of penstock.
S_g = Allowable stress of penstock material.
a = Unit cost of steel in penstock.
p = Ratio of annual fixed operating and maintenance charges to construction cost of penstock.
i = Percentage by which steel in penstock is overweight.

The economic diameter can also be estimated approximately from the charts of Fig.26. However, detailed studies are required by considering various diameter pipes and variation of thickness of pipes along profile to arrive at economical diameter. An example is given in Appendix II.

The cost of power and annual charges like interest on capital cost, depreciation, operation and maintenance charges shall be determined accurately before hand as per the practice followed by State.

4. STRUCTURAL DESIGN CRITERIA OF PENSTOCK

4.1 GENERAL

4.1.1 The structural design of penstock involves determination of various forces and stresses in pipe shell for various operating conditions by the methods generally adopted by Penstock designers. These are discussed in following paragraphs. The working stresses and joint efficiency to be adopted for the design depends upon the type of material used, method of fabrication and testing as described in chapter 10,11 and 12. The factor of safety generally adopted for various operating conditions are discussed in Art. 4.6.

4.2 FORCES AND STRESSES IN SHELL

4.2.1 The surface penstock is a continuous beam supported over a number of intermediate supports between anchors with or without an expansion joint installed between anchors.

For normal condition of operation, the pipe shell of a surface penstock shall be designed to withstand the forces as follows:

4.2.1.1 <u>At Mid-Span</u>

i) The Hoop stresses developed due to internal pressure equal to sum of static pressure due to maximum water level in reservoir or surge tank plus the dynamic pressure due to water hammer as calculated in Art. 3.2 for operating conditions specified in Art. 4.3.

ii) The longitudinal stresses developed due to its own weight and weight of water by beam action.

iii) The longitudinal stresses developed due to sliding friction over the supports.

iv) The longitudinal stresses developed due to expansion or contraction of pipe shell due to variation of temperature.

4.2.1.2 <u>At supports</u>

i) The circumferential stresses developed at the supports due to bending caused by internal pressure.

ii) Longitudinal stresses due to secondary bending moments caused by the restraints imposed by Ring Girder or stiffner Rings.

iii) Longitudinal stresses developed at the support due to beam action as in (ii) or Art. 4.3.1.1.

iv) Longitudinal stresses developed by the forces enumerated as (iii) and (iv) of Art. 4.2.1.1.

4.2.1.3 The pipe shell shall also be examined to withstand the stresses developed due to following exceptional forces.

i) Longitudinal stresses developed due to earthquake and wind forces acting on shell during normal operating condition.

ii) Stresses developed due to filling and draining of pipe.

4.2.2 Combined stresses

The circumferential and longitudinal stress obtained as specified in Art. 4.2.1.1, 4.2.1.2 and 4.2.1.3 above, shall be combined to obtain equivalent stresses in accordance with Hencky Mises Theory, which states that,

$$S_e = \sqrt{S_x^2 + S_y^2 \pm S_x S_y} \qquad \text{...(19)}$$

Where

S_e = Equivalent stress - Psi or Kg/sq cm

S_x = Principal stresses in Psi or Kg/cm^2

$$S_x, S_y = \frac{f_x + f_y}{2} \pm \sqrt{\frac{\left(f_x - f_y\right)^2}{2} + q^2} \qquad \text{.... (20)}$$

f_x = Circumferential stress - Psi or Kg/cm^2

f_y = Sum of all longitudinal stresses Psi or Kg/cm^2

q = Shear stress - Psi or Kg/cm^2

The equivalent stress can readily be obtained from Fig. 27.

4.2.3 Embedded Penstock

4.2.3.1 Penstocks embedded in the concrete or laid in tunnel and backfilled with concrete shall be designed to withstand the stress developed in closing the initial gap between liner and surrounding concrete plus the stress developed in liner due to remainder of pressure less the portion of the pressure carried by surrounding concrete and rock.

4.2.3.2 Penstocks placed in tunnel and backfilled with concrete shall be designed to withstand the external pressure due to ground water and grout pressure. The ground water level should be taken upto ground level unless otherwise specified or established by geological exploration. The critical buckling pressure for various R/t ratio can be obtained as specified in Article 4.4.5

4.2.3.3 Penstocks embedded in mass concrete in a dam need not be designed for any external pressure due to seepage water or grout pressure, since, provision of formed drains and galleries in the body of dam together with percolation ring limits the external pressure on embedded penstock and penstock embedded in mass concrete, these do not require any grouting.

4.3 OPERATING CONDITION

4.3.1 The dynamic pressure rise due to water hammer as calculated in Art. 3.3.2 in a turbine penstock installation shall be considered for the following operating condition :

4.3.2 Normal Operating Condition

The design criteria for dynamic pressure rise or drop due to water hammer under normal operating condition shall be due to full load rejection or acceptance. The basic conditions to be considered as normal operations are as follows :-

i) The turbine-penstock installation may be operated at any head between the maximum and minimum water levels in the reservoir or forebay or surge tank.

ii) Where the turbine – penstock installation is equipped with any of the pressure control devices like surge tanks, relief valves, governor control device and cushioning stroke device, it is assumed that these devices are properly adjusted and function in the manner as contemplated in the design.

iii) Unless the actual turbine characteristics are known the effective flow area through the turbine gates during maximum rate of gate movement may be assumed to be linear with respect to time.

iv) The turbine gates may be moved at any rate of travel by the action of the governor head upto a pre-determined rate or at a slower rate by manual control through auxiliary relays. The water hammer effects may be computed on the basis of governor rate which is set by the governor relay valves stops for speed regulation.

v) The penstock alignment shall be checked such that due to load acceptance water column separation shall not cause a penstock failure due to collapse.

vi) When the closure is set at slow rate, the water hammer caused by runway when full load discharge reduces to runway discharge during the speed rise shall be considered.

4.3.3 <u>Emergency Condition of Operation</u>

For emergency condition of operation the dynamic pressure rise is due to sudden load rejection. The basic conditions to be considered as Emergency Operation for an impulse and reaction turbine is as follows.

4.3.3.1 (1) <u>Impulse Turbine</u>

i) The dynamic pressure rise due to needle slam on loss of oil pressure or mechanical failure. As the needles are hydraulically balanced at mid point, the turbine flow cut off shall be taken as instantaneous due to slam closure of the needles from half position.

4.3.3.2 (2) <u>Reaction Turbine</u>

i) The turbine gates may be closed at any time by the action of the governor head, manual control of the main relay valve or by the emergency solenoid device. The cushioning stroke shall be assumed to be inoperative in one unit.

ii) The water hammer shall be computed for the maximum reservoir head condition for final part gate closure to zero gate position on one unit at the maximum governor rate of $\frac{2L}{a}$ secs.

4.4 RECOMMENDED METHODS OF CALCULATION OF STRESSES IN PIPE SHELL.

4.4.1 The stress for different forces enumerated in Art. 4.2 shall be calculated as follows :-

4.4.2 Hoop Stress due to Internal Pressure.

4.4.2.1 The Hoop stress developed due to internal pressure as specified in Art. is given by :-

$$S = \frac{Pr}{t} \quad \ldots(21)$$

Where

S - Hoop stress in steel - Psi or Kg/cm^2

r - Radius of pipe shell - inches or cm.

t - Thickness of pipe shell - inches or cm.

P - Internal pressure due to static head + Dynamic Head.

4.4.2.2 For embedded penstock, the design pressure shall be equal to internal pressure `P' due to static and dynamic head less the portion of the pressure carried by surrounding concrete and rock as specified in Art 4.4.4.

4.4.3 Membrane shell stresses

4.4.3.1 Longitudinal stresses due to Beam action

The stress developed due to self weight and weight of water in pipe spanning over supports due to beam action is given by –

(a) At Mid span

$$f_1 = 1.2\frac{WL^2}{Z} \text{ Psi} \quad \text{or} \quad \frac{WL^2}{Z}\text{ Kg/cm}^2 \quad \ldots(22)$$

(b) At Support

$$f_1 = \frac{WL^2}{Z} \text{ Psi} \quad \text{or} \quad \frac{WL^2}{1.2\,Z}\text{ Kg/cm}^2 \quad \ldots(23)$$

Where

W - Total weight i.e. self weight of shell + weight of water lbs/ft or kg/cm

L - Span - ft or M

Z - r^2t - Section modulus – in^3 or cm^3

f_1 - Longitudinal stress due to beam action – Psi or Kg/cm^2

4.4.3.2 Longitudinal stress due to sliding friction over support

$$f_2 = \frac{\mu W}{A}$$

Where

μ - Co-efficient of friction depending on type of support as given in table below.

A - Area = $2 \pi rt$ - sq. in or cm^2

W - Total weight i.e. weight of shell + weight of water – lbs or kg.

Sl.No.	Type of support	Friction co-efficient
1.	Steel on concrete	0.60
2.	Steel on concrete with asphalt roofing paper between	0.50
3.	Steel on steel (Rusty)	0.50
4.	Steel on steel (Greased)	0.25
5.	Rocker support	0.15
6.	Roller support	0.10

4.4.3.3 Temperature stresses

i) Longitudinal stresses caused due to expansion or contraction of pipe shell without expansion joint

$$f_3 = E \alpha T \quad \ldots (25)$$

Where

E - Modulus of Elasticity - Psi or kg/cm^2

α - Co-efficient of linear expansion or contraction per degree centigrade.

T - Rise or drop of temperature in ^0C

ii) Longitudinal stress caused due to expansion or contraction when an expansion joint is provided is given by following formula:

f_3 = 500 x A

Where

A- Area = $2 \pi rt$ - sq. in or sq. cm

This is in addition to the stress given in Art. 4.4.3.2.

4.4.3.4 Stress due to restraint

Pipe shell which are provided with stiffener rings or ring girders at the support are restrained due to relative radial deformation between the shell and ring girder or stiffener under internal pressure

The secondary bending stress due to restraint is given by

$$f = \frac{1.82\left(A_r - bt\right)}{A_r + 1.56\ t\sqrt{rt}} \times \frac{p.r}{t} \qquad .... \qquad (27)$$

Where

A_r - Area of supporting ring
b - Width of circular ring
t - Thickness or pipe shell liner
r - Radius of pipe shell
p - Internal pressure.

This stress is local and the effect shall be taken for a distance of 3/q where $q = \frac{1.285}{\sqrt{rt}}$ on either side of ring and pipe thickness shall be increased if required in this zone.

4.4.3.5 Circumferential bending stresses

The circumferential bending stresses at supports caused by internal pressure are calculated as specified in Article 5.3.

4.4.3.6 Stresses in pipe with free elbows

When the pipe is a rigidly jointed line with one or more bends free between the anchors it resembles an arch beam along the line of mean curve. This introduces the extra moments of flexure, eccentric forces etc. in the pipe shell. The liner thickness shall be increased to withstand these forces.

The design analysis for these moments etc. are worked out as per the arch analysis and the pipe design is based on the resultant stress theory. The arch analysis for the pipe arch which is hyperstatic arch with ends fixed at anchors is done by working out the reactions of the arch when rendered isostatic by arch analysis, and to add to these reactions a complementary reaction made up of the horizontal component `Q', the virtual component `B' together with the moment `M' in relation to a point taken as the origin of coordinates. The formula for the moment, vertical reaction and horizontal reaction are:

$$M = -\frac{\int \frac{\mu ds}{i}}{\int \frac{ds}{i}} \qquad \ldots(28)$$

$$\beta = -\frac{\int \frac{\mu\, x\, ds}{i}}{\int \frac{x^2 ds}{i}} \qquad \ldots(29)$$

$$Q = \frac{Ec\Delta Tl + \int \frac{\mu y ds}{i}}{\int \frac{y^2 ds}{i} + \int \left(\frac{dx}{ds}\right)^2 \frac{ds}{\Omega}} \qquad \ldots(30)$$

Where:

μ	-	Moment at a point of the isostatic arc
C	-	Cooefficient of expansion of steel
ΔT	-	Difference of temperature at the origin
l	-	Span of arch

i	-	Moment or inertia of section of pipe
Ω	-	Area of cross section of pipe.

The origin of reference is taken at the centre of gravity of mean line of arc of the hypothetical masses and the axes of coordinates are taken as two mutually perpendicular axis, one being parallel to the line joining the abutment anchors of the arch.

This method cannot be applied to self hooped pipes as the shell thickness will be too thin to support arch action and for pipes provided with flexible joints such as dresser couplings etc. Also for the pipe having bends in horizontal direction the design computations and erection would be difficult owing to the complicated intermediate supports to limit lateral deflections of the pipe arc.

4.4.4 Rock Participation

4.4.4.1 As specified in Article 4.2.3; when the liner is placed in a rock tunnel and backfilled with concrete, the transference of load to the surrounding rock, taking into consideration the initial gap, deformation of liner, deformation of concrete, deformation of rock in cracked zone and sound rock is given by:

$$\lambda = \frac{\frac{r^2}{Et} - \frac{Y_o}{P}}{\frac{r^2}{Et} - \frac{r}{E_r}(1+u) + \frac{r_c^2 - r^2}{2r_c E_c} + \frac{r}{2r_c d}\left[\frac{d^2 - r_c^2}{E_r}\right]} \quad \ldots (31)$$

or

$$\lambda = \frac{\sigma_t - EY_o/r}{\sigma_t - P\left\{\frac{E}{Er}(1+\mu) + \frac{E}{2E_c}\frac{r}{r_c}(r_c^2 - r^2) + \frac{Er^2}{2E_r r_c d}(d^2 - r_c^2)\right\}}$$

…(32)

λ	-	Proportion of internal pressure transferred to rock
E	-	Modulus of Elasticity of steel.
E_r	-	Modulus of Elasticity of rock
E_c	-	Modulus of Elasticity of concrete
r	-	Inside radius of steel liner
r_c	-	Outside radius of concrete lining
d	-	Radius to the end of radial fissures in rock
σ_t	-	Allowable stress in the steel liner

Yo - Initial gap between steel liner and concrete.
P - Internal pressure in conduit
μ - Poisson's ratio of rock.

4.4.4.2 The ratio of rock participation for various types of rock with different modulus of elasticity rock can also be obtained from Fig.28.

4.4.4.3 The circumferential stress in the liner which is embedded in mass concrete is given by:

$$\frac{Pr}{t} \quad K \qquad \ldots (33)$$

The value of K for uncracked concrete or cracked concrete is obtained from the Fig. 29.

4.4.5 External Pressure

As specified in article 4.2.3.2 buckling stresses are caused in embedded steel pipe due to ground water and grout pressure. On the assumption that there would be a radial gap between steel and surrounding concrete, the critical stress in the liner is given by the solution of following two equations:

$$\left\{\frac{\sigma_t}{E^*} + \frac{Y_o}{r}\right\}\left[1 + \frac{3K^2\sigma_t}{E^*}\right]^{3/2}$$

$$= 1.68\,K\left\{\frac{\sigma_y - \sigma_t}{E^*}\right\}\left[1 - \frac{K}{4} \text{ x } \frac{\sigma_y{}^* - \sigma_t}{E^*}\right] \qquad \ldots(34)$$

and

$$1 - \frac{PK}{2\sigma_t} = 0.175\,\frac{K}{E^*}\left(\sigma_y{}^* - \sigma_t\right) \qquad \ldots(35)$$

Where

$$E^* = \frac{E}{1-\mu^2}, \sigma_y{}^* = \frac{\sigma_y}{1-\mu-\mu^2}, \quad K = \frac{2r}{t}$$

Where
σ_t - Allowable stress of material
σ_y - Yield stress of material
E - Modulus of elasticity of material
Y_o - Initial gap between liner and concrete
μ - Poisson's' ratio

For different values of Y_o /r and D/t a family of curves is shown on Fig.30 which gives critical external pressure for a material with yield stress 32,000 psi.

A value of 3×10^{-4} for initial gap is recommended and Fig.31 gives a family of curves which gives critical external pressure for a gap of $Y_o /r = 3 \times 10^{-4}$, for various types of steel generally used in penstock design.

4.4.6 Initial Gap

4.4.6.1 As seen from Article 4.4.4 and 4.4.5 the initial gap between steel liner and concrete gap influences the percentage of rock participation against internal pressure and also critical buckling external pressure. The initial gap Y_o is originated by the combination of the following effects:

i) Shrinkage of concrete,
ii) Temperature variation, and
iii) Plastic deformation of concrete and surrounding rock under internal pressure.

These can be calculated as follows:-

4.4.6.2 Concrete shrinkage

Assuming that maximum shrinkage of 450 millionth of radius (Ref USBR concrete Manual Page17). The radial deformation is

$$Y_{sr} = 4.5 \times 10^{-5} (r_c - r) \qquad \text{….(36)}$$

4.4.6.3 Temperature Variation

The gap originated by the decrease of temperature and is proportional to the expansion co-efficients of concrete and steel.

$$Y_{tr} = (\alpha_s - \alpha_c)(T - T_o) \qquad \text{....(37)}$$

Where:

α_s = Co-efficient of expansion of steel
= 0.000011 per ^{0}C
α_c = Co-efficient of expansion of concrete
= 0.00007 per ^{0}C
T = Average temperature during placing of concrete ^{0}C
T_o = Actual temperature ^{0}C

4.4.6.4 Plastic deformation of concrete and rock

A gap is created due to plastic deformation of surrounding concrete and rock due to transference of a certain part of internal pressure. This is given by-

$$\gamma_p = \lambda \Pr \left\{ \frac{\log\left(\frac{r_c}{r}\right)}{E_c^1} + \frac{1}{E_{cr}^1} \log\left(\frac{d}{r_c}\right) + \frac{1}{E_{sr}^1}\left(1+\mu_r\right) \right\}.$$

Where

- λ - Proportion of internal pressure transferred to surrounding rock
- P - Internal Pressure
- r - Internal radius of steel liner
- r_c - Outer radius of concrete lining
- d - Outer radius of cracked rock.
- E_c^1 - Modulus of plastic deformation of concrete.
- E_{cr}^1 - Modulus of Plastic deformation of cracked rock same as concrete.
- E_{sr}^1 - Modulus of plastic deformation of sound rock
- μ - Poisson's ratio 0.2

4.4.6.5 The total gap is the sum of gaps calculated in Article 4.4.6.2, 4.4.6.3 and 4.4.6.4. Wherever contact grouting is specified between liner and concrete, the shrinkage gap is generally eliminated. A value of $Y_0/r = 3 \times 10^{-4}$ is recommended for the calculations of rock participation and external buckling pressure.

4.5 LINER THICKNESS

4.5.1 The liner thickness of an exposed penstock shall withstand the equivalent stress as specified in Article 4.2.2 whereas the liner embedded in concrete and tunnel shall withstand the forces enumerated in Art.4.2.3.

4.5.2 Notwithstanding the thickness obtained as specified in Article 4.5.1 and regardless of pressure, a minimum thickness of liner shall be provided to resist the distortion during fabrication and erection. A minimum thickness of $\frac{D+20}{400}$ inches or $\frac{D+50}{400}$ cm is recommended, where, D-Diameter of shell in inches, or cm.

4.5.3 No corrosion allowance is recommended. Instead, it is suggested to paint the inside and outside surface of pipe with a suitable paint.

4.6 WORKING STRESSES AND FACTOR OF SAFETY

4.6.1 Normal operating condition

4.6.1.1 It is recommended that under normal operating condition, the working stresses with a factor of safety of 3 based on the minimum ultimate tensile strength shall be adopted for designs, but in no case the maximum stresses obtained by Article 4.5 shall exceed 0.5 times the specified minimum yield point.

4.6.1.2 For embedded penstocks, it is recommended that under normal operating condition, allowable working stress for the free shell (non-embedded) shall not exceed 0.67 y_p to 0.8 y_p depending upon the type of rock surrounding it.

4.6.1.3 Under normal operating condition, the maximum allowable stresses in wyes and manifold shall be limited to 0.45 to 0.5 times the specified minimum yield strength of material.

4.6.2 Exceptional loading condition

4.6.2.1 A factor of safety of 2.5 based on the minimum specified ultimate strength is recommended for the stresses caused during filling and draining as specified in Article 4.2.1.3 (ii) but in no case the allowable stresses shall exceed 2/3rd the yield strength of material.

4.6.2.2 When penstock is subjected to wind forces or earthquake forces as specified in Article 4.2.1.3 (i) the allowable working stresses shall be increased by 33% over the stress specified in Article 4.6.1.1 i.e. a factor of safety of 2.25 on specified minimum ultimate tensile strength or 2/3rd of specified yield strength whichever is minimum.

4.6.3 Emergency condition

Under Emergency loading condition as specified in Article 4.3.3 the maximum allowable stresses shall not exceed the minimum ultimate strength by a factor of safety of 2.00 or 0.8 times minimum yield strength of material, whichever is minimum.

4.6.4 <u>External Pressure</u>.

Whenever a penstock laid in tunnel is designed to resist external pressure, it is recommended to provide a factor of safety of 1.25 to 1.5 over and above the critical external pressure specified in Article 4.2.3.2.

4.6.5 <u>Joint Efficiency</u>.

All the penstock weld joints shall be radiographically or ultrasonically tested and stress relieved, if required as specified in Chapter 11. Depending on type of examination and treatment the following joint efficiency shall be adopted over and above the allowable stresses specified in Article 4.6.

Table 3 – *Maximum Allowable Joint Efficiency for Arc and Gas Welded Joint*

Sl.No.	Type of Joint Description	Limitations	Joint Efficiency			
			Fully radio-graphed	Fully radio-graphed and stress relieved	Fully radio-graphed and not stress relieved	Spot radio-graphed
1	2	3	4	5	6	7
1.	Double welded butt joint with single "V" excluding butt joints with backing strips.	Plate thickness not more than 20 mm thick	1.00	-	-	0.85
2.	Double welded buttjoint with double `V' excluding butt joints requiring no stress relieving.	Plate thickness more than 22 mm but not greater than 36 mm	1.00	-	-	0.85
3.	Double welded butt joint with double `V' requiring stress relieving	Plate thickness more than 36 mm	-	1.00	0.90	0.80
4.	Single welded butt joint with backing strip.	But weld with one plate offset for circumferential joints only.	0.90	-	-	0.80

5. SUPPORTS

5.1 GENERAL

5.1.1 The exposed penstock which are laid on the surface are generally anchored at bends and sometimes at intermediate points to prevent shift in alignment during installations, to prevent sliding down hill at intermediate support and to resist the forces causing displacement at bends. The anchors are obligatory at every change in direction and spacing between two anchors is limited to 300 to 400 ft.

5.1.2 In between two anchors, the pipe is supported over a number of piers, on which it is free to move. The pipe acts as a continuous beam over these supports and spacing of these supports are limited by the beam stresses as discussed in Chapter 4.

5.2 The type of support generally provided are

i) Saddle support
ii) Ring girder and column support

5.2.1 <u>Saddle Support</u>

The saddle supports are generally used for the penstock of diameter less than 8' or 2.5 meters. The spacing of these supports are restricted since the frictional forces are very high. The portion of shell immediately adjacent to horns of saddles is subject to high localized bending stresses and requires extra thickening of liner or provision of stiffeners at supports. The bending moment at support are calculated as specified in Article 5.3.1.

In this type, the pipe rests on the saddles with contact angle varying from 90^0 to 120^0. The bearing plate on support is provided with suitable lubrication devices to reduce the friction between the pipe line and supports during contraction and expansion so as to reduce the load coming on anchors. Typical details of saddle supports are shown in Fig. 32.

5.2.2 <u>Ring Girder with Column Supports</u>.

5.2.2.1 This type of support is provided when the penstock is carried on rocker or roller type of supports or on sliding type of support. In this type, the load is transferred through the ring to two points on column on side unlike the saddle support over a contact area of 90^o to 120^o. This reduces the bending moment at supports and hence preferable for larger spans and bigger diameter. A typical ring girder and column support details are shown in Fig. 33.

5.2.2.2 The secondary bending stresses are developed due to restraint caused by the ring girder and require thickening of liner at supports. The stress developed due to restraint is calculated as specified in Art. 4.4.3.4. The stresses in the ring girder due to internal pressure and load transmitted by shear shall be evaluated as specified in Art. 5.3.2.

5.2.3 Rocker and Roller Supports.

5.2.3.1 Rocker or roller supports provide very little resistance to movements due to temperature changes and are usually used for conduits of bigger diameter. These are either of cast steel or fabricated out of mild steel plates. The various types of rocker supports adopted on various projects are shown on Fig. 34. Fig 34 (a) and 34 (b) shows cast steel rockers proposed to be used at Nagarjuna Sagar Project and Upper Sindh Project respectively. Fig.34 (c) and Fig.34 (d) shows fabricated rockers used at Jaldhaka Project and Lower Sileru Project respectively. Fig. 34(e) shows a roller support used at Bhira tunnel.

5.2.3.2 The diameter of roller or rocker shall be such that the load per liner inch or cm at contact area shall not exceed the load given by following formula.

For cast steel rocker or roller supports load per linear length shall not be greater than 600 d lbs/in or 108 d kg/cm. … (39)

For fabricated structural steel rocker or roller supports load per length shall not be greater than

$$\frac{P-13000}{20{,}000} \text{ X } 3000\sqrt{d} \quad \text{lbs/in}$$

or

$$\frac{P-920}{1415} \text{ X } 500\sqrt{d} \quad \text{kg/m} \qquad \text{…. (40)}$$

Where

P – Yield strength of material in tension – psi or kg/cm^2.
d – Diameter of roller or rocker – in or cm.

Fabricated rockers are generally preferred rather than cast steel rockers, because of control over quality of finished unit.

5.2.3.3 The rockers require proper setting in field such that at average temperature for most of the period it remains vertical. The arc of rocker shall be fixed for maximum expansion or contraction and depending upon distance of support from anchor block the rocker shall be set at an angle obtained from chart shown on Fig. 35.

5.2.4 Fig. 36 shows a typical sliding support. This type is generally used in open tunnels where clearances are restricted and where the sliding plates are not subjected to abrasion by blowing sand. Frictional resistance is reduced by providing self lubricated steel plates.

5.3 RECOMMENDED METHOD OF CALCULATION OF STRESSES AT SUPPORTS

5.3.1. Stresses at Saddle Supports

The circumferential bending moment at the saddle supports is given by

$$M = CPR \quad \ldots \quad (41)$$

The value of C for different angles of support is given in Fig. 37. The effective length of the shell resisting the bending moment is equal to 4 times the radius of shell.

5.3.2 Stresses in Ring Girder Supports.

5.3.2.1 Pipe full

The total load on pipe shell is transmitted by shear to ring girder. In calculating section modulus of ring girder a portion of adjacent shell may be considered acting with the ring girder. The effective length is given by

$$l = b + 1.56\sqrt{rt} \quad \ldots \quad (42)$$

Where

b	-	Width of ring girder – inches or cms
r	-	Radius of shell in inches or cms
t	-	Thickness of shell – inches or cms.

The ring is loaded with shearing force acting tangential along the circumference. The ring is in equilibrium by the vertical reaction W/2 at the support applied at a distance `a' from the centroid of ring. Hence ring girder is subjected to direct load T and bending moment M, which are given as follows.

Bending Moment

For $0 < \theta < 90^o$

$$M = \frac{WR}{2\pi}\left[\theta \sin\theta + \frac{3}{2}\mathrm{Cos}\theta - \frac{\pi}{2} + \frac{2a}{R}\left(\cos\theta - \frac{\pi}{4}\right)\right] \ldots \quad (43)$$

Where

R - Radius of centroid of ring.

Thrust

For $\theta = 90^o$ $\quad T = \frac{W}{4}$ …(45)

For $\theta = 0^o$ $\quad T = \frac{W}{4}\left\{\frac{r}{R} - \frac{a}{R} - \frac{3}{4}\right\}$ …(46)

In addition to stresses caused by dead load, tensile force is caused by internal pressure and is given by –

$$N_t = P_r\left[b + 1.56\sqrt{rt}\left(\frac{A_r - bt}{A_r + 1.56\sqrt{rt}}\right)\right] \quad \ldots(47)$$

The bending moment M = KWR is minimum when a/R = 0.4. Fig.38 shows absolute bending moment co-efficient values vs. values of a/R. Maximum bending moment occurs at $\theta = 61^o\,39'$, when M = 0.010 WR.

The stress at outer and inner fibre is given by –

Stress in outer fibre $= \frac{T}{A} - \frac{MX}{I} + \frac{N}{A}$ … (48)

Stress in inner fibre $= \frac{T}{A} + \frac{MZ}{I} + \frac{N}{A}$ …(49)

When a pipe is partly full, due to discontinuous surface, bending stresses develop in addition to the direct stress.

Under such condition the bending moment produced is given as follows:

Bending Moment for $0 < \theta < 90^o$

$$M = \frac{W_w R}{2}\left[\frac{2r}{\pi\theta} - \frac{\pi}{4}\left(1+\frac{a}{R}\right) + \left(\frac{5}{4} - \frac{r}{R} + \frac{a}{R}\right) Cos\,\theta\right]$$

…(50)

For $90^o < \theta < 180^o$

$$M = \frac{W_w R}{2}\left[\frac{2r}{R} + \frac{\pi}{4}\left(1+\frac{a}{R}\right) + \left(\frac{1}{4} + \frac{r}{R} + \frac{a}{R}\right) Cos\,\theta - (\pi - \theta)\sin\theta\right]$$

…(51)

Where

W_w - Total water load over one support for a full pipe.

To these moments add moment due to dead weight of pipe given by equation (43) to (46) of Art. 5.3.2.1.

Fig.39 shows the bending moment diagram in the supporting ring for a pipe half full and also gives the moment co-efficient for maximum moment in function of a/R.

The stress in inner and outer fibre is given by respectively as –

Stress in inner fibre = $\frac{T}{A} + \frac{MZ}{I}$ ... (52)

Stress in outer fibre = $\frac{T}{A} - \frac{MX}{I}$ …(53)

5.3.2.3 Stresses in earthquake forces

The bending moment thrust and shear caused by earthquake forces is given by following formulae :

For - $0^o > \theta > 90^o$

Bending Moment

$$M = \frac{nWR}{\pi}\left[\frac{1}{2} + \frac{\sin\theta}{4} - \frac{(\theta + \pi/2)}{2} Cos\,\theta\right] \quad ...(54)$$

Direct Thrust

$$T = \frac{-nW}{4\pi}\left[-\sin\theta + 2\left(\theta + \frac{\pi}{2}\right)\cos\theta\right]$$

$$\frac{-nWr}{\pi R}\left(1-\frac{2k}{qr}\right)\sin\,\theta + \frac{nW_w}{\pi L}\left[C+\frac{2}{q}\left(1-\mu^2\right)\right] ...(55)$$

Shear

$$S = \frac{nW}{4\pi}\left[\cos\,\theta - 2\left(\theta + \frac{\pi}{2}\right)\sin\,\theta + \frac{nW}{\pi}\left(\frac{r}{R}-1\right)\left(1-\frac{2k}{qr}\right)\cos\,\theta\right]$$

$$....(56)$$

$$C = \left(\frac{r}{R} - 1\right)\left(1-\frac{2k}{qr}\right) - \frac{a}{r} \quad .... (57)$$

Where n = Earthquake Acceleration

$$q = \sqrt{3\,\frac{(1-\mu^2)}{r^2\,t^2}} \quad .... (58)$$

$$K = \frac{r}{L}\left[\frac{\mu^2 L^2}{12\,r^2} + (1-\mu^2)\left(1-\frac{W_w}{2W}\right) + \left(\frac{2+\mu}{4qr}\right)L\right] \quad .. (59)$$

The stresses at inner or outer fibre is given by formulae (45) and (46).

5.3.2.4 Ring Girder Column

The ring girder shall be supported on either end of penstocks by columns. These columns shall be designed as short columns to withstand direct and bending stresses as specified in I.S. Code 800-1962 (revised) for steel structures.

5.3.3 Stiffener Rings

The penstocks embedded in concrete at anchor blocks or in dams or subjected to any other external pressure may be provided `with stiffener rings. The stiffener rings provided at the spacing of L in. or cm. shall have a moment of inertia given by following formula to resist the external pressure.

$$I = \frac{0.37\, R^3 L\, P_c}{E} \qquad \ldots(61)$$

Where

I	=	Moment of inertia of ring girder in^4 or cm^4
R	=	Radius of centroid of ring – in. or cm.
L	=	Distance between the rings – in. or cm.
P_c	=	External Pressure - psi or kg/cm^2
E	=	Modulus of Elasticity - psi or kg/cm^2

6. EXPANSION JOINTS AND DRESSER COUPLING

6.1 GENERAL

6.1.1. The exposed penstocks which are laid on surface are subjected to large variation of temperature resulting in longitudinal movement either by expansion or contraction of pipes. In order to permit these longitudinal movement, expansion joints are provided between two fixed points viz. anchors blocks. When no expansion joints are provided, the anchor block and penstock liner shall have to be designed to take the stresses caused due to temperature variation as specified in Art. 4.4.3.3 (i).

6.1.2 The expansion joints also accommodate to some extent change in length due to any differential settlement or any discrepancies in the pipe length. Due allowance for these changes in length shall have to be provided in expansion joint gap over and above the anticipated change in length due to temperature variation.

6.1.3 The expansion joints are rarely provided when penstocks are laid in tunnel or buried, as there is likely to be little variation in temperature.

6.2 LOCATION

6.2.1 The expansion joints are located in between two anchor blocks generally next to uphill anchor block. The facilitates easy erection of pipes on steep slopes.

However, sometimes the expansion joint is also located at mid length as this cancels all the friction forces, as well as provides less movement in the joint.

6.3 TYPES OF JOINTS

6.3.1. There are two general types of expansion joints used for the penstocks:-

i) Bellows type of expansion joint
ii) Sleeve type of expansion joint.

6.3.2 <u>Bellows Type of Expansion Joint.</u>

6.3.2.1 These are simple type of joints and normally used for low heads and moderate size of pipes and for slight movements. The movement of the pipe is allowed for by the flexibility of a bell shaped flange coupling connection fitted to the pipe. The flexible diaphragm will either stretch or compress in the direction of pipe axis to allow for the longitudinal movement of the pipe. This cannot be adopted for high heads above 15m to 20m, because the thickness of the diaphragm required to withstand these internal pressure will be too stiff to allow for any flexibility of expansion. Also the bends in the flange of large thickness are always source of weakness. Also such type of joint shall be boxed to prevent freezing in cold climates. They are prone to leakage and hence not used for high heads A typical detail of Bellows type of joint is shown in Fig. 40.

6.3.3 Sleeve Type of Expansion Joints.

6.3.3.1 These are the usual type of expansion joints provided for the large penstocks. In this type the longitudinal movement of the pipe is permitted by the provision of two closely fitting sleeves, the outer sleeve sliding over the inner sleeve. Packing rings are provided between the sleeves within a stuffing box and held by a retainer ring and a packing gland with bolts. The outer surface of inner sleeve is usually given a nickle cladding to prevent corrosion and facilitate smooth movement of packings. The recent practice is to metalise the surface with stainless steel and machine smooth.

6.3.3.2 The gland bolts are to be tightened enough to press the packing against the retainer ring so that the packing in turn exerts sufficient pressure on the inner sleeve to prevent leakage. These joints are to be used only on the pipes which are accessible for tightening the bolts or replacing the packings.

6.3.3.3 The packing material consists of square, long fibre, braided flax or rubber rings impregnated with suitable lubricant. Rings plaited from asbestos yarn graphited throughout are also used. The size of the rings vary from ½” square to 1-1/4” square and the number of rings to be provided vary from three to ten depending on the size of the joints and the internal pressure of the pipe. These packing rings are to be replaced after some years of service because they may loose their plasticity and water sealing effect after some years of operation

6.3.3.4 A typical details of the sleeve type expansion joint is shown in Fig. 41 (b). Fig. 41(a) shows a special double sleeve type of expansion joints provided with two stuffing boxes and packing glands which is more flexible, to permit longitudinal movement as well as transverse deflection as mentioned earlier.

6.4 RECOMMENDED METHOD OF DESIGN

6.4.1 The inner sleeve shall be designed for the external pressure P_2 exerted on it by the packing due to the bolt force applied on packing – see Fig. 42 (a).

6.4.2 The general formulae useful in designing the sleeve type of expansion joints are given below:-

P - Normal internal pressure in the pipe.

P_2 - Pressure mobilized between packing and inner sleeve by the bolt pressure P_1

P_2 □ 1.25 to 1.5 P

$$P_2 = \frac{\mu}{1-\mu} \; x \; P_1 \qquad \ldots(61)$$

M - Bulk modulus of packing

μ - 0.3 for flax

μ - 0.5 for rubber

6.4.2.1 Total bolt force : = $\dfrac{mAY_b}{\text{Factor of safety}}$ …(62)

Where

m - No. of bolts

A - Root area of bolt

Y_b - Yield strength material.

P_1 - $\dfrac{\text{Total bolts force}}{\text{Area of packing}} = \dfrac{mAY_b}{f_s \, \pi D' W}$ …(63)

Where

D′ - Diameter to the centre of Packing Rings.

W - Width of Packing Ring

f_s - Factor of safety.

6.4.2.2 Inner sleeve design

Minimum required length of sleeve $L' = \frac{2\pi}{\lambda}$

Where

$$\lambda = \sqrt[4]{\frac{3\left(1-\mu^2\right)}{R^2 t^2}}, \quad \text{For } \mu = 0.3,\ \lambda = \frac{1.285}{\sqrt{Rt}}$$

Maximum radial displacement

$$Y = \frac{P_2 R^2}{Et}\left[1 - e^{\frac{-\lambda L}{2}} \cos\left(\frac{\lambda L}{2}\right)\right] \qquad \text{… (64)}$$

Maximum axial moment

$$'M' = \frac{P_2}{2\lambda^2}\left[e^{\frac{-\lambda L}{2}} \sin\left(\frac{\lambda L}{2}\right)\right] \qquad \text{…(65)}$$

Maximum Hoop Stress

$$S_2 = \frac{-EY}{R} = -\frac{P_2 R}{t}\left[1 - e^{\frac{-\lambda L}{2}} \cos\left(\frac{\lambda L}{2}\right)\right] \qquad \text{… (66)}$$

Axial Bending Stress $S_1 = \pm \frac{6M}{t^2}$ … (67)

The combined working stress as specified in Art. 4.2.2 shall not exceed the allowable working stress as specified in Art. 4.6

6.4.2.3 Design of gland

The gland flange shall be able to resist the bending moment developed by the gland bolt forces. The gland shall be designed such that the gland bolts yield before the gland – see Fig. 42 (b).

A	=	Root area of one gland bolt	in^2
m	=	Number of gland bolts	in
R_b	=	Radius of bolt circle	in
r	=	Inside radius of gland	in
t_g	=	Thickness of leg of gland	in
Y_b	=	Yield point of bolt material	
Y_g	=	Yield point of gland material	

$$\lambda = \frac{1.285}{\sqrt{rt}}$$

F = Bolt force per inch of inside circumference

.

$$= \frac{mA.Y_b}{2\pi r} \qquad \ldots (68)$$

M_t = Applied moment per inch of inside circumference.

$$= F\left\{Rb - \left(r + \frac{tg}{2}\right)\right\} \qquad \ldots (69)$$

$$M_0 = M_t \cdot \frac{1}{1 + \frac{\lambda a}{2} + \frac{1.513}{\lambda r}\left(\frac{a}{t}\right)^3 \log_{10}\left(1 + \frac{b}{r}\right)} \qquad \ldots (70)$$

$$\sigma_b = \text{Bending stress in leg} = \pm \frac{6M_0}{tg^2} \quad lb/in^2 \qquad \ldots (71)$$

$$\sigma_c = \text{Compressive stress in leg} = -F/g \quad lb/in^2 \qquad \ldots (72)$$

f_g = Total stress in leg = $\sigma_c \pm \sigma_b$

f_g shall be less than y_g with an allowable factor of safety.

6.5 COUPLINGS

6.5.1 Couplings are used in the installation of steel pipes of moderate sizes say upto 6 to 8 ft. for joining the pipe lengths in the field. These are commercially patented type of pipe joints. The advantages for the couplings are:-

i) They are flexible for movement of pipe. Generally these couplings allow for 3/8" of movement per joint and 3^0 to 4^0 deflections at each joint.

ii) Because of the simple components of the coupling the assembly of joints for the installation is speedy and can be done under any conditions of the site. Therefore they are economical.

With these couplings the requirement of expansion joints are eliminated. Also in view of the flexibility of each joint it is possible to avoid or even completely eliminate many bends and anchor blocks by providing series of straight pipe length jointed with these couplings in a long gradual curves. They are specially suitable where it is desirable to eliminate all field welding and for pipe crossing canyons on suspension bridges where flexible joints are required to adjust itself to the catenary or suspension cables. A typical detail of dresser coupling is shown in Fig. 43.

6.5.2 The joint consist of one cylindrical steel middle ring, two follower rings, two resilient gaskets of special compound and a set of high strength steel track head bolts. The middle ring has conical flare at each end to receive the wedge portion of the gaskets and the follower rings confine to the outer shape of the gaskets. The bolts are tightened so as to draw the follower rings together thereby compressing the gaskets between the middle ring and pipe surface to effect a flexible and leak proof sealing. For large pipes and high heads the joints are designed to meet the special requirement. The pipe stops fitted to the middle ring can be omitted if desired. The design of coupling is similar to that for expansion joints. However, sufficient volume of rubber with following specification is provided so that movements are taken up by deformation of rubber rather than sliding.

Durometer	75 $\pm$ 5	
Compression set	4%	max. 30 minutes
	3%	max. 3 hrs.

7. BRANCHES AND WYES

7.1 The wye braches shall be given special care in the design to make the assembly safe under the internal pressure of water. On account of the special shapes necessary for these sections at bifurcations it is obvious all forces due to internal pressure are not automatically resisted fully by the bifurcated pipe shell only, as in the case of a normal circular pipe section. To compensate for the opening made in the normal circular section for these fittings some provision in the shape of reinforcement shall be made to take care of the unbalanced forces acting on unsupported areas resulted by these junctions. The basic criteria for designing these wyes shall be the structural safety combined with hydraulic efficiency. Several types of these branches and wyes for the penstocks are described in Article 3.2.4. The branches pipes shall be proportioned to ensure smooth, stream line flow from the header to the branch and to minimize hydraulic losses, by introducing conical reducers and keeping angle of deflection small. The Hydraulic losses in various types of bifurcation is described in Article 3.2.4. The Hydraulic losses in various types of bifurcation is described in Article 3.2.4. Generally the branches are provided with deflection angles ranging from 30^o to 75^o. However, if this angle is too small it would be difficult during fabrication to have access to all parts for making joints of the assembly and to provide for adequate reinforcements for the assembly. Normally a deflection angle not less than 45^o is adopted for wyes of penstock pipes.

7.2 TYPES OF REINFORCEMENT

7.2.1 Various types of reinforcements are used for these branches and wyes of the pipe lines. The type and size of the reinforcement depend upon the extent of unsupported areas, internal water pressure ratio of main and branch pipe areas, clearance restrictions for fabrication etc.

7.2.2 Most common practice for reinforcing the branches and wyes is to provide one or more exterior girders welded with tie rods or ring girder or a combination of these. The various types of reinforcement are (i) one plate (ii) two plate reinforcement and (iii) three plate reinforcement. The exterior girder, yoke, is of horseshoe shape which is welded to the periphery of the junction of pipes and finally welded to a tie rod or a ring girder provided at the beginning of the bifurcation. The section of the girder may be T shaped attached to the penstock surface. Some portion of the penstock steel liner also is assumed to act monolithically as a flange of the yoke girder as in the case of stiffener rings (see Fig. 44).

7.2.3 Another type of reinforcement is to provide a internal horse-shoe girder called splitter or sickle plate. This type of Wye is developed by Escher wyes and generally consist of crescent shaped rib inside the branch pipe and it is designed in such a way that rib is directly subjected to tension and has the same magnitude as the stress in shell section of pipes adjacent to it. Apart from being structurally strong this type is more economical because of smaller external dimensions takes lesser space and enables large branch pipes to be fabricated, transported, stress relieved and erected as a single unit. The recent development and modification in the design by providing tapered sections and increasing diameter at inlet has improved the hydraulic efficiency of sickle type.

7.2.4 Sometimes a spherical type of bifurcation is provided wherein a specially designed spherical dome with the proper openings is provided in between the main and branch pipes. The sphere is designed to take all the unbalanced water loads.

7.3 ANALYSIS OF WYES

7.3.1 The exact stress analysis of these reinforcements for branches and wyes involves complicated mathematical analysis which is rather too elaborate to be of use for normal practical purposes. Therefore, the analysis is simplified by making proper assumptions and approximations to yield a quick, easy and economic design procedure yet to be sufficiently safe structurally. The total load to be resisted by the reinforcement is the product of the internal pressure and unsupported areas projected to the plan of the wyes.

7.3.2 In the type of a simple curved reinforcing plate (Fig. No. 44), it is assumed that the place is acting as a plane ring and the loads in both directions are uniformly distributed and the plate is circular. These approximations are reasonably correct because the ring is fixed throughout the periphery to the pipe and the loading assumption is on safe side. Regarding the circularity of the ring, though the exact shape is egg-shaped, the ring will be nearly circular in cases of large deflections and this approximation does not seriously affect the design.

7.3.3 When the external girders are used in combination with tie rods or ring girders the analysis becomes statically indeterminate. For the analysis of the girders the deflections of the girder at the junctions of the tie rods or ring girder under the load in both directions are evolved and equated to the deflections of the tie rods or ring girder. The analysis is simplified by assuming suitable section for beam girder and integrated using Simpson's rule. The various forces are evaluated as follows:

7.3.4 Analysis of External Reinforcement

The yoke is considered as an elliptical cantilevered beam. It is assumed to be loaded by vertical forces varying linearly from zero at X = 0 to P (r_1 Cos θ_1 + r_2 Cos θ_2) at X = L and by the forces V_1 and V_2 due to tie rod at 0 and C and by the moment M, see Fig.45, where P - Internal pressure. The moment, shear and tension in beam for the region.

$0 < x < x_L$ is given by

$$M = M_1 + V_1 x + V_2 \ (X - X_c) + \frac{Kx^3}{6}$$

$$V = \left(V_1 + V_2 + \frac{Kx^2}{2}\right) \ \text{Cos}\ \beta \qquad \text{...(73)}$$

$$T = \left(V_1 + V_2 + Kx^2\right) \ \text{Sin}\ \beta$$

For $x > x_L$

$$M = M_1 + V_1 x + V_2 \left(X - X_c\right) + \frac{Kx_L^2}{2}\left(x - \frac{2x_L}{3}\right)$$

$$V = \left(V_1 + V_2 + \frac{Kx_L^2}{2}\right) \text{Cos}\ \beta \qquad \text{... (74)}$$

$$T = \left(V_1 + V_2 + \frac{Kx_L^2}{2}\right) \text{Sin}\ \beta$$

The equations for deflection and rotation of beam 'OB' and ring OA at point 'O' is given by

Deflection

$$\Delta = \int_{x=o}^{x=L} \frac{Mmds}{EI} + \int_{x=o}^{x=L} \frac{V\nu ds}{GA} + \int_{x=o}^{x=L} \frac{Ttds}{EA} \qquad \text{... (75)}$$

$m = x$, $\nu = \cos\beta$, $t = \sin\beta$

Rotation

$$\psi = \int_{x=o}^{x=L} \frac{\text{Mmds}}{\text{EI}}, \quad m = 1, \ \nu = o, \ t = o \qquad \ldots(76)$$

In case of an Un-Symmetrical bifurcation where a second ring is used, the expression for moment, shear and tension in the ring are given by:

$$M = M_4 + V_4 \ R \sin Ø$$

$$V = V_4 \ \cos Ø \qquad \ldots (77)$$

$$T = V_4 \ \sin Ø$$

Where Ø is angle measured from the vertical center line of pipe in the plane of the ring.

The deflection and rotation at point 'O' is given by

Deflection

$$\Delta_R = \frac{M_4 R^2 + \frac{\pi}{4} V_4 R^3}{EI_R} + \frac{2.8274 \ V_4 R + \left(1.42 \ \sqrt{rt} + C\right) \Pr R}{EA_R} \qquad \ldots. (78)$$

Where

r	=	Inside radius of cylindrical shell
R	=	Radius to center of gravity of ring cross section
I_R	=	Moment of Inertia of Ring Cms section, using the effective flange width, $W = 1.56 \ \sqrt{rt} + C$
C	=	Web thickness, t – Shell thickness
A_R	=	Cross sectional area of ring

Rotation

$$\psi_R = \frac{\pi}{2} \frac{M_4 R + V_4 R^2}{EI_R} \qquad \ldots (79)$$

The solution of various forces is obtained by solving the following basic equation:

$$\Delta c = \frac{-V_2 L_c}{2A_c E} \quad \ldots \quad (80)$$

$$\Delta = \Delta' = \Delta_R = \frac{-(V_1 + V_3 + V_4) L}{2AE} \quad \ldots \quad (81)$$

$$\psi_R \sin(\theta_4 + \theta_1) + \psi' \cos\theta_1 + \psi \cos\theta_4 = 0 \quad \ldots \quad (82)$$

$$M_1 \operatorname{Cos} \theta_1 = M_3 \operatorname{Cos} \theta_4 \quad \ldots \quad (83)$$

$$M_1 \operatorname{Sin} \theta_1 + M_3 \operatorname{Sin} \theta_4 = M_4 \quad \ldots \quad (84)$$

If no tie rods are provided then, $V_2 = 0$, $\Delta_c = 0$,

then $V_1 + V_3 + V_4 = 0$ and $\Delta = \Delta^1 = \Delta_R$

The solution of these equation yield M_1, V_1, M_3, V_3, M_4, V_4 and V_1.

7.3.5 Once the reactions are found out the bending moments at any point in the girder is calculated as for a centilevered beam. A correction factor may have to be applied to the stresses calculated as above to take into account the curvature of the girder as in the curved beams. These correction factors may be obtained from "Formulae for stress and strain" by Roark and "Theory of Applied Mechanics" by F.B. Seely.

The resultant equivalent stress at any section of the reinforcement girder calculated as outlined above shall not exceed the safe allowable stress as specified in Art. 4.6.

7.3.6 Sickle Type Reinforcement

7.3.6.1 As an alternative to the yoke type reinforcement at the junction of bifurcating pipes, Escher Wyes propounded strengthening the same with a sickle shaped steel plate broad at the apex (crown) of the profile of junction and narrow at the other end.

The design of the sickle reinforcement involves (1) determining the shape of the sickle to ensure sufficient radial plate width to keep the resultant reaction exactly at the centre of the width at any particular place and thus obviate eccentricity and its effects and (2) the thickness of the sickle to keep the stresses within the permissible limits, same as stress in shell.

7.3.6.2 The equation developed to determine the dimensions of the sickle reinforcement for a bifurcation or Y with cylindrical branches can be reduced to the forms given hereunder:-

1. Radial distance of a point on the profile of intersection of two cylindrical branches.

$A = \Psi_r$ (r- the uniform radius of branches)

2. Radial width of the reinforcing sickle shape plate

$b = \xi d$ (d – the diameter of the branches)

3. Plate thickness of the sickle reinforcement

$T = \eta t$ (where 't' is the plate thickness of the branch pipes which is equivalent to pr/S, p being the internal pressure, r – the radius of the branches, S – the permissible stress in the plate)

Ψ, ξ and η are the non-dimensional parameters of the bifurcating branches.

These parameters vary with the bifurcation angle β in between the branches, and these are given by following formula for a simple symmetrical bifurcation.

$$\psi = \operatorname{Sin}\beta \frac{1 + 2/3 \operatorname{Cot}^2\beta \operatorname{Sin}^2\alpha}{\sqrt{\sin^2\beta + \operatorname{Cos}^2\beta \operatorname{Sin}^2\alpha}} \qquad \text{...(85)}$$

$$\xi = \frac{1}{3} \operatorname{Cos}\beta \operatorname{Cot}\beta \operatorname{Sin}\alpha \sqrt{\operatorname{Sin}^2\beta + \operatorname{Cos}^2\beta . \operatorname{Sin}^2\alpha} \qquad \text{.... (86)}$$

For $\alpha = \frac{\pi}{2}$ width is maximum and given by

$$b = \xi d \text{ at } \alpha = \frac{\pi}{2} \text{ and}$$

$$\xi = \frac{1}{3} \operatorname{Cos}\beta \operatorname{Cot}\beta$$

$$b = 1/3 \operatorname{Cos}\beta \operatorname{Cot}\beta \qquad \dots (87)$$

$$\text{and } \eta = \frac{\sqrt{3}}{\operatorname{Cos}\beta} \qquad \dots (88)$$

7.3.7 Reinforced Concrete Bifurcation

7.3.7.1 Wyes for large penstocks are normally too heavy with considerable physical dimensions and present transportation difficulties. Such bifurcations are normally split into portions and assembled at site; conventional yokes and ring girders are also deleted and reinforcing steel arranged in the form of a cubic parabola as shown in Fig. 46 to resist discontinuity forces in pure tension. This design has been adopted for Lower Sileru Bifurcation.

Principles followed in the design are indicated below:-

From Fig.45 at any point x

$$T \sin\phi = \frac{W}{L} \quad \frac{X^2}{2}$$

$$T \cos\phi = T_1; \quad T \tan\phi = \frac{W}{L} \quad \frac{X^2}{2T_1}$$

$$\text{But} \tan\phi = \frac{dy}{dx}$$

$$\therefore dy = \frac{W}{L} \quad \frac{X^2}{2T_1} \quad dx$$

Integrating

$$y = \frac{W}{6T_1L} X^3 \quad , \text{ at } x = \phi$$

And for Curve Equation, $y = \frac{W}{6T_1L} x^3$

At $x = L$

$$\text{Tan } \theta = \frac{W}{L} \text{ x } \frac{L^2}{2T_1} = \frac{WL}{2T_1}$$

$$\text{or } T_1 = \frac{WL}{2\,\text{Tan}\,\theta}$$

$$T_2 = \frac{WL}{2\,\text{Sin}\,\theta}$$

Given W, L and Q, T can be computed, then for any value θ

$$T = \frac{T_1}{\text{Cos }\phi} = \frac{WL}{2\,\text{Tan}\,\theta\ \ \text{Cos}\,\phi}$$

For theoretical stress conditions to exist, the discontinuity forces must be transferred lineally to the supporting bars. The assumption here is that the bars are close enough to the conduit intersections to ensure that the concrete in between will not alter the force pattern.

8. BENDS AND REDUCER PIECE

8.1 The topographical features of the sloping terrain mainly determines the ideal alignment of the penstock pipes. Often the direction of the alignment of these penstocks are to be changed in order to obtain the most economical profile avoiding excess of excavation, poor foundation strata, and also to keep up the aesthetic beauty of the natural scenery. These changes in the direction of alignment are negotiated by providing successive segments in a curve called penstock Bends. The change in the direction of alignment may be either in profile or in plan or in both directions. Also in case of very long penstocks it is often necessary to reduce the diameter of the pipe as the head on the pipe increases to obtain maximum economy as analysed in the economic diameter study for the penstock. This reduction from one diameter to another is effected gradually by introducing special pipe piece called as reducer piece. However, it is economical to combine the function of reducer with a bend wherever possible at the same place by providing a special bend called reducer bend.

8.2 DESIGN OF BENDS

8.2.1 The bends of the penstocks shall be designed to minimise the hydraulic loss due to change in the direction of the flow. To achieve this the successive segments of the curved portion shall be designed with the optimum deflection angles to avoid sharp changes in direction of flow and the bend shall be provided with large radius. Again for these bends the plates are required to be cut to form meter joints. As this involves extra cost, it is not economical to provide too many mitred joints. However, the designer shall judiciously determine the criteria for proportioning the bend pieces keeping in view the economy of fabrication, coupled with the minimum head loss as specified in Art. 3.2.3.1. The general practice is to provide the radius of the bend three to five times the diameter of the pipe. The deflection angle between each successive segments are to be limited to in between 5^o to 10^o.

The most recommended value of successive deflection is however 5^o to 6^o. Typical bend sections are shown in Fig.47.

8.2.2 <u>Calculation for Bends</u>

The calculation for proportioning bend details are given as under:-

Tangent Length

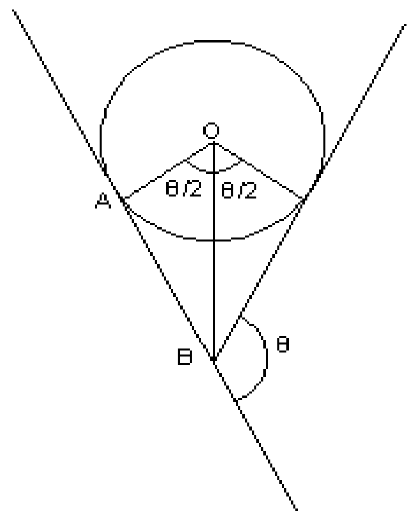
From the property of circle and tangents:

Tangent length = AB

Bend Radius = R = OA

Deflection angle= θ

$$\angle AOB = \frac{\theta}{2}$$



From Triangle OAB

$$\text{Tan AOB} = \text{Tan}\,\frac{\theta}{2}$$
$$= \frac{AB}{AO}$$
$$= \frac{Tangent\ length}{Radius\ R}$$

$$\therefore \quad Tangent\ length = R\ Tan\,\frac{\theta}{2}$$

Total deflection angle = θ

Deflection of each successive segment = $\Delta\theta$ = 5^o to 10^o

$$\text{Total segments} = \frac{\theta}{\Delta\theta} = n$$

Where, n = Number of segments

8.2.3 Simple Bends

When the change of alignment is only in vertical plane i.e., profile or only in horizontal plane i.e., in plan, the bend is called simple bend and the deflection angle is the deviation in the direction of alignment.

8.2.4 Compound Bends

Sometimes the penstock alignment will be deflected both in horizontal plane and vertical plane to conform the contour and alignment. The construction is greatly simplified if the pipe is bent to one angle which will accommodate the deflection both in profile and plan. This is called a compound bend and in case of the compound bend, it is required to determine true or developed bend angle since the design and fabrication of the curved bend segments of the bend is to be based on this true angle. This determination of true angle shall be done as follows:

$$\text{Cos } x = \text{Cos } A \ \text{Cos } B \ \text{Cos } C \pm \text{Sin } A \ \text{Sin } B$$

Where

x = True bend angle.

A and B = Projected angles (with Horizontal) in a vertical plane.

C = Projected angle in Horizontal plane.

The minus (-) sign is used when both vertical angles (A&B) are above horizontal line. Plus (+) sign is used when one vertical angle is above the horizontal and the other is below the horizontal.

8.2.5 Reducer Bends

For the design of the reducer bends the following simplified formulae can be made use of:

Δ = Angle of intersection

R = Radius of bend

n = 2 (number of deflection)

D_1 = Inside dia of large pipe

D_n = Inside dia of small pipe

$$\rho = \frac{\Delta}{n}, \quad 2\rho = K + \phi$$

$$\text{Sin } \theta = \frac{D_1 - D_n}{2(n-2)R \tan\phi}, \quad \tan\phi = \frac{\text{Sin } 2\rho}{\text{Cos } 2\rho + \text{Cos } \theta}$$

$$r_1 = \frac{D_1}{2}, \quad r_n = \frac{D_n}{2}$$

$$Z_1 = \frac{r_1 \text{ Sin } \theta}{\text{Cos } 2\rho + \text{Cos } \theta}, \quad Z_n = \frac{r \text{ Sin } \theta}{\text{Cos } 2\rho + \text{Cos } \theta}$$

$$Y_x = \frac{r_x \text{ Sin } \theta}{\text{Sin } \rho}$$

$$r_x = r_1 - (x-1) \; R \tan \rho \sin \theta$$

$$D_x = \frac{D_1 - 2(x-1) \; R \tan \rho \; \text{Sin } \theta}{\text{Cos } \theta}$$

Where X = Number of divisions from point of reduction to point under consideration.

8.3 REDUCER PIECES

According to the economic studies for the diameter of penstocks if the diameter of the pipe is to be changed from D_1 to D_2 this change is brought out by introducing one special piece called reducer piece. This reducer piece is a frustum of a cone. Normally the angle of divergence shall be kept between 5^o to 10^o so as to minimise the hydraulic loss at the juncture where the diameter is reduced.

Angle of convergence = θ

Length of reducer pipe = L

Change in radius = $\frac{D_1}{2} - \frac{D_2}{2}$ = AB

$$\text{Tan } \theta = \frac{AB}{AO} = \frac{D_1 - D_2}{2L}$$

$$L = \frac{(D_1 - D_2)}{2. \tan \theta}$$

9. PENSTOCK ACCESSORIES

9.1 Besides the main components of the penstock system described in earlier chapters several accessories will also have to be provided for in a pipeline to facilitate fabrication, installation, testing, safe operation, and inspection and maintenance. These accessories are described below:-

9.2 MANHOLES

Manholes are required in the course of the penstock length to provide access to the pipe interior for inspection and maintenance and repair. These are spaced at practicable distances normally not more than 400 to 500 ft. apart so that no part of the pipe length is unduly too far from the manhole. The location of the manholes can be at top, bottom and side quadrant of the pipe depending upon the individual profile and size of penstocks. If the penstocks are above the natural ground level the manhole is located about 2 or 3 ft. from the ground level depending upon the diameter of the pipe or the bottom half of the pipe at 45^0 off the vertical diameter. If the penstock is below the natural ground level the practicable position for the manhole is in the top position of the pipe. In such cases a portable ladder is to be used by the personnel to reach the bottom of the pipe. Also as far as possible the location of the manholes shall be fixed so as to provide natural ventilation to the interior surface for easy inspection and repairs. The general size of the opening of the manhole is normally 20” diameter. Typical details of the manhole is shown in the Fig. 48.

The forged steel type of manholes are normally used for high heads whereas the plate steel type are suitable for medium to low head penstocks. The manhole in general consists of a circular nozzle head or wall at the opening in the pipe, with a cover plate fitted to it by bolts. To prevent leakage the sealing gaskets are to be provided between the nozzle head and cover plate as shown in the Fig. 48. In some type of manholes a filler plate called shield which is curved to suit the internal shape of the pipe section at the manhole opening is fitted to the inside of the cover plate. This ensures the smoothening of the interior of pipe and avoids turbulence in the flow at the manhole opening which is otherwise created by the depression in the pipe surface. The nozzle head, the cover plate and the bolts shall be designed to withstand the internal water pressure head in the penstock at the position of manhole. It is essential that the pipe shall be reinforced around the manhole opening by providing extra reinforcing plate adjacent to the nozzle head, to compensate for the material removed from the normal circular section of the pipe. Generally the sectional area of compensating reinforcement shall at least be 5 to 10 percent more than the sectional area of the circular pipe shell which is cut away from the opening. The size, shape and design of these manhole openings shall conform with the specifications provided in the I.S.I. code for unfired pressure vessels.

9.3 PIEZOMETRIC CONNECTIONS

The piezometric connections are to be provided in the penstock pipes to facilitate connections for measuring devices for use in the turbine performance tests. Normally these piezometric connections are provided in the straight length of penstock away from bends and branches and in the near vicinity of the power house or valve house. They are provided in groups of four, equally spaced, around the periphery of the pipe section. From each group of these connections the piezometric line is connected to the metre box of the pressure measuring device. Details of a typical piezometric connection is shown in the Fig. 49.

9.4 FLANGED CONNECTIONS

The flanged connections are provided to connect the penstock pipe line with any equipment such as valves, expansion joints, pumps turbine scroll cases etc. The type and the design of the flanges are to be designed to suit the connecting flanges of the equipment to which the penstock is to be connected. The general type of the flange connections are the welding neck type, the slip-on-type and plate type of flanges as shown in the Fig. 50. Generally the welding neck type is of forged steel and is used for high heads and pipes of large diameter while the other type are used with medium to low heads and with pipes of smaller size. The design procedure for the bolt sizes spacings, joints of the flange plates and types of the sealing gaskets to be used for the connections shall be specified in the I.S.I. code for the unfired pressure vessels.

9.5 BULK HEADS AND TEST HEADS

Test heads are required for the purpose of hydrostatic pressure testing of the steel pipes and its joints. Similarly bulk heads are provided whenever the penstocks are to be closed for temporary periods as in phased constructions until future stage construction is taken up. The shapes of the test heads, generally adopted, are hemispherical, semi-ellipsoidal or standard dished flange ends as shown in the Fig.51. Allowance should be given in the ends of the pipe for connecting the straight ends of these test heads which will be removed after the testing of the pipe. The test heads and bulk heads shall be designed to withstand the test pressures of the pipe section. For the empirical formulae for proportioning the shape, size and connection with pipe lines etc. of these test heads I.S.I.Codes for the unfired pressure vessels may be referred to.

9.6 CLOSING PIECES

Often small unavoidable errors creep into the penstock system due to discrepancies between theoretical calculations and actual laying of the pipe lengths at site, or due to errors in process of fabrication or erection at site; or due to shrinkage of field weld joints. In order to permit the final field adjustments and to obtain perfect assembly of the pipe line system it is often necessary to provide for one or more special piece length of pipe. These are called as closing pieces or make up pieces. The number and length of these closing pieces shall be fixed for fabrication only after the pipe line is erected and actual measurements for perfect fitting of pipe line are made. Normally these pipes will be fitted either at the connection to valves or near expansion joints and turbine scroll cases or at the portals of the tunnel.

9.7 FILLING CONNECTIONS

Before putting the penstock system into operation the same shall be filled slowly with water, care being taken to prevent shock or hammering effect. Also by filling the pipe with water the controlling gates will be kept under balanced pressure which facilitates its easy opening. For this purpose intake nozzles will be provided in the pipe section at suitable positions for connections with filling lines. Normally these intake nozzle opening are provided at the horizontal centre of pipes either at upstream end of the pipe length. It is preferable to provide these connections on the downstream of the penstock gate so that filling can be effected under submerged conditions. These filling lines are connected with the reservoir on the other end and provided with proper control valves. These lines are to be of sufficient capacity to complete the filling of the entire length of with a possible reasonable time depending the size and the length of the penstock system. It is advisable to provide separate filling lines for each individual pipe line for easy operation.

9.8 DRAINAGE CONNECTIONS

Whenever the penstocks are to be inspected for maintenance and repairs they are to be drained off. For this purpose drainage connections shall have to be provided. These drainage nozzles located at the bottom most reach of the penstock at the lowest point of the pipe with proper gratings flush with the inner surface of pipe. These drainage lines are normally connected to the draft tube of the turbine or to sump provided in the lower plant. The capacity of these drain lines are determined according to the time in which the pipe is to be emptied depending on size and length of the pipe system.

9.9 AIR VENTS AND AIR VALVES

Air vents shall be provided on the immediate downstream side of the control gate or valve to facilitate connection with atmosphere. These air inlets serve the purpose of admitting the air into the pipes when the control gate or valve is closed and the penstock is drained thus avoiding collapse of the pipe due to vacuum or excessive negative pressure. Also the air admitted will accelerate the draining action of the pipe. Similarly when the penstock is being filled up these vents facilitate the proper escape of the air from the pipes. In long discharge lines from pumping stations especially where there are steep slopes depending on the topographical features of the rough terrain it is advisable to provide at the summit points either air vents or air valves to release air at the time of sudden shut down. These summit pockets in a pipe line should be eliminated as far as possible. Care should be taken to design the air vents with adequate capacity of the air entry as serious accidents and failures may result due to inadequate venting. The factors governing the size of the vents are the length, diameter, thickness, head of water and discharge in the penstock and strength of the penstock under external pressure viz. collapsible strength of the pipe.

Following are some formulae for the design of these air vent to be provided for a steel penstock pipe:

a) $$F = \frac{Q\sqrt{S}}{2,460,000C}\left(\frac{d}{t}\right)^{3/2}$$

Where:

F = Area of air inlet in square ft.
Q = Flow of air through inlet in cft/second.
S = Factor of safety against collapse of pipe.
C = Coefficient of discharge through air inlet.
d = diameter of steel penstock in inches.
t = thickness of steel pipe in inches.

This formula is based on studies by Carman and Carr's equation for strength of steel pipe and studies of air vents on steel pipe line by M.L. Enger and F.O. Seely. It is customary to provide air valves on a penstock line always in pairs to ensure required degree of safety. The most important requirement is that all the air valves must be protected against freezing. This is done by enclosing the air valves in separate compartment and using electric heaters or by insulating the valve sufficiently to avoid freezing.

9.10 VALVES AND CONTROL GATES

Gates and valves are to be provided for control of the flow into the penstocks for operation, inspection and repairs. The type of the gate or valve to be provided will be selected based on the type of intake, size of intake and operating conditions.

The general types of the head gates are:-

a) Sliding gates
b) Wheeled or tractor gates
c) Stoney gates
d) Caterpillar gates
e) Taintor gates
f) Cylinder gates.

Similarly types of the valves which will be used for a pipe line are:-

a) Butterfly valves
b) Needle valves
c) Gate valves
d) Spherical valves.

In general any type of the gates enlisted above will be used at the intake of the conduit whereas the valves are used at the strategic points in the Course of the pipe line for effecting control and safe operation. It is general practice to provide valves wherever the length of pipe is long. These are normally provided at two places one at the upper end of the conduit say after the surge tank and one at the lower end of the pipe line near the entry to the turbine. The present (1971) trend is to put the valve below surge tank in case of pressure shafts in sound rock. The valve at top if provided is fitted with an automatic over-velocity tripling device which closes the pipe when velocity exceeds 20% normal. The construction of the valve in general can be described of having a closing member which operates and remains within the passage way. The design of the valve should be quite safe against the cavitation which is the most important criteria for successful operation of the valve. These controlling devices can be operated hydraulically, electrically and by manual operation also. These controlling devices for penstocks will normally be used only either in full open conditions or in full closed conditions.

10.MATERIALS, SPECIFICATION AND TESTS

10.1 INTRODUCTION

10.1.1 The steel plates to be used for the fabrication of penstock shall be of pressure vessel quality. Prior to 1950 the penstocks were fabricated from low carbon steel plates or mild steel plates. But with the development of high heads and increasing number of high capacity power plant, the steel with high yield point stress is developed to provide economy and facility of fabrication. These are low alloy steel plates, including some which are quenched and tempered.

10.1.2 The type and grade of steel is defined by chemical composition, mechanical properties, method of production and heat treatment given to it.

Some of the commonly used steel plates for penstocks in India at present are ASTM 285 Gr.`C', A 537 Gr.`A', A 517 from USA, Aldur-58 from West Germany and IS 2002 from India. The chemical composition and physical properties of these steel along with a few more type of steel are given in Annexure - III.

10.2 CHEMICAL COMPOSITION

10.2.1 The chemical composition of the material shall be such that the mechanical and technological properties are guaranteed.

The steel in addition to iron and carbon contains manganese, silicon, nickel, chromium, molybedenum, copper, aluminum with impurities like Sulphur and Phosphorous to give required strength.

The equivalent carbon content given by following formula is usually restricted to 0.45 %.

Equivalent Carbon content

$$= \%\ C + \%\ \frac{Mn}{6} + \%\ \frac{Ni}{15} + \%\ \frac{Mo}{4} + \%\ \frac{Cr}{5} + \%\ \frac{Cu}{15}$$

This formula is valid when $\%\ C < 0.5$, $\%\ Mn < 1.6$,
$\%\ Ni < 3.5$, $\%\ Mo < 0.6$
$\%\ Cr < 1.0$, $\%\ Cu < 1.0$

The impurities like sulphur and phosphorous each shall be restricted to a maximum of 0.04 percent.

10.3 HEAT TREATMENT

10.3.1 The steel plates can further be classified depending upon the degree of heat treatment and process of rolling:

10.3.2 Rimmed

Rarely used for penstocks due to their lack of homogenity.

10.3.3 Semi-Killed

Recommended for use in penstock upto 25 mm thickness.

10.3.4 Killed

Rolled at controlled temperature and silicon killed steel plates are more homogenous and used for all thicknesses and for more severe low temperature.

10.3.5 Normalized

Normalization consists of heating at temperature 900^0 C and cooling in still air.

10.3.6 Quenched

Tempered Steel - Special heat treatment is given to increase the strength of material and notch toughness. The process involves heating to a temperature at about 900^0C, quenched in water and subsequently tempered at about 700^0C.

10.4 PHYSICAL PROPERTY

10.4.1 The following physical properties must be guaranteed by the manufacturers in final fabrication:

i) Yield point stress
ii) Ultimate Tensile Strength
iii) Percentage Elongation at rupture.
iv) Bending properties
v) Notch toughness or Breaking strength for brittle fracture before and /or after ageing.
vi) Weldability

10.4.2 For the selection of suitable type of steel, apart from chemical and physical properties of steel plates, its commercial availability and combined costs of material, fabrication, transportation, erection, shop and field tests shall be known.

10.5 TESTS AND INSPECTION

10.5.1 The features enumerated in Article 10.2 and 10.4 shall be checked by suitable tests and inspection.

10.5.2 The chemical analysis to determine the contents of carbon, silicon, manganese, sulphur, phosphorous and other alloy elements shall be carried out by plate manufacturers as per the prevalent standards of ASTM specification.

10.5.3 The physical properties of material shall be guaranteed the following tests:

i) Tensile Test : To determine breaking strength, yield point and elongation.

ii) Bending Test: To determine the capacity of deformation under cold bending.

iii) Impact Test : To determine the breaking strength and energy at various conditions and temperature. This also constitutes a check on the tendency of ageing and to brittle failure.

10.5.4 Apart from above tests to determine physical properties of material, each plate shall be subjected to following test:

10.5.4.1 Ultrasonic Examination

Plates subjected to ultrasonic examination ensure the absence of any serious internal defects in the plates if any. The ultrasonic examination of plates are recommended.

10.5.4.2 Homogenity Tests

10.6 FEATURES OF PLATE

10.6.1 The surface of plates shall be smooth and plane. The dimensions of plates length, width and thickness, the accuracy of angles and weight of the plates must meet the requirements specified; taking into account the permissible tolerance specified in standards.

11.PENSTOCK FABRICATION

11.1 INTRODUCTION

11.1.1 The fabrication of penstocks involve fabrication of straight pipes, bends special fittings like Wyes, Supporting Rings, Expansion joints and Bearings, etc. The fabrication procedure of these items depend upon the available fabrication facilities and fabricators shop practice.

11.1.2. The fabricator shall adopt suitable welding process, the shape of bevels, electrodes and filler metal. In order to obtain quality as laid down in the specification, the fabricator shall take care that they are complied with by proper inspection during fabrication as laid down in Art. 11.4.

11.2 PROCESS OF FABRICATION

11.2.1 The process of fabrication involves marking, chamfering, rolling and welding.

11.2.2 Marking

11.2.2.1 The plates are laid out and trimmed to true rectangular shape. In case of bends, bifurcations and other specials, the developments are marked on the plates with great accuracy.

11.2.3 Cutting and Bevelling

11.2.3.1 Chamfers or bevels are generally prepared by flame cutting, shearing, planning or milling. The chamfers which are not satisfactory after flame cutting particularly as regards to shape and metallurgical conditions shall be ground.

11.2.3.2 The shape of chamfer depend upon the thickness of material, operating condition of part or equipment of the workshops, as well as on the welding process called for. The most common shapes for butt weld and fillet welds are shown in Fig. 52.

11.2.4 Rolling

11.2.4.1 The plates shall be rolled to true curvature in a bending machine. A typical method of Bending is shown in Fig. 53.

11.2.4.2 The diametrical distance between any two points on the pipe so formed shall be within the tolerance limit of D $\pm$ 5 mm. The other usual tolerances for the shape and appearance of longitudinal and circumferential joint shall be as given in Appendix IV.

11.3 WELDING

11.3.1 The welds can be made by well tried methods. Usually in shop, welding is carried out by automatic welding machine. The type of electrode and filler metal shall be as per Art. 11.3.2. The current strength and speed of deposition shall be as per the prevalent practice.

11.3.2 The selection of quality of welds shall depend upon the basic material and stresses on the same, since the longitudinal and circumferential welds undergo some forces as the basic material.

The mechanical properties of electrode and filler metal shall confirm to those of parent metal. The weld metal shall satisfy the tests as per I.S.I. code for unfired pressure vessel.

11.3.3 The welding sequence shall be determined in advance specially when the shape of the part is likely to cause shrinkage or in case of complicated shapes.

11.3.4 The preheating of material will depend upon the material to be welded, thickness of wall and process used.

11.4 TESTS AND INSPECTION

11.4.1 The fabricator shall be responsible for the quality control and shall make necessary inspection of welds by non-destructive method of testing specified in Chapter 13 and shall submit a report giving all the results of test and assessment of radiographic or Ultrasonic Examination and Hydrostatic testing.

11.5 STRESS RELIEVING

11.5.1 After fabrication, when the shape or magnitude of structure requires, the welded joint must undergo stress relieving heat treatment either locally or as a whole as specified. It is a post heat treatment given to a welded body to eliminate any stress caused due to welding.

11.5.2 The stress relieving shall be carried out on (a) All the pipes fabricated out of the plates of thickness greater than 36mm, (b) All the complicated fabricated structure like man-hole opening, bifurcation and trifurcation, ring girder, fabricated rocker supports etc.

11.5.3 The stress relieving shall be carried out as per I.S.I. Code for Unfired Pressure Vessel. The stress relieving process consist of heating the welded structure under controlled condition in a furnace to a temperature of 580^{o}C to 620^{o}C and then cooling in the furnace to 400^{o}C at a rate of 55 deg. per hour. Below 400^{o}C, the vessel may be cooled in still air.

11.5.4 In the field the stress relieving of girth joint is not carried out. In special cases, where stress relieving in field is specified, the stress relieving is usually carried out by Electric Pad Method with suitable precautions.

12.ERECTION OF PENSTOCK

12.1 INTRODUCTION

12.1.1 Erection consists of laying down the penstock sections between two anchor points and assembly by welding – manually or by any other process.

12.1.2 For accurate alignment and designing suitable erection procedure, the following data shall be made available to erector:

a) Site Plan
b) Ground longitudinal profile
c) Preparatory works on layout, like anchor blocks, supports, etc.
d) Storage area and premises
e) Erection season and time available
f) Transport facilities – Road and Rail
g) Handling facilities.
h) Extreme temperature conditions for setting Rocker Supports and adjustment of expansion joint.

12.1.3 The choice of erection procedure depend upon the details of penstocks and site condition. These can be generally classified as:

12.2 SURFACE PENSTOCKS

12.2.1 Surface Penstocks consist of sections anchored at their ends with or without expansion joint. These are usually laid either by crawler crane, trolleys moving on side track or by overhead cableways depending upon ground profile and grading.

The penstock supported on rockers need special setting for temperature condition.

12.3 PENSTOCK IN TUNNEL OR PRESSURE SHAFT

12.3.1 In case of penstocks or steel lining concreted in a tunnel or shaft, the pipes are pre-assembled in long sections of 5 to 7.5m length and carried on trolleys or skidded into shaft with the help of winches. Enough clearances of about 300 mm all around the liner shall be maintained for welding and inspection before concreting (Fig. 54).

12.3.2 Suitable internal bracings shall be provided to withstand the external pressure caused during concreting or grouting process.

12.3.3 In case of free penstocks laid in tunnel, there shall be adequate room between liner and tunnel wall for subsequent inspection and maintenance.

12.4 PENSTOCK IN DAM

12.4.1 Penstocks in dam shall be laid prior to dam is raised to full height. The erector shall provide suitable supports, internal and external to withstand external pressure carried during concreting and grouting process (Fig.55).

12.5 BURIED PENSTOCKS

12.5.1 In case of penstocks laid in trench and backfilled, the penstock steel liner must be covered with asbestos felt wrap and white wash before backfilling and the backfill must be deposited by successive compacted layers. (Fig. 56).

12.6 FIELD WELDING

12.6.1 The welding procedure at field is similar to shop welding and the fabricator shall observe the similar manufacturing control as those carried out in the shop and specified in Art. 11.4.

12.6.2 Wherever required the field welds shall be stress relieved by suitable method as specified in Art. 11.5.4,

12.7 COMPLETION OF WORK

12.7.1 On completion of erection the unpainted parts (welded joints) shall be prepared and painted with specified paints as a protective measure.

In case of pressure shafts, the grout openings shall be plugged, ground flush and painted.

12.7.2 Before putting into service, all the internal spiders, etc. shall be removed and penstock cleaned from inside from all foreign bodies.

12.7.3 On completion of erection, finishing of protective measures and cleaning, the penstock shall be subjected to acceptance test as specified in Art 14.6, and results, if found satisfactory, the acceptance of installation shall be pronounced.

13.INSPECTION TESTS & ACCEPTANCE TEST

13.1 INTRODUCTION

13.1.1 For the quality control of work the welded joints shall be subjected to inspection and non-destructive testing. The non-destructive testing gives the information about the homogenity of weld and the quality of work. The following methods are generally used for inspection of welds:

a) Radiography Examination
b) Ultrasonic Examination
c) Magnetic Particle Method
d) Dye Penetration Method

Usually, Radiographic Examination, Ultrasonic Examination or a combination of two processes is used for inspection.

13.2 RADIOGRAPHY EXAMINATION

13.2.1 Radiographic Examination is carried out either by X-ray or Gamma Ray, depending upon the source of radiation. In either case the radiographic films are placed on one side of weld and subjected to specified intensity of radiation, the source being placed on other side of weld. Depending upon the quality of weld the films are exposed and indicate any flaws in welding, such as pores, slag inclusion, lack of fusion and cracks, etc. These films shall be submitted as permanent records.

13.2.2 It is recommended that all the longitudinal joints shall be radiographed for 100% length. The circumferential joints shall be spot radiographed for 10% length of each joint. It is also recommended that all the T-junctions between longitudinal and circumferential joint shall be radiographed.

13.2.3 Any defects shown during the radiography shall be repaired and subjected to re-examination.

13.3 ULTRASONIC EXAMINATION

13.3.1 Ultrasonic Examination enables faults to be located more accurately and access the necessity for repairs. The ultrasonic examination is carried out by electronic equipment and requires highly qualified operator. The disadvantage of this method is that no records can be maintained.

13.3.2 During ultrasonic examination the base material on either side of weld shall be free from segregation, lamination and other faults.

13.3.3 All fields welds, if not spot radiographed or such joints which are difficult to be radiographed or inaccessible to radiographic examination such as girth joint of liner in a tunnel or shaft with backing strip, may be subjected to ultrasonic examination in lieu of radiographic examination.

13.4 OTHER TESTS

Other non-destructive tests like a magnetic particle method or dye penetration method can be done to detect the surface cracks. This is usually adopted for the inspection of field welds in case of a difficult weld the intermediate runs of welds are subjected to these tests.

13.5 HYDROSTATIC TESTING

13.5.1 All the fabricated sections, straight pipes, bends, expansion joints, wyes, etc. shall be subjected to Hydrostatic testing in shop.

13.5.2 During testing, each piece shall be subjected to a test pressure of 1.5 times design pressure or to a pressure which will develop a stress equal to 0.8 times yield point, whichever is more.

13.5.3 Each individual section shall be completely filled with water and the pressure is gradually raised to test pressure. The pressure shall be applied three times successively increasing and decreasing at uniform rate. The test pressure shall be held stationary for such a time as is considered sufficient for inspection of all plates, joints and connections to detect leakage and signs of failure.

13.5.4 The straight pipes are tested between two head or in a testing rig. A typical testing rig is shown in Fig 57. The annular space between liner and concrete block is filled with water under required pressure and inspection is made. The leakage from top and bottom is stopped by providing seals.

The bends are tested as a single piece between two heads as shown in Fig. 58 or each bend piece can be tested as straight member before being finished.

The wyes and expansion joints are tested with bulk heads.

13.5.5 If test discloses any defects such as leakage or local strains, these shall be rectified as mutually agreed upon.

13.6 ACCEPTANCE TEST

13.6.1 On completion of penstock erection, before handing over to customer, the penstock is filled and checked for stability and tightness.

13.6.2 The filing of penstock shall be done at a slow rate and during filling the closing and tightness of all the valves, inspection openings and other accessories shall be checked and the penstock shall be properly vented at high points to prevent formation of air pocket.

13.6.3 For field Hydrostatic test, the penstock shall be filled to full reservoir level i.e. to static head or to a higher pressure (Fig. 59). The water in the penstock shall be maintained to required head for such a time as is considered necessary for inspection of all joints. Any joint leakage shall be repaired and retested.

14.PAINTING OF PENSTOCK

14.1 Good painting on the interior of a penstock will reduce the frequency of power house shut downs and consequent loss of revenue during maintenance. It will also withstand high water velocities, impact and shock; with a smooth glossy finish, friction loss in the penstock will be minimized.

14.2 INTERIOR PAINTING

Irrespective of the type of penstock, painting on the inside consists of one coat of cold applied coal tar primer followed by one coat of coal-tar enamel 3/32 inch to 1/32 inch. Alternatively, 3 coats of cold applied coal tar apoxy (British Epilux 5 paints) have been provided for some penstock in India.

Painting of the interior with hot coal-tar enamel is usually done in the shop. Straight pipe courses can be spun and the coal-tar enamel is deposited in the spinning pipes. This results in a smooth glossy finish. Sections of pipes which cannot be spun, such as elbows or sections with man-holes are hand-daubed. The hand-daubed coating seems to protect the steel as effectively as the spun lining, but it is quite rough and is avoided wherever possible to minimise friction losses.

14.3 EXTERIOR PAINTING

Prior to the despatch of fabricated pipes from the shop to site, the out side of pipe is protected with one coat of Red oxide or Zinc Chromate. A second coat of red oxide is also given in the field followed by a coat of aluminium paint. The highly reflective surface of the aluminium paint is believed necessary to keep the interior of the pipe, when empty, below a temperature that would damage the coal-tar enamel and also to minimise the movement of expansion joints.

Outside surface of buried pipes are painted with coal-tar enamel and to keep this coat from being damaged by the back filling operation are given a thin coat of reinforced gunite. Alternatively, a layer of fibrous glass mat wrap followed by a coat of Asbestos Felt wrap and finally a coat of white wash are given (see Fig. 62).

Portions of penstocks embedded in concrete anchors are given a coat of red-oxide or zinc chromate. Penstocks embedded in tunnels form steel liners and are given a similar coat and a coat of asphalt or bitumen 1/8 inch thick immediately upstream from the power house for a distance of about 25ft. so that the thrust on the liners, as a result of closing the power house valves would not be transmitted to the power house wall.

14.4 SEQUENCE OF OPERATIONS

The various operations involved in paintings for interior surfaces are (i) cleaning and preparation of surface (ii) Primer coating (iii) coal-tar enamel painting and finally (iv) inspection and testing. The operations are described in detail below:

I. CLEANING AND PREPARATION OF SURFACE

a) Oil and grease on the surface are removed thoroughly by flushing and wiping with "Xylol".

b) All other foreign matter, weld spatter, burrs and any objectionable surface irregularities are removed by sand-blasting till exposure of grey coloured base metal. The sand or steel grit used for blasting should be dry and should pass a No. 16 standard screen and at least 85% should be retained on a 50 standard screen.

14.5 PRIMER COATING

Primer coating is applied by hand brushing, air gun spraying and brushing at a coverage of 350 to 400 square feet per gallon. The surface should be dry at the time of application of primer to facilitate spraying and spreading; the primer may be heated and maintained during the application at a temperature of not more than 120^{o}F.

14.6 COAL-TAR ENAMEL PAINTING

Coal-tar enamel conforming to AWWA specification No. C 203-57 may be used. The enamel should be heated in special kettles equipped with tight closing lids and easily readable thermometers (See Fig. 63). Application temperature may vary between 450 to 480^{o}F. A coverage of 125 square feet may be expected from one gallon of coal-tar enamel. Finished coal-tar enamel lining should be free from wrinkles, sags, blisters or blow-holes.

14.7 PAINT CHARACTERISTICS AND TESTS

A good and durable paint should have the following characteristics, these have to be verified on test plates:

Sl. No.	**Test**	**Min.**	**Max.**
1.	Softening Point	220^oF	-
2.	Filler (Ash)	25%	35%
3.	Fineness filler through 200 mesh	90%	-
4.	Specific gravity at 25 ^0F	1.4	1.6
5.	Penetration a) At 77^o F-100 g weight – 5 secs b) At 115^o F – 50 g weight – 5 secs.	 10 15	 20 55
6.	High temperature test at 160^o F – 50 g weight – 5 secs	-	2/32 inch
7.	Low temperature test at 20^o F (cracking)	-	None
8.	Deflection test (initial heating) a) Initial crack b) Disbonded area	 0.8 -	 - 3 sq.miles
9.	Deflection test (after heating) a) Initial crack b) Disbonded area	 0.6 m -	 - -
10.	Impact test (at 77^o F – 650 g – 8 ft. drop) a) Direct impact – disbonded area b) Indirect impact – disbonded area	 - -	 10 sq.inch 2 sq.inch
11.	Peel test	No feeling	

PENSTOCKS DESIGNED IN CW&PC

Sl. No.	Name of Project and State	Static Head in ft.	Design Head in ft.	Installed Capacity in MW	Size and No. of Penstock	Length in ft.	Tonnage in Tons	Type of Steel	Type of Installation
1	2	3	4	5	6	7	8	9	10
1.	Upper Sind Project J & K	599	885	2 of 11.2	1 of 7' dia bifurcating into two of 5' Ø each	1380	500	ASTMA-285 Gr. 'C'	Surface Penstock supported on Rockers.
2.	Lower Jhelum Project J & K	221	275	3 of 35	3 Nos. 14: 75 Ø straight	1120	1400	IS 2002/62 Gr. 'A'	Surface Penstock supported on Rockers.
3.	Chenani Project J & K	1240	1428	3 of 4.6 5 of 2 of 5.0	1 No. 5' Ø reducing to 4' and bifurcating into 2'-3" Ø 1 No. 4' Ø reducing to 3' Ø and bifurcating into 2'-3" Ø	3400 each		ASTM 285 Gr. 'C'	Surface Penstock supported on Rockers.
4.	Nogli Project Himachal Pradesh	242	303		3 Nos. of 3' Ø bifurcating into 6 of 25" Ø each	No.1 800 No.2 810 No.3 830		ASTM 285	Surface Penstock supported on Rockers.
5.	Giri Project Himachal Pradesh	590	820	2 of 30	2 Nos. 8 ft. Ø each	1835		Fire Box quality steel	Surface Penstock supported on Rockers.
6.	Baira Siul Project Himachal Pradesh	870	935	3 of 67	3 Nos. 9. 02 ft. Ø straight	840	2503	ASTM A-285 Gr. 'C' & ASTM-A-537 Gr. 'A'	Partly surface & partly shaft.
7.	Rana Partap Sagar Project Rajasthan	177	220	4 of 43 each	4 Nos. 20' Ø straight	121 each			Penstock embeded in concrete.
8.	Jawahar Sagar Project Rajasthan	120	138	3 of 138	3 of 20' Ø	424 No. 1 387 No. 2 350 No. 3	906	ASTM A-285	Penstock embeded in concrete.
9.	Gandhi Sagar Project M. P.	159	210	5 of 23	5 of 15'-6" Ø	183 each	450	ASTM-A-285	Penstock embeded in Dam.
10.	Ukai Dam Project Gujarat	137	157	4 of 75	4 of 23.00' Ø	4 of 197' each	4 of 215 tons each	ASTM-285 Gr. C	Embeded in concrete.
11.	Upper Sileru Project A.P.	310	385	4 of 60	2 of 18 Ø penstocks reducing to 17' Ø	No.1 1024 No.2 1076	1250 639	15-K Russian Steel & T-1 steel	Surface penstock supported on Rockers.
12.	Lower Sileru Project A.P.	650	792	6 of 115	3 Nos. 18' Ø varying to 16.5' Ø	1515 each	1200 4200	Aldu 58 & ASTM 285 Gr. 'C'	Steel lined tunnel, surface penstock and shaft.
13.	Nagarjunasagar Left Bank Power House A.P.			8 of 50	8 Nos. 16' Ø each	360			
14.	Balimela Project Orissa	299.686M	374.606	I 6 of 60 II 2 of 60	6 Nos. 8.2' Ø (av.) straight 8.75 to 7.75	1800 2382	10000 16,000	15-K Russian steel	Surface penstock supported on Rockers.
15.	Subernarekha Project PH II Bihar	445	560	65	1 No. 12'-10" Ø	about 1300	550	ASTM 285 Gr. 'C' & ASTM 537 Gr. 'A'.	-do-
16.	Subernarekha Project PH I Bihar	480	570	65	-do-	about 1600	850	ASTM 285 Gr. 'C' & ASTM 537 Gr. 'A'.	-do-
17.	Barapani Project Assam	550	663	4 of 9.4	2 of 6'-6" Ø	2 of 1644	1700	ASTM 285 Gr. 'C' & CT-3.	Steel lined tunnel & surface penstock.
18.	Loktak Project Manipur	1100	1300	2 of 35	3 of 7'-6" Ø	5340 each	4800	ASTM A-285 & ASTM A-537	Surface penstock supported on Rockers.
19.	Gumti Project Tripura	136	157	4 of 75	4 of 23.00' Ø	4 of 197.23 each	4 of 215 each	ASTM 285 Gr. 'C'	Penstock embeded in concrete.
20.	Kadana Dam Project Gujarat	156	210	4 of 60	4 of 18' Ø straight	245	1017	ASTM 285 Gr. 'C'	Penstock partly embeded in Dam and partly surface.

ECONOMIC DIAMETER

Max. Static Head = 499 FT.
Max Discharge = 615 CFS.
Equivalent Discharge = 286 CFS.
Material ASTM 285 Grade 'C'
Corrossion Allowance = 1/16"
ASSM. 5000 MM. Plate With 15% Extra

Water Hammer = 33%
Load Factor = 39%
Allowable Stress = 13500 PSI
Annual Loss in Revenue Due to Friction Loss $= \frac{0.06\ Ks\ Qe^{2.2}}{D4.9}$ Re/FT or $\frac{8.29 \times 10^{5} \times K's}{D\,4.9}$ Re/FT
Cost of Steel Per Ton Rs. 3400/-
Power Generation @ Rs. 0.06/kW

Loss Factor - 0.10

S.No.	Pipe Dia. in ft.	MATERIAL: Plate Thickness in MM	Head in ft.	Length in ft.	Weight per ft. in Tons $A\frac{Dt}{12}x\frac{1.15x490}{2240}$ Tons/Ft.	Cost per ft. @ Rs. 3400 per Ton Rs.	Weight for each Plate Thickness Tons	HYDRAULIC LOSS: Velocity	Friction Loss FT	Loss of Revenue in Friction Loss/Year/Ft. = $\frac{8.25x10^{5}xK's}{D\,4.9}$ Rs.	CAPITALIZATION: Interest DEP. & Maint. @ 8% Rs.	Total Annual Cost Rs.	Weighted Average $\frac{Col. 11xCol. 3}{1387}$
1	2	3	4	5	6	7	8	9	10	11	12	13	14
	6'-0" Bifurcating to 4'-3" Dia	8 MM.	206'	434'	0.124	422	54.0	Max. Velocity = 21.6 FPS	Total Friction Loss=26.6 ft. K's 0.408	51.8	33.8	85.8	26.80
		10 MM.	286'	150'	0.155	526	22.3				42.1	93.0	10.20
		12 MM.	353'	120'	0.186	632	22.4				50.6	102.4	8.55
		14 MM.	412'	90'	0.218	740	19.6				59.2	111.0	7.20
		16 MM.	490'	120'	0.246	835	29.5				66.8	118.6	10.30
		18 MM.	560'	180'	0.279	950	50.3				76.00	127.8	16.60
		20 MM.	620'	150'	0.310	1052	46.5				84.2	136.00	14.70
		22 MM.	630	30'	0.341	1160	10.2				93.0	144.8	3.13
		15 MM.	640'	25'	0.330	1120	8.4				89.6	141.4	2.55
		18 MM.	690'	88'	0.352	1196	31.0				95.6	147.4	9.35
				1387			294.1						109.38
	6'-6" Bifurcating to 4'-6" Dia	8 MM.	202'	400'	0.135	460	54	18.55 FPS	19.19 FT. K's 0.42	36.50	36.8	73.3	21.2
		10 MM.	265'	140'	0.169	575	23.7				46.0	82.5	8.34
		12 MM.	328'	120'	0.203	690	24.4				54.2	100.7	8.71
		14 MM.	390'	90'	0.237	805	21.4				64.5	101.0	6.56
		16 MM.	453'	90'	0.27	916	24.3				73.5	110.0	7.15
		18 MM.	516'	140'	0.302	1025	42.2				82.0	118.5	12.00
		20 MM.	580'	160'	0.338	1150	54.0				92.0	128.5	14.82
		22 MM.	630'	134'	0.372	1265	49.8				101.2	137.7	13.30
		16 MM.	655'	60'	0.376	1280	22.6				102.3	138.8	6.00
		16 MM.	664'	53'	0.422	1435	22.4				114.8	151.3	5.78
				1387			336.8						103.86
	7'-0" Bifurcating to two of 5'-0" each	8 MM.	187'	300'	0.146	496	57.00	10 FPS	13.49 FT. K's 0.433	26.0	39.7	65.7	18.5
		10 MM.	246'	110'	0.180	613	19.8				49.0	75.0	5.95
		12 MM.	304'	110'	0.218	742	24.0				59.4	85.4	6.77
		14 MM.	362'	100'	0.255	866	25.5				69.4	95.4	6.88
		16 MM.	421'	80'	0.291	990	23.3				79.2	105.2	6.06
		18 MM.	480'	100'	0.328	1115	32.8				89.2	115.2	8.32
		20 MM.	538'	140'	0.364	1238	51.0				99.0	125.0	12.60
		22 MM.	596'	150'	0.40	1360	60.0				108.0	134.0	14.50
		24 MM.	630'	94'	0.436	1485	41.00				119.0	145.0	9.84
		18 MM.	672'	113'	0.468	1590	52.8				127.2	153.2	12.48
				1387			387.2						101.90
	7'-6" Bifurcating to two of 5'-3" each	8 MM.	174'	360'	0.146	496	52.5	13.3 FPS	10.05 FT. K's 0.464	19.6	39.7	59.3	15.40
		10 MM.	229'	110'	0.195	664	21.5				53.0	62.6	4.98
		12 MM.	284'	110'	0.234	795	25.8				63.6	83.2	6.60
		14 MM.	338'	20'	0.273	930	24.6				74.5	94.1	6.12
		16 MM.	393'	80'	0.312	1060	25.0				84.8	104.4	6.02
		18 MM.	448'	80'	0.351	1192	28.1				95.5	115.1	6.65
		20 MM.	503'	120'	0.390	1325	46.8				106.0	125.6	10.86
		22 MM.	555'	130'	0.429	1458	55.8				116.5	136.1	12.75
		24 MM.	610'	140'	0.468	1590	65.6				127.0	146.6	14.8
		26 MM.	630'	54'	0.506	1720	27.3				137.5	157.1	6.11
		18 MM.	640'	25'	0.492	1670	12.3				133.5	153.1	2.76
		20 MM.	720'	88'	0.546	1860	48.1				149.5	169.1	10.75
				1387			433.4						103.78

PROPERTIES OF PENSTOCK STEEL PLATE

Sl. No.	Designation and type of steel	Source	CHEMICAL COMPOSITION IN PERCENTAGE												PHYSICAL PROPERTIES	
			C	Mn	S	P	Si	Ni	Cr	Mo	V	Cu	B	Ti	Yield stress Kg/mm^2	Ultimate tensile strength Kg/mm^2
1.	A-517 (T_1 steel)	USA	0.1 to 0.20	0.6 to 1.0	0.4 to Max.	0.035 to Max.	0.15 to 0.35	0.7 to 1.0	0.4 to 0.65	0.4 to 0.6	0.03 to 0.08	0.15 to 0.5	0.002 0.006	-	71-63	73-95
2.	A-517 (T_1 Type A)	USA	0.12 to 0.21	0.21 to 1.00	0.04	0.035	0.2 to 0.35	-	0.4 to 0.65	0.15 to 0.25	0.03 to 0.08	-	0.005	0.01 to 0.03	71	81.95

Sl. No.	Designation and type of steel	Source	C	Si	Mn	Phos	Sul	Mo	Cu	Van	Yield stress Kg/mm^2	Ultimate tensile strength Kg/mm^2
			CHEMICAL COMPOSITION IN PERCENTAGE								PHYSICAL PROPERTIES	
3.	A-212 Grd.A		0.28 to 0.30	0.14 to 0.33	0.90	0.35	0.04	-	-	-	25	46 - 54
4.	A-212 Grd.B		0.31 to 0.35	0.14 to 0.33	0.90	0.35	0.04	-	-	-	27	49 - 60
5.	A-302 Grd.B		0.2 to 0.25	0.13 to 0.32	1.1 to 1.55	0.035	0.035	0.41 to 0.64	-	-	35	56 - 70
6.	A-225 Grd.A		0.18	0.13 to 0.32	1.45	0.035	0.04	-	-	0.07 to 0.16	28	49 - 60
7.	A-225 Grd.B		0.20	0.13 to 0.32	1.45	0.035	0.04	-	-	0.07 to 0.16	30	53 - 63
8.	A-285 Grd.A		0.15 to 0.17	-	0.80	0.04	0.04	-	0.18 to 0.37	-	17	32 - 39
9.	A-285 Grd.B		0.20 to 0.22	-	0.80	0.04	0.04	-	0.18 to 0.37	-	19	53 - 42
10.	A-285 Grd.C		0.25 to 0.30	-	0.80	0.04	0.04	-	0.18 to 0.37	-	21	39 - 46

Appendix III (Contd.)

Sl. No.	Designation and type of steel	Source	CHEMICAL COMPOSITION IN PERCENTAGE									PHYSICAL PROPERTIES	
												Yield stress	Ultimate tensile strength
			C	Si	Mn	Phos	Sul	Cu	Ni	Cr	Mo	Kg/mm^2	Kg/mm^2
11.	**IS-2041-1962**	**India**											
	a) Type I 20MN55		0.15 to 0.25	0.10 to 0.35	0.40 to 0.70	0.05	0.05	+0.40	+0.30	0.25	+0.45 to 0.65	28	48-62
	b) Type 2 20MN2	-do-	0.16 to 0.24	0.10 to 0.35	1.30 to 1.70	0.05	0.05	0.40	0.30	0.25	0.15 to Max.	30-36	52-65
12.	IS-2002-1962 (Amended 1965)												
	a) Grade I	-do-	0.18	0.10 to 0.35	-	0.04	0.04	-	-	-	-	20.40	37
	b) Grade 2A	-do-	0.20	-do-	-	0.05	0.05	-	-	-	-	21.00	42
	c) Grade 2B	-do-	0.22	-do-	-	0.05	0.05	-	-	-	-	26.00	52

Appendix III (Contd.)

Sl. No.	Designation and type of steel	Source	CHEMICAL COMPOSITION IN PERCENTAGE					PHYSICAL PROPERTIES		
								Yield stress	Ultimate tensile strength	
								Kg/mm^2	Kg/mm^2	
			Si	Mn	Phos Max.	Sul Max.	C	upto 30 mm	30 to 60 mm	
13.	ALDUR 35	West Germany	0.25	0.60	0.04	0.04	0.09 to 0.15	26	25	35 to 44
14.	ALDUR 41	-do-	0.25	0.70	0.04	0.04	0.15 to 0.18	29	28	41 to 50
15.	ALDUR 41	-do-	0.30	1.00	0.04	0.04	0.16 to 0.19	31	30	44 to 54
16.	ALDUR 47	-do-	0.35	1.20	0.04	0.04	0.17 to 0.20	33	32	47 to 57
17.	ALDUR 50	-do-	0.40	1.30	0.04	0.04	0.18 to 0.21	36	35	50 to 60
18.	ALDUR 55	-do-	0.45	1.50	0.04	0.04	0.19 to 0.22	39	38	55 to 65
19.	ALDUR 58	-do-	0.50	1.60	0.04	0.04	0.20 to 0.23	41	40	58 to 68
20.	ALDUR 45/60	-do-	0.45	1.60	0.04	0.04	0.18 to 0.21	55	45	60 to 75
21.	ALDUR 50/65	-do-	0.45	1.50	0.04	0.04	0.20 to 0.23	30	50	65 to 80
22.	ALDUR 55/68	-do-	0.50	1.60	0.04	0.04	0.20 to 0.23	25	55	68 to 83
23.	ALDUR 58/72	-do-	0.50	1.70	0.04	0.04	0.20 to 0.23	25	58	72 to 85

Sl. No.	Designation and type of steel	Source	CHEMICAL COMPOSITION IN PERCENTAGE					PHYSICAL PROPERTIES		
			C	Mn	S	P	Si	Yield stress Kg/mm^2	Tensile strength Kg/mm^2	Remarks
	OPEN HEARTH RIMMED									
24.	MCT-0	Russia	0.23 to max.	-	0.06	0.07	Traces of Si	19	32-47	
25.	MCT-1	-do-	0.07 to 0.12	0.35 to 0.50	0.055	0.050	-do-	-	32-40	
26.	MCT-2	-do-	0.08 to 0.15	0.35 to 0.50	0.055	0.050	-do-	22	34-42	
27.	MCT-3	-do-	0.14 to 0.22	0.4 to 0.65	0.055	0.050	-do-	22	38-47	
28.	MCT-4	-do-	0.18 to 0.27	0.4 to 0.70	0.055	0.050	-do-	25	42-52	
	OPEN HEARTH KILLED OR SEMI KILLED									
29.	MCT-3	Russia	0.14 to 0.22	0.04 to 0.05	0.055	0.050	0.12 -0.30	24	38-47	
	MCT-4	-do-	0.18 to 0.27	0.4	0.055	0.050	0.12 to 0.30	26	21-29	

Appendix III (Contd.)

Sl. No.	Type and designation of steel	Source	C	Mn	S	P	Si	Yield stress Kg/mm²	Tensile strength Kg/mm²	Remarks
			CHEMICAL COMPOSITION IN PERCENTAGE					PHYSICAL PROPERTIES		
	BESSEMER RIMMED									
31.	BCT-0		0.14 max.	-	0.07	0.090	Traces of Sil	19	32-47	
32.	BCT-3		0.12 max.	0.25 to 0.55	0.065	0.085	-do-	24	38-47	
33.	BCT-4		0.12 to 0.20	0.35 to 0.55	0.065	0.085	-do-	26	42-52	
	BESSEMER KILLED									
34.	BCT-3		0.12 max.	0.25 to 0.55	0.065	0.085	0.1 to 0.35	24	38-47	
35.	BCT-4		0.12 to 0.20	0.35 to 0.55	0.065	0.085	0.10 to 0.35	26	38-47	
36.	BCT-5		0.17 to 0.30	0.5 to 0.80	0.065	0.085	0.10 to 0.35	28	50-62	
	OPEN HEARTH									
37.	CT - 3 K		0.12 to 0.22	-	0.05	0.05	-	-	38-40	
38.	CT - 3 K		0.12 to 0.22	-	0.04	0.04	-	26	36-38	

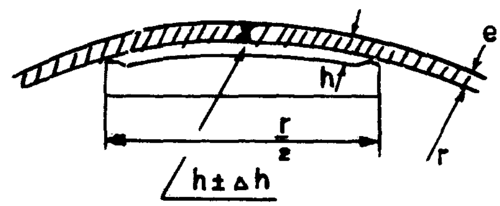
Appendix III (Concld)

Sl. No.	Type and Designation of steel	Source	C	Mn	S	P	Cr	Ni	Cu	Si	Yield stress Kg/mm^2	Tensile strength Kg/mm^2	REMARKS
			CHEMICAL COMPOSITION IN PERCENTAGE								PHYSICAL PROPERTIES		
	OPEN HEARTH RIMMED												
39.	CT-2		-		0.045	0.045	0.3	0.3	0.3	-	-	32-42	
40.	CT-3		0.12 to 0.23	-	0.05	0.045	0.3	0.3	0.3	-	-	38-47	
	OPEN HEARTH KILLED												
41.	15 K		0.12 to 0.20	0.65	0.045	0.045	0.3	0.03	-	0.3	22	36-44	
42.	20 K		0.16 to 0.24	0.65	0.045	0.045	0.3	0.3	-	0.3	25	41-50	
43.	25 K		0.21 to 0.28	0.80	0.045	0.045	0.3	0.3	-	0.3	28	45-55	

APPENDIX IV

1_ PROJECTION OF FLATTENING ADJACENT TO THE WELDS AS FOR THE PIPE_ SECTION i.e

$\Delta h \leqslant \pm \left(\frac{2r}{1000} + \frac{20}{e} + 0{,}5\right)$



2_ DISPLACEMENT OF THE LONGITUDINAL JOINT

CLASSES

I $\Delta \leqslant \frac{e}{50} + 1 + \frac{\Delta e}{2}$

II $\Delta \leqslant \frac{e}{30} + 1 + \frac{\Delta e}{2}$

III $\Delta \leqslant \frac{e}{10} + 1 + \frac{\Delta e}{2}$

Δe DIFFERENCE BETWEEN THE ACTUAL THICKNESSES OF THE EDGES INVOLVED

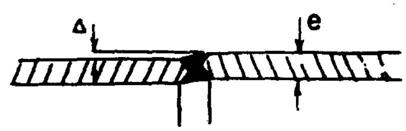
3_ DISPLACEMENT OF THE CIRCUMFERENTIAL JOINT

CLASSES

I $\Delta \leqslant \frac{e}{50} + 2 + \frac{\Delta e}{2} + \frac{\Delta p}{2\pi}$

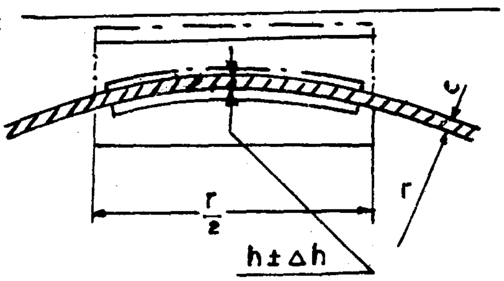
II $\Delta \leqslant \frac{e}{30} + 2 + \frac{\Delta e}{2} + \frac{\Delta p}{2\pi}$

III $\Delta \leqslant \frac{e}{10} + 2 + \frac{\Delta e}{2} + \frac{\Delta p}{2\pi}$



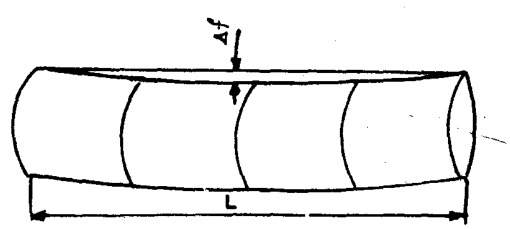
4. ROUNDNESS - TO CONTROL THE ROUNDNESS PIPES WITH LARGE DIAMETERS AND SMALL THICKNESS CAN BE SUSPEND ED OR INTERNALLY STIFFENED.

$\Delta h < \pm \left(\frac{2r}{1000} + \frac{20}{e} + 0{,}5\right)$



5. VARIATION FROM THEORETICAL SHAPE

$\Delta p < \pm \frac{2r}{1000} + 2\pi\,(e\ eff - e\ theor) + 4)$



6. STRAIGHTNESS OF GENERATING LINES

$\Delta f < \frac{2L}{1000}$

TOLERANCE ON SHAPE

BIBLIOGRAPHY

1. Welded Steel Penstocks by P.J. Bier.

2. Power Penstocks – Analysis of various penstocks, designs and construction methods – By P.J. Bier, Water Power – June, July, August, 1958.

3. Turbines and Pumps – Design standard No.6, U.S.B.R., Publication.

4. Valves, Gates and Steel Conduits – Designs Standard No.7, U.S.B.R. Publication.

5. Water Power Development - Vol. I & II – By E. Mosony.

6. Hydro Electric Engineering Practice Vol. I, II, III by J. Guthrie Brown.

7. Water Hammer Analysis by J. Parmakian.

8. Hydraulic Transient by G. Rich.

9. Fluid Mechanics by Teaguer.

10. Pressure Vessels - Division I – Section VIII A.S.M.E., Boiler and Pressure Vessel Code – 1969.

11. Indian Standard – Institute code for unfired Pressure Vessel.

12. Recommendations for the design, manufacture and erection of steel penstocks of welded construction for Hydro Electric Installation by European Committee for Boiler making and kindred steel structures – December, 1967.

13. "Penstocks" by Y.K. Murthy, P.C. Nag and K. Madhavan, - Indian Institute of Engineering – January, 1959.

14. A.S.T.M. Standards – Ferrous Metal – 1969.

15. Rock Properties and steel tunnel liners by George H. Kruse – Journal of Power Division – Proceeding of American Society of Civil Engineers.

16. New Design Criteria for U.S.B.R. Penstocks – By Harold G. Arthur - Journal of Power Division A.S.C.E. January – 1970.

17. "Design of large underground conduits in Rocks" by F.W.I. Patterson R.C. Clinch, W. Mc Caig – Journal of Power Division A.S.C.E. December 1957.

18. “Water Hammer Design Criteria” by John Parmakian Journal of Power Division, A.S.C.E. Vol. 83 – April 57.

19. “Design of high head penstocks” by W.J. Smith, SSME EIC – Hydraulic Conference Paper No.61 EIC – 10.

20. “Theory of Resonance in Pipe” by C. Jaeger – Water Power Journal – February, March, April, 1954.

21. “Penstock Codes – U.S. and Foreign Practice” by Andrew Eberhardt – Journal of Power Division – A.S.C.E.

22. “Buckling of pre-stressed steel lined shafts” by E. Amstutz – Journal of Applied Mechanics A.S.M.E. 1962 Vol.84 – P – 675-682.

23. “Symposium on Penstocks” Journal of the Power Division A.S.C.E. March , 1961.

24. “Design and Control of linings of Pressure Tunnels and shafts based on measurements of deformability of rock” by Dr. Ing H. Lauffer R –91 of Seventh Congress on large Dams – Rome – Pages 679 –705.

25. “Theory for design of underground pressure conduits” by D.J. Bleifuss – Journal of Power Division A.S.C.E., July, 1955.

26. “Stresses in rock about cavities” by K. Terzajhi and F.E. Richart Geotechnique Vol. II No.2 – June, 1952.

27. “Das Einbenlen Von Vorgespannter Schachtund Stollenpanzirungen” by E. Emstutz Schweizerische Bauzentong – April, 1953 (No.16).

28. “Steel linings for pressure shafts in solid rock” by E.W. Vaughan – Journal of Power Division, A.S.C.E. – April, 1956.

29. Factors influencing flow in large conduits – Journal of Hydraulic Division A.S.C.E. Vol.91 No.HY6 Nov’65.

30. “Discussions on factors influencing flow in large conduits” – Journal of Hydraulic Division A.S.C.E. Vol.92 Hy4 – July 1966.

31. “ Head Losses on Wyes and Manifold “ by Eugen Russ – Journal of Hydraulic Division A.S.C.E. Vol.96 Hy3, March, 1970.

32. “Hydraulic studies of large penstock Trifurcation” by John S. Gladwell and Roy Tinney – Journal of Power Division A.S.C.E. Vol.91 May,1965.

33. "Solzer Penstocks" by W. Muller and K.Brandle – Sulzer Technical Review No.2 1834 – 1959.

34. "Design of Wye Branches for Steel Pipe" by H.S. Swanson, H-J Chapton, W.J. Wilkinson, C.L. King and E.D. Nelson – Journal of American Water Works Association Vol.47 No.6, June 1955.

35. "Stress Analysis of Wye Branches" by F.O. Rund, Engineering Monograph No.32, Bureau of Reclamation, U.S.B.R. Publication.

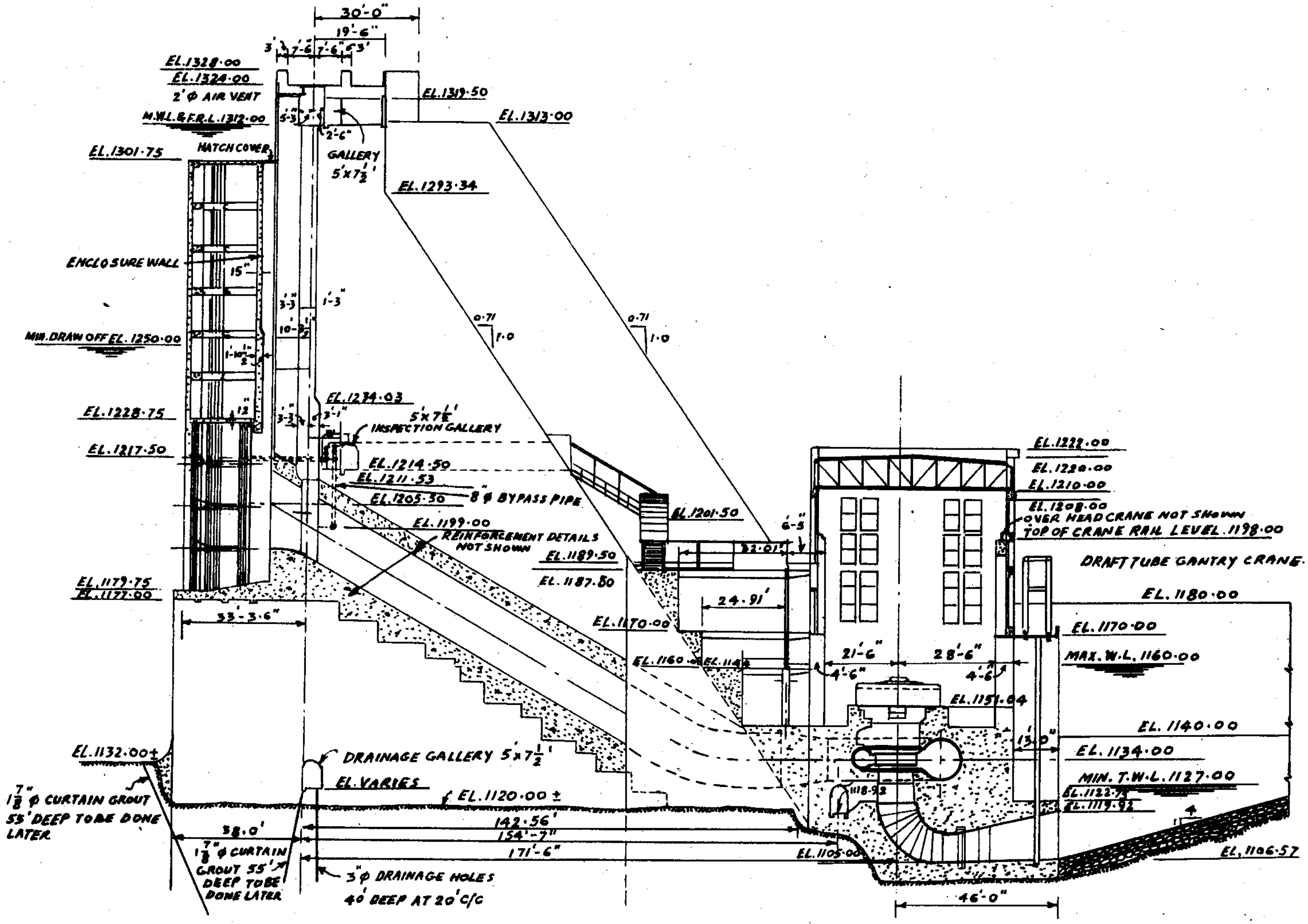
36. "Reduction of the weight and loss of energy in distribution pipes for hydraulic power plants" by A Suss and Dr. Hassan Scher Wyss News, Vol.30 No.3, 1957, Vol.31 No.1, 1958.

37. "Penstocks and outlet pipes" Part IV Bulletin 5, Boulder Canyon Report, Bureau of Reclamation, USBR.

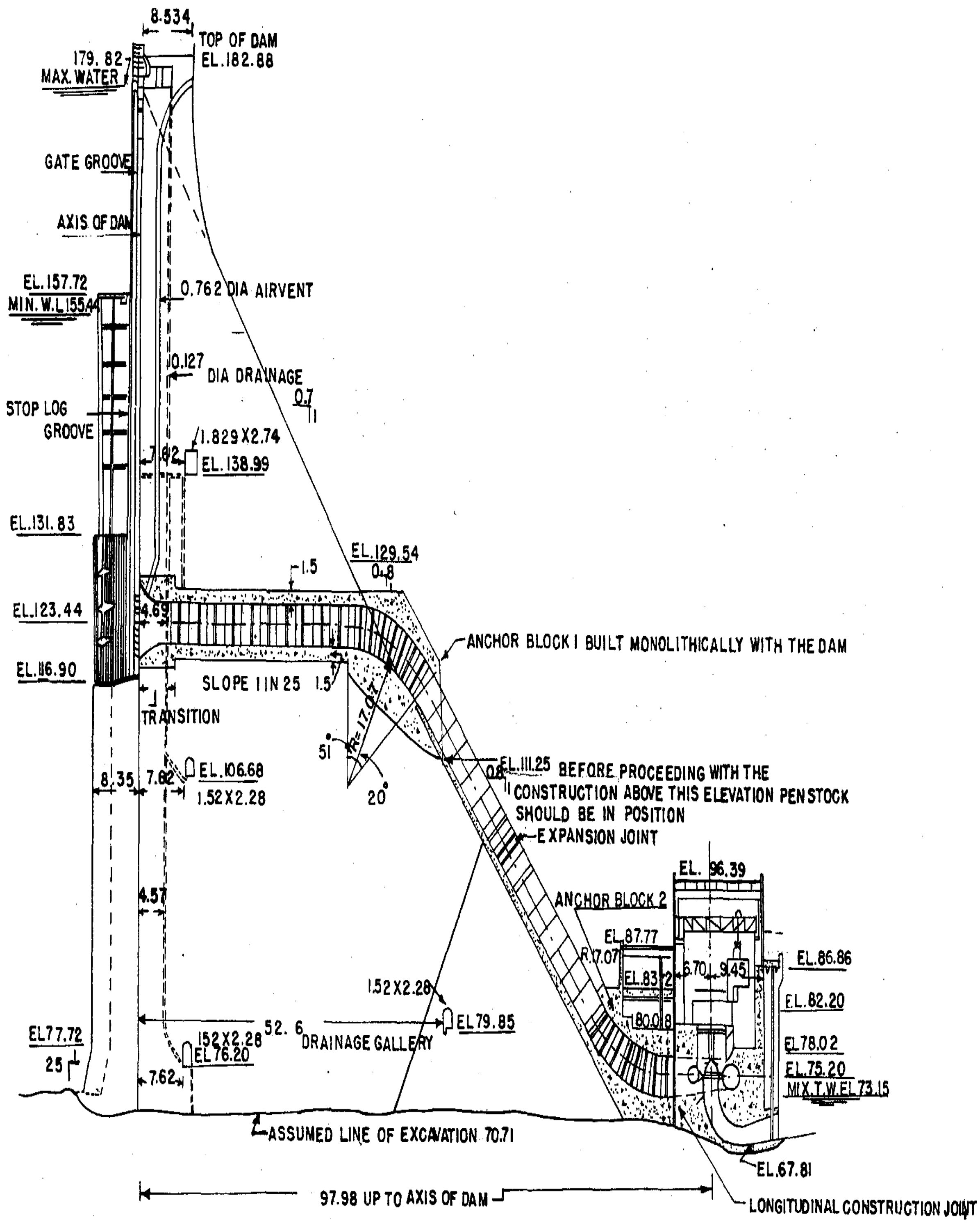
38. "Escherwyss distributor pipes with Internal Reinforcement free from bending stress by G. Dolder Escherwyss News – Vol.39 1966 No.2.

39. "Research on head losses in Escher wyss type distribution pipes" by Dr. A. Christ Escherwyss News Vol.39, 1966 No.2.

40. Design of Bifurcation, Journal of Power Division American Society of Civil Engineers Oct.1969.



GANDHI SAGAR PROJECT (MP) – SECTION THROUGH DAM & POWER HOUSE
FIG. NO. - 2



NAGARJUNASAGAR PROJECT – POWER DAM SECTION

FIG.NO.3

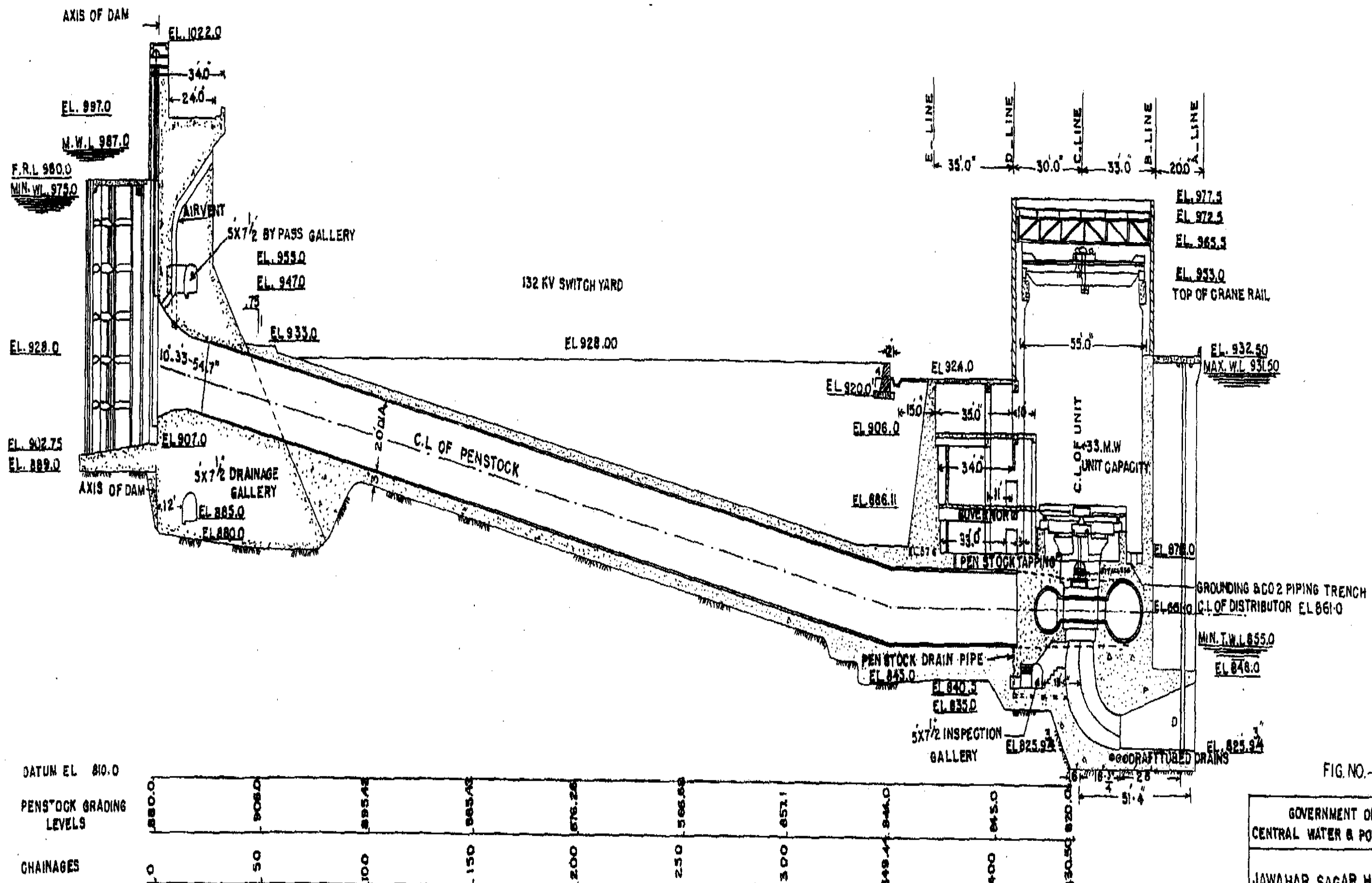
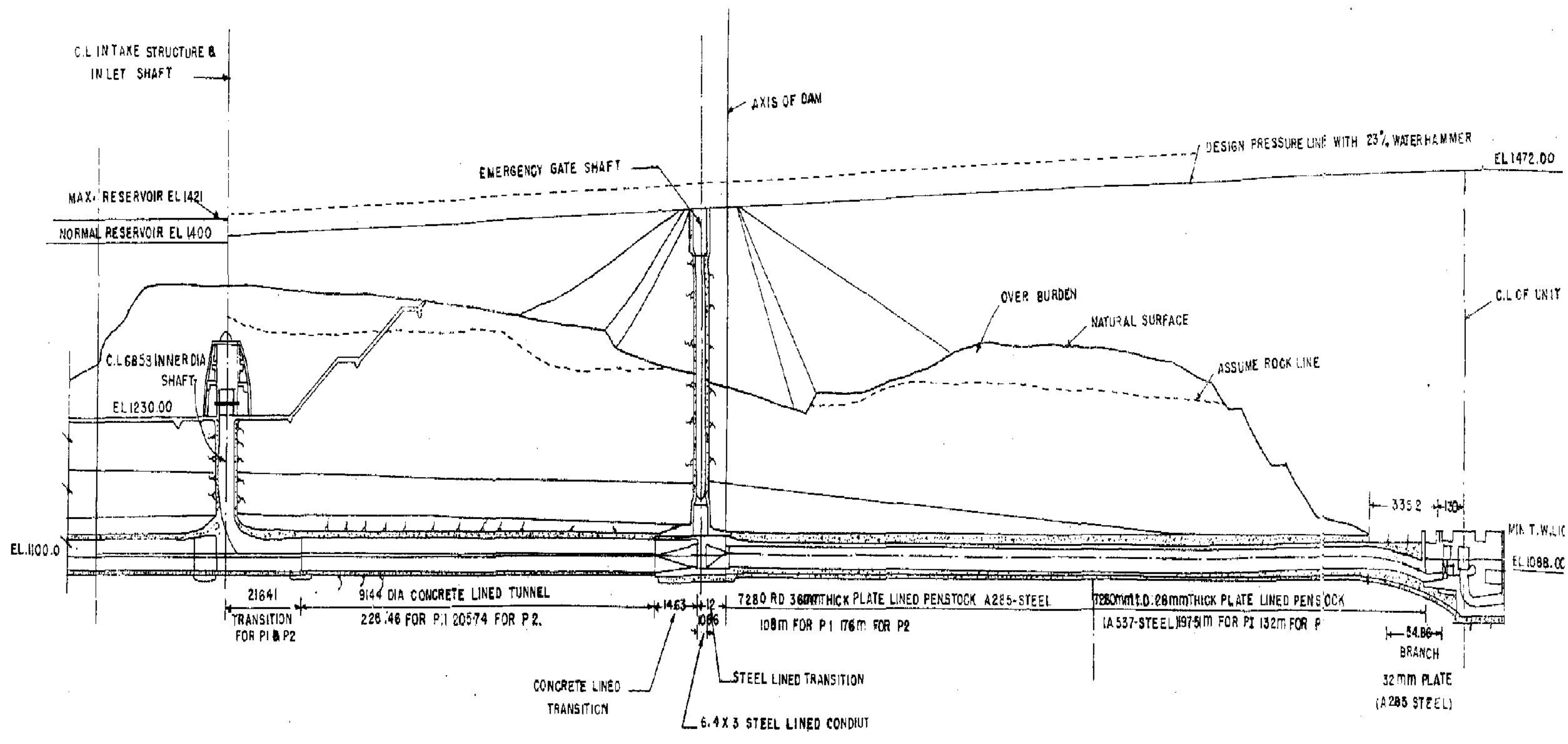


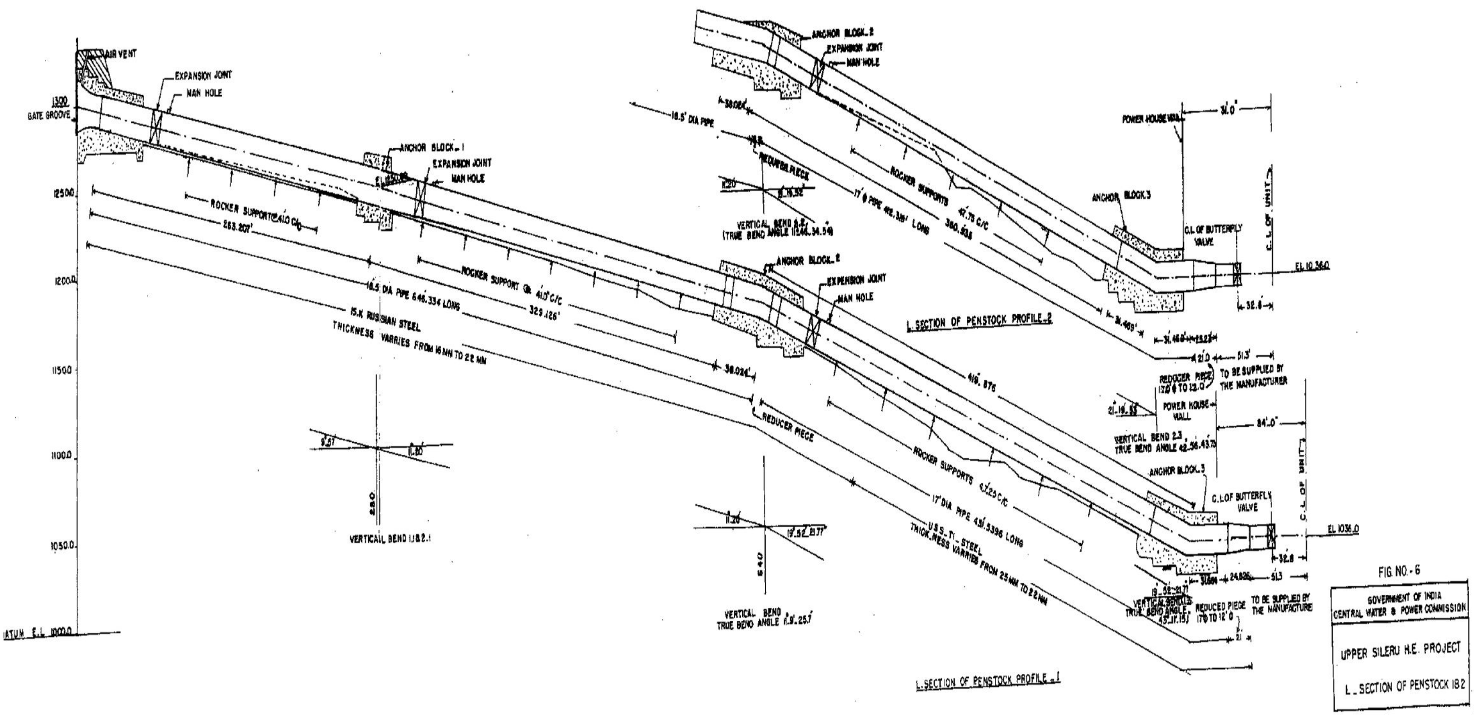
FIG. NO.- 4.

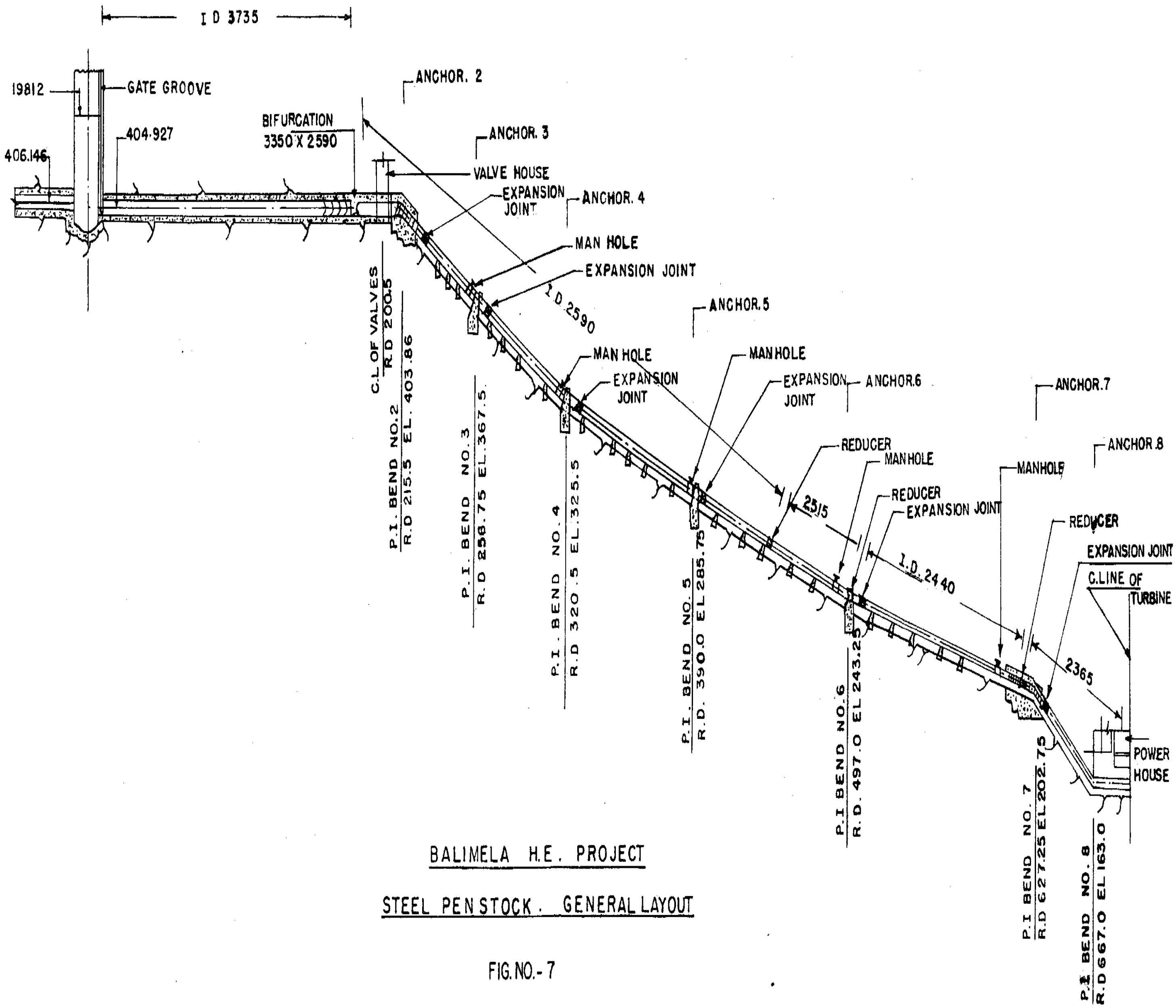
GOVERNMENT OF INDIA
CENTRAL WATER & POWER COMMISSION

JAWAHAR SAGAR H.E. PROJECT
X- SEC: OF POWER DAM
AND POWER HOUSE



PONG DAM PROJECT
FIG.NO.5

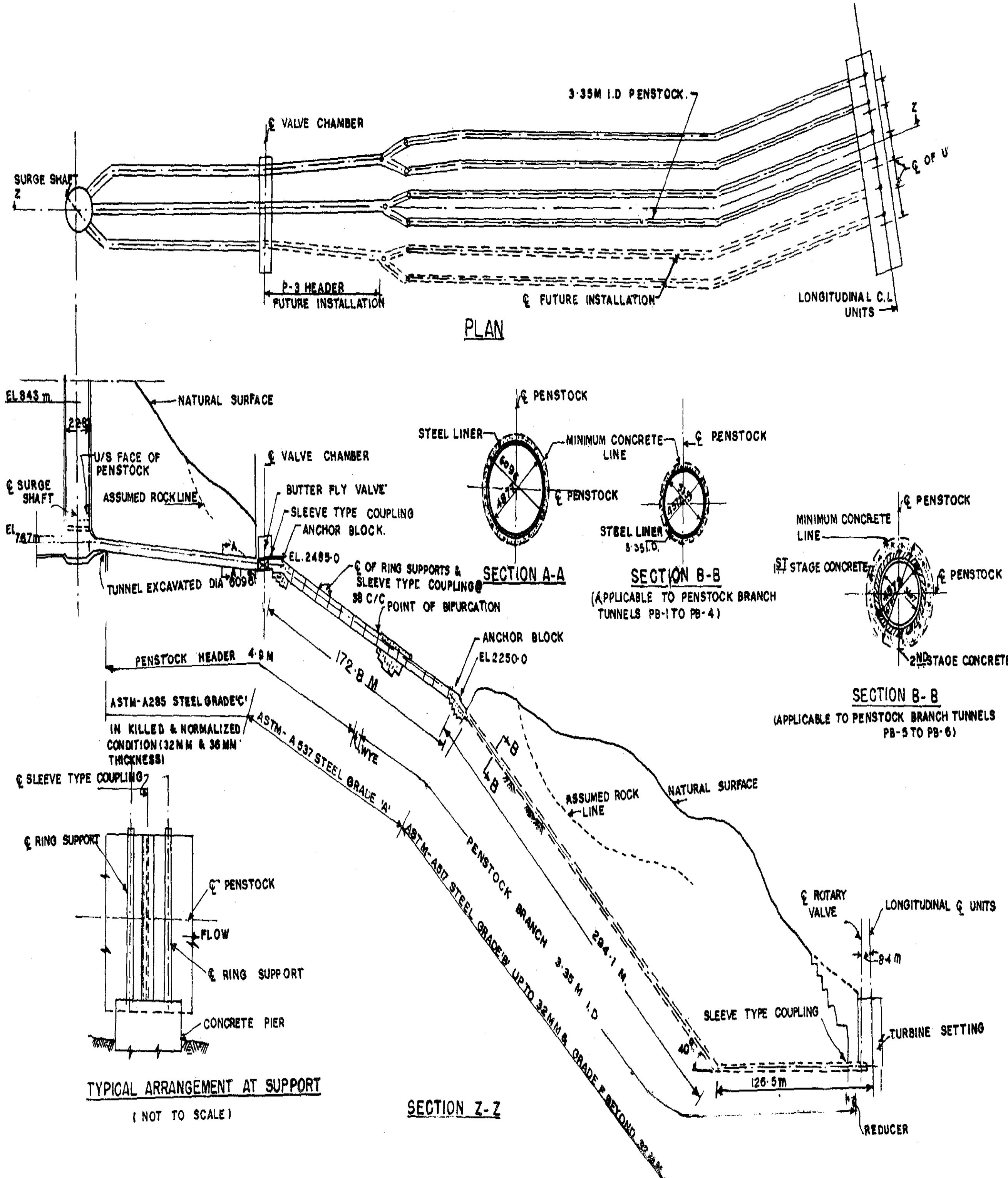

AIR VENT
EXPANSION JOINT
MAN HOLE
GATE GROOVE
ANCHOR BLOCK - 1
ROCKER SUPPORT @ 41.0' C/C
18.5' DIA PIPE
15.K RUSSIAN STEEL
THICKNESS VARRIES FROM 16 MM TO 22 MM
VERTICAL BEND 1 1 & 2.1
REDUCER PIECE
ANCHOR BLOCK - 2
ROCKER SUPPORTS
17' DIA PIPE
U.S.S. T1 - STEEL
THICKNESS VARRIES FROM 25 MM TO 22 MM
VERTICAL BEND
ANCHOR BLOCK 3
POWER HOUSE WALL
C.L OF BUTTERFLY VALVE
C.L OF UNIT
TO BE SUPPLIED BY THE MANUFACTURER
L. SECTION OF PENSTOCK PROFILE - 2
L. SECTION OF PENSTOCK PROFILE - 1
FIG NO. - 6
GOVERNMENT OF INDIA
CENTRAL WATER & POWER COMMISSION
UPPER SILERU H.E. PROJECT
L. SECTION OF PENSTOCK 1&2



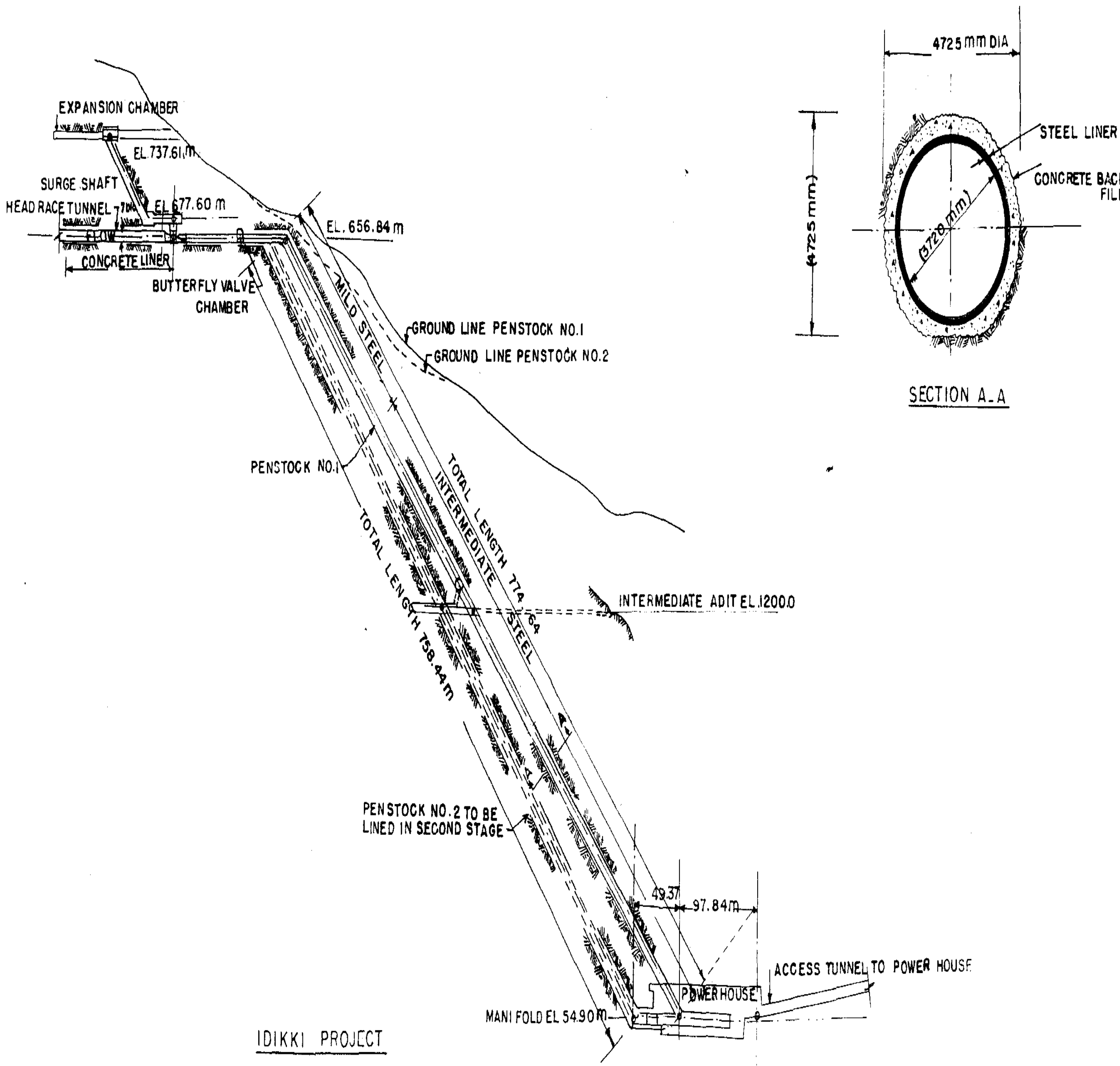
BALIMELA H.E. PROJECT

STEEL PEN STOCK . GENERAL LAYOUT

FIG. NO.- 7



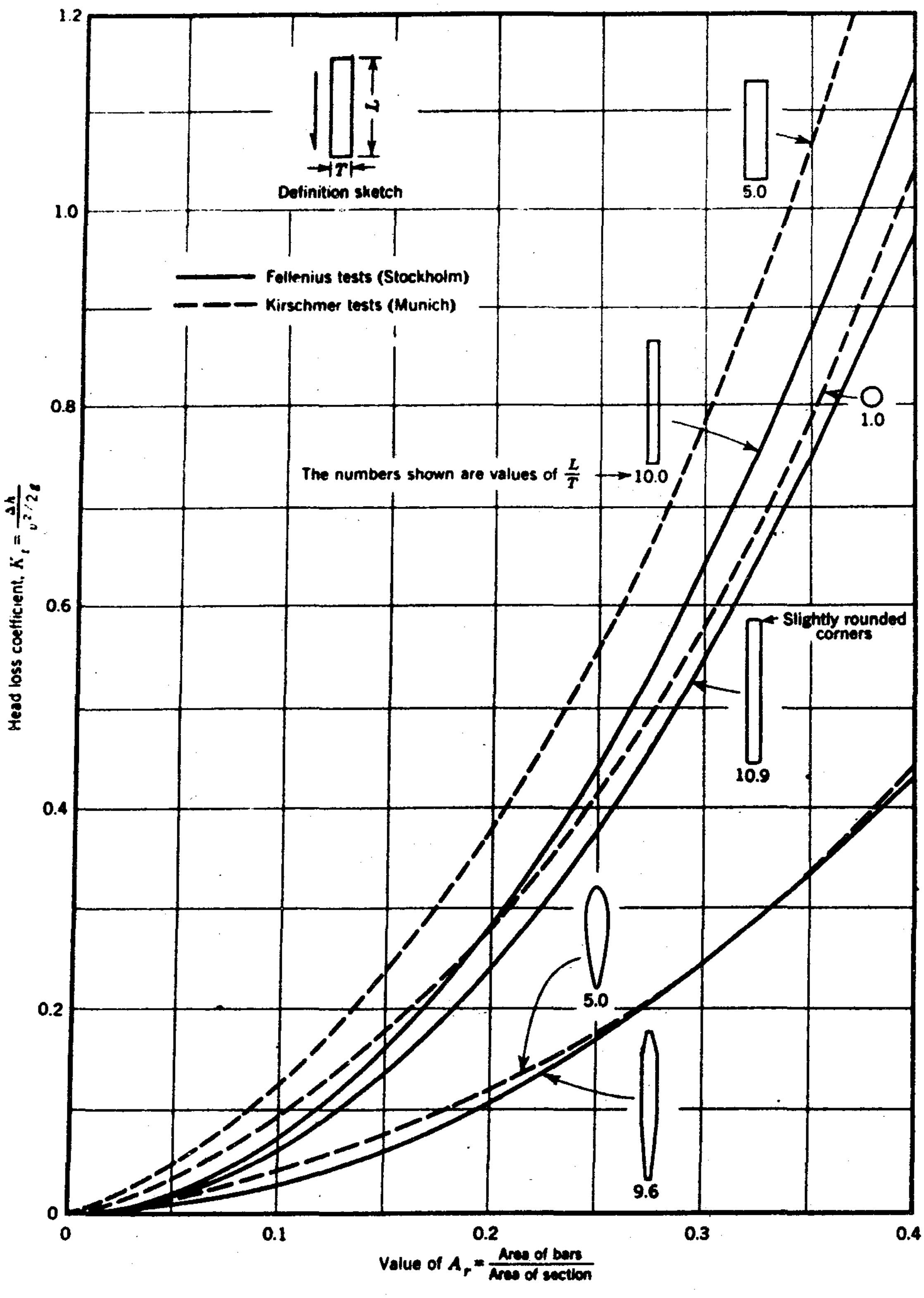
PENSTOCK LAYOUT
BEAS SUTLEJ LINK PROJECT
FIG. NO.- 8



IDIKKI PROJECT

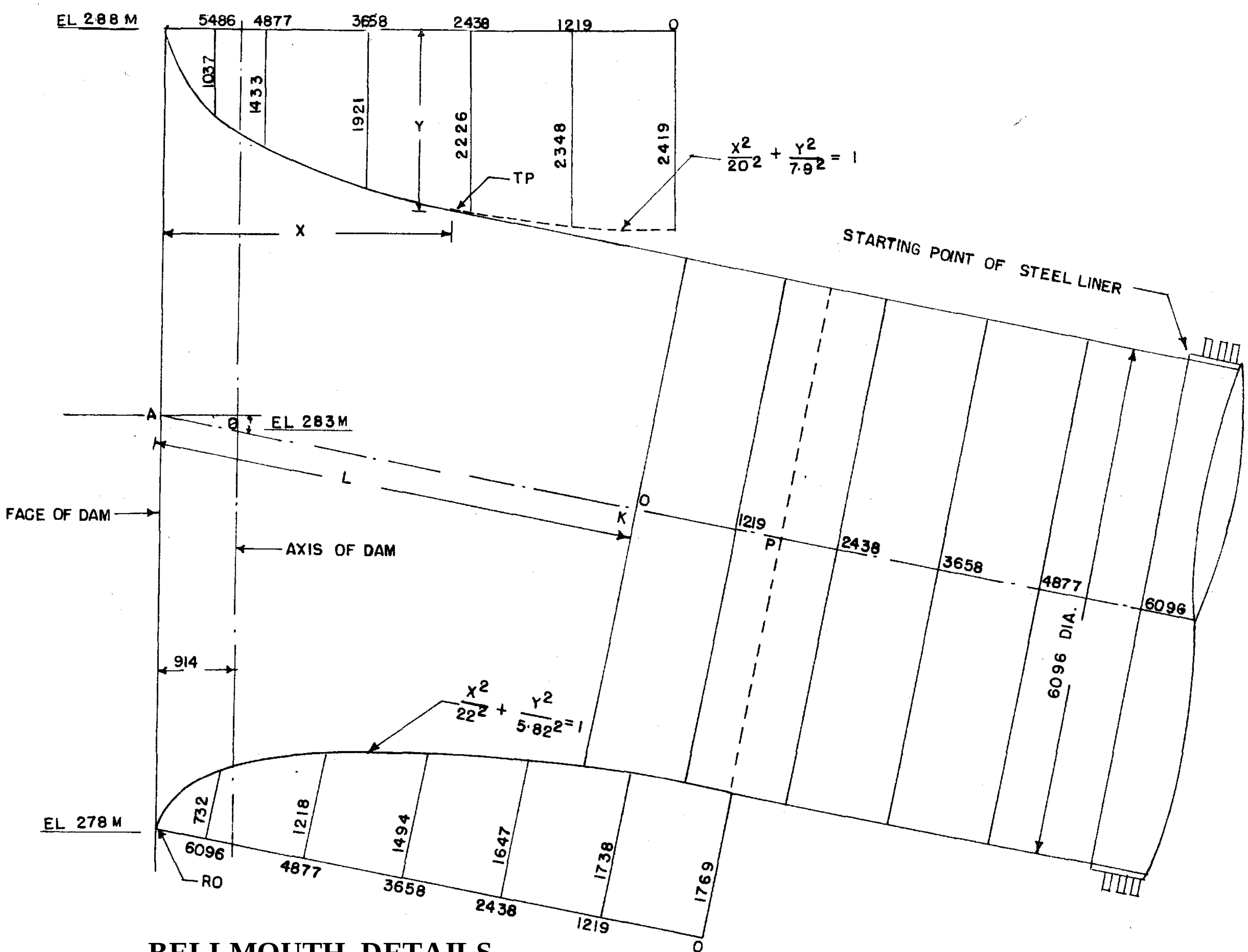
PENSTOCK GENERAL ARRANGEMENT

FIG. NO. 9



1.2
1.0
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
L
T
Definition sketch
5.0
Fellenius tests (Stockholm)
Kirschmer tests (Munich)
1.0
The numbers shown are values of $\frac{L}{T}$
10.0
Slightly rounded corners
10.9
5.0
9.6
Head loss coefficient, $K_t = \frac{\Delta h}{v^2/2g}$
Value of $A_r = \frac{\text{Area of bars}}{\text{Area of section}}$

Fig. No.10



BELLMOUTH DETAILS
FIG.NO.11

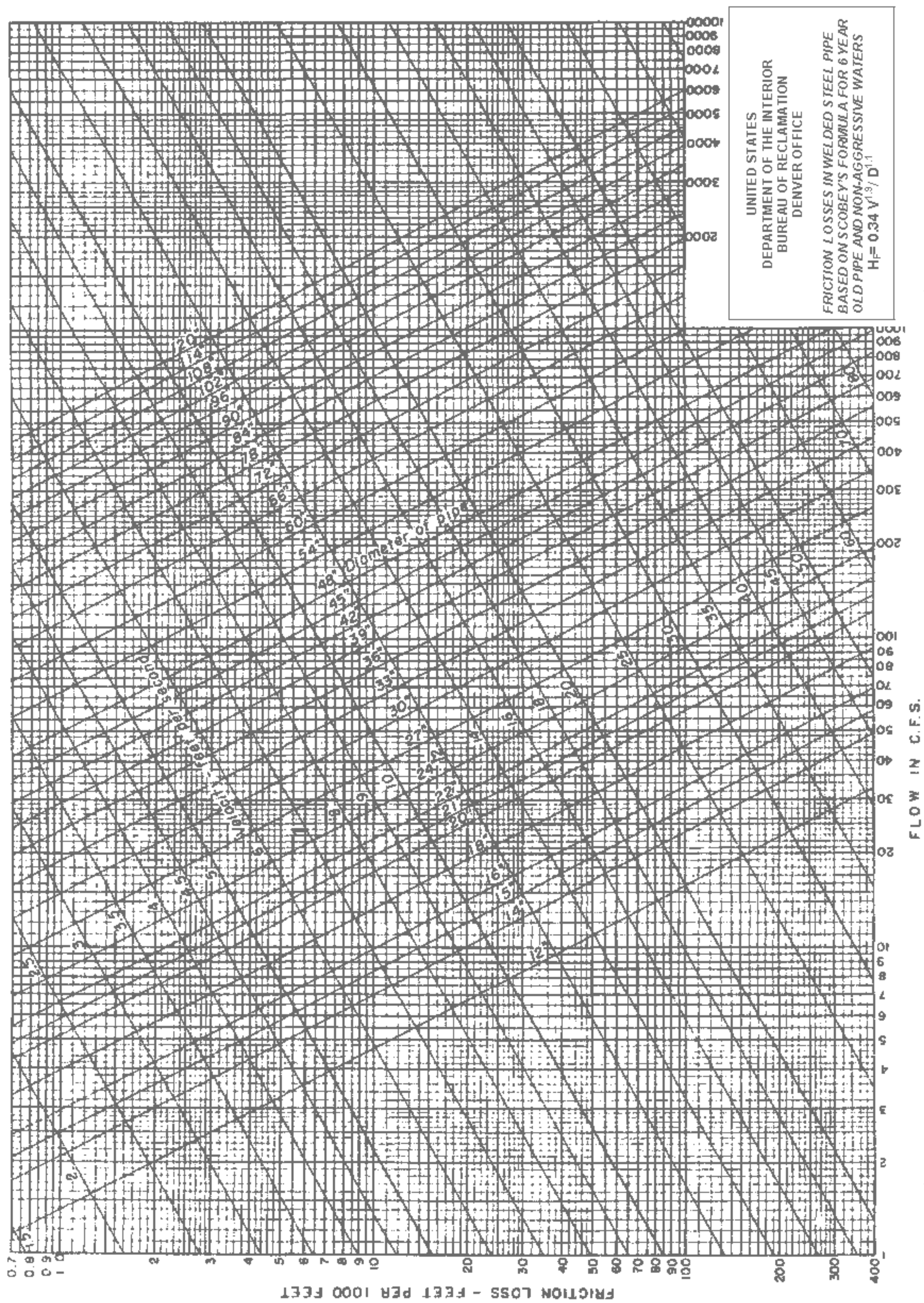
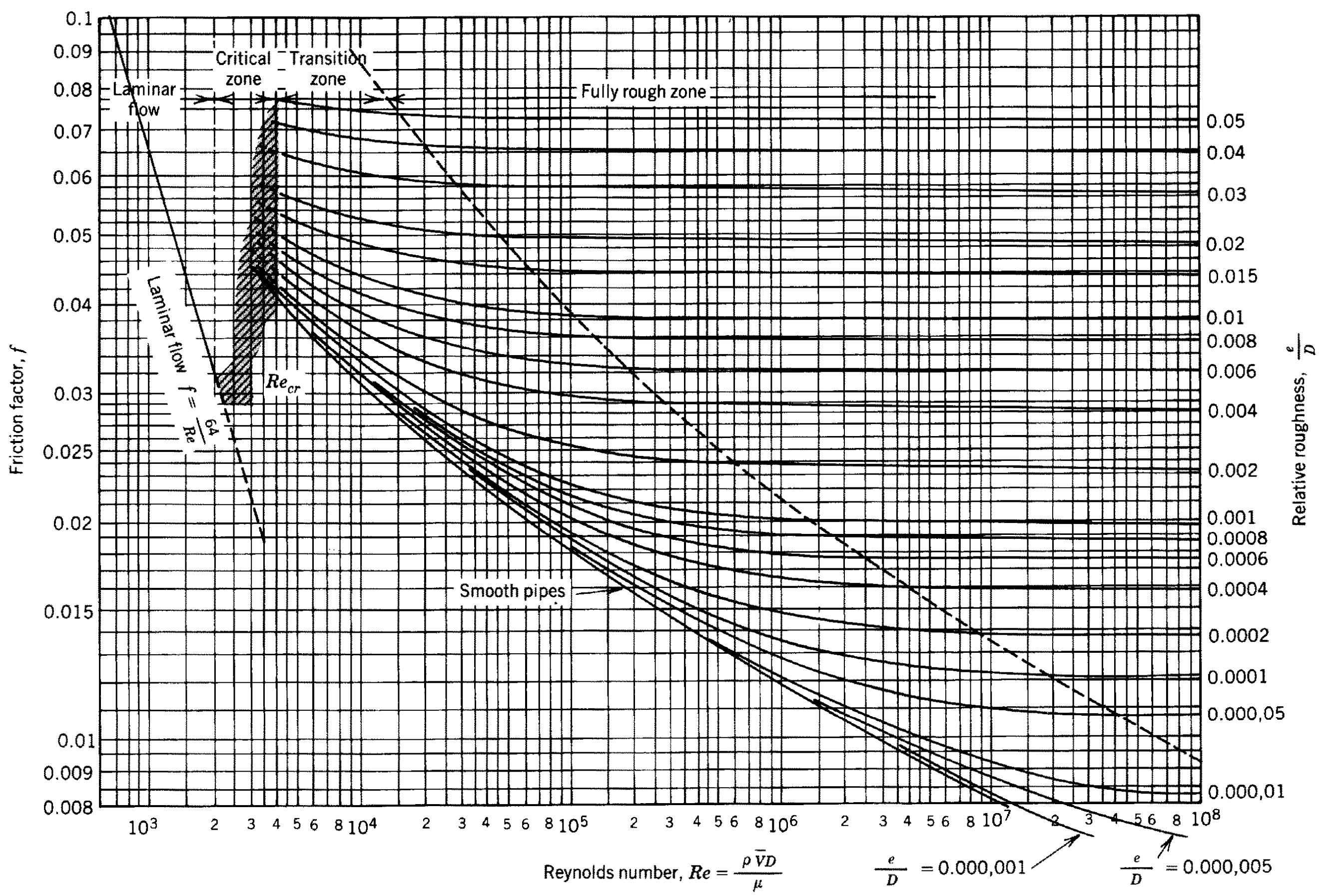

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER OFFICE
FRICTION LOSSES IN WELDED STEEL PIPE
BASED ON SCOBEY'S FORMULA FOR 6 YEAR
OLD PIPE AND NON-AGGRESSIVE WATERS
$H_F = 0.34\, V^{1.9} / D^{1.1}$
Diameter of pipe
Velocity - feet per second
FLOW IN C.F.S.
FRICTION LOSS - FEET PER 1000 FEET

FIG.NO. 12



MOODY DIAGRAM FOR FRICTION IN PIPES

FIG. NO.13

LOSS COEFFICIENTS FOR PIPE BENDS OF SMOOTH INTERIOR

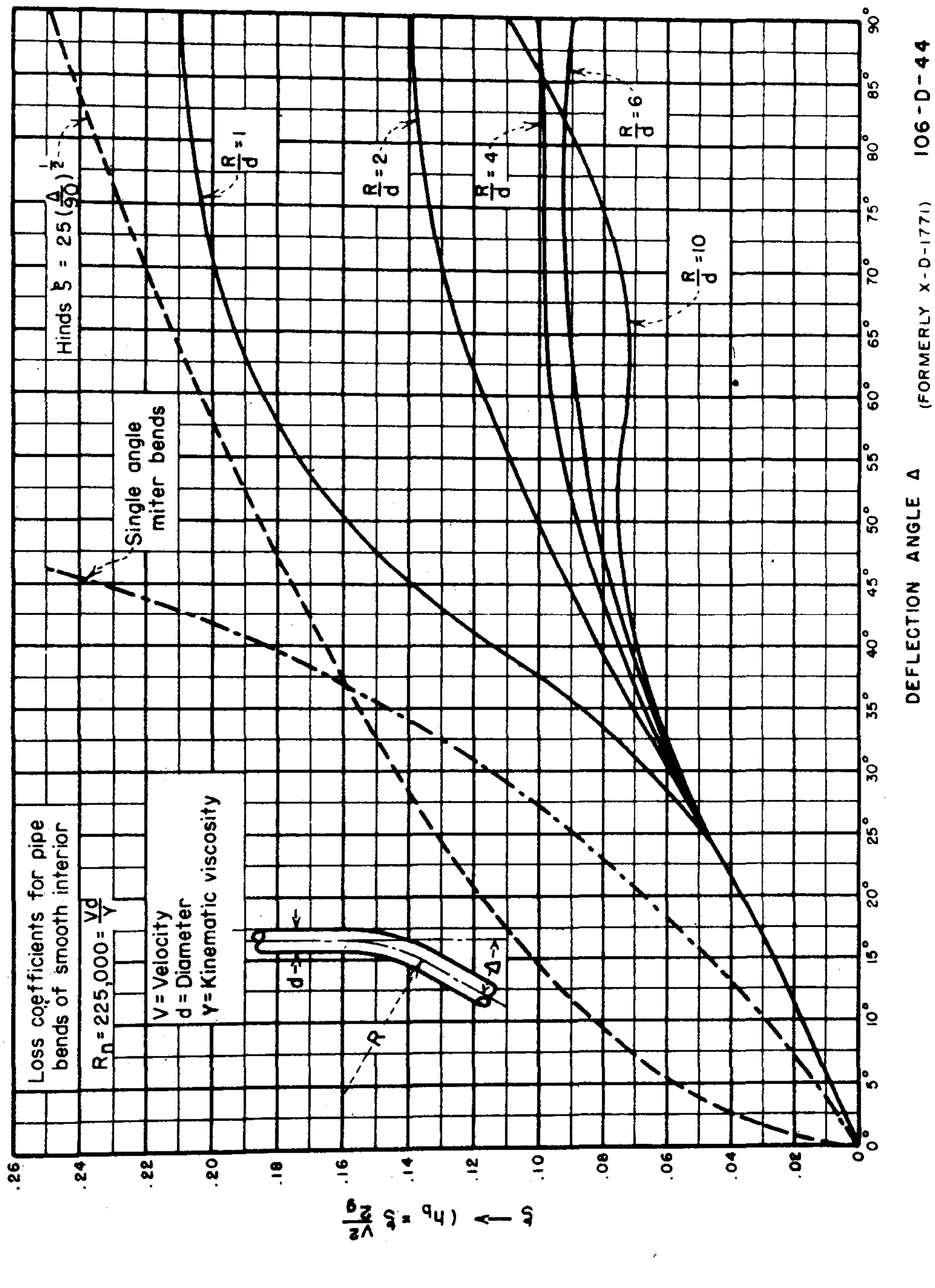
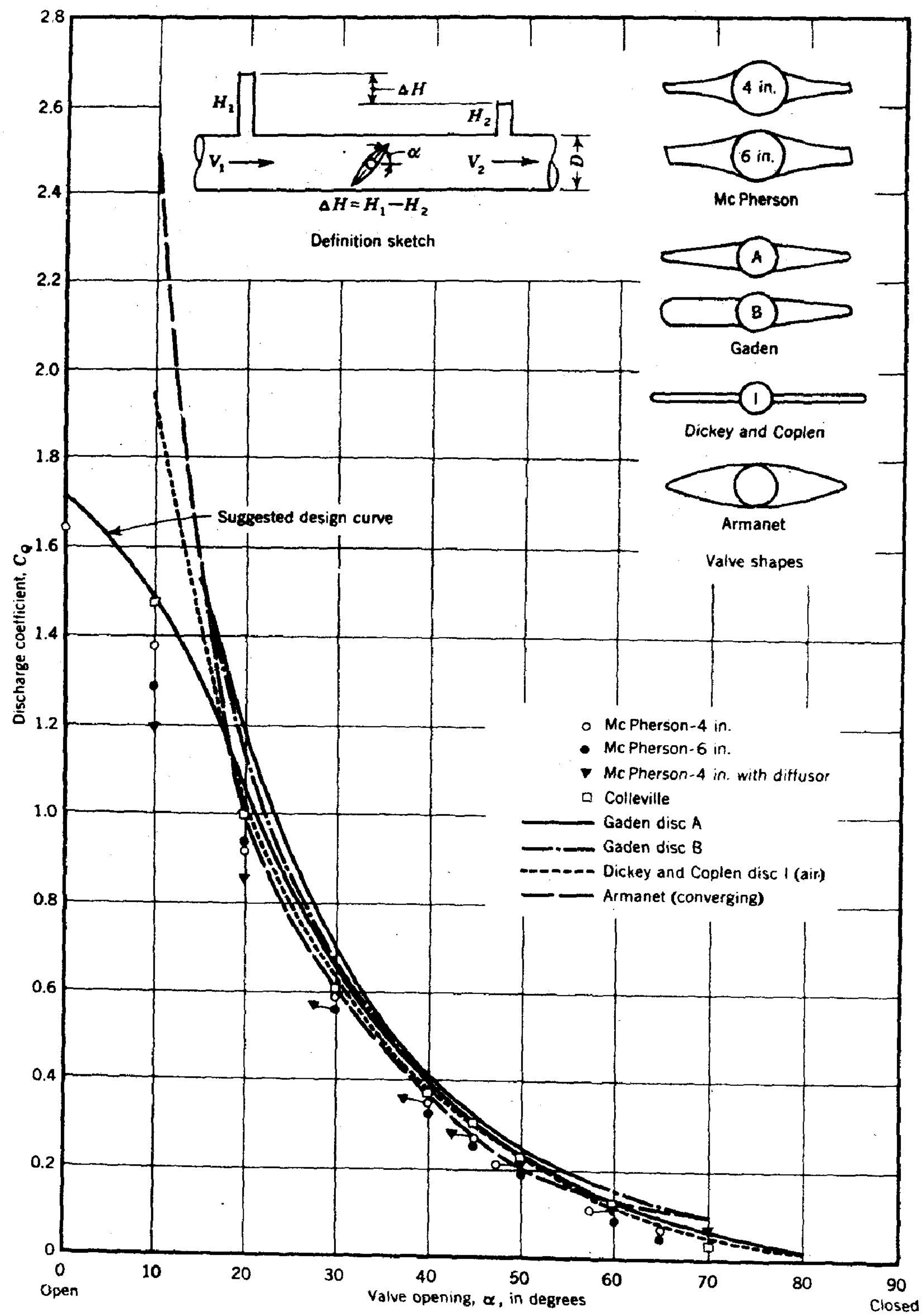
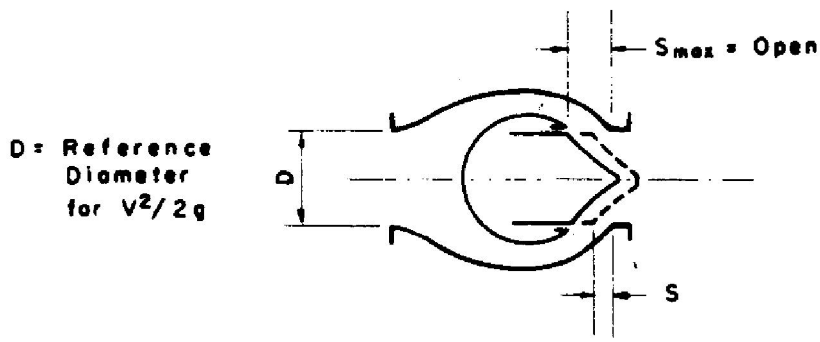


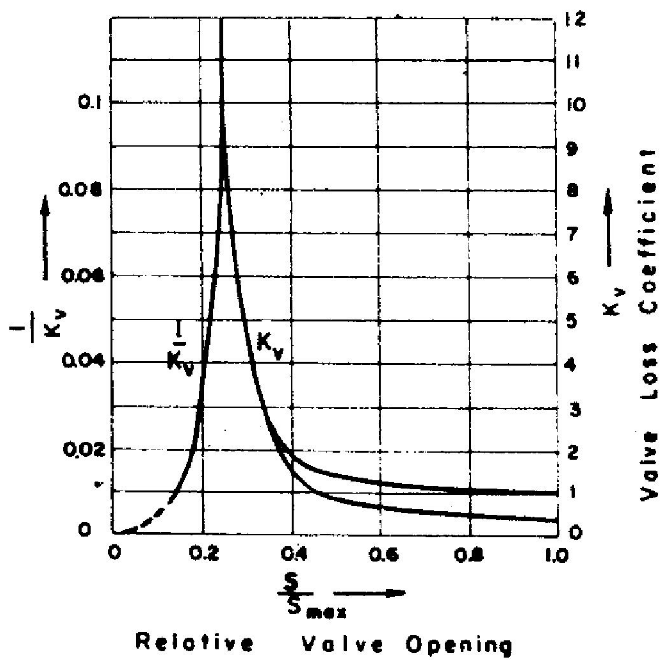
FIG. NO.14



H₁
ΔH
H₂
V₁
α
V₂
D
ΔH = H₁ − H₂
Definition sketch
4 in.
6 in.
Mc Pherson
A
B
Gaden
I
Dickey and Coplen
Armanet
Valve shapes
Suggested design curve
Discharge coefficient, Cq
Mc Pherson-4 in.
Mc Pherson-6 in.
Mc Pherson-4 in. with diffusor
Colleville
Gaden disc A
Gaden disc B
Dickey and Coplen disc I (air)
Armanet (converging)
0 Open
90 Closed
Valve opening, α, in degrees

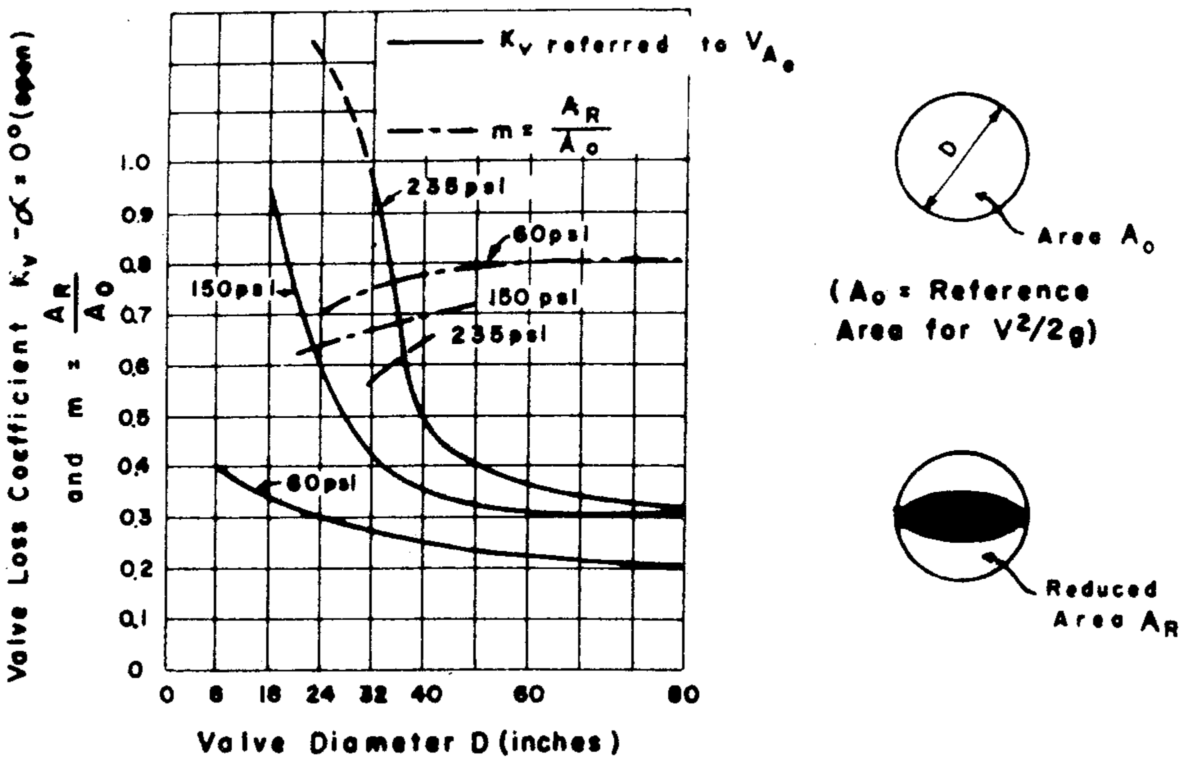
FIG.NO.15





– TYPICAL CHARACTERISTICS OF REGULATING NEEDLE VALVES

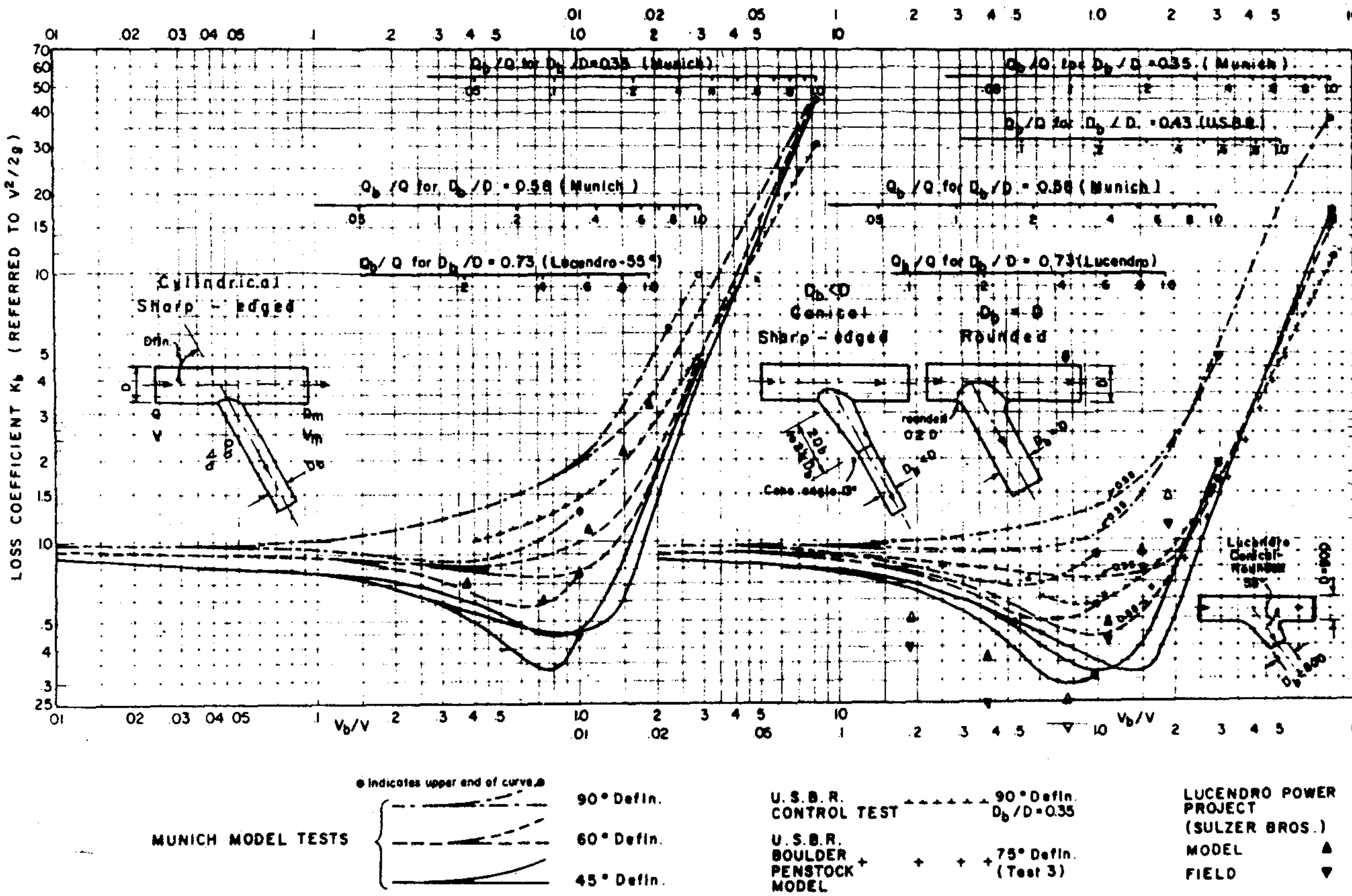
FIG.NO.16



—GENERAL TREND OF K_V (OPEN) AND RESTRICTION OF PASSAGE FOR BUTTERFLY VALVES

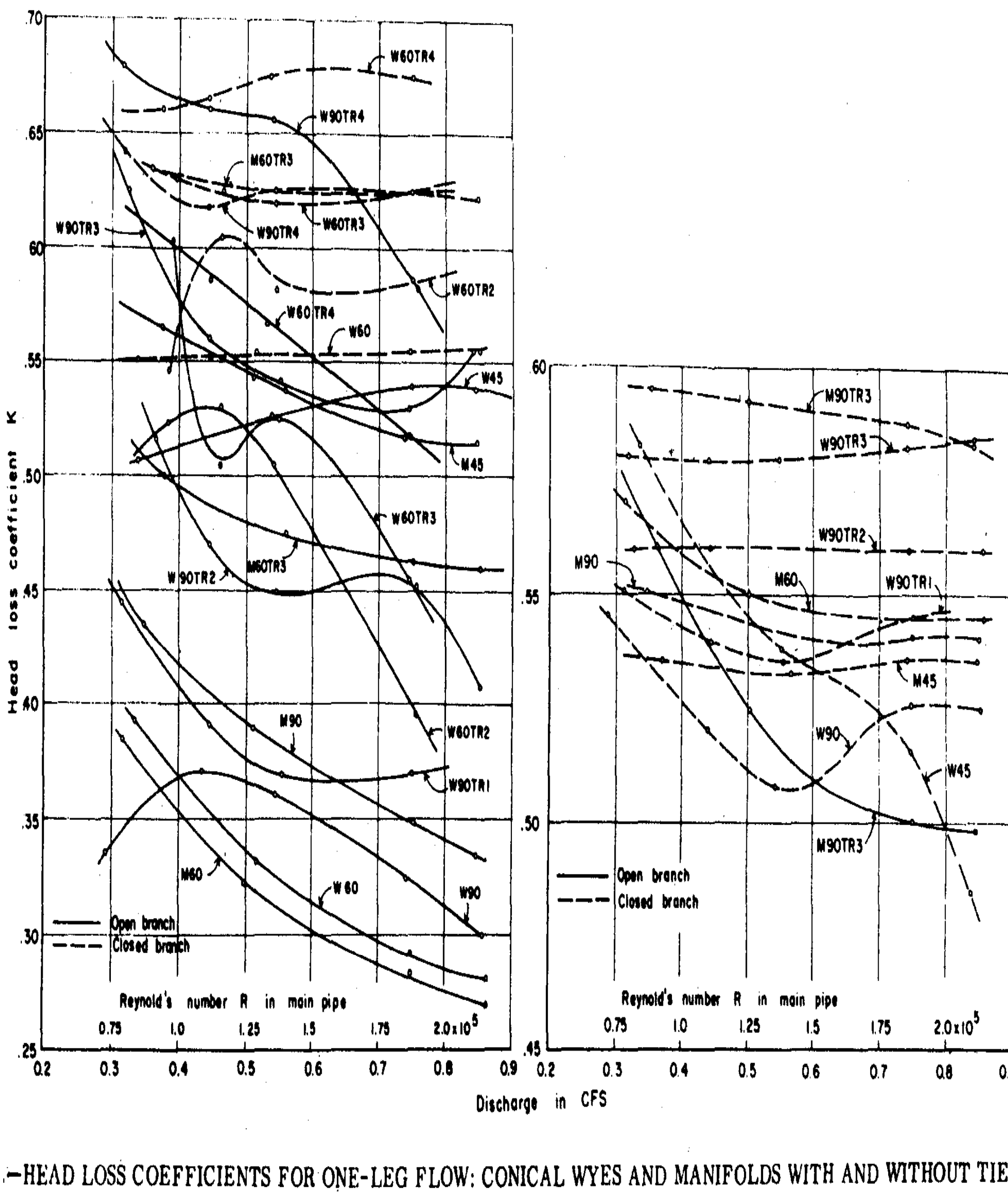
FIG.NO.17

Fig. 18

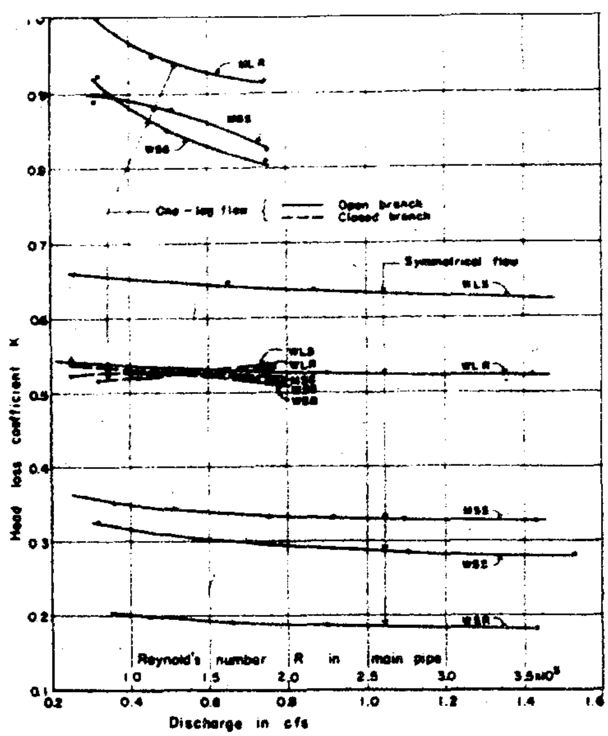


.—LOSS AT PIPE JUNCTIONS WITH DIVIDING FLOW

Fig. 19



.—HEAD LOSS COEFFICIENTS FOR ONE-LEG FLOW: CONICAL WYES AND MANIFOLDS WITH AND WITHOUT TIE-ROD



HEAD LOSS COEFFICIENTS FOR SYMMETRICAL AND ONE-LEG FLOW: SPHERICAL WYES AND MANIFOLDS

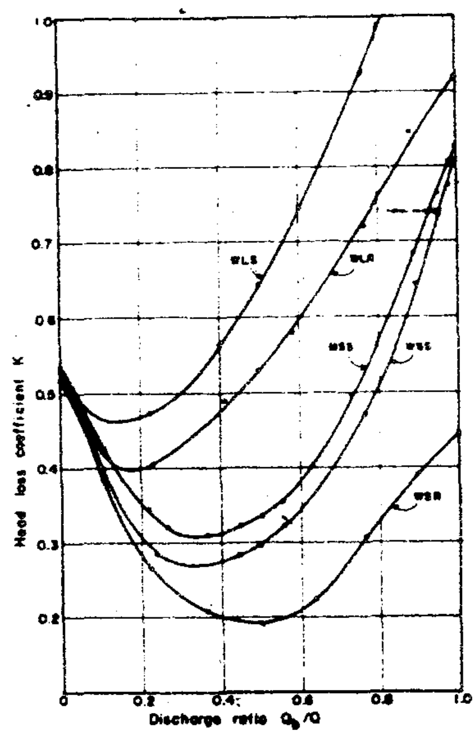


FIG. 11.—HEAD LOSS COEFFICIENTS FOR UNSYMMETRICAL FLOW: SPHERICAL WYES AND MANIFOLDS

FIG.NO.20

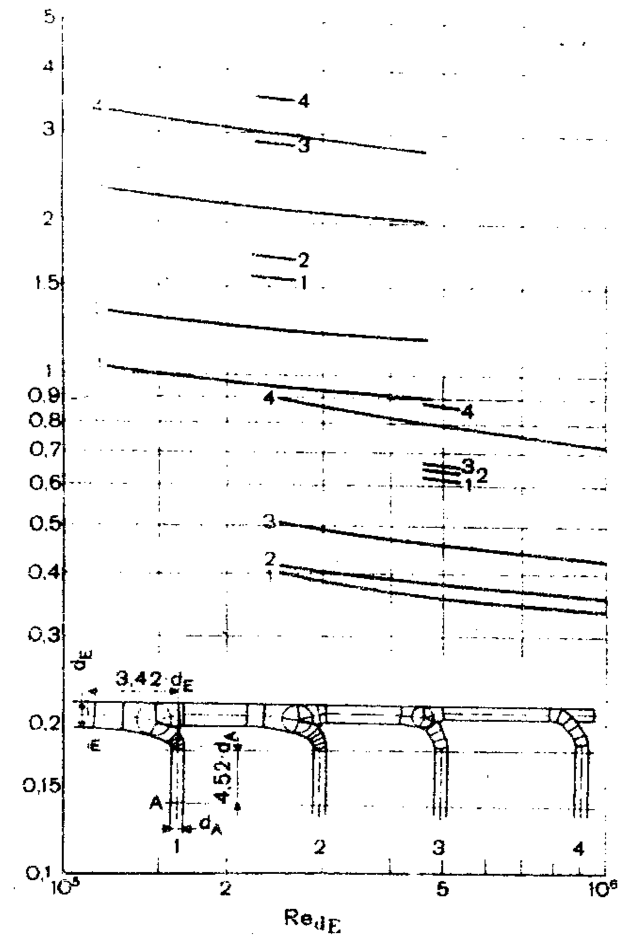


Fig. 8 Pressure loss coefficients resulting from comparison tests on models like Fig. 7. The friction losses of the straight tubes are included. The internally reinforced design is clearly superior to the conventional one.

Top group of curves 1 to 4: part load. Curves 1 and 2 were measured with only branches 1 and 2 open, curves 3 and 4 with only 3 and 4 open, whereas the other two branches were closed.

Lower group: full load; all branches are open.

The corresponding curves printed in black represent the respective losses of a distribution pipe of conventional design (with outer reinforcement).

E = entrance measuring cross section

A = exit measuring cross section

$$\zeta = \frac{H_v}{v^2_{inlet}/2g}$$

H_v = loss of head between the inlet and the individual exit cross sections.

FIG.NO.21

Fig. 22

EXPLANATION

P - Pressure Rise as a proportion of h_{max}
h - Pressure Rise or excess Head above normal, Feet
h_{max} - Pressure Rise of instantaneous closure = aV_0/g, Feet
g - Acceleration of Gravity, Feet per second, per second
a - Velocity of Pressure Wave along Pipe, Feet per second. See graph.
V_0 - Velocity in Pipe near gate, corresponding to H_0 and Q_0. Feet per second.
H_0 - Initial Steady Head near gate, corresponding to V_0, Feet.
Q_0 - Initial Steady Flow in pipe prior to start of gate closure corresponding to H_0. Cu. Ft. per sec.
T - Time of gate closure travel. Seconds
L - Length of pipe from gate to forebay or other point of relief, Feet.

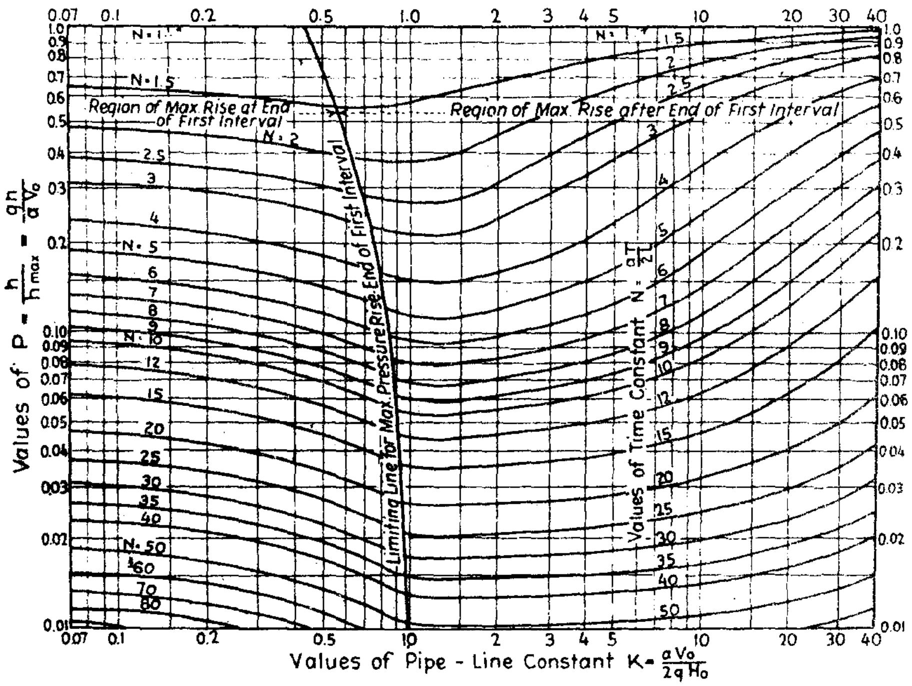


CHART SHOWING MAXIMUM PRESSURE RISE WITH UNIFORM GATE MOTION AND COMPLETE CLOSURE : BASED ON ELASTIC-WATER-COLUMN THEORY

NOTE: Ratio of Pressure Rise "h" to Initial Steady Head "H_0" determined from relation $2KP = h/H_0$

From Mech. Eng. Magazine. FORMERLY X-D-589

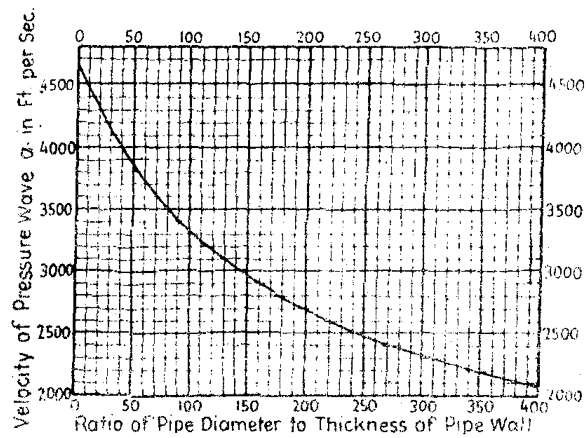
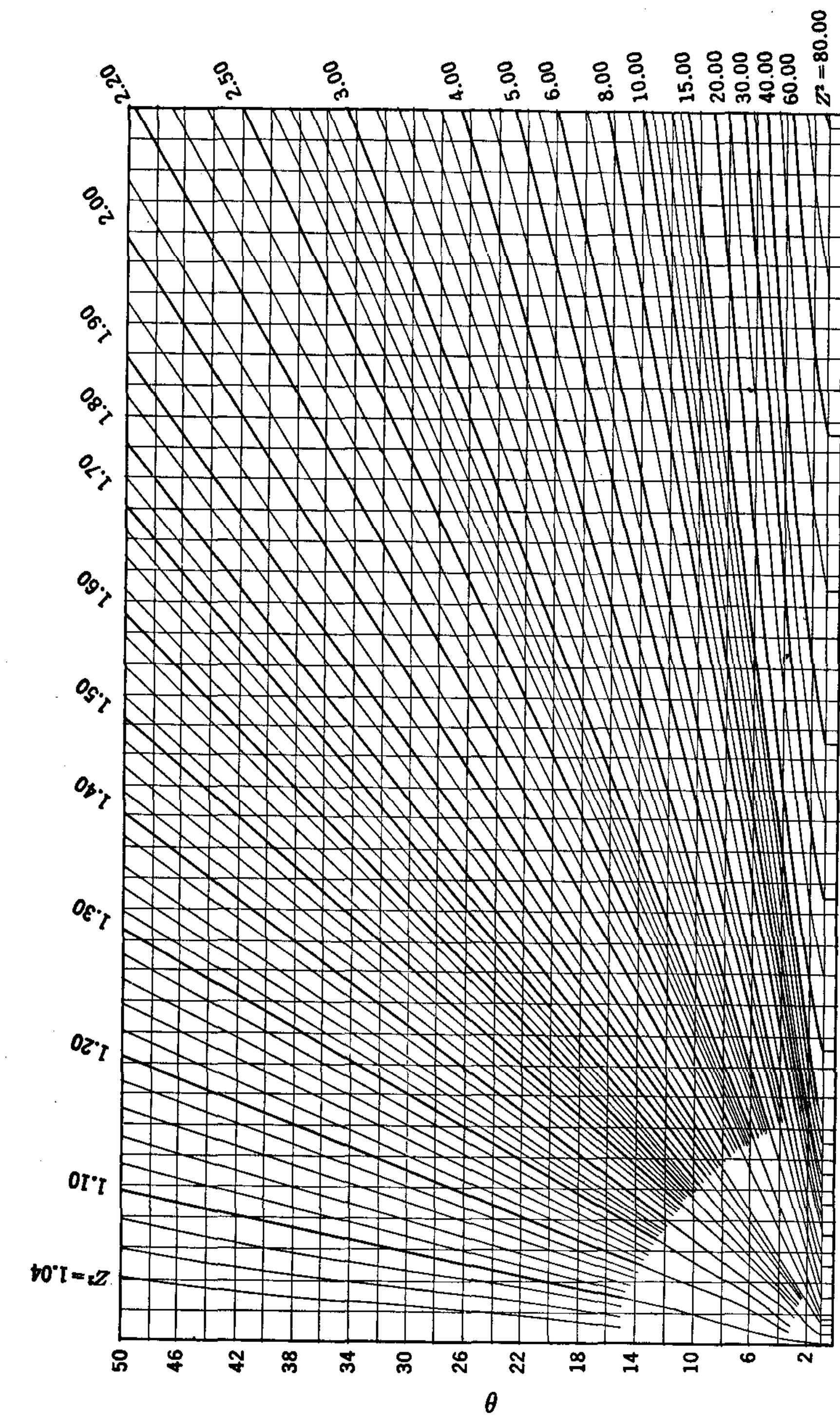


CHART SHOWING VELOCITY OF TRAVEL OF PRESSURE WAVE IN ELASTIC WATER COLUMN

Formula $$a = \frac{4660}{\sqrt{1 + \frac{Kd}{Eb}}} = \frac{4660}{\sqrt{1 + \frac{d}{100b}}}$$

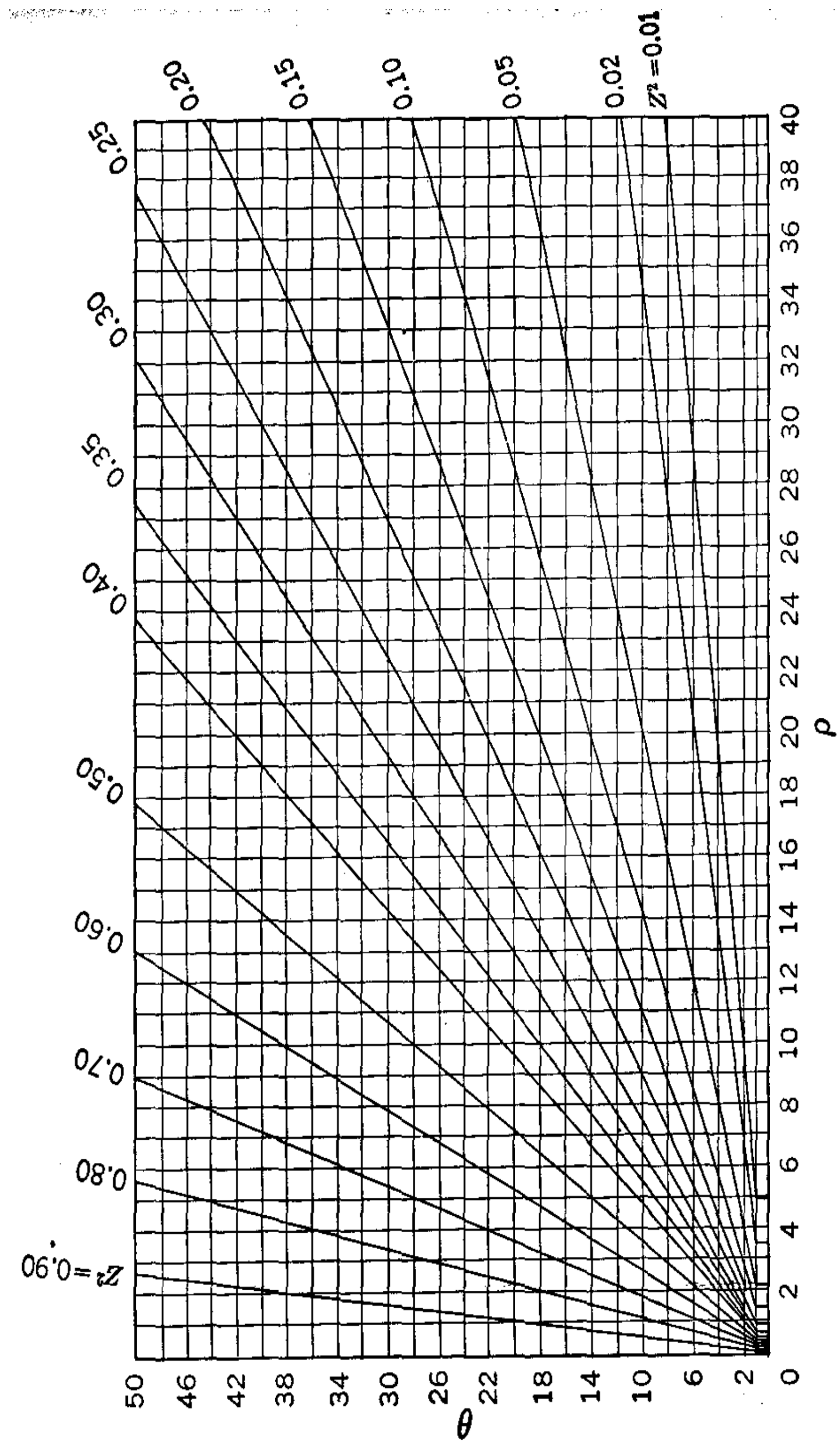
Where a = Velocity of Travel of Pressure Wave Ft. per Sec.
K = Bulk Modulus of Elasticity of Water = 294,000 Lbs. per Sq. In.
E = Young's Modulus for Pipe Walls = 29,400,000 Lbs. per Sq. In. approx. for Steel.
b = Thickness of Pipe Walls, Inches
d = Inside Diameter of Pipe, Inches

106-D-29



Alleivi Chart- Pressure rise for uniform gates and simple conduits. Large values of ρ and θ) . .ASME Paper No. 44-A-42

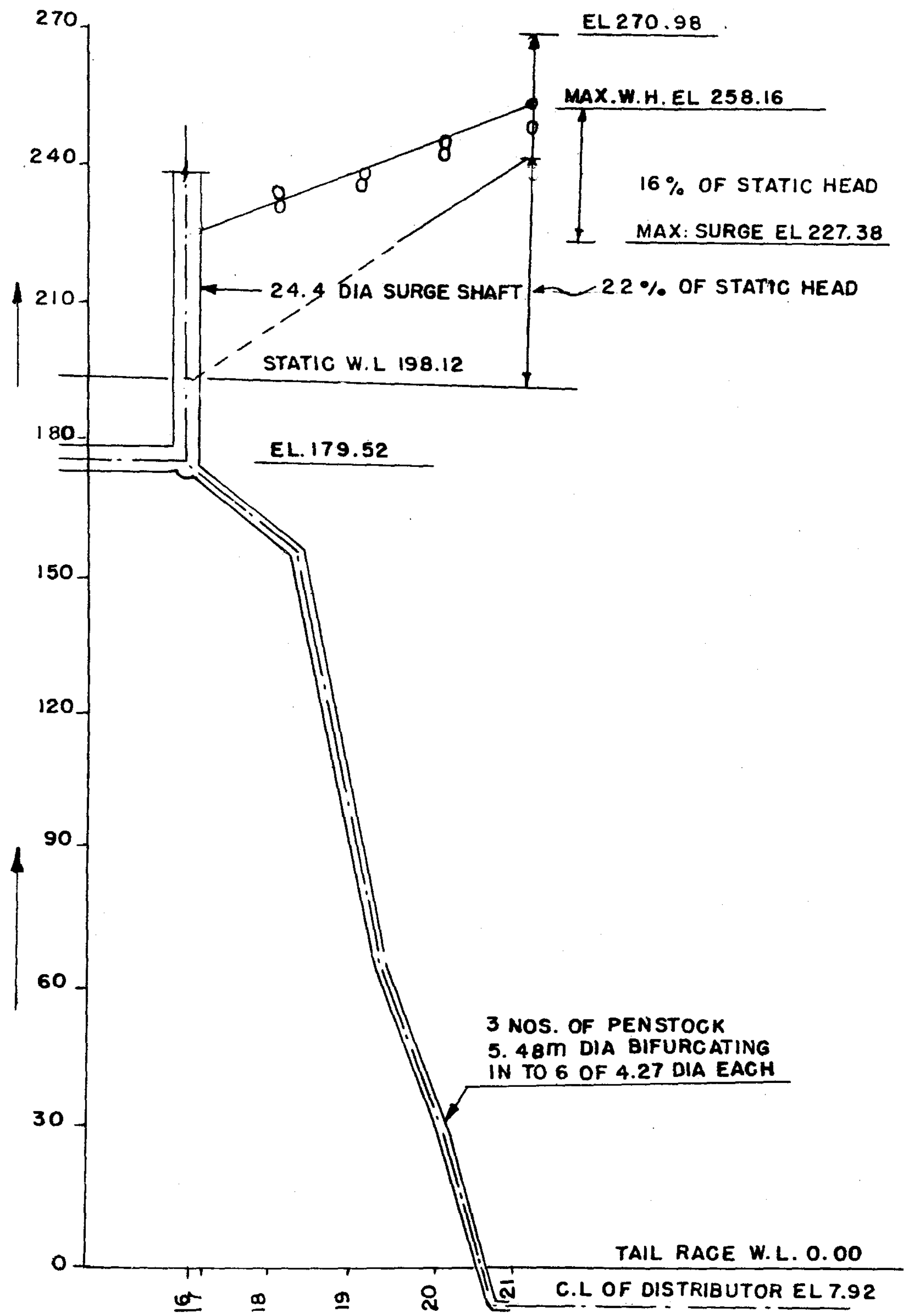
FIG.NO.23



Alleivi Chart- Pressre Drop (ASME Paper No. 44-A-42)

FIG.NO. 24

PRESSURE GRADIENT FOR TURBINE PENSTOCK INSTALLATION



WITH SURGE TANK

FIG.NO.25

ECONOMIC DIAMETER FOR STEEL PENSTOCKS AD PUMP LINES

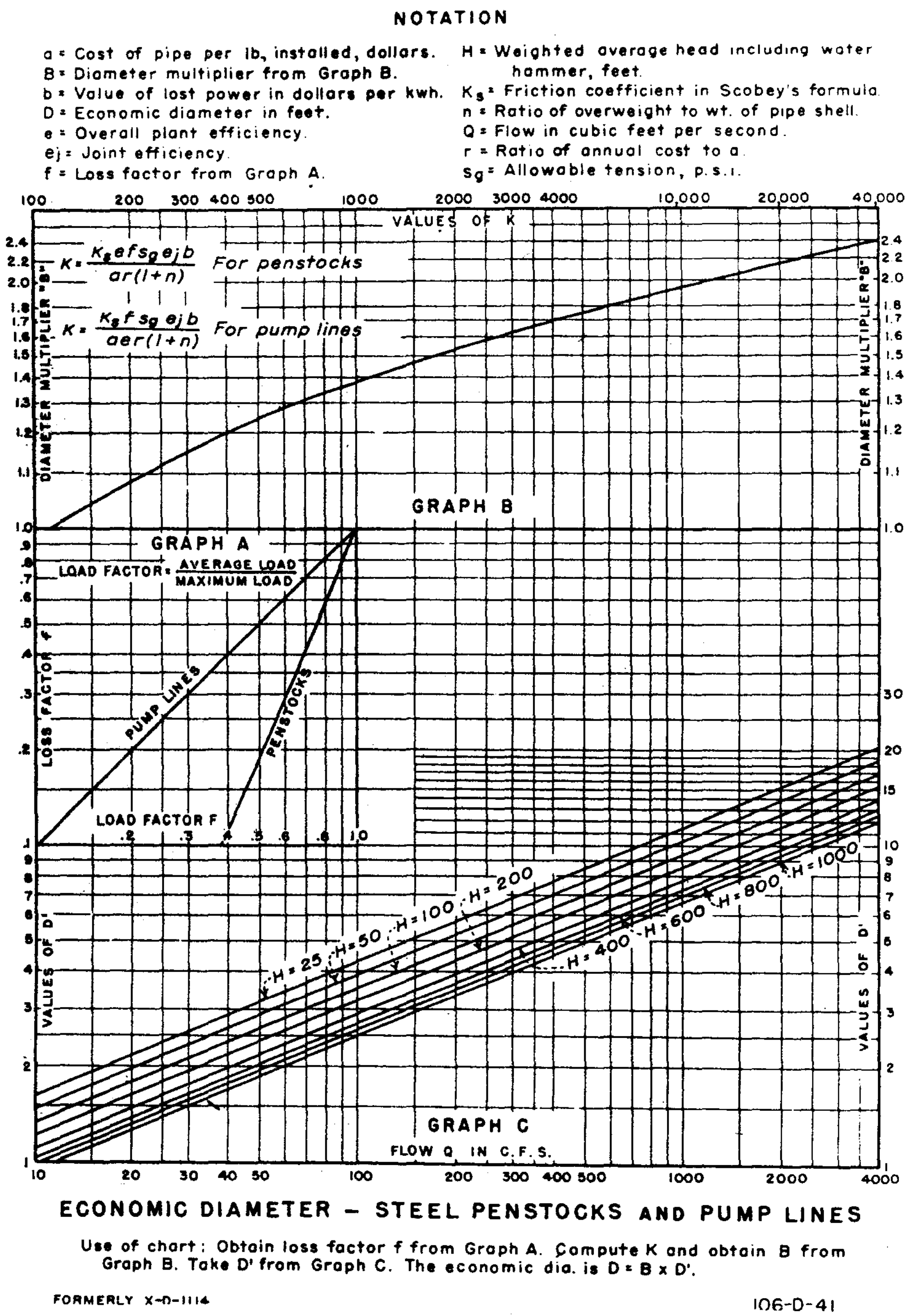


FIG.NO.26

EQUIVALENT STRESS DIAGRAM

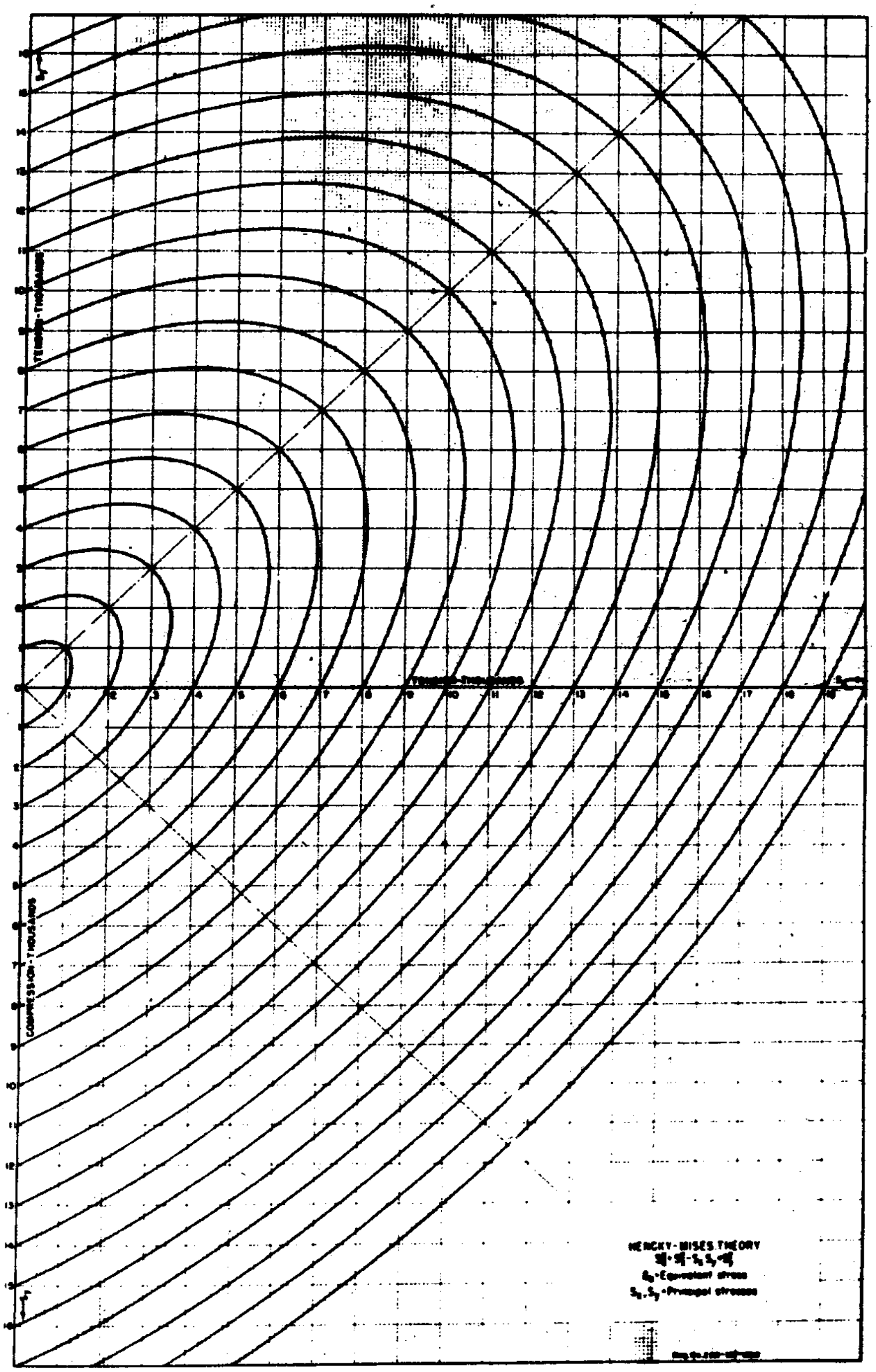


FIG.NO.27

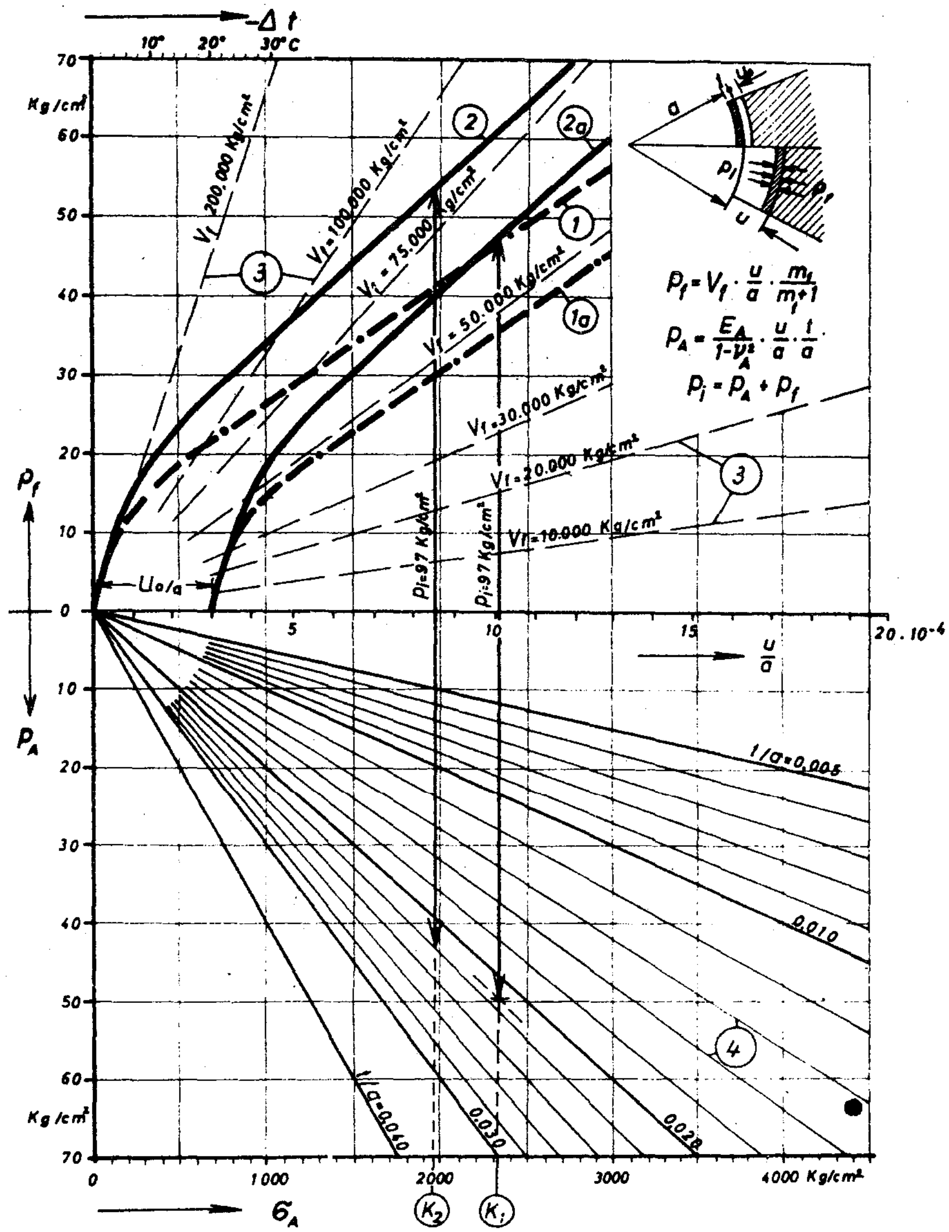


Fig. 7.
Design table for steel linings.

(1) Deformation-line for non grouted laminated limestone according to test-zone F II (*fig.* 9).

(2) Deformation-line for grouted laminated limestone according to test-zone F II (*fig.* 9).

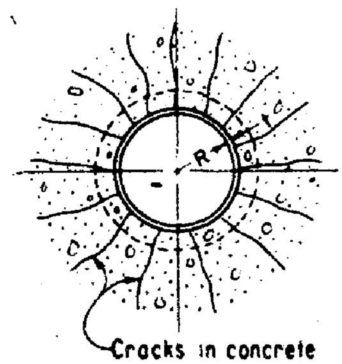
(1 *a*), (2 *a*) Parallelly displaced deformation-lines considering a gap u_0.

(3) Deformation-lines for a constant modulus of deformation V

(4) Portion of internal pressure taken up by the lining for different proportions of thickness to internal radius $\frac{t}{a}$

(K_1), (K_2) Examples of dimensioning according to chapter 8. 1.
Other reference letters, *see* Table 1.

FIG.NO.28



P = Pressure inside pipe.

σ = Circumferential stress in pipe.

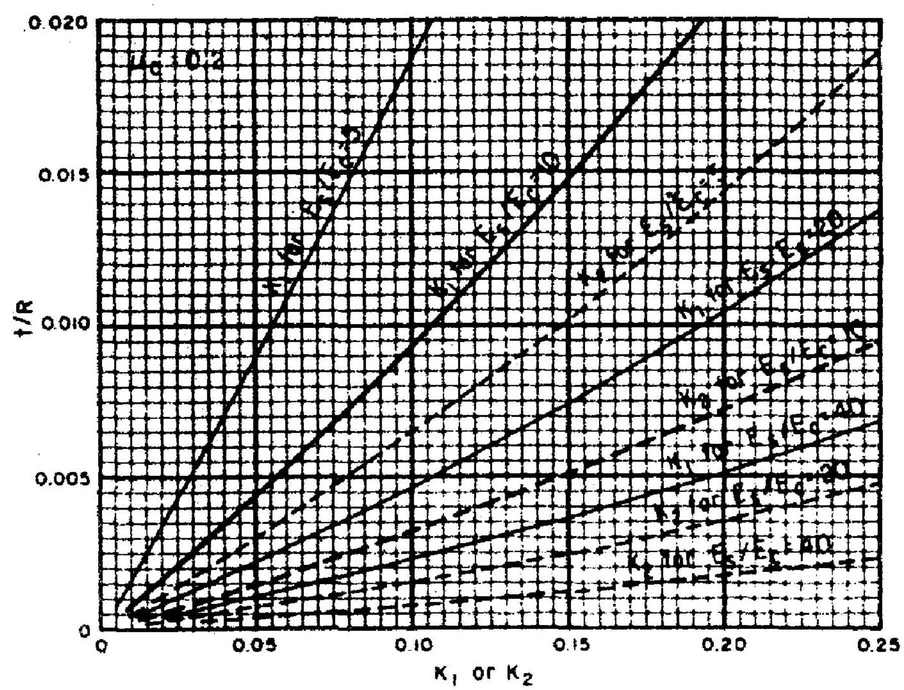
$\sigma_1 = \frac{PR}{t} K_1$ * (For uncracked concrete)

$$K_1 = 1 - \frac{1}{1 + \frac{E_s}{E_c}\frac{t}{R}(1+\mu_c)}$$

$\sigma_2 = \frac{PR}{t} K_2$ * (For cracked concrete, length at cracks ≥ 9R)

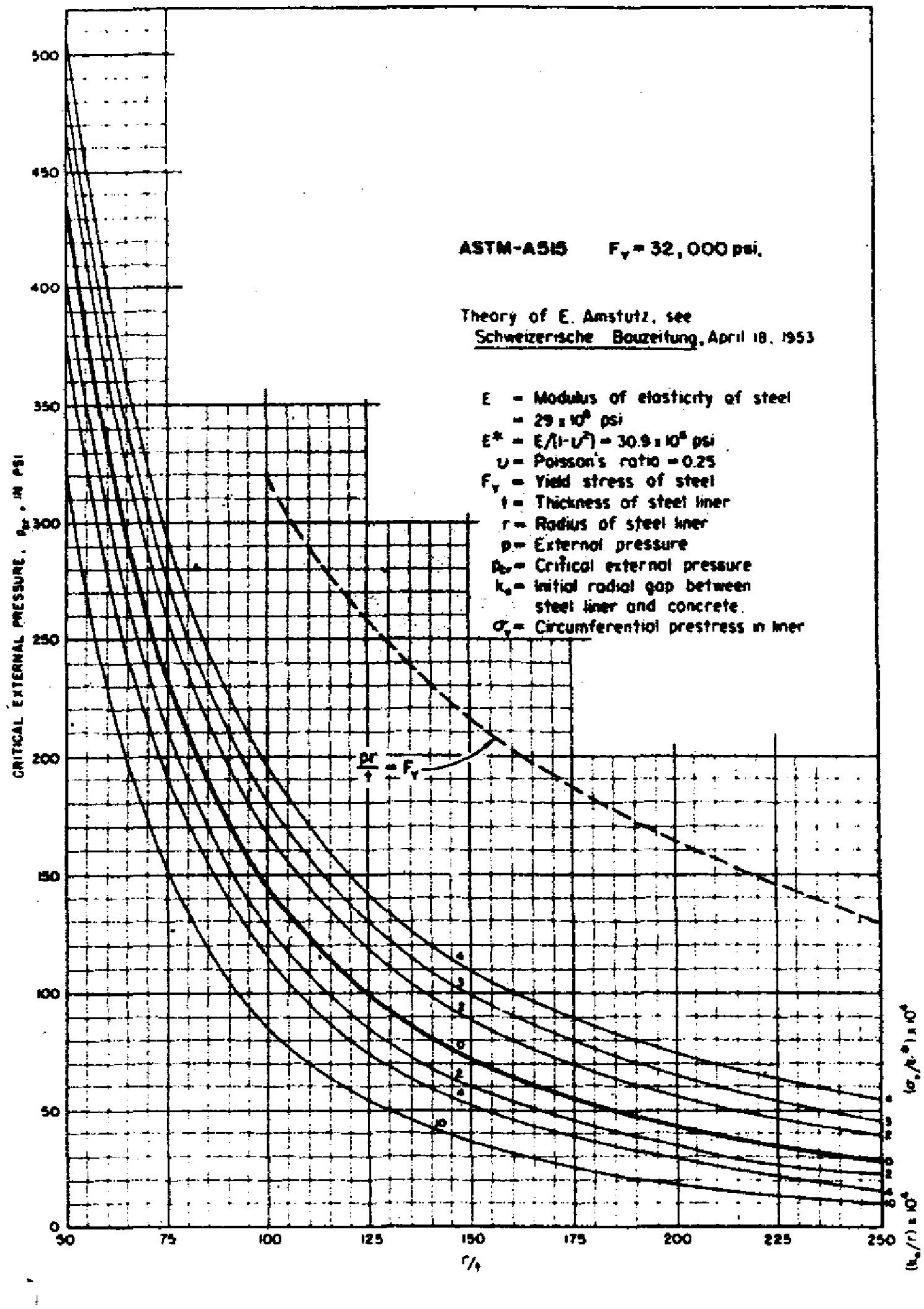
$$K_2 = 1 - \frac{1}{1 + 3.5\frac{E_s}{E_c}\frac{t}{R}}$$

*Use σ_1 when internal pressure is less than tensile strength of concrete (abt. 250 p.s.i)
Use σ_2 when internal pressure is more than tensile strength of concrete (abt. 250 p.s.i)



STRESS ANALYSIS FOR PIPE SHELL EMBEDDED IN CONCRETE

FIG.NO.29



CRITICAL EXTERNAL PRESSURE FOR PLATE STEEL LINER

FIG.NO.30

EQUATIONS :—

$$\ldots + \frac{\sigma_N}{E^*}\Big)\left(1 + \frac{3K^2\sigma_H}{E^*}\right) = 1.68\,K\left(\frac{\sigma_{\text{[illegible]}} - \sigma_N}{E^*}\right)\left(1 - \frac{K}{4}\,\frac{\sigma_y - \sigma_N}{E^*}\right)$$

AND

$$1 - \frac{P\,K}{2\,\sigma_N} = 0.175\,\frac{K}{E^*}\left(\sigma_y^* - \sigma_N\right)$$

$$E^* = \frac{E}{1-\nu^2} \qquad \sigma_y^* = \frac{\sigma_y}{\sqrt{1-\nu+\nu^2}}$$

$$K = \frac{D}{t}$$

$$\frac{Y_o}{R} = 3 \times 10^{-4} \quad \& \quad E = 30 \times 10^{6}\ \text{PSI}$$

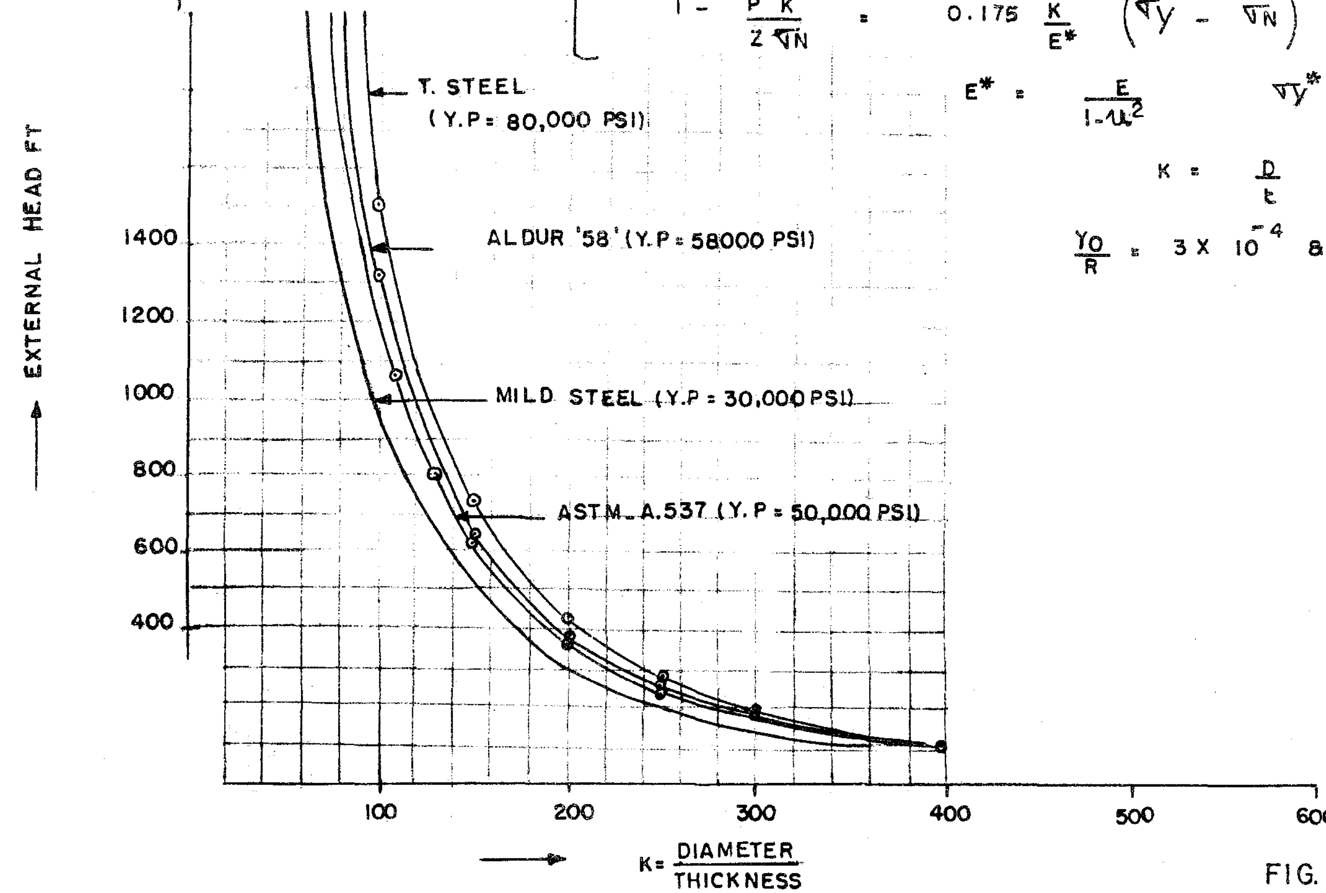
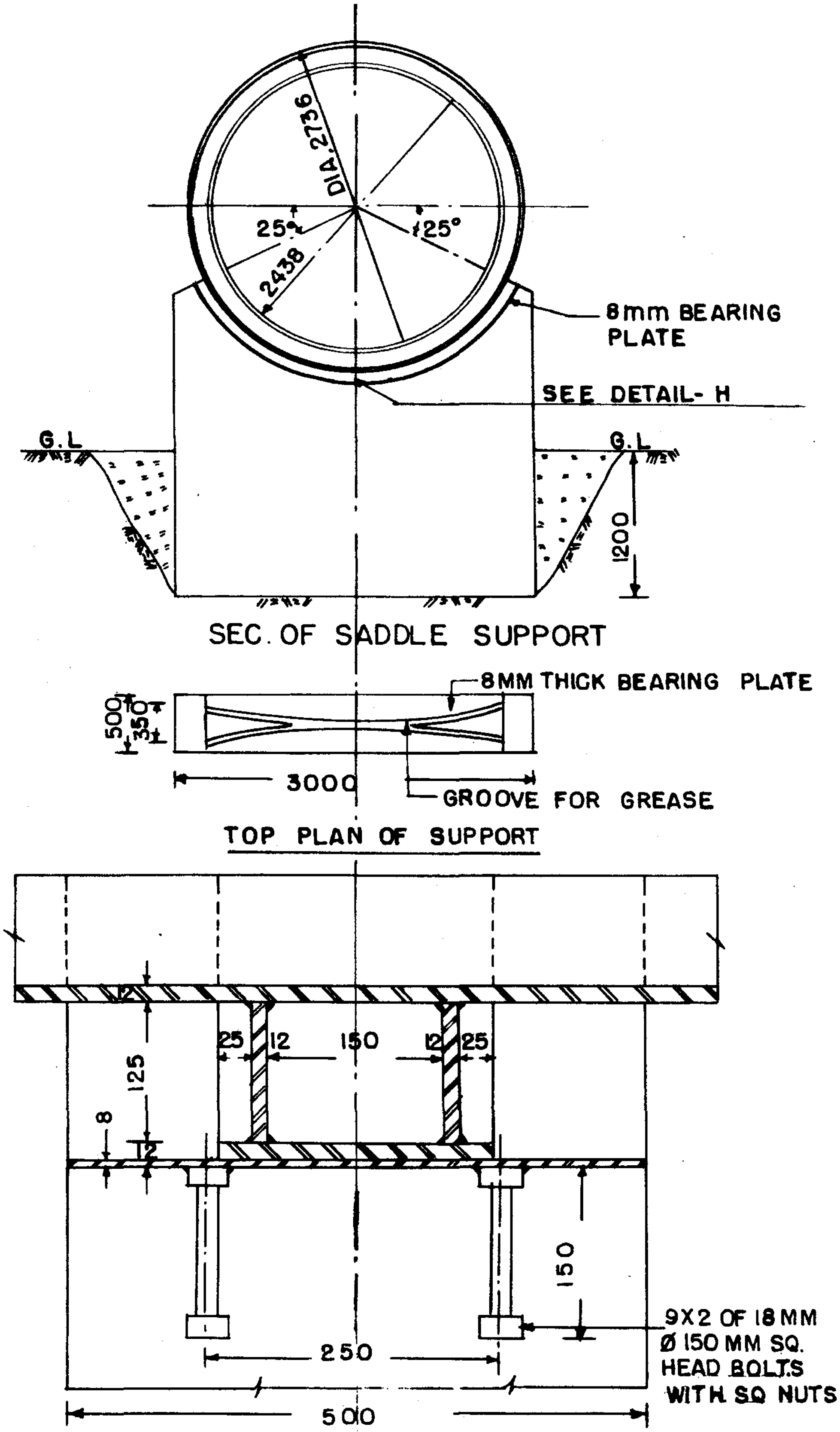


FIG. NO.-31

CRITICAL BUCKLING PRESSURE

AMSTUTZ CURVE

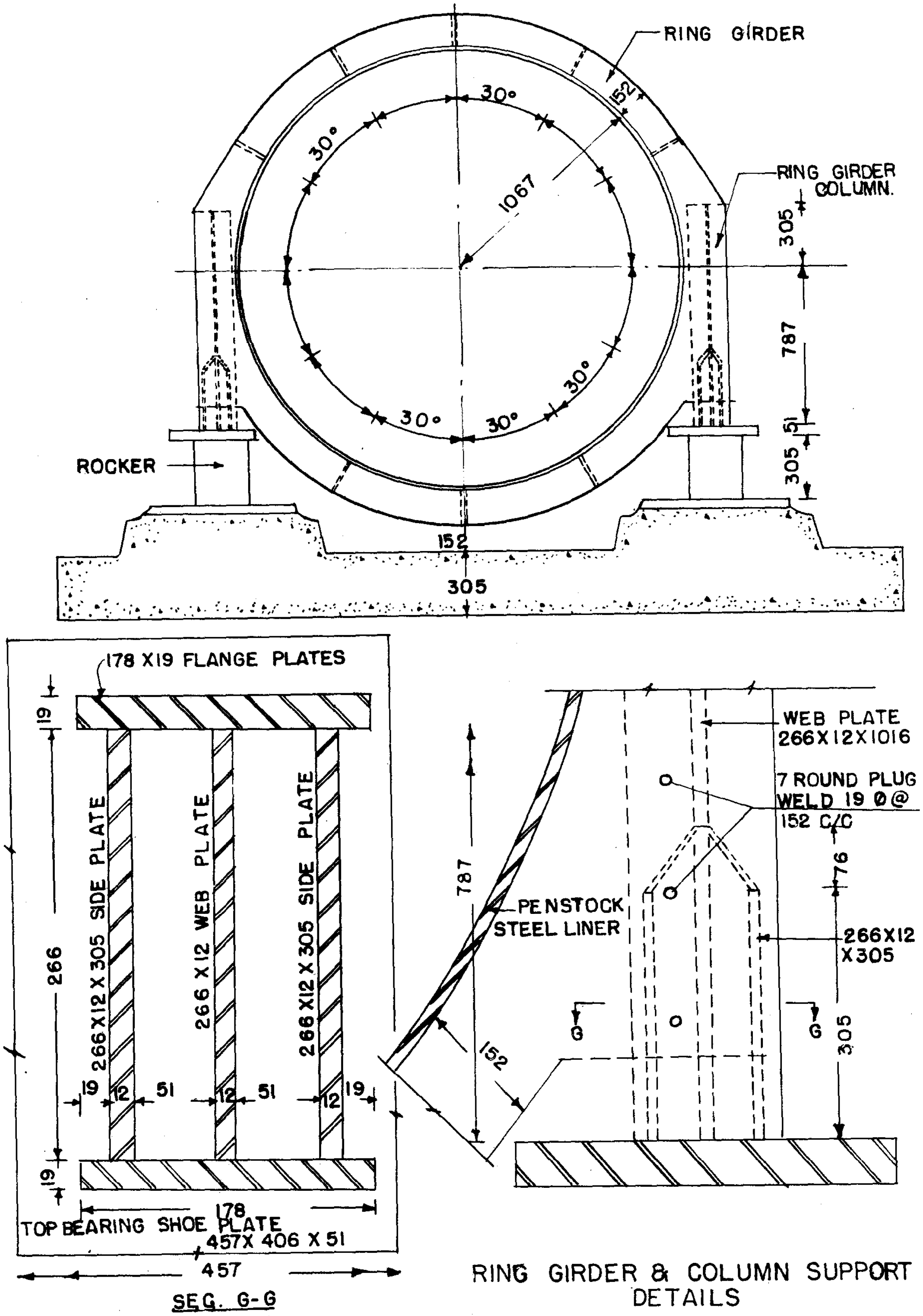
FOR VARIOUS TYPES OF STEEL



DETAIL - H

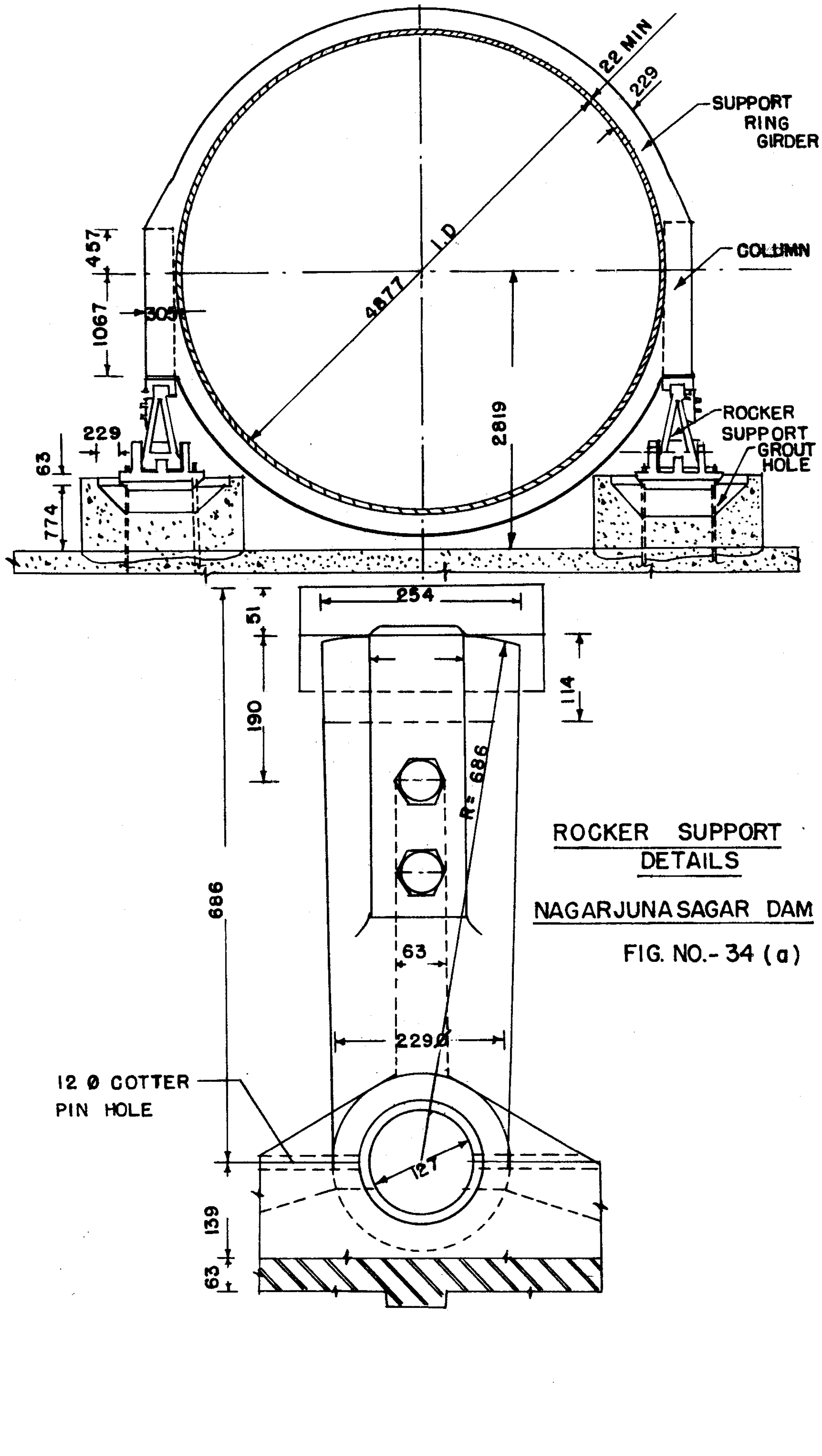
TYPICAL SADDLE SUPPORT DETAIL.

FIG. NO.- 32



RING GIRDER & COLUMN SUPPORT DETAILS

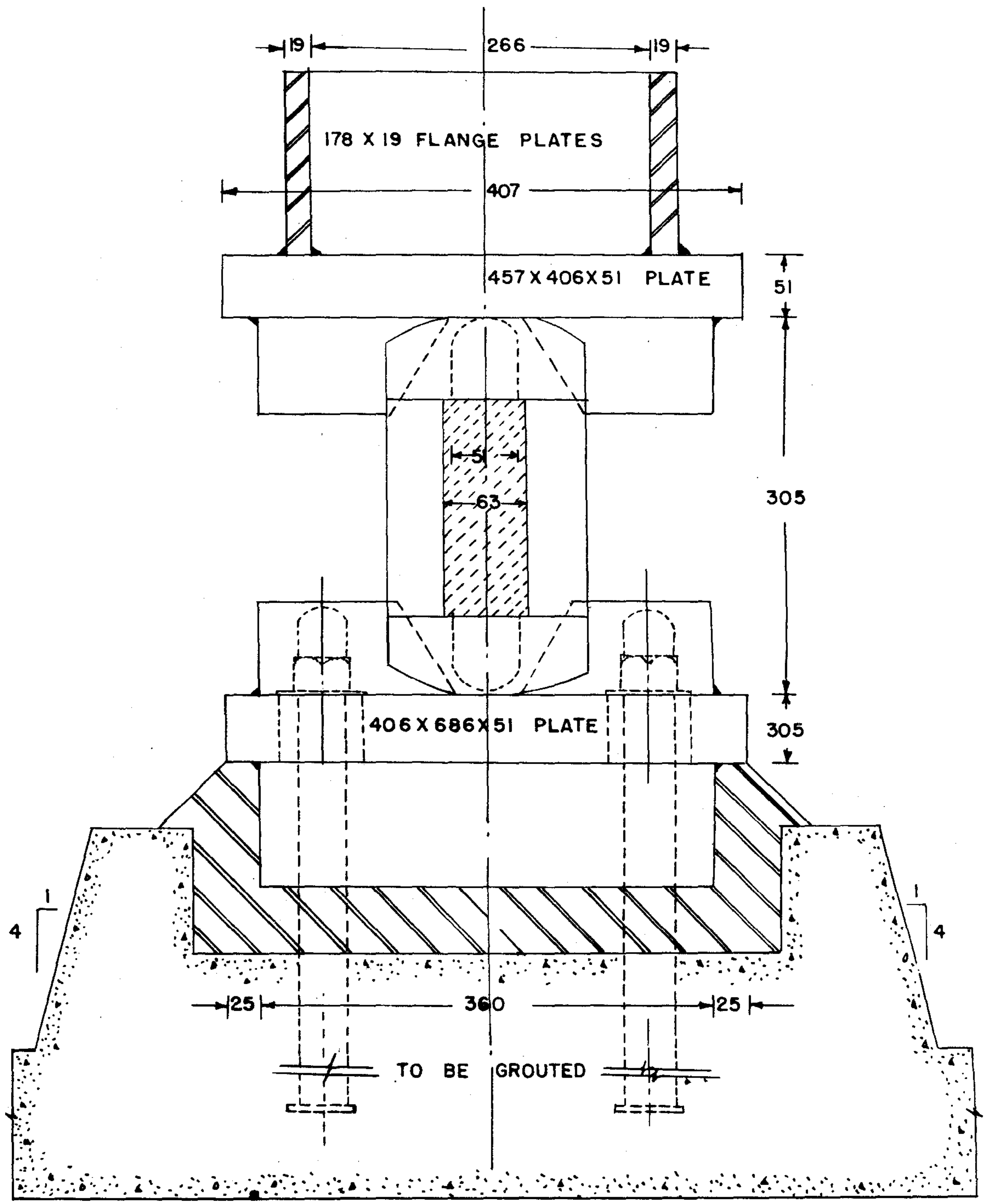
FIG. NO.-33



ROCKER SUPPORT DETAILS

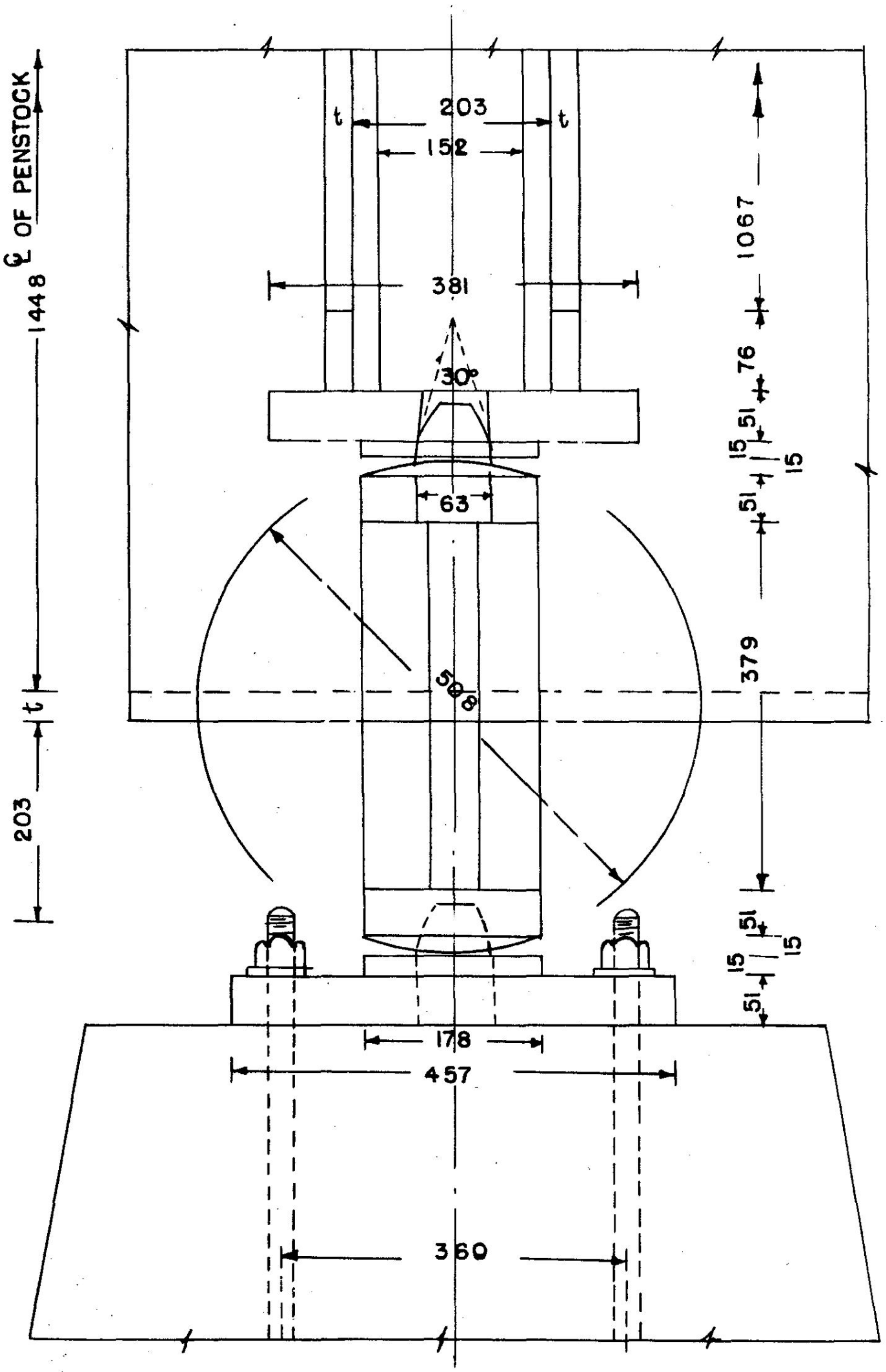
NAGARJUNASAGAR DAM

FIG. NO.- 34 (a)



ROCKER SUPPORT DETAILS
(UPPER SINDH H.E. PROJECT.)

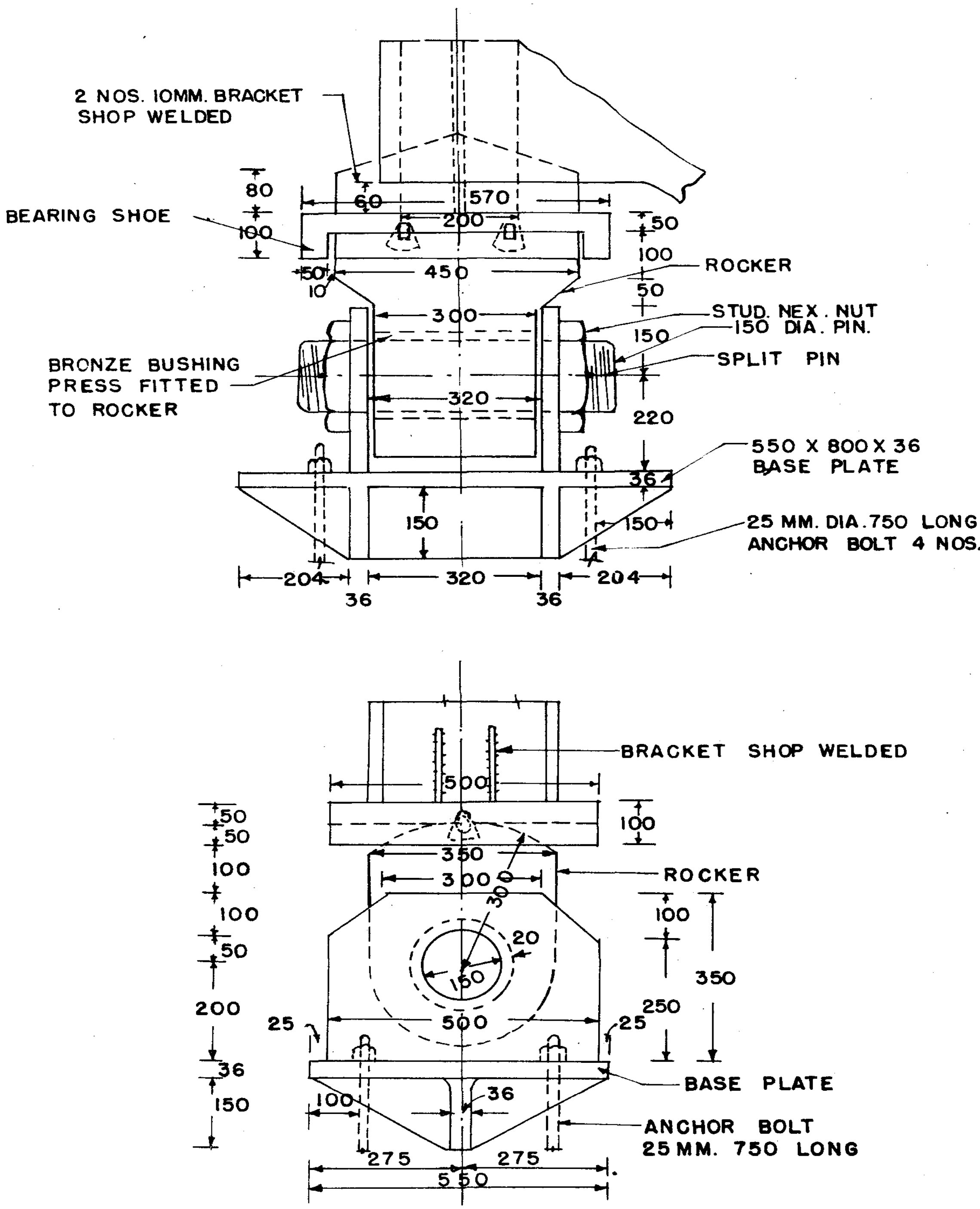
FIG. NO.- 34 (b)



ROCKER SUPPORT DETAILS

JALDHAKA H.E. PROJECT.

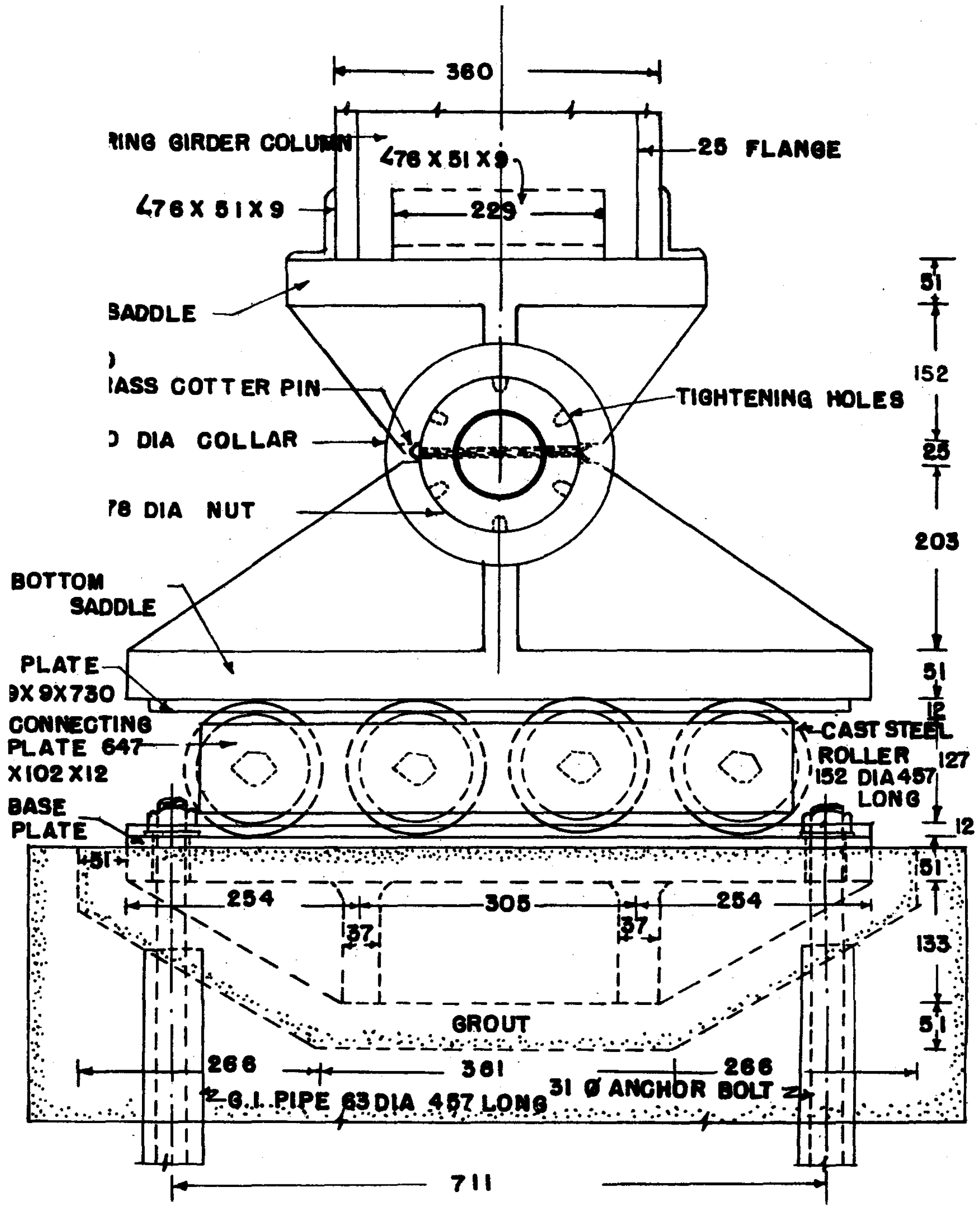
FIG. NO.- 34(c)



LOWER SILERU PROJECT

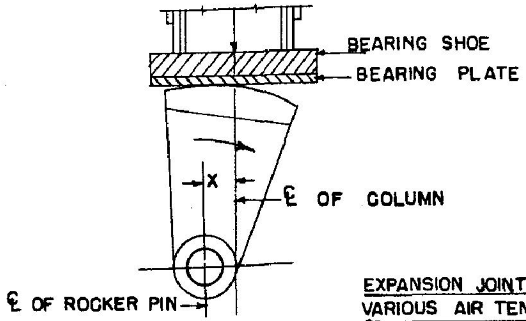
ROCKER SUPPORT

FIG. NO.- 34 (d).



ROLLER SUPPORT

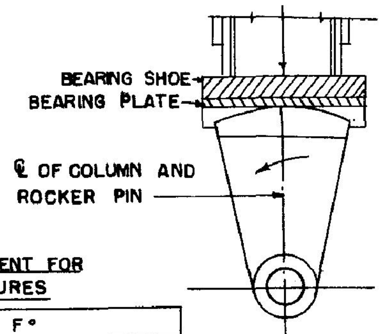
FIG. NO.-34 (e)



TEMP - SETTING= X

EXPANSION JOINT MOVEMENT FOR VARIOUS AIR TEMPERATURES

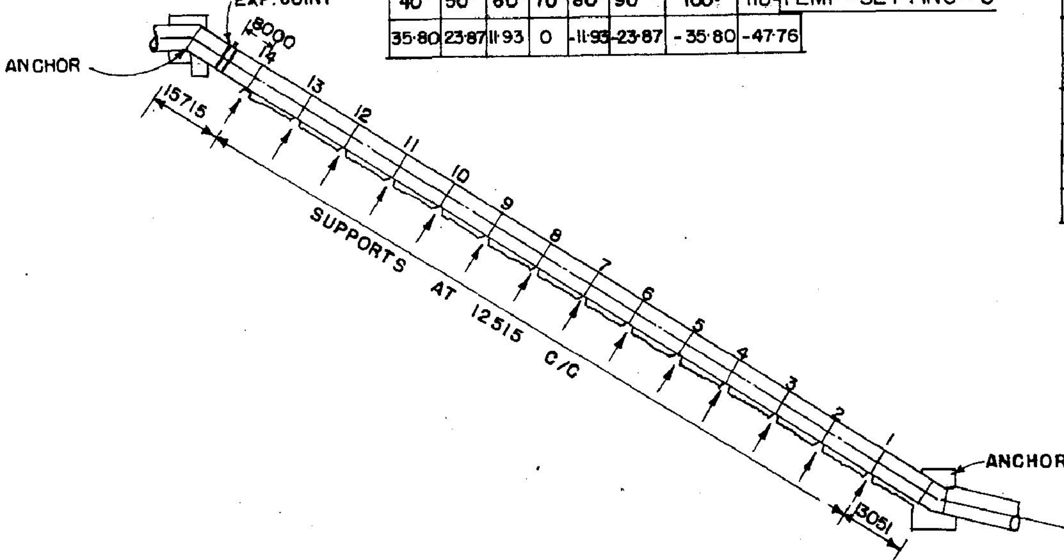
AIR TEMPERATURE F°							
40°	50°	60°	70°	80°	90°	100°	110°
35·80	23·87	11·93	0	-11·93	-23·87	-35·80	-47·76



TEMP-SETTING= O

TILT MEASUREMENTS FOR VARIOUS AIR TEMPERATURE

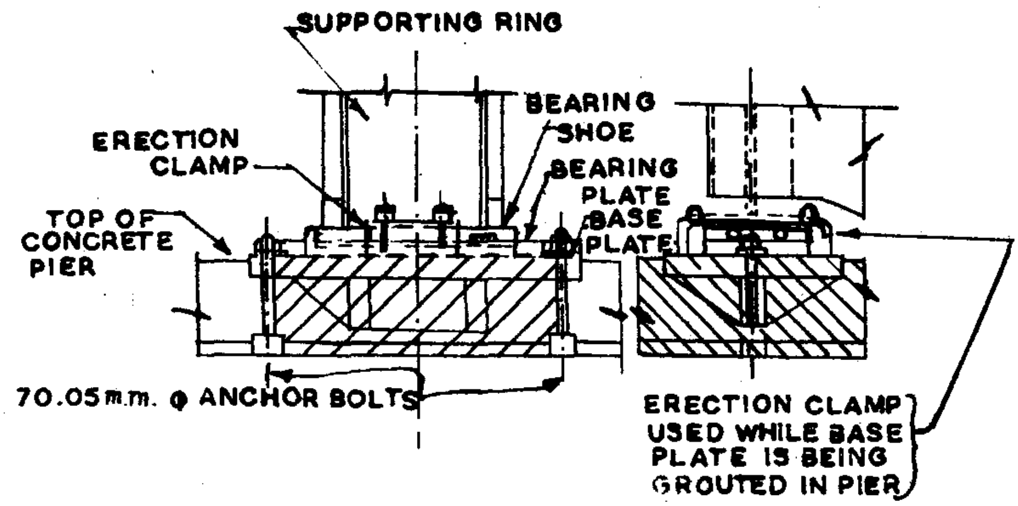
PIER	AIR TEMPERATURE F°							
NO	40°	50°	60°	70°	80°	90°	100°	110°
1	147·67	146·83	145·98	134·6	122·01	122·37	121·52	120·57
2	146·86	146·02	145·17	134·6	122·82	123·18	122·33	121·38
3	146·05	145·21	144·36	134·6	123·68	123·99	123·14	122·19
4	145·24	144·40	143·55	134·6	124·44	124·80	123·95	123·10
5	144·43	143·59	142·74	134·6	125·25	125·61	124·76	123·91
6	143·62	142·78	141·93	134·6	126·06	126·42	125·57	124·72
7	142·81	141·97	141·12	134·6	126·87	127·73	126·38	125·53
8	142·00	141·16	140·31	134·6	127·68	128·04	127·19	126·34
9	141·19	140·35	139·50	134·6	128·49	128·85	128·00	127·15
10	140·38	139·54	138·69	134·6	129·30	129·66	128·81	127·96
11	139·57	138·73	137·88	134·6	130·92	130·47	129·62	128·77
12	138·78	137·92	137·07	134·6	131·73	131·28	130·43	129·58
13	137·95	137·11	136·26	134·6	132·54	132·09	131·24	130·39
14	137·14	136·30	135·45	134·6	133·75	132·90	132·06	131·20



ELEVATION OF PENSTOCK

SETTING OF ROCKER

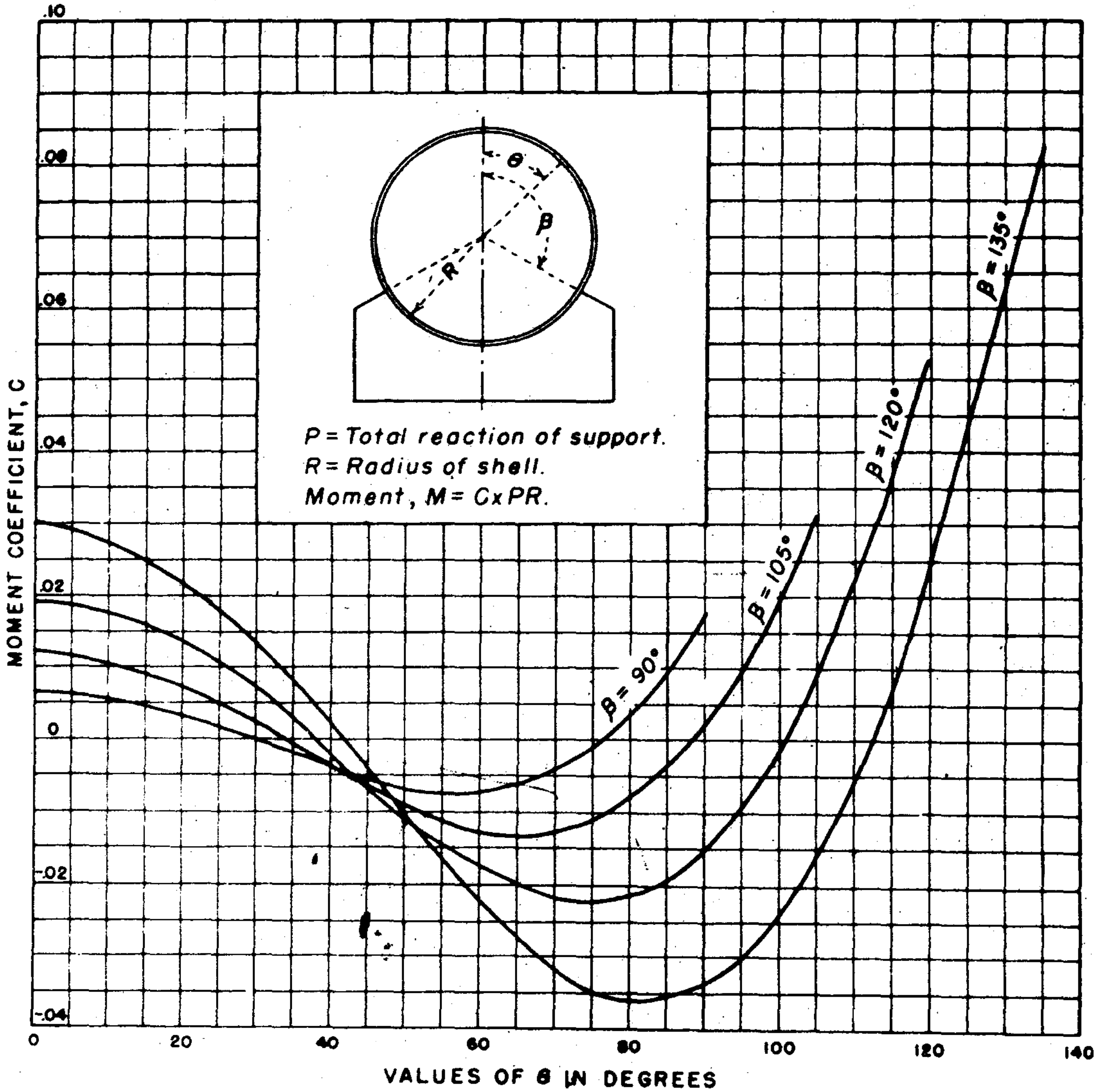
FIG.NO.35



SLIDING SUPPORT

FIG. NO.-36

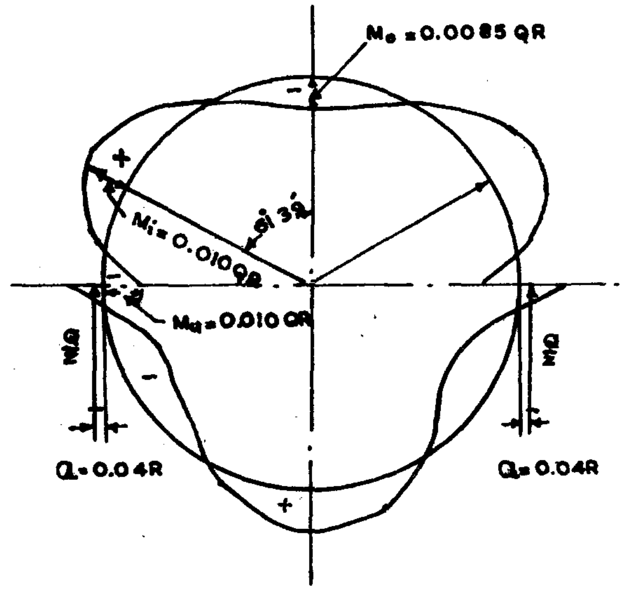
VARIATION OF CIRCUMFERENTIAL MOMENT AROUND SHELL
RESTING ON SADDLE SUPPORT



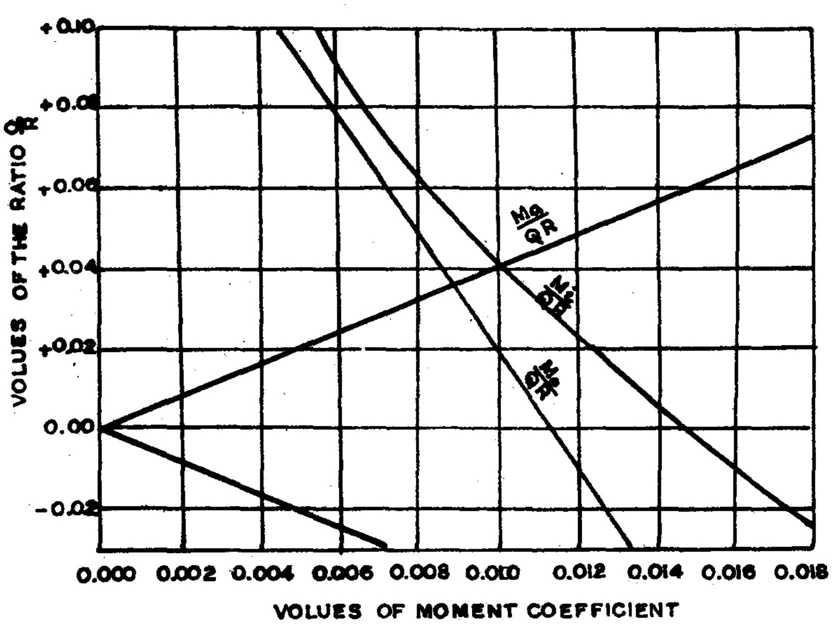
VARIATION OF CIRCUMFERENTIAL MOMENT AROUND SHELL RESTING ON SADDLE SUPPORT

From University of Illinois Bulletin, Sept. 23, 1941 "Test of Cylindrical Shells"

FIG.NO.37



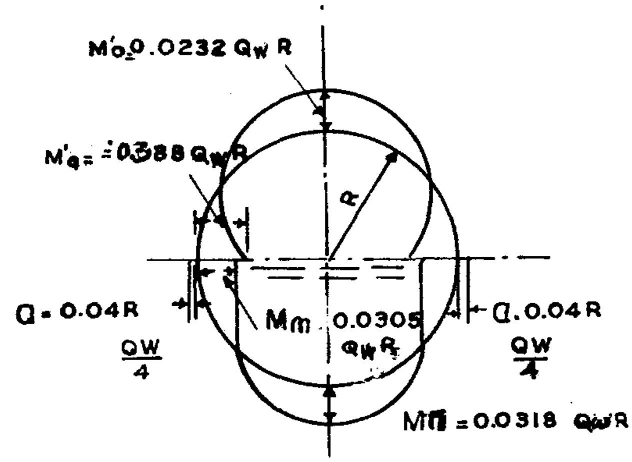
BENDING MOMENTS IN SUPPORTING RING FOR $\frac{Q}{R}$ = 0.04



BENDING MOMENTS IN SUPPORTING RING

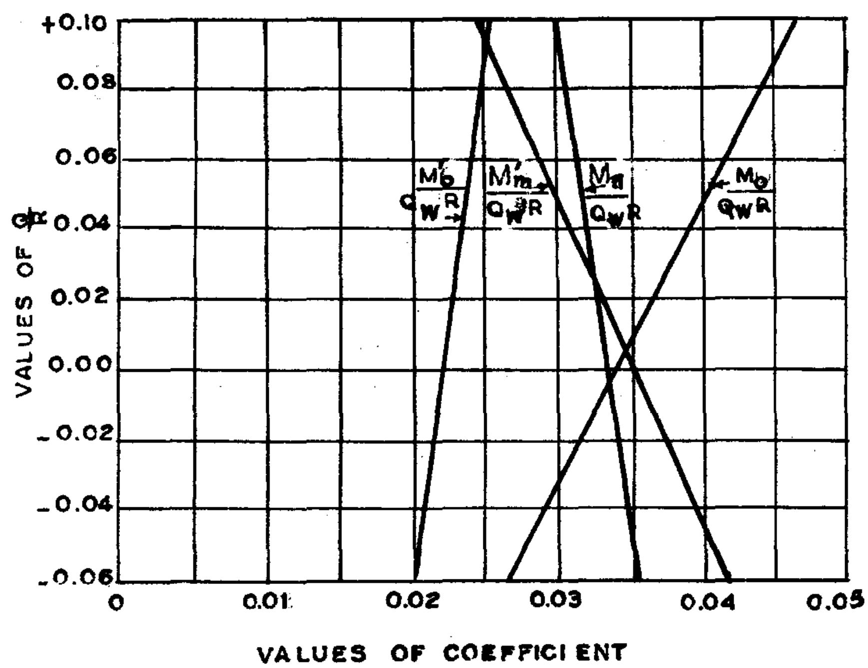
PIPE FULL

FIG. NO. - 38



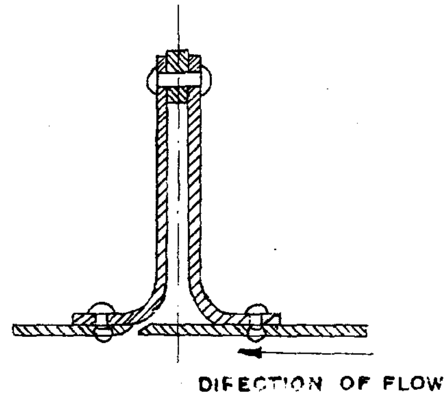
BENDING MOMENT IN SUPPORTING RING
PIPE HALF FULL

FIG. NO. 39 (a)



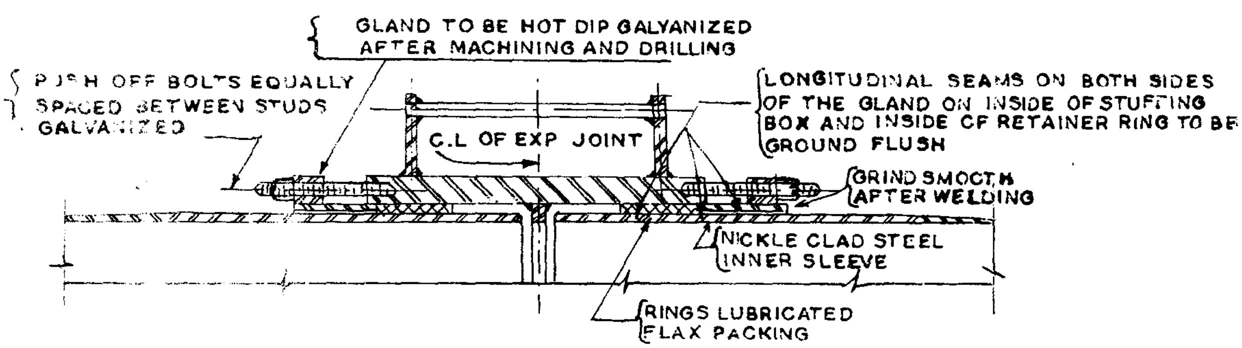
PIPE HALF FULL-BENDING MOMENTS CO-EFFICIENT
IN SUPPORTING RING

FIG. NO. 39 (b)



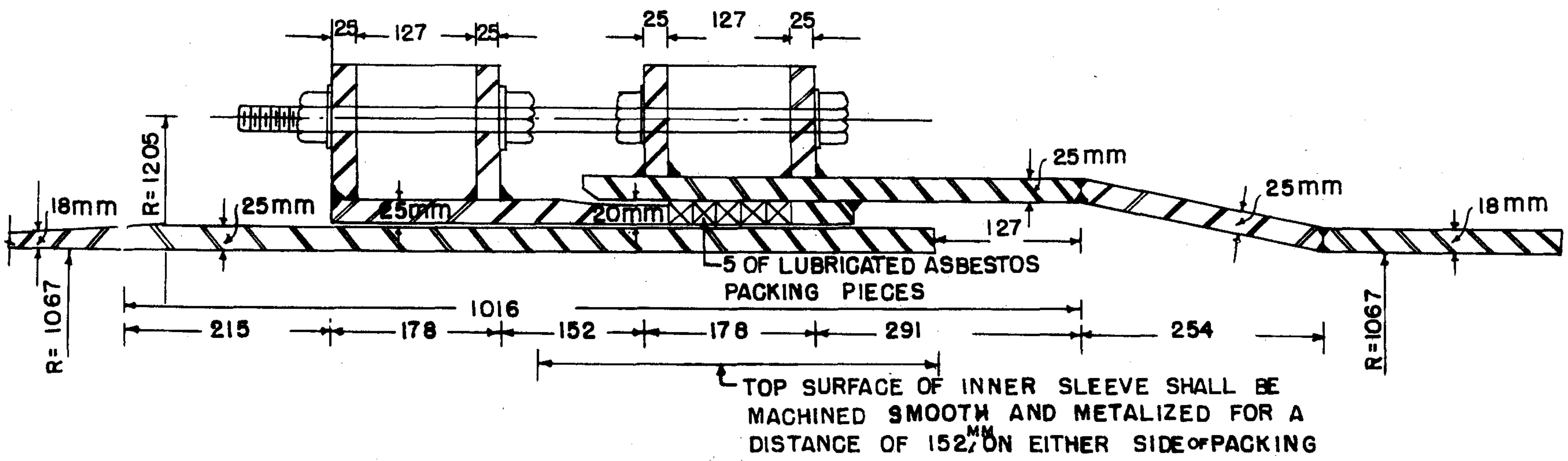
BELLOW TYPE OF JOINTS

FIG. NO.- 40



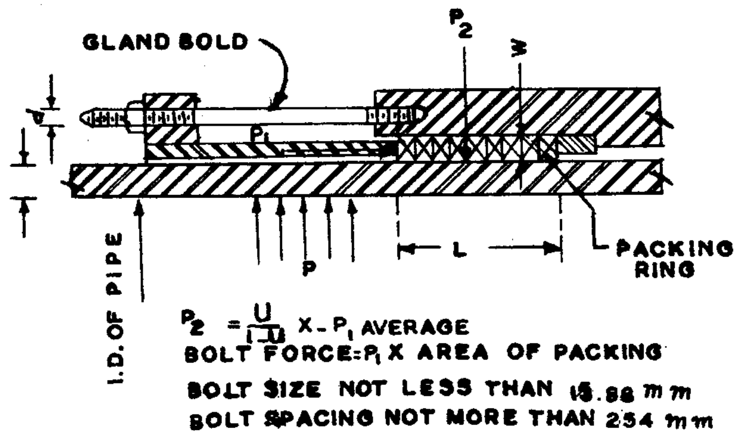
EXPANSION JOINT – DOUBLE SLEEVE TYPE

FIG.NO.41 (a)



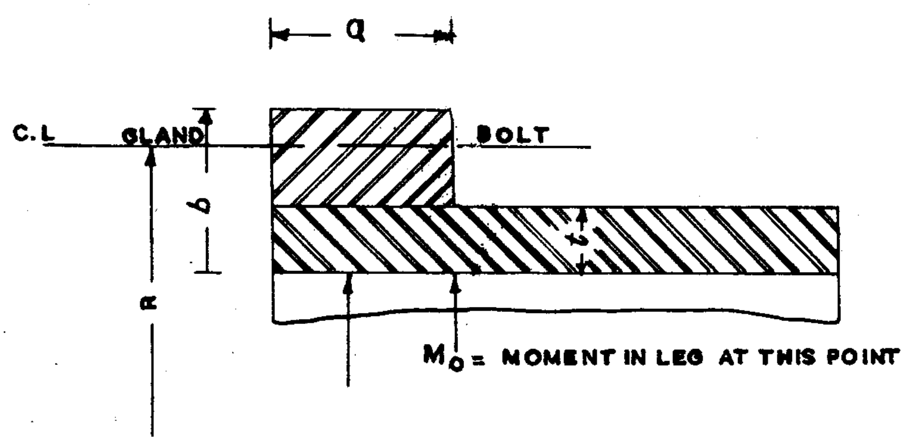
SLEEVE TYPE EXPANSION JOINT

FIG.NO. - 41(b)



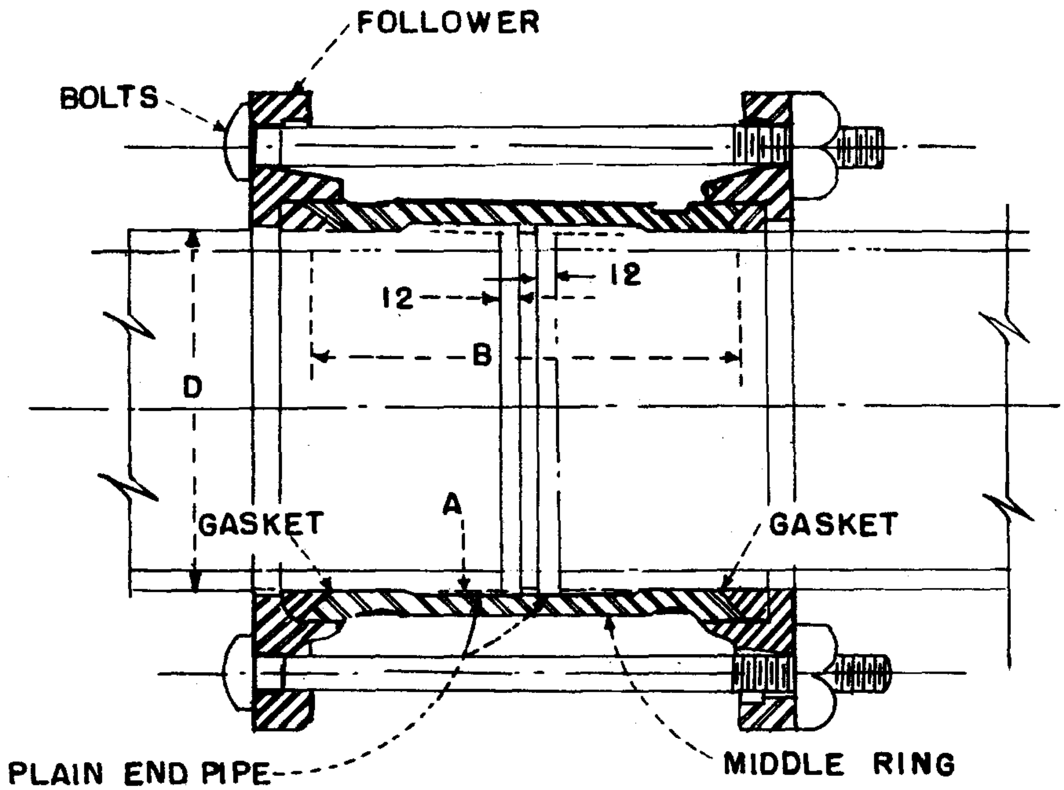
FORCES ON EXPANSION JOINT

FIG. NO.- 42 (a)



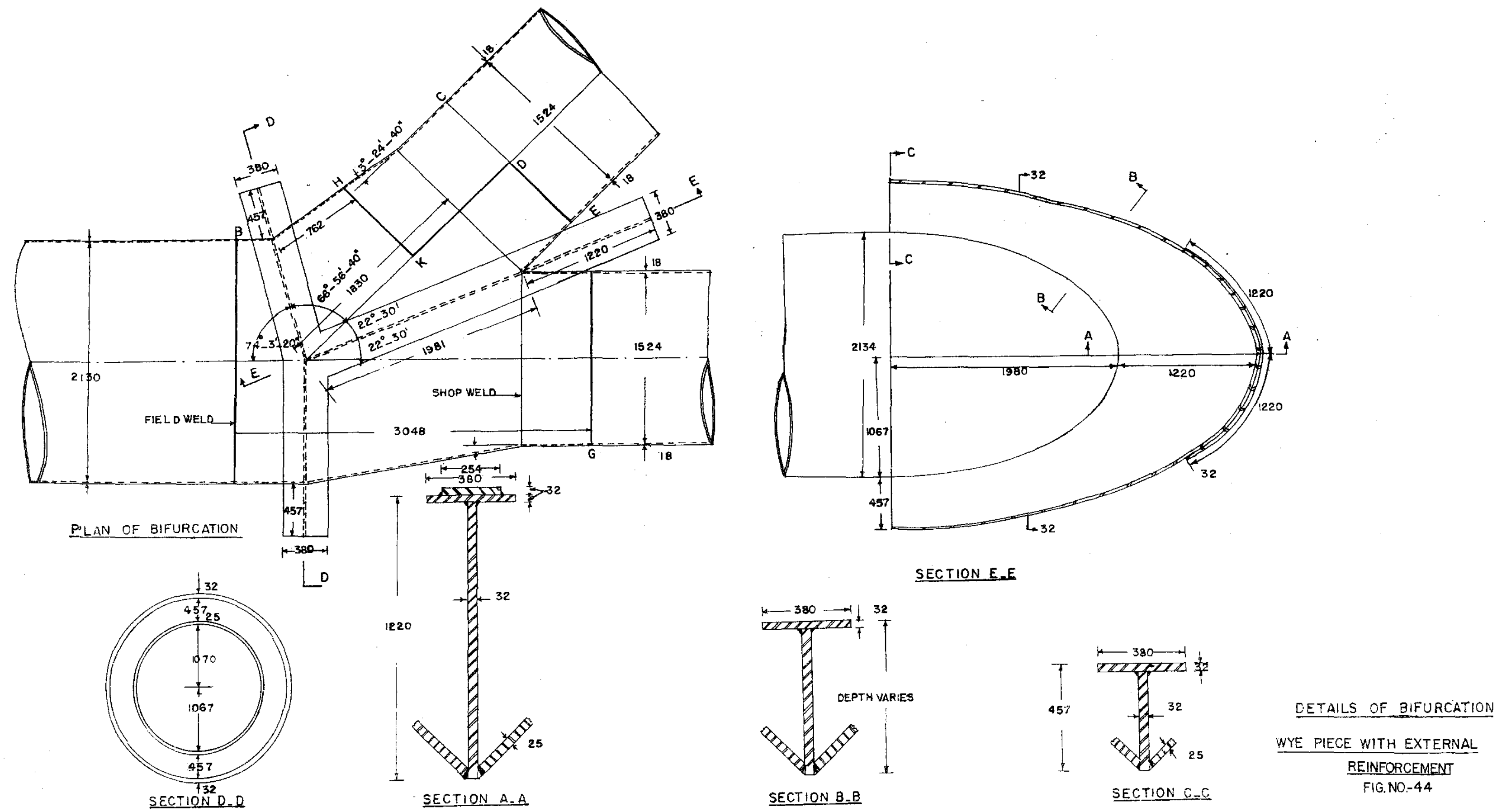
FORCES ON GLAND

FIG. NO.- 42 (b)



SLEEVE TYPE COUPLING

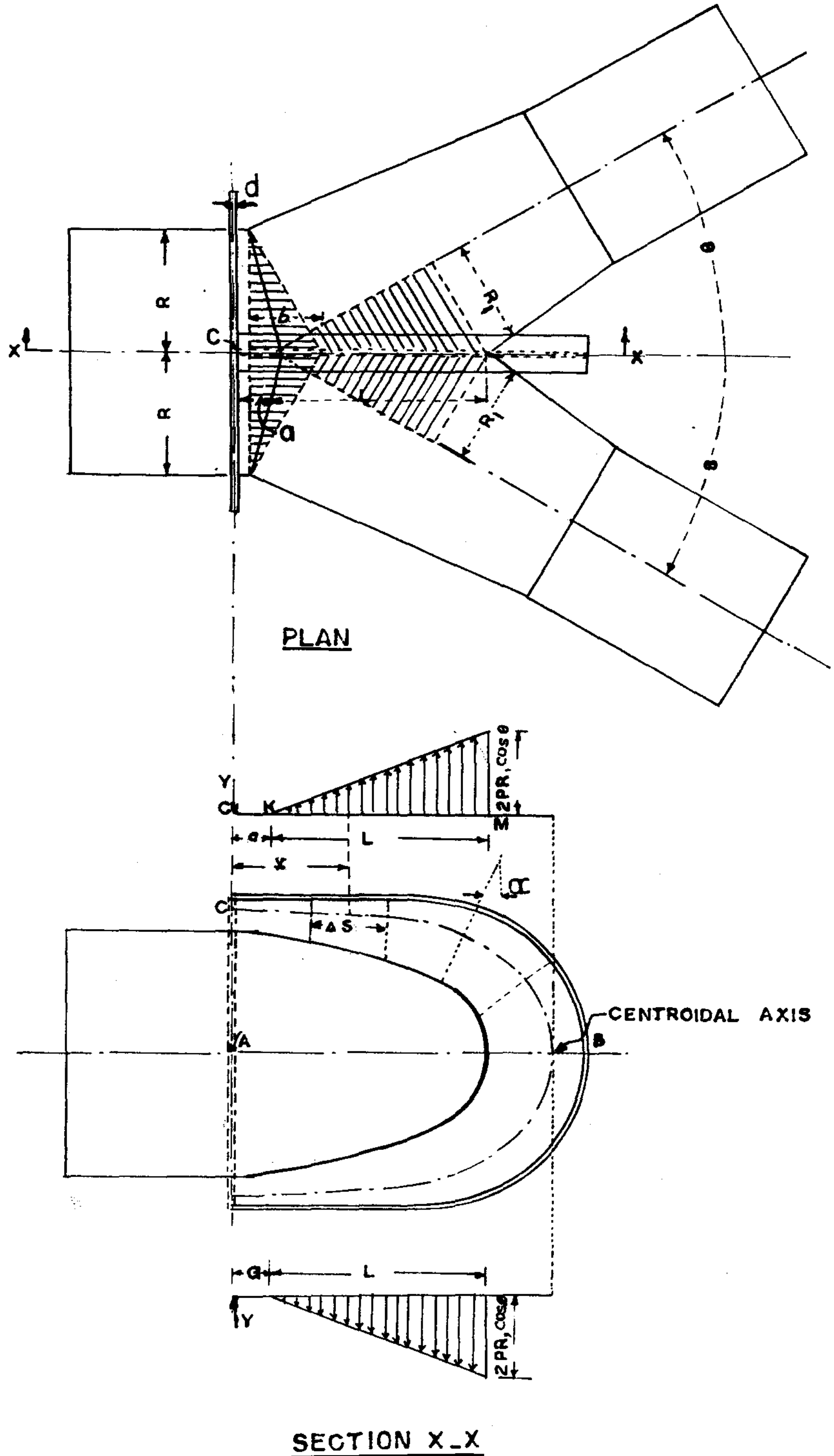
FIG. NO. - 43



DETAILS OF BIFURCATION

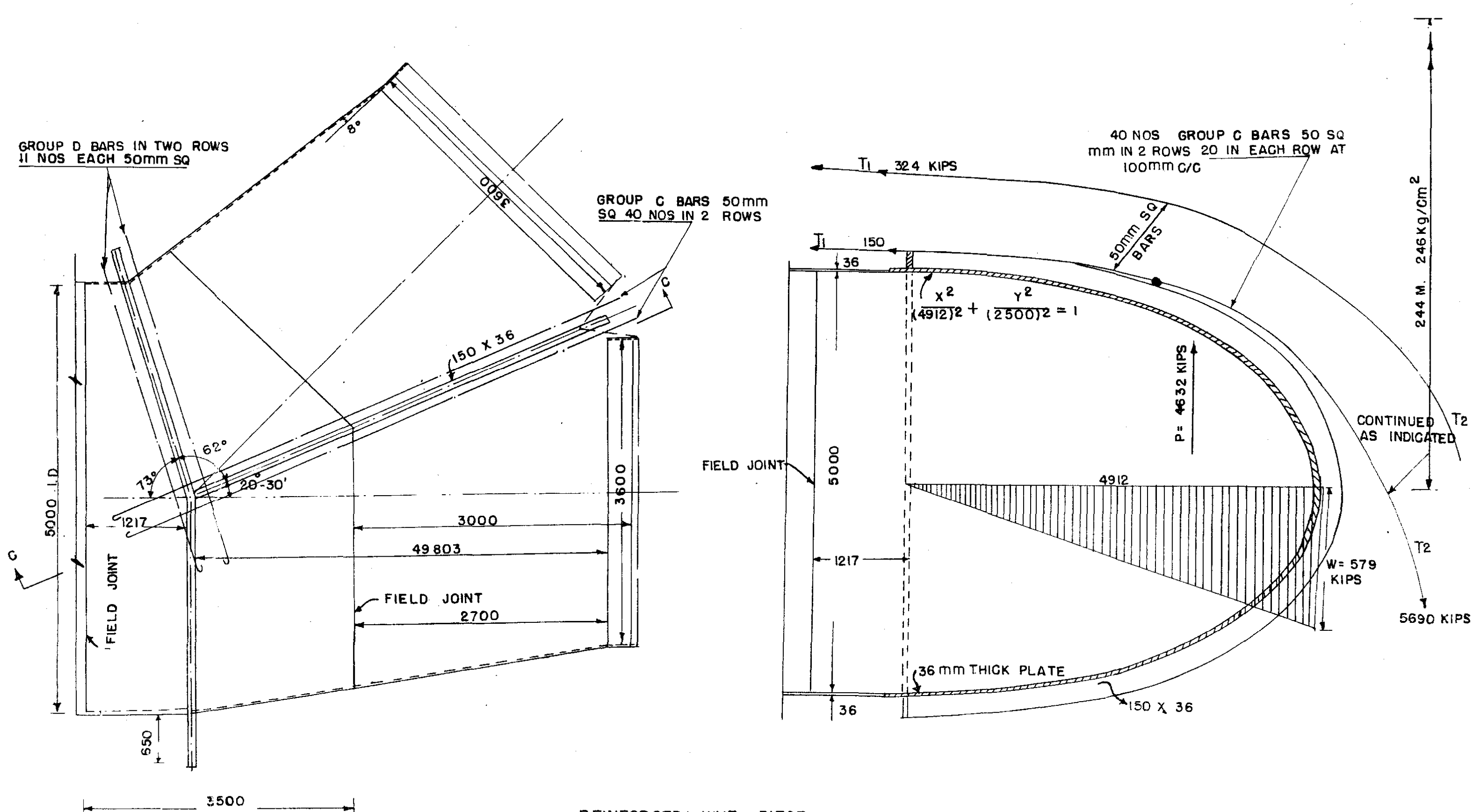
WYE PIECE WITH EXTERNAL REINFORCEMENT

FIG. NO.-44



FORCES ON BIFURCATION

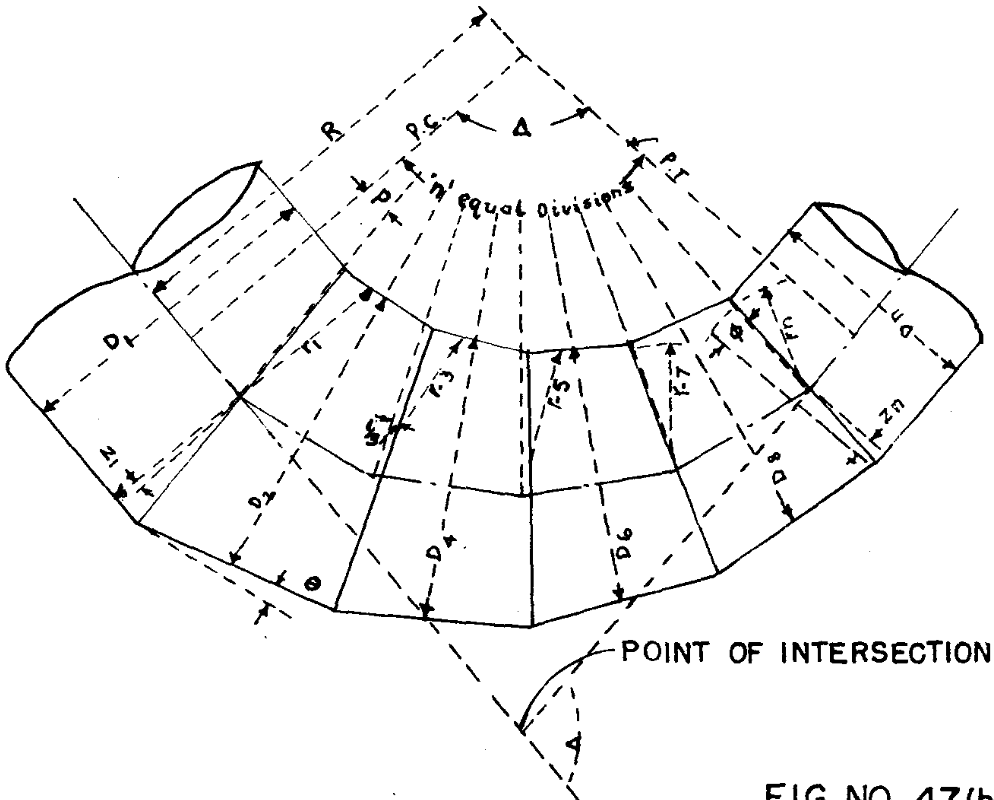
FIG. NO.- 45



REINFORCED WYE - PIECE

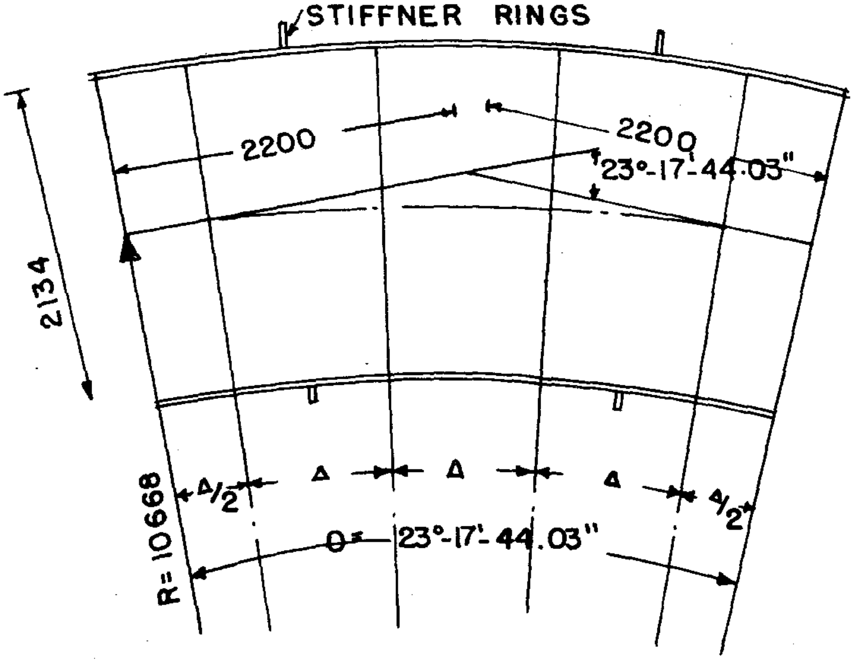
(LOWER SILERU PROJECT)

FIG. NO. - 46.



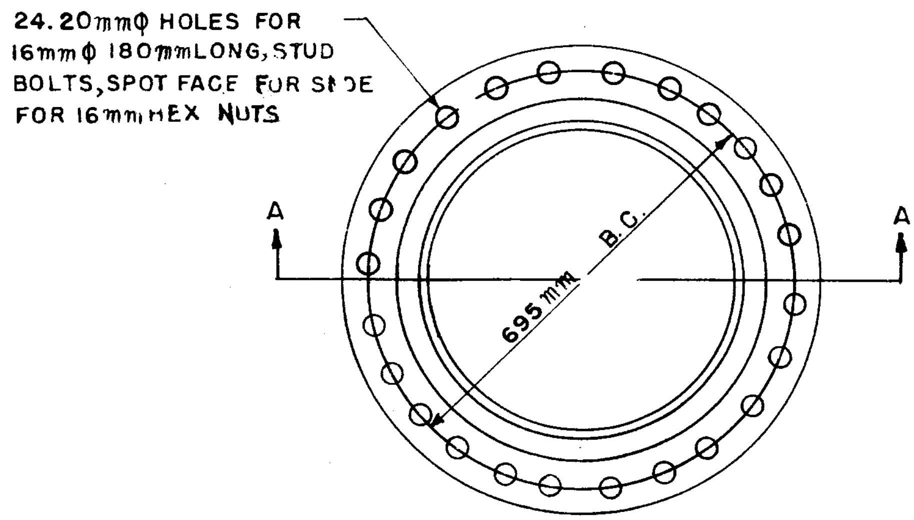
REDUCING BENDS

FIG. NO.-47(b)

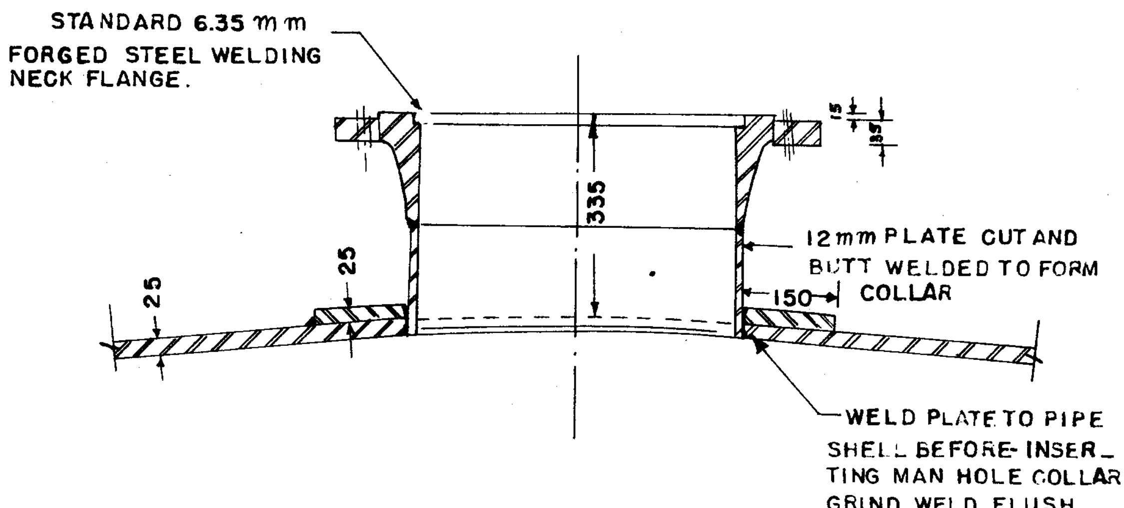


BEND DETAILS

FIG. NO.- 47 (a)



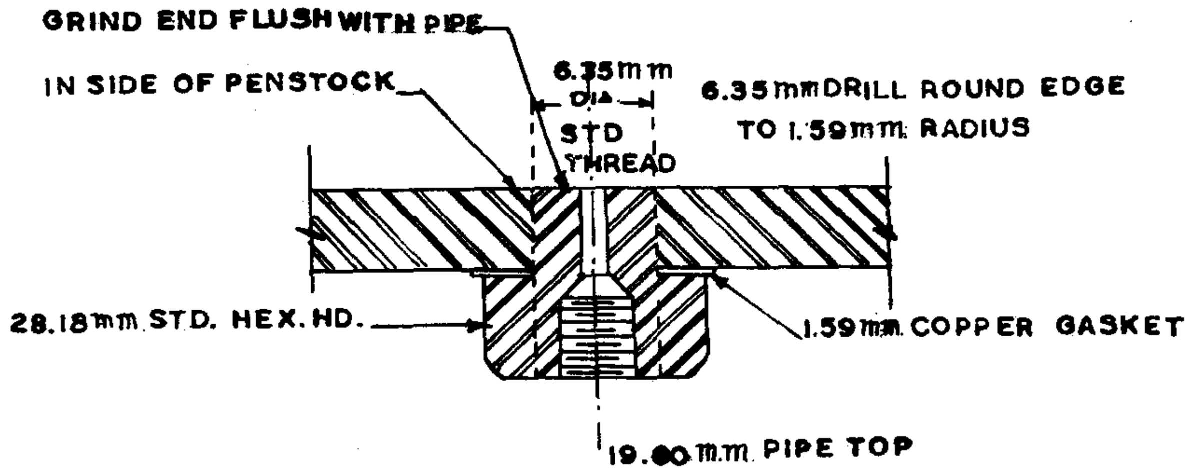
PLAN AT X_X



SECTION A_A

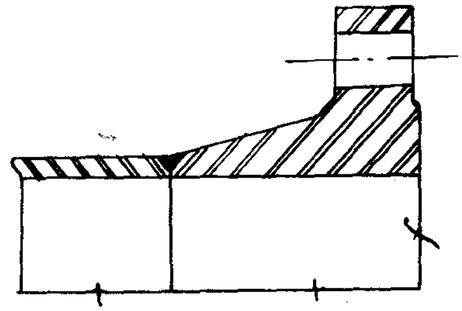
MAN HOLE DETAILS

FIG. NO.- 48

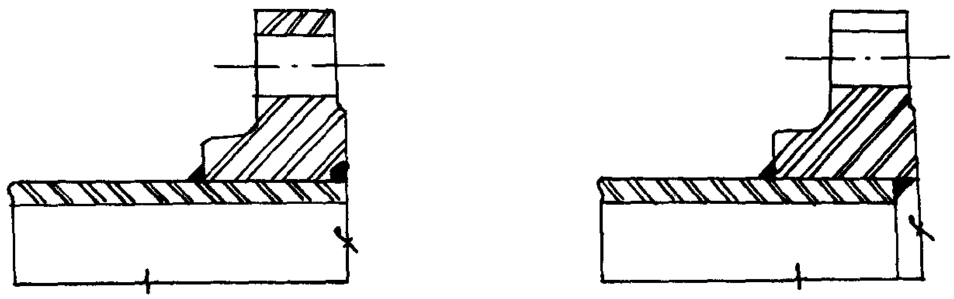


PIEZOMETRIC CONNECTION

FIG. NO. - 49



WELDING NECK TYPE



SLIP-ON TYPES

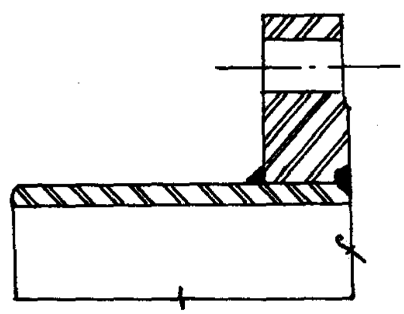
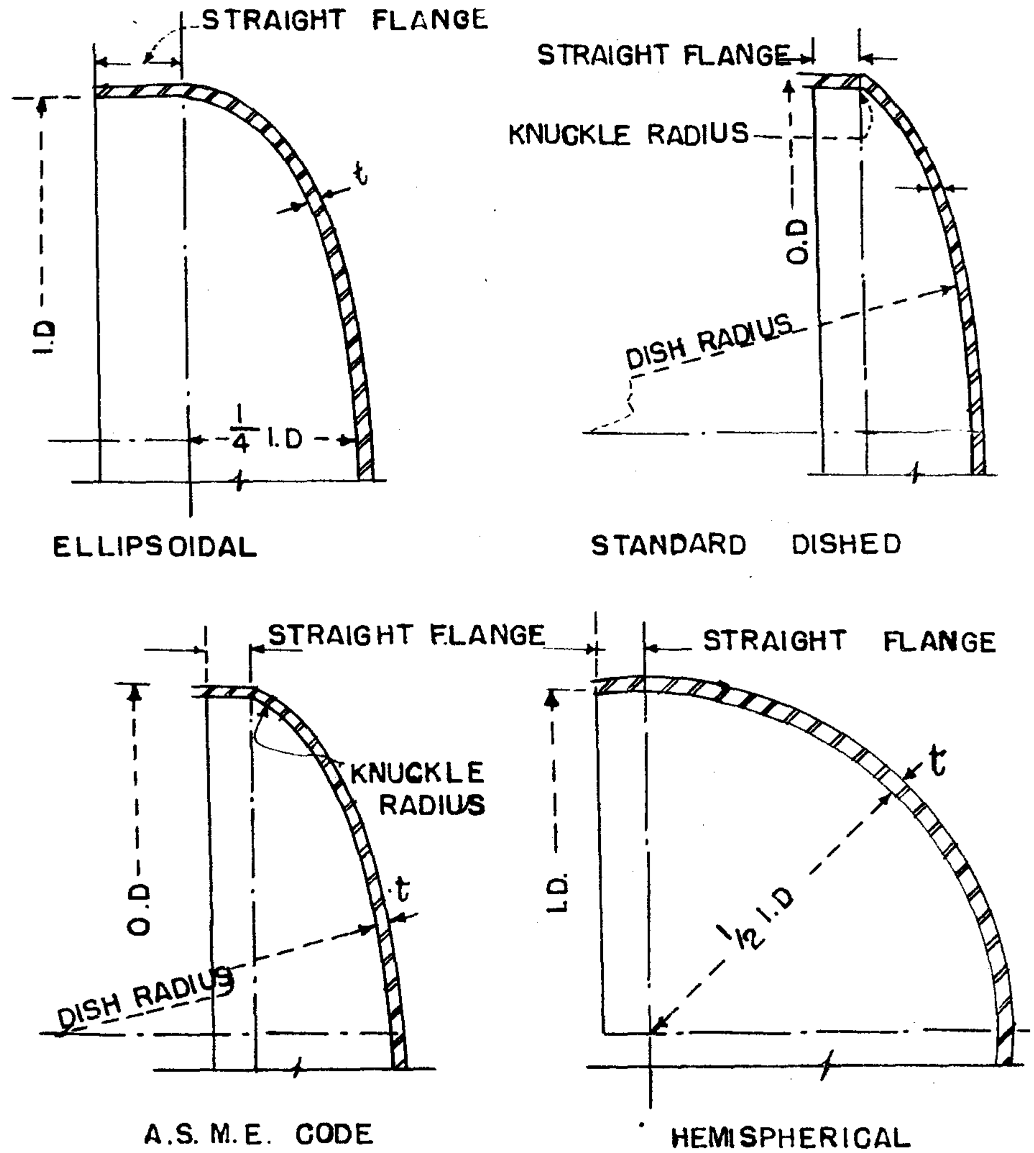


PLATE TYPE

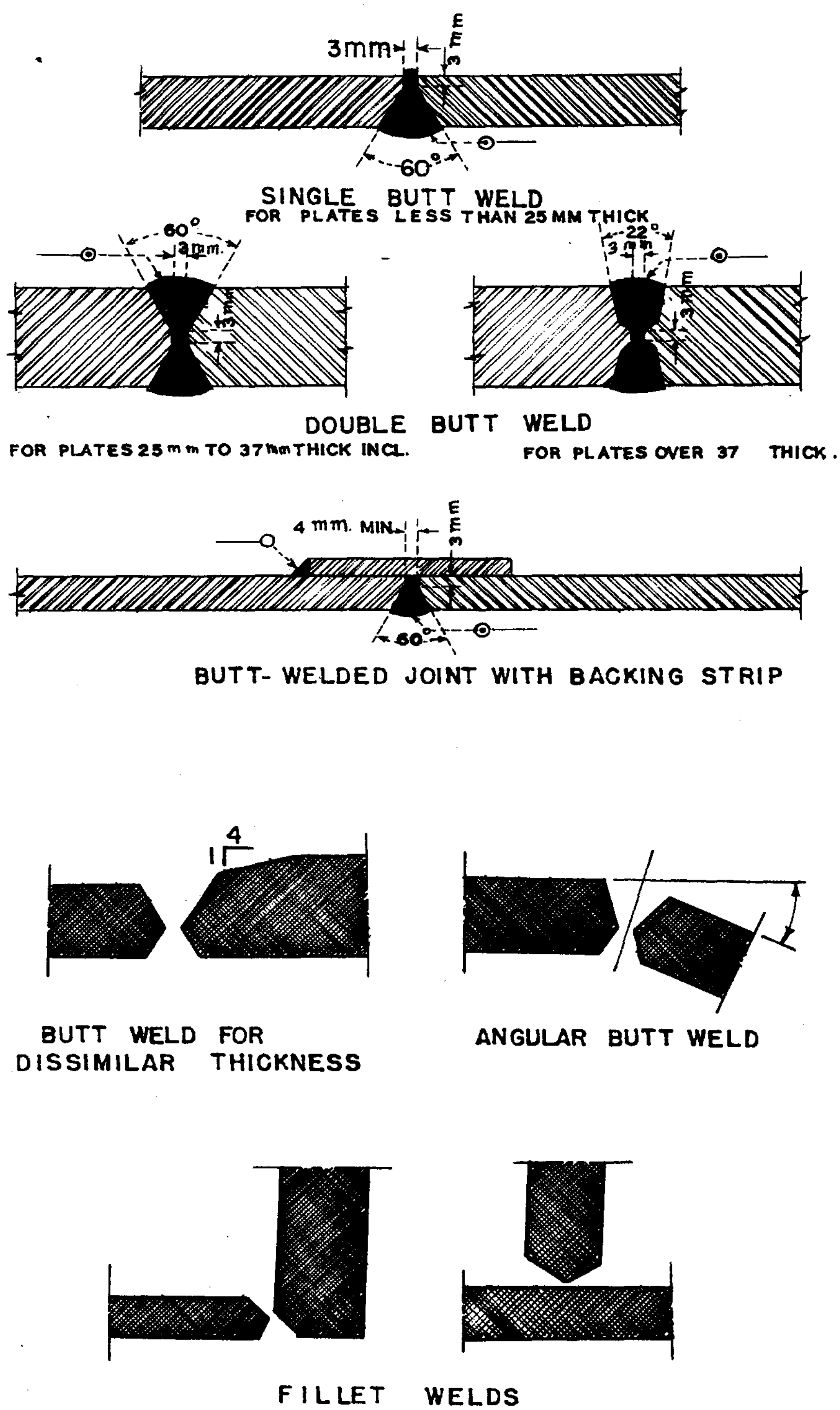
FLANGED CONNECTIONS

FIG. NO. - 50



BULK HEADS

FIG. NO. - 51.



TYPICAL WELDED JOINT

FIG. NO.- 52

ALTERNATIVE (a)

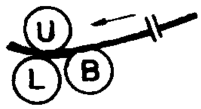


FIG. I

SETTING INGOING EDGE

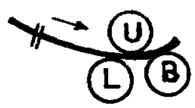


FIG. 2

REVERSING AND RE_ENTERING PLATE

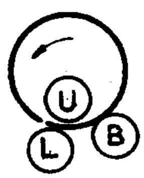


FIG. 3

FINISH BENDING

U=UPPER ROLLER
L = LOWER ROLLER (PINCH)
B = BENDING ROLLER

FOR LIGHTER GAUGE PLATES AND BATCH PRODUCTION
ROLLING BY WITHDRAWING AND REVERSING PLATE

ALTERNATIVE (b)

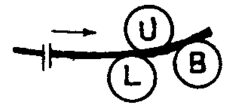


FIG. I

INTRODUCING OF PLATE

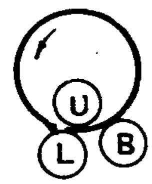


FIG. 2

BENDING AND SETTING OUTGOING EDGE OF PLATE

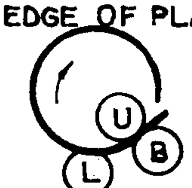


FIG. 3

RE_ARRANGING LOWER AND BENDING ROLLERS, REVERSING DRIVE

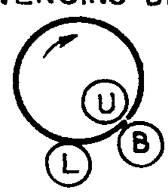
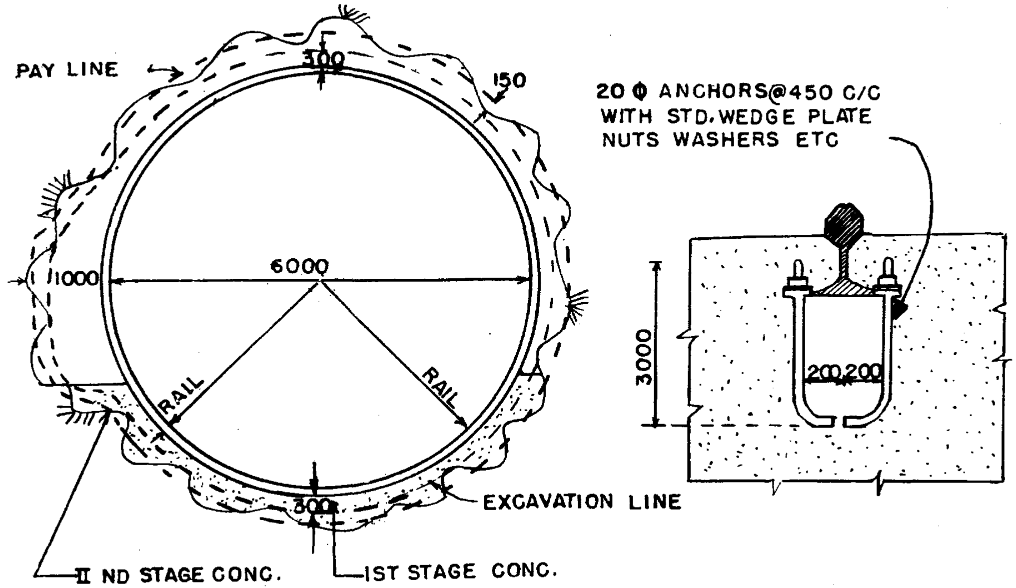


FIG. 4

SETTING INGOING EDGE
FOR HEAVY PLATES AND CYLINDERS OF LARGE DIMENSIONS
ROLLING IN ONE PASS WITHOUT REVERSING PLATE

METHOD OF BENDING

FIG. NO.- 53

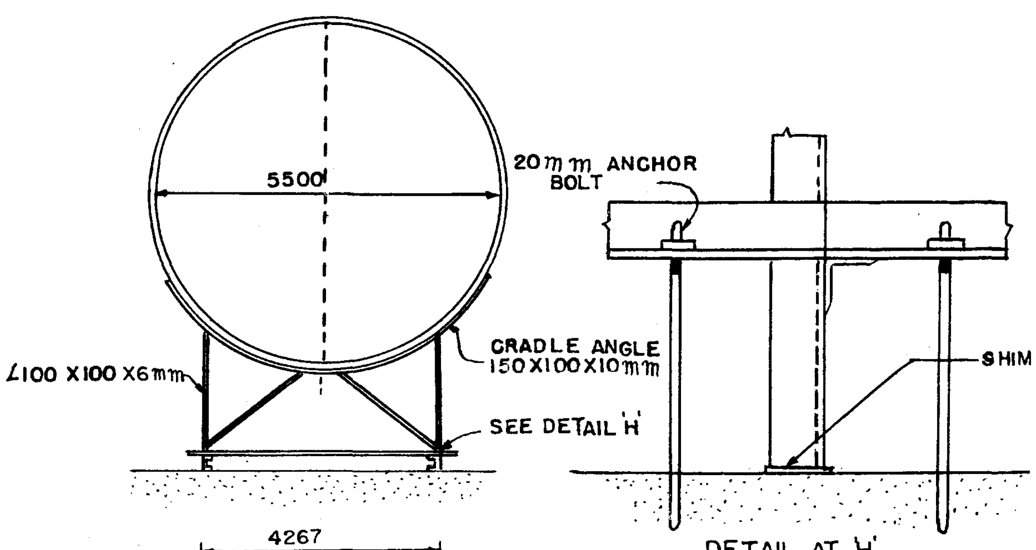


TUNNEL BORE

RAIL WITH EMBEDED PART

PENSTOCK IN TUNNEL

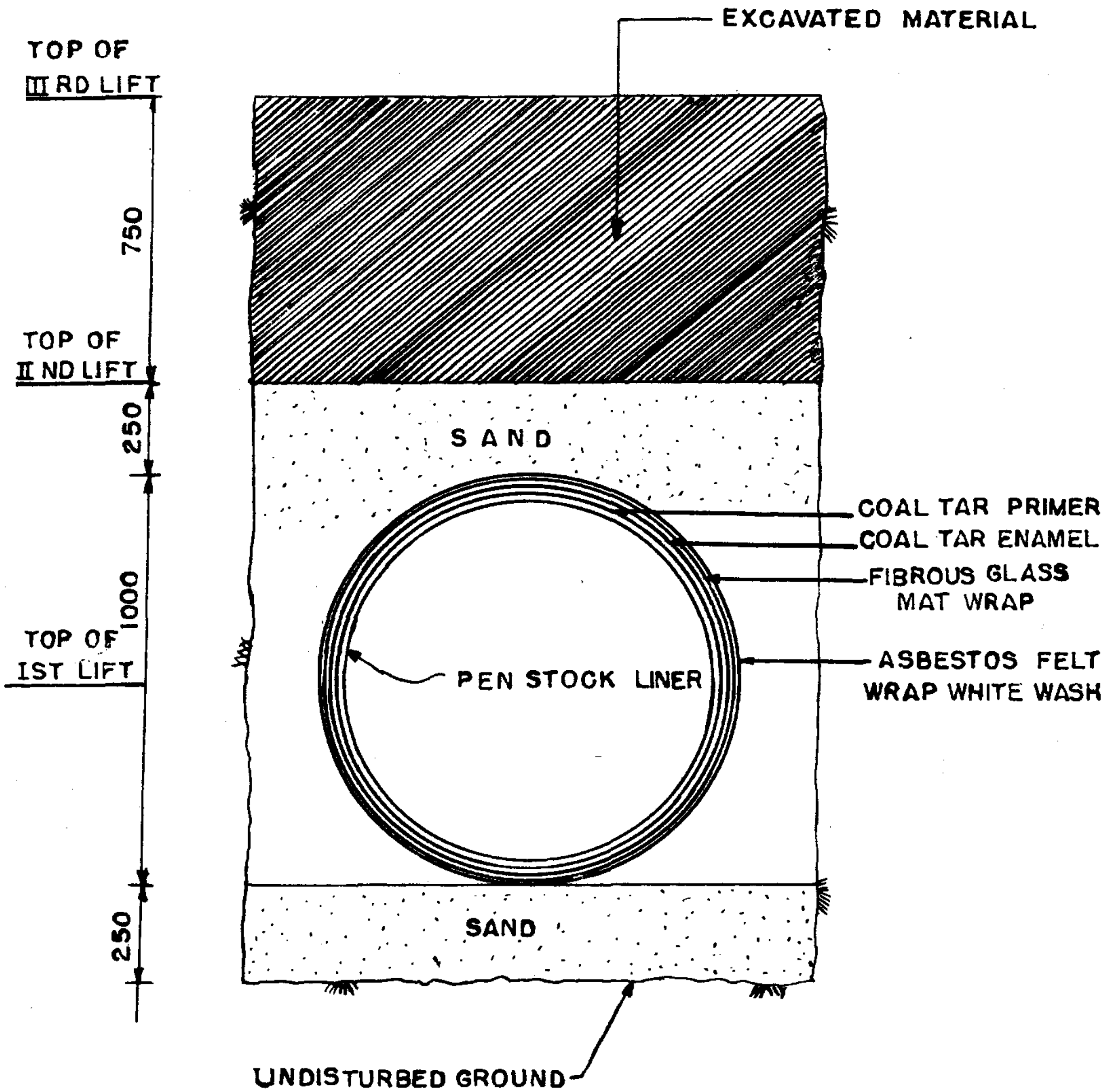
FIG. NO.-54



TYPICAL SUPPORT FOR PENSTOCK IN DAM

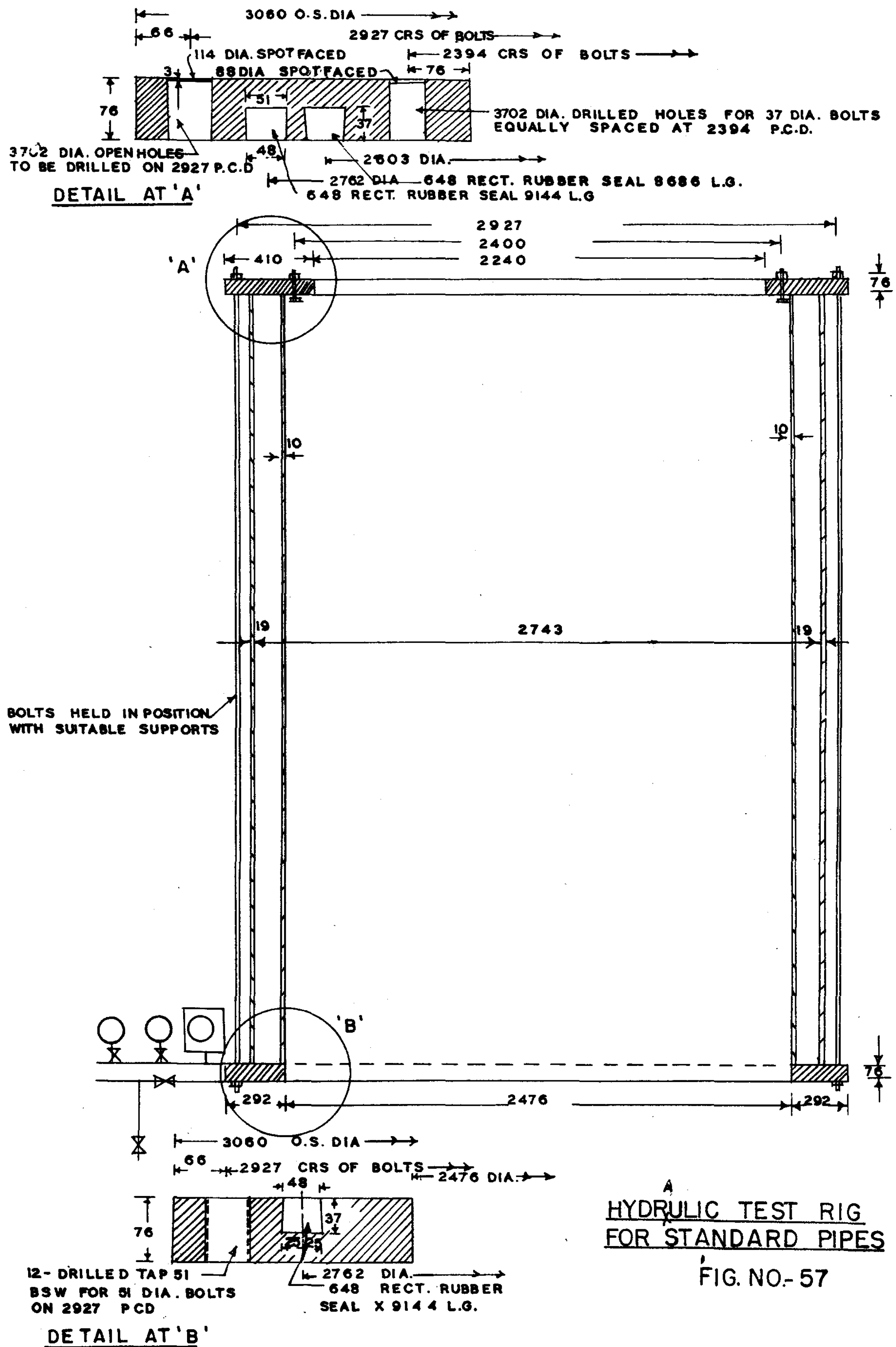
DETAIL AT 'H'

FIG. NO.- 55



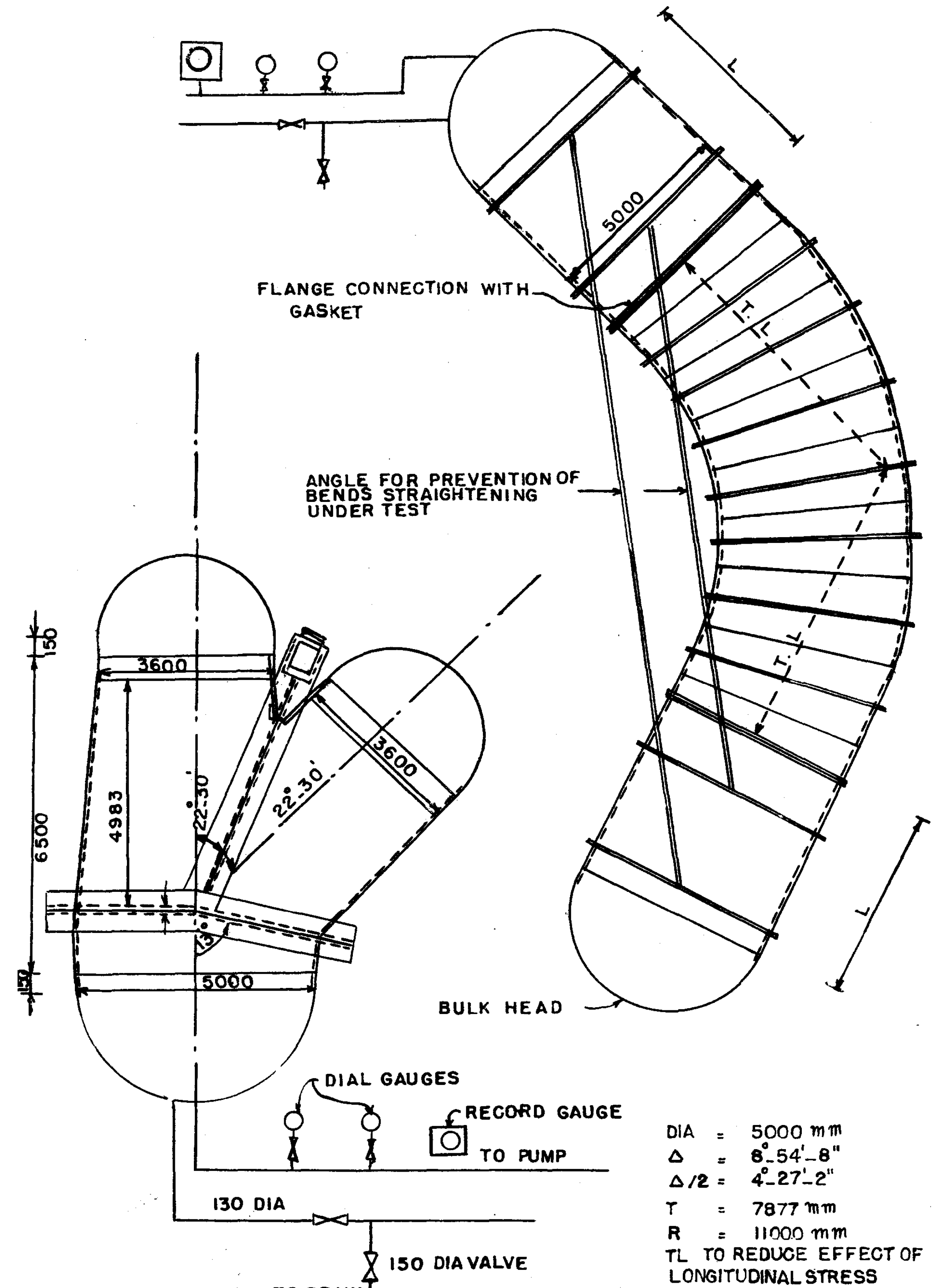
TYPICAL DETAILS OF BURIED PENSTOCK

FIG. NO.-56.



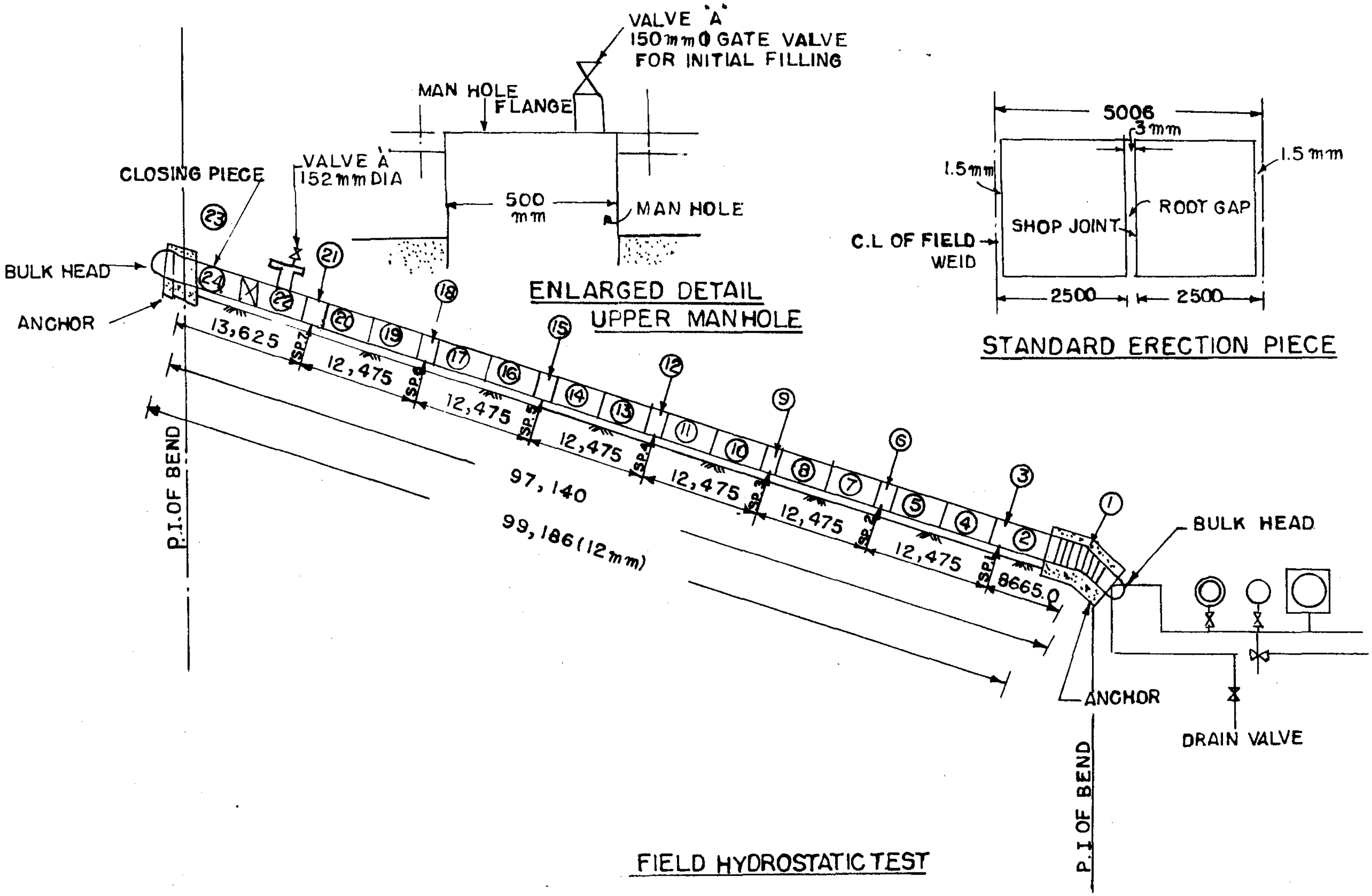
HYDRAULIC TEST RIG FOR STANDARD PIPES

FIG. NO.- 57



TYPICAL ARRANGEMENTS FOR SHOP HYDRAULIC TEST ON BENDS AND BIFURCATIONS

FIG. NO- 58



FIELD HYDROSTATIC TEST

FIG. NO.- 59

Last page

****